BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:	)	
AMENDMENTS TO	)	
35 ILL. ADM. CODE 225.233	)	R18-20
MULTI-POLLUTION STANDARDS	)	(Rulemaking – Air)
(MPS)	)	

NOTICE OF FILING

PLEASE TAKE NOTICE that I have filed with the Illinois Pollution Control Board the Pre-Filed Testimony of Brian Urbaszewksi on behalf Sierra Club, Environmental Law and Policy Center, and Respiratory Health Association of Metropolitan Chicago on the Pollution Control Board's First Notice Proposal, a copy of which is hereby served upon you.

Respectfully submitted,

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Dated: February 6th, 2018

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CERTIFICATE OF SERVICE

I, Akriti Bhargava, so certify that on February 6th, 2018, I served copies of Pre-Filed Testimony of Brian P. Urbaszewski on the Pollution Control board's First Notice Proposal, and the Notice of filing upon the parties and persons listed in the attached Service List by email for those who have consented to email service and by U.S. Mail for all others.

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IN THE MATTER OF:	)	
AMENDMENTS TO	)	
35 ILL. ADM. CODE 225.233	)	R18-20
MULTI-POLLUTION STANDARDS	)	(Rulemaking – Air)
(MPS)	)	

PRE-FILED TESTIMONY OF BRIAN P. URBASZEWSKI ON THE POLLUTION CONTROL BOARD'S FIRST NOTICE PROPOSAL

Environmental Law & Policy Center, Respiratory Health Association of Metropolitan Chicago, and Sierra Club, hereby file the testimony of Brian P. Urbaszewski directed to the Illinois Pollution Control Board ("Board") in this matter, as provided by the Hearing Officer Order issued on January 29, 2017.

I. INTRODUCTION

I am the Director of Environmental Health Programs at Respiratory Health Association of Metropolitan Chicago. I work to promote clean air in Illinois and metropolitan Chicago through public policy advocacy and public education. I have worked to implement protective local, state and national air quality policies and legislation covering coal power plant emissions, diesel and gasoline vehicle emission standards, national air quality health standards, climate change health risks, as well as various air pollution education and awareness campaigns. I have spoken at local university and college classes, presented at academic and professional symposia. I have also testified before both the Illinois General Assembly and the Chicago City Council on environmental health policy matters and has provided public comment on behalf of RHA to the US Environmental Protection Agency. I joined Respiratory Health Association in 1998. I hold degrees from the University of Chicago (AB Geographical Studies) and the University of Illinois

(Masters in Urban Planning and Policy). I previously worked for the Illinois Environmental Protection Agency.

Respiratory Health Association's mission is to prevent lung disease, promote clean air and help people live better through education, research, and policy change. Respiratory Health Association has been a local public health leader since 1906. As health practices and treatments, medicines, and environmental factors have evolved, so has RHA. Today we address asthma, COPD, lung cancer, tobacco control and air quality with a comprehensive approach.

II. HEALTH EFFECTS OF SO_2

High concentrations of sulfur dioxide (SO_2) for short periods of time can harm the respiratory system and cause breathing problems. Short-term exposure to SO_2 can cause wheezing, chest tightness and shortness of breath. Even low concentrations of sulfur dioxide, however, still pose a threat of respiratory problems for children, the elderly, and those who suffer from asthma. Repeated, long-term exposure to lower levels of sulfur dioxide may decrease pulmonary function and cause bronchitis.

In addition, SO_2 reacts with other compounds in the atmosphere to form small particles and contribute to particulate matter (PM) pollution. Fine particulates penetrate deeply into the lungs and cause serious health problems including heart attacks, aggravated asthma and decreased lung function. Studies have found significant evidence of adverse effects of exposure to fine particle pollution at levels below current national standards—the National Ambient Air Quality Standards (NAAQS).[1] [2]

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[1] Di, Qian et al., *Association of Short-term Exposure to Air Pollution With Mortality in Older*

This effect was most pronounced racial minorities and low income individuals.[3] In other words, the scientific consensus, including at USEPA is that there is no safe threshold level of fine particle pollution below which there is no risk to human health from exposure.[4]

The NAAQS are required to protect public health "with an adequate margin of safety." "An adequate margin of safety" obviously still requires a judgment call by the United States Environmental Protection Agency (U.S. EPA) and does not mean that U.S. EPA picks a threshold below which no health harms occur.[5]

U.S. EPA's assessment for the SO_2 NAAQS was slightly different than PM because of the manner in which SO_2 causes negative health effects. For SO_2, it is short term spikes that trigger measurable health harms. But short spikes are hard to measure, so U.S. EPA set a longer-term average (i.e. hourly) that is sufficiently low in order to limit excessive short term spikes and also the magnitude of spikes. But even then U.S. EPA expressed concerns that this method under-estimated potential exposure:

> These results may suggest that a single peak approach (i.e., 24 peak concentrations per day) for estimating the number of persons and days with 5-minute SO exposures as a

Adults, 318 JAMA 2446 (Dec. 26,2017).
Attached hereto as Exhibit 1

[2] Di, Qian et al., *Air Pollution and Mortality in the Medicare Population*, 376 NEJM 2513 (June 29, 2017)
Attached hereto as Exhibit 2

[3] *Id.*

[4] Letter from Gina McCarthy, Asst. Administrator, EPA, to Fred Upton, Chairman, US House Committee on Energy and Commerce, (Feb. 3, 2012) (on file with EPA)
Attached hereto as Exhibit 3

[5] *Id.*

> surrogate for all possible peak exposure events may lead to an under-estimate in the number of potential exposures.[6]

In addition, there are higher risks for sensitive subgroups:

> Overall, the ISA concludes that epidemiologic and controlled human exposure studies indicate that individuals with pre-existing respiratory diseases, particularly asthma, are at greater risk than the general population of experiencing SO_2-associated health effects (ISA, section 4.2.1.1).[7]

The range of levels for the one hour SO_2 NAAQS that the U.S. EPA was considering was 50 to 150 ppb. Ultimately, U.S. EPA selected 75ppb. There were, however, demonstrated health effects down to 50 ppb levels. The U.S. EPA administrator noted that there were at least two studies that documented health effects at levels as low as 50ppb that were available at the time of the last SO_2 NAAQS review process:

> The Administrator notes that selecting a standard level of 50 ppb would place considerable weight on the two U.S. emergency department visit studies conducted in locations where 99th percentile 1-hour SO2 concentrations were approximately 50 ppb (i.e., Wilson et al., (2005) in Portland, ME and Jaffe et al., (2003) in Columbus, OH).[8]
>
> Of the alternative regulatory scenarios analyzed, only the 50 ppb/99th percentile daily maximum 1-hr standard is estimated to reduce risks in one of the two modeling study areas (i.e., St. Louis) relative to the "as is" air quality scenario. [9]

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[6] U.S. EPA SO_2 Risk and Exposure Assessment, July 2009 at 302. Found at https://www3.epa.gov/ttn/naaqs/standards/so2/data/200908SO2REAFinalReport.pdf
Attached hereto as Exhibit 4

[7] *Id.* at 24

[8] Primary National Ambient Air Quality Standards, 75 Fed. Reg. 35,543 (Jun. 22, 2010) (to be codified at 40 C.F.R. pt. 50, 53 and 58)
Attached hereto as Exhibit 5

[9] U.S. EPA SO_2 Risk and Exposure Assessment, July 2009 at 302. Found at https://www3.epa.gov/ttn/naaqs/standards/so2/data/200908SO2REAFinalReport.pdf
Attached hereto as Exhibit 4

In addition, in areas with air pollution caused by multiple pollutants, there were also increased risks to sensitive subgroups:

> A 99th percentile 1-hour daily maximum standard at 50 ppb would provide an increased margin safety against the air quality levels observed in the cluster of epidemiologic studies observing statistically significant positive associations between SO_2 and respiratory-related ED visits and hospitalizations in studies with multipollutant models with PM (i.e. 99th percentile 1-hour daily maximum SO_2 concentrations $\geq$ 78 ppb).[10]

U.S.EPA's findings that there are health effects even below the level of the NAAQS is further documented in the Federal Register notice setting the SO_2 NAAQS level:

> Finally, the Administrator noted that two epidemiologic studies reported generally positive associations between ambient SO_2 and emergency department visits in cities when 99th percentile 1-hour daily maximum SO_2 concentrations were approximately 50 ppb, but did not consider that evidence strong enough to propose setting a standard level lower than 50 ppb. [11]
>
> In addition, the St. Louis exposure analysis estimates that a 99th percentile 1-hour daily maximum standard set at a level of 50 ppb would likely protect > 99% of asthmatic children at moderate or greater exertion from experiencing at least one 5-minute exposure both ≥ 400 and > 200 ppb per year (see proposal section II.F.4.b and Table 3).[12]
>
> The Administrator noted that the lower end of the proposed range was consistent with CASAC advice that there is clearly sufficient evidence for consideration of standard levels starting at 50 ppb (Samet 2009, p. 16). [13]

III. CONCLUSION

In short, from a health perspective, even though Illinois Environmental Protection Agency claims the proposed rule does not allow SO_2 emissions to exceed the NAAQS, it still poses a risk to public health. The current rule, by imposing a fleet wide average, has prevented

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[10] *Id.* at 394
[11] Primary National Ambient Air Quality Standards, 75 Fed. Reg. 35,542 (Jun. 22, 2010) (to be codified at 40 C.F.R. pt. 50, 53 and 58)
Attached hereto as Exhibit 5
[12] *Id.* at 35.542
[13] Id. at 35,542

SO_2 "hot spots" and prevented many short term spikes in SO_2 that have been tied to health effects. An annual cap removes the mechanism that has prevented SO_2 'hot spots' by allowing SO_2 emissions to increase at individual plants if other plants shut down.

As indicated above, higher localized SO_2 emissions (especially if they occur in short term spikes) pose a health threat, especially to sensitive subgroups and even if they do not exceed the NAAQS.

Respectfully submitted,

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Dated: February 6th, 2018

<u>Exhibits to Pre-Filed Testimony of Brian P. Urbaszewski</u>

Exhibit 1 - Di, Qian et al., *Association of Short-term Exposure to Air Pollution With Mortality in Older Adults,* 318 JAMA 2446 (Dec. 26,2017).

Exhibit 2 - Di, Qian et al., *Air Pollution and Mortality in the Medicare Population*, 376 NEJM 2513 (June 29, 2017)

Exhibit 3 - Letter from Gina McCarthy, Asst. Administrator, EPA, to Fred Upton, Chairman, US House Committee on Energy and Commerce, (Feb. 3, 2012) (on file with EPA)

Exhibit 4 - U.S. EPA SO_2 Risk and Exposure Assessment, July 2009 at 302. Retrieved from: https://www3.epa.gov/ttn/naaqs/standards/so2/data/200908SO2REAFinalReport.pdf

Exhibit 5 - Primary National Ambient Air Quality Standards, 75 Fed. Reg. 35,542 (Jun. 22, 2010) (to be codified at 40 C.F.R. pt. 50, 53 and 58)

Electronic Filing: Received, Clerk's Office 2/6/2018

EXHIBIT 1

JAMA | Original Investigation

Association of Short-term Exposure to Air Pollution With Mortality in Older Adults

Qian Di, MS; Lingzhen Dai, ScD; Yun Wang, PhD; Antonella Zanobetti, PhD; Christine Choirat, PhD; Joel D. Schwartz, PhD; Francesca Dominici, PhD

IMPORTANCE The US Environmental Protection Agency is required to reexamine its National Ambient Air Quality Standards (NAAQS) every 5 years, but evidence of mortality risk is lacking at air pollution levels below the current daily NAAQS in unmonitored areas and for sensitive subgroups.

OBJECTIVE To estimate the association between short-term exposures to ambient fine particulate matter ($PM_{2.5}$) and ozone, and at levels below the current daily NAAQS, and mortality in the continental United States.

DESIGN, SETTING, AND PARTICIPANTS Case-crossover design and conditional logistic regression to estimate the association between short-term exposures to $PM_{2.5}$ and ozone (mean of daily exposure on the same day of death and 1 day prior) and mortality in 2-pollutant models. The study included the entire Medicare population from January 1, 2000, to December 31, 2012, residing in 39 182 zip codes.

EXPOSURES Daily $PM_{2.5}$ and ozone levels in a 1-km × 1-km grid were estimated using published and validated air pollution prediction models based on land use, chemical transport modeling, and satellite remote sensing data. From these gridded exposures, daily exposures were calculated for every zip code in the United States. Warm-season ozone was defined as ozone levels for the months April to September of each year.

MAIN OUTCOMES AND MEASURES All-cause mortality in the entire Medicare population from 2000 to 2012.

RESULTS During the study period, there were 22 433 862 million case days and 76 143 209 control days. Of all case and control days, 93.6% had $PM_{2.5}$ levels below 25 μg/m^3, during which 95.2% of deaths occurred (21 353 817 of 22 433 862), and 91.1% of days had ozone levels below 60 parts per billion, during which 93.4% of deaths occurred (20 955 387 of 22 433 862). The baseline daily mortality rates were 137.33 and 129.44 (per 1 million persons at risk per day) for the entire year and for the warm season, respectively. Each short-term increase of 10 μg/m^3 in $PM_{2.5}$ (adjusted by ozone) and 10 parts per billion (10^{-9}) in warm-season ozone (adjusted by $PM_{2.5}$) were statistically significantly associated with a relative increase of 1.05% (95% CI, 0.95%-1.15%) and 0.51% (95% CI, 0.41%-0.61%) in daily mortality rate, respectively. Absolute risk differences in daily mortality rate were 1.42 (95% CI, 1.29-1.56) and 0.66 (95% CI, 0.53-0.78) per 1 million persons at risk per day. There was no evidence of a threshold in the exposure-response relationship.

CONCLUSIONS AND RELEVANCE In the US Medicare population from 2000 to 2012, short-term exposures to $PM_{2.5}$ and warm-season ozone were significantly associated with increased risk of mortality. This risk occurred at levels below current national air quality standards, suggesting that these standards may need to be reevaluated.

JAMA. 2017;318(24):2446-2456. doi:10.1001/jama.2017.17923

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In the United States, the Clean Air Act[1] requires a review of National Ambient Air Quality Standards (NAAQS) for fine particulate matter ($PM_{2.5}$) and ozone every 5 years.[2] In 2012, the annual and 24-hour NAAQS for $PM_{2.5}$ were set to 12 μg/m^3 and 35 μg/m^3, respectively. With no annual standard for ozone, the 8-hour NAAQS for ozone was set to 70 parts per billion (ppb). Currently, the review of these standards is ongoing, with public comments expected in the fall of 2017.[3]

Several studies have provided evidence that short-term exposures to $PM_{2.5}$ and ozone were associated with mortality,[4-8] but these studies primarily included large and well-monitored metropolitan areas. While the US Environmental Protection Agency (EPA) is considering more stringent NAAQS, evidence is needed to clarify the association between mortality risk and exposure levels below the daily NAAQS and in rural and unmonitored areas.

The Clean Air Act[1] also requires the US EPA to set standards to protect "sensitive subgroups." To estimate the health risk of short-term exposure to air pollution for specific subgroups (eg, underrepresented minorities and those with low socioeconomic status, such as persons eligible for Medicaid), a large population is necessary to achieve maximum accuracy and adequate statistical power.

A case-crossover study was conducted to examine all deaths of Medicare participants in the continental United States from 2000 throughout 2012 and estimate the mortality risk associated with short-term exposures to $PM_{2.5}$ and ozone in the general population as well as in subgroups. The study was designed to estimate the association between daily mortality and air pollution at levels below current daily NAAQS to evaluate the adequacy of the current air quality standards for $PM_{2.5}$ and ozone.

Key Points

Question What is the association between short-term exposure to air pollution below current air quality standards and all-cause mortality?

Finding In a case-crossover study of more than 22 million deaths, each 10-μg/m^3 daily increase in fine particulate matter and 10–parts-per-billion daily increase in warm-season ozone exposures were associated with a statistically significant increase of 1.42 and 0.66 deaths per 1 million persons at risk per day, respectively.

Meaning Day-to-day changes in fine particulate matter and ozone exposures were significantly associated with higher risk of all-cause mortality at levels below current air quality standards, suggesting that those standards may need to be reevaluated.

Methods

This study was approved by the institutional review board at the Harvard T.H. Chan School of Public Health. As a study of previously collected administrative data, it was exempt from informed consent requirements.

Study Population

Using claims data from the Centers for Medicare & Medicaid Services, all deaths among all Medicare beneficiaries were identified during the period 2000 to 2012, providing enough power to analyze the risk of mortality associated with $PM_{2.5}$ and ozone concentrations much lower than the current standards (**Table 1**). For each beneficiary, information was extracted on the date of death, age, sex, race, ethnicity, zip code of residence, and eligibility for Medicaid (a proxy for low income) to assess the associations of mortality with $PM_{2.5}$ and ozone concentrations in potentially vulnerable subgroups. Self-reported information on race and ethnicity was obtained from Medicare beneficiary files.

Outcome

The study outcome was all-cause mortality. Individuals with a verified date of death between January 1, 2000, and December 31, 2012, were included. Individuals with an unverified date of death, or still living after December 31, 2012, were excluded.

Study Design

We estimated the association between short-term exposure to $PM_{2.5}$ (adjusted by ozone) and short-term exposure to ozone (adjusted by $PM_{2.5}$) and all-cause mortality using a case-crossover design.[9] Specifically, "case day" was defined as the date of death. For the same person, we compared daily air pollution exposure on the case day vs daily air pollution exposure on "control days." Control days were chosen (1) on the same day of the week as the case day to control for potential confounding effect by day of week; (2) before and after the case day (bidirectional sampling) to control for time trend[10,11]; and (3) only in the same month as the case day to control for seasonal and subseasonal patterns.[10,12] Individual-level covariates and zip code-level covariates that did not vary day to day (eg, age, sex, race/ethnicity, socioeconomic status, smoking, and other behavioral risk factors) were not considered to be confounders as they remain constant when comparing case days vs control days.

Environmental Data

Daily ambient levels of $PM_{2.5}$ and ozone were estimated from published and validated air pollution prediction models.[13,14] Combining monitoring data from the EPA, satellite-based measurements, and other data sets, neural networks were used to predict 24-hour $PM_{2.5}$ and 8-hour maximum ozone concentrations at each 1-km ×1-km grid in the continental United States, including locations with no monitoring sites. Cross-validation indicated good agreement between predicted values and monitoring values (R^2 = 0.84 for $PM_{2.5}$ and R^2 = 0.76 for ozone) and at low concentrations (R^2 = 0.85 when constraining to 24-hour $PM_{2.5}$ <25 μg/m^3 and R^2 = 0.75 when constraining to daily 8-hour maximum ozone <60 ppb). Details have been published elsewhere.[13,14] Warm season was defined to be from April 1 to September 30, which is the specific time window to examine the association between ozone and mortality.

Meteorological variables, including air and dew point temperatures, were retrieved from North American Regional Reanalysis data and estimated daily mean values were determined for each 32-km × 32-km grid in the continental United States.[15]

For each case day (date of death) and its control days, the daily 24-hour $PM_{2.5}$, 8-hour maximum ozone, and daily air and dew point temperatures were assigned based on zip code of residence of the individual (eAppendix 1 in the Supplement). Because we estimated air pollution levels everywhere in the continental United States, the number of zip codes included in this study was 39 182, resulting in a 33% increase compared with the number of zip codes with a centroid less than 50 km from a monitor (n = 26 115).

Table 1. Baseline Characteristics of Study Population (2000-2012)

Baseline Characteristic	Value
Case days, No.	22 433 862
Control days, No.	76 143 209
Among All Cases (n = 22 433 862), %	
Age at death, y	
≤69	10.38
70-74	13.37
75-84	38.48
≥85	37.78
Sex	
Male	44.73
Female	55.27
Race/ethnicity	
White	87.34
Black	8.87
Asian	1.03
Hispanic	1.51
Native American	0.31
Medicaid Eligibility (n = 22 433 862), %	
Ineligible	77.36
Eligible	22.64

Statistical Analysis

The relative risk (RR) of all-cause mortality associated with short-term exposures to $PM_{2.5}$ (adjusted by ozone) and warm-season ozone (adjusted by $PM_{2.5}$) was estimated by fitting a conditional logistic regression to all pairs of case days and matched control days (eAppendix 2 in the Supplement).[9] The regression model included both pollutants as main effects and natural splines of air and dew point temperatures with 3 *df* to control for potential residual confounding by weather. For each case day, daily exposure to air pollution was defined as the mean of the same day of death (lag 0-day) and 1 day prior (lag 1-day), denoted as lag 01-day.[5,16,17] Relative risk increase (RRI) was defined as RR − 1. The absolute risk difference (ARD) of all-cause mortality associated with air pollution was defined as ARD = α × (RR − 1)/RR, where α denotes the baseline daily mortality rate (eAppendix 3 in the Supplement).

The robustness of the analysis results was assessed with respect to (1) choosing the *df* used for the confounding adjustment for temperature, (2) using lag 01-day exposure as the exposure metric, (3) the definition of warm season, and (4) using only air pollution measurements from the nearest EPA monitoring sites. Splines on meteorological variables with 6 and 9 *df* yielded results with a difference of less than 5% of the standard error (eFigure 1 in the Supplement). The main analysis, which used the lag 01-day exposure, yielded the lowest values of the Akaike Information Criteria values, indicating better fit to the data (eTable in the Supplement). Different definitions of warm season yielded similar risk estimates (eAppendix 4 in the Supplement), and using exposure mea-

Table 2. Relative Risk Increase and Absolute Risk Difference of Daily Mortality Associated With Each 10-µg/m³ Increase in $PM_{2.5}$ and Each 10-ppb Increase in Ozone

Air Pollutant Analysis	Relative Risk Increase, % (95% CI)		Absolute Risk Difference in Daily Mortality Rates, No. per 1 Million Persons at Risk per Day (95% CI)[a]	
	$PM_{2.5}$	Ozone[b]	$PM_{2.5}$	Ozone[b]
Main analysis[c]	1.05 (0.95-1.15)	0.51 (0.41-0.61)	1.42 (1.29-1.56)	0.66 (0.53-0.78)
Low-exposure analysis[d]	1.61 (1.48-1.74)	0.58 (0.46-0.70)	2.17 (2.00-2.34)	0.74 (0.59-0.90)
Single-pollutant analysis[e]	1.18 (1.09-1.28)	0.55 (0.48-0.62)	1.61 (1.48-1.73)	0.71 (0.62-0.79)
Nearest monitors analysis[f]	0.83 (0.73-0.93)	0.35 (0.28-0.41)	1.13 (0.99-1.26)	0.45 (0.37-0.53)

Abbreviations: $PM_{2.5}$, fine particulate matter; ppb, parts per billion.

[a] The daily baseline mortality rate was 137.33 per 1 million persons at risk per day; the warm-season daily baseline mortality rate was 129.44 per 1 million persons at risk per day.

[b] Ozone analyses included days from the warm season only (April 1 to September 30).

[c] The main analysis used the mean of daily exposure on the same day of death and 1 day prior (lag 01-day) as the exposure metric for both $PM_{2.5}$ and ozone, and controlled for natural splines of air and dew point temperatures with 3 *df*. The main analysis considered the 2 pollutants jointly included into the regression model and estimated the percentage increase in the daily mortality rate associated with a 10-µg/m³ increase in $PM_{2.5}$ exposure adjusted for ozone and the percentage increase in daily mortality rate associated with a 10-ppb increase in warm-season ozone exposure adjusted for $PM_{2.5}$.

[d] The low-exposure analysis had the same model specifications as the 2-pollutant analysis and was constrained for days when $PM_{2.5}$ was below 25 µg/m³ or ozone below 60 ppb.

[e] The single-pollutant analysis estimated the percentage increase in the daily mortality rate associated with a 10-µg/m³ increase in $PM_{2.5}$ exposure without adjusting for ozone and the percentage increase in the daily mortality rate associated with a 10-ppb increase in ozone exposure without adjusting for $PM_{2.5}$.

[f] $PM_{2.5}$ and ozone monitoring data were retrieved from the US Environmental Protection Agency Air Quality System, which provides the daily mean of $PM_{2.5}$ and daily 8-hour maximum ozone levels at each monitoring site. Daily ozone concentrations were averaged from April 1 to September 30. Individuals were assigned to the $PM_{2.5}$ and ozone levels from the nearest monitor site within 50 km. Those living 50 km from any monitoring site were excluded.

surements from the nearest monitors resulted in attenuated, but still significant, risk estimates (**Table 2**).

The subgroup analyses were conducted by sex (male and female), race/ethnicity (white, nonwhite, and others), age (≤69, 70-74, 75-84, and ≥85 years), eligibility for Medicaid, and population density (quartiles). We fitted separate conditional logistic regressions to the data for each subgroup and obtained subgroup-specific estimates of RR and ARD. We implemented a 2-sample test for assessing statistically significant differences in the estimated RR and ARD between categories within each subgroup (eg, female vs male), based on the point estimate and standard error (se) (eAppendix 5 in the Supplement):

$$Z \quad \frac{RR_{male} \quad RR_{female}}{\sqrt{se(RR_{male})^2 + se(RR_{female})^2}}$$

The goal was to estimate mortality rate increases (both RRI and ARD) at air pollution levels well below the current daily NAAQS. The analysis was restricted to days with daily air pollution concentrations below 25 μg/m^3 for $PM_{2.5}$ and 60 ppb for ozone. We chose 25 μg/m^3 and 60 ppb instead of the current daily NAAQS (35 μg/m^3 for daily $PM_{2.5}$ and 70 ppb for 8-hour maximum ozone) because levels of $PM_{2.5}$ and ozone on most of the days included in the analysis were already below the current safety standards.

Exposure-response curves were estimated between $PM_{2.5}$ or ozone and mortality by replacing linear terms for the 2 pollutants with penalized splines for both $PM_{2.5}$ and ozone.

All analyses were performed in R software version 3.3.2 (R Foundation). Computations were run on (1) the Odyssey cluster supported by the Faculty of Arts and Sciences Division of Science, Research Computing Group at Harvard University and (2) the Research Computing Environment supported by the Institute for Quantitative Social Science in the Faculty of Arts and Sciences at Harvard University.

Results

During the study period, there were more than 22 million case days (deaths) and more than 76 million control days (Table 1). Of all case and control days, 93.6% had $PM_{2.5}$ levels below 25 μg/m^3, during which 95.2% of deaths occurred (21 353 817 of 22 433 862), and 91.1% of days had ozone levels below 60 ppb, during which 93.4% of deaths occurred (20 955 387 of 22 433 862). The baseline daily mortality rates were 137.33 and 129.44 (per 1 million persons at risk per day [per 1M per day]) for the entire year and for the warm season, respectively. The mean time between case and control days was 12.55 days (range 7-28 days), with minimal differences in air and dew point temperatures between case and control days (0.003°C and 0.01°C, respectively). During the study period, the mean concentrations of $PM_{2.5}$ and ozone were 11.6 μg/m^3 and 37.8 ppb, respectively. **Figure 1** and **Figure 2** show the daily $PM_{2.5}$ and ozone time series by state, respectively.

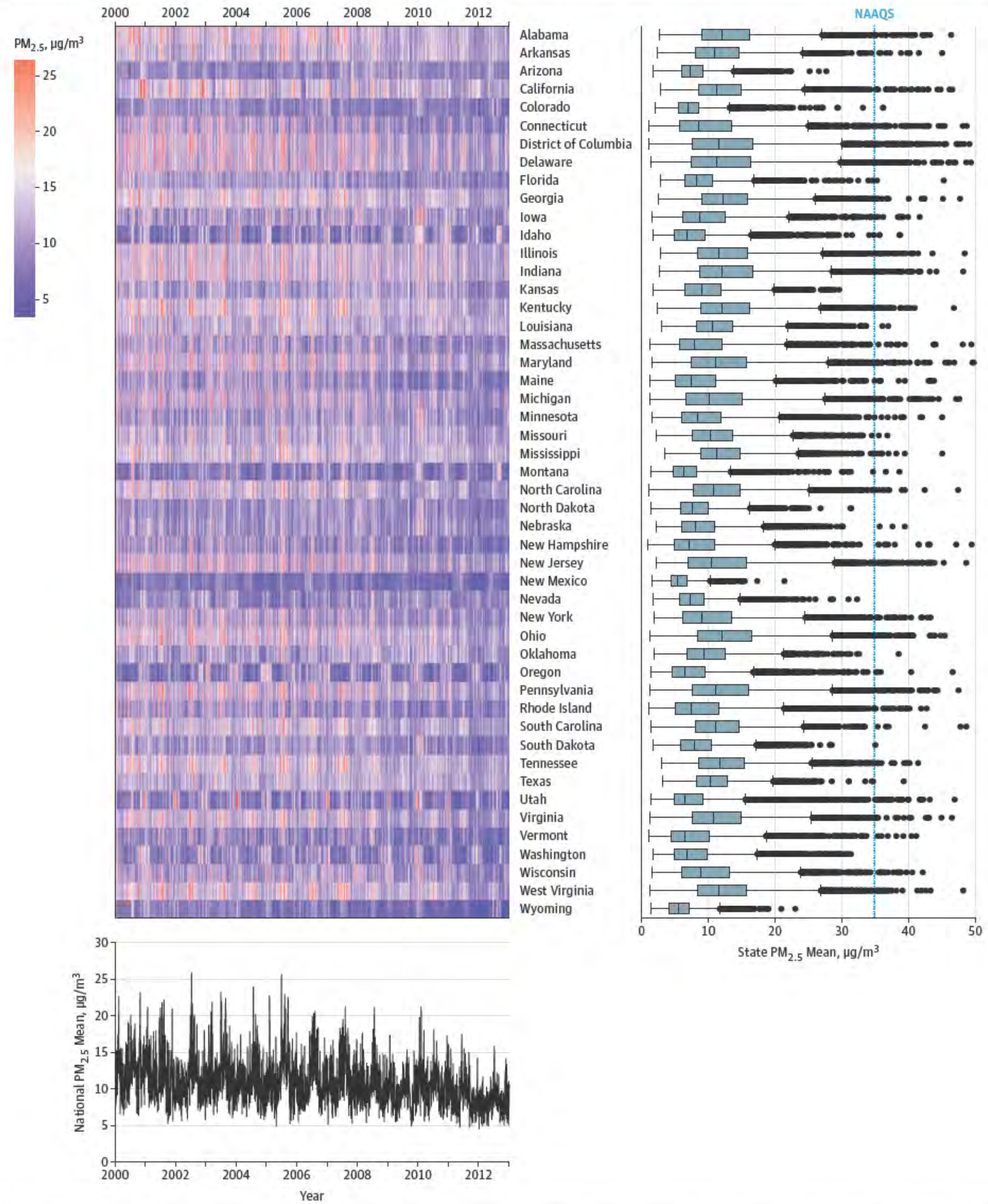
Each 10-μg/m^3 and 10-ppb increase in the lag 01-day exposure for $PM_{2.5}$ and warm-season ozone was associated with an RRI of 1.05% (95% CI, 0.95%-1.15%) and 0.51% (95% CI, 0.41%-0.61%) in the daily mortality rate. The ARDs were 1.42 (95% CI, 1.29-1.56) and 0.66 (95% CI, 0.53-0.78) per 1M per day. These associations remained significant when examining days below 25 μg/m^3 for $PM_{2.5}$ and below 60 ppb for ozone, with larger effect size estimates for both $PM_{2.5}$ and ozone (RRI: 1.61% [95% CI, 1.48%-1.74%] and 0.58% [95% CI, 0.46%-0.70%]; ARD: 2.17 [95% CI, 2.00-2.34] and 0.74 [95% CI, 0.59-0.90] per 1M per day, respectively) (Table 2). $PM_{2.5}$ was associated with higher mortality rate in some subgroups, including Medicaid-eligible individuals (RRI: 1.49% [95% CI, 1.29%-1.70%]; ARD: 3.59 [95% CI, 3.11-4.08] per 1M per day; interaction: $P < .001$), individuals older than 70 years (eg, for ≥85 years, RRI: 1.38% [95% CI, 1.23%-1.54%]; ARD: 5.35 [95% CI, 4.75-5.95] per 1M per day; interaction: $P < .001$), and females (RRI: 1.20% [95% CI, 1.07%-1.33%]; ARD: 1.56 [95% CI, 1.39-1.72] per 1M per day; interaction: $P = .02$) (**Figure 3** and **Figure 4**). The effect estimates for $PM_{2.5}$ increased with age. The effect estimate for black individuals was higher than that for white individuals ($P = .001$; eFigure 2 in the Supplement). For ozone, similar patterns were observed, but with less contrast between groups. No significant differences were found in the short-term associations between air pollution exposure ($PM_{2.5}$ and ozone) and mortality across areas with different population density levels (Figure 3 and Figure 4). Effect estimates using different lags of exposure are shown in eFigure 3 in the Supplement.

Figure 5 shows the estimated exposure-response curves for $PM_{2.5}$ and ozone. The slope was steeper at $PM_{2.5}$ levels below 25 μg/m^3 ($P < .001$), consistent with the low-exposure analysis (Table 2). Both $PM_{2.5}$ and ozone exposure-responses were almost linear, with no indication of a mortality risk threshold at very low concentrations. eFigure 4 in the Supplement shows the exposure-response curves for $PM_{2.5}$ when restricted to just the warm season and for ozone when not restricted to the warm season; results were similar.

Discussion

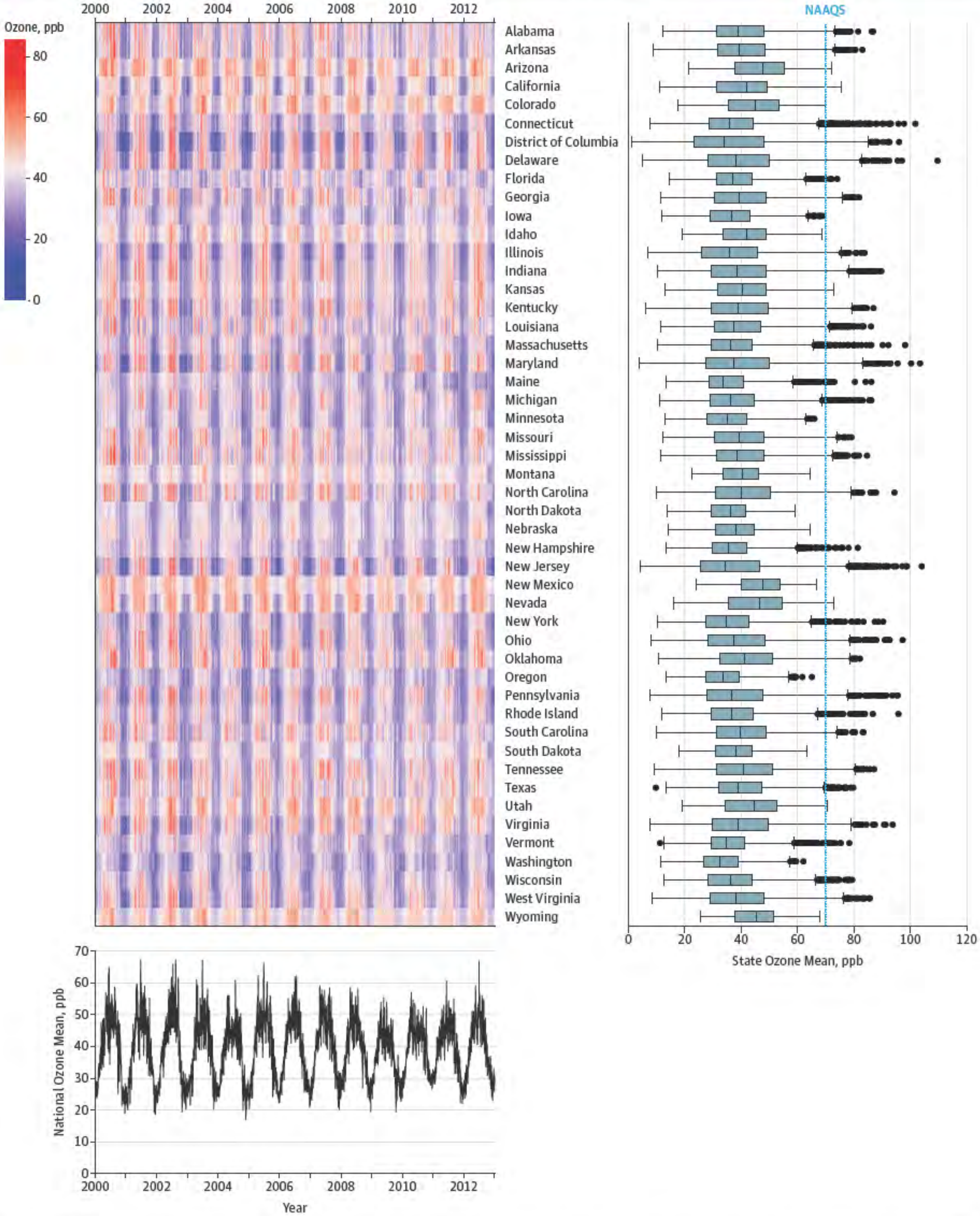
In this large case-crossover study of all Medicare deaths in the continental United States from 2000 to 2012, a 10-μg/m^3 daily increase in $PM_{2.5}$ and a 10-ppb daily increase in warm-season ozone exposures were associated with a statistically significant increase of 1.42 and 0.66 deaths per 1M per day, respectively. The risk of mortality remained statistically significant when restricting the analysis to days with $PM_{2.5}$ and ozone levels much lower than the current daily NAAQS.[18] This study included individuals living in smaller cities, towns, and rural areas that were unmonitored and thus excluded from previous time series studies. There were no significant differences in the mortality risk associated with air pollution among individuals living in urban vs rural areas. Taken together, these results provide evidence that short-term exposures to $PM_{2.5}$ and ozone, even at levels much lower than the current daily standards, are associated with increased mortality, particularly for susceptible populations.

Figure 1. Daily Mean $PM_{2.5}$ Concentrations in the Continental United States, 2000-2012



Daily mean fine particulate matter ($PM_{2.5}$) concentrations were calculated and plotted by state. The time-series plot at the bottom indicates the national daily mean values across all locations. Boxplots show the distribution of daily $PM_{2.5}$ levels for each state. The blue dashed line indicates the daily National Ambient Air Quality Standards (NAAQS) for $PM_{2.5}$ (35 μg/m^3). The line across the box, upper hinge, and lower hinge represent the median value, 75th percentile (Q3), and 25th percentile (Q1), respectively. The upper whisker is located at the smaller of the maximal value and Q3 + 1.5 × interquartile range; the lower whisker is located at the larger of the minimal value and Q1 – 1.5 × interquartile range. Any values that lie beyond the upper and lower whiskers are outliers.

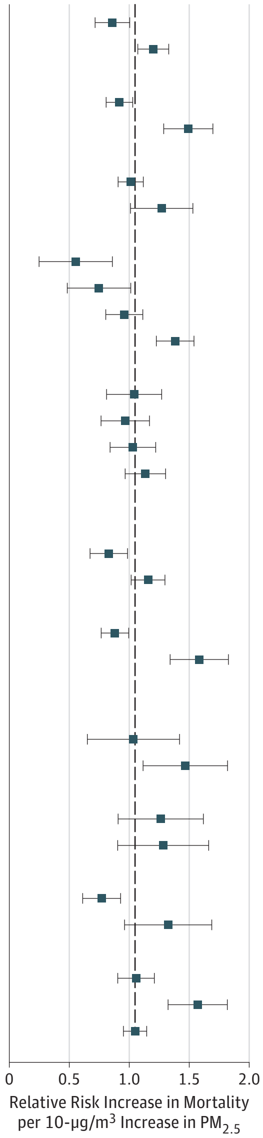
Figure 2. Daily 8-Hour Maximum Ozone Concentrations in the Continental United States, 2000-2012

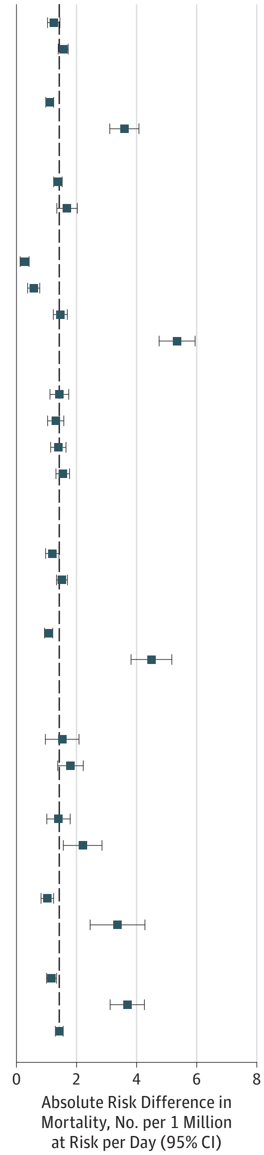


Daily mean 8-hour maximum ozone concentrations were calculated and plotted by state. The time-series plot at the bottom indicates the national daily mean values across all locations. Boxplots show the distribution of daily ozone levels for each state. The blue dashed line indicates the daily National Ambient Air Quality Standards (NAAQS) for ozone (70 parts per billion [ppb]). The line across the box, upper hinge, and lower hinge represent the median value, 75th percentile (Q3), and 25th percentile (Q1), respectively. The upper whisker is located at the smaller of the maximal value and Q3 + 1.5 × interquartile range; the lower whisker is located at the larger of the minimal value and Q1 − 1.5 × interquartile range. Any values that lie beyond the upper and lower whiskers are outliers.

Figure 3. Relative Risk Increase and Absolute Risk Difference of Daily Mortality Associated With 10-μg/m^3 Increase in Fine Particulate Matter ($PM_{2.5}$)

Model	Relative Risk Increase in Mortality per 10-μg/m^3 Increase in $PM_{2.5}$, % (95% CI)	*P* Value for Effect Modification	Absolute Risk Difference in Mortality, No. per 1 Million at Risk per Day (95% CI)	*P* Value for Effect Modification
Sex				
Male	0.86 (0.72-1.00)	[Reference]	1.24 (1.03-1.45)	[Reference]
Female	1.20 (1.07-1.33)	<.001[a]	1.56 (1.39-1.72)	.02[a]
Medicaid eligibility				
Noneligible	0.92 (0.81-1.03)	[Reference]	1.11 (0.98-1.24)	[Reference]
Eligible	1.49 (1.29-1.70)	<.001[a]	3.59 (3.11-4.08)	<.001[a]
Race/ethnicity				
White	1.01 (0.91-1.12)	[Reference]	1.38 (1.24-1.52)	[Reference]
Nonwhite	1.27 (1.01-1.53)	.07	1.69 (1.34-2.03)	.11
Age, y				
≤69	0.55 (0.25-0.86)	[Reference]	0.27 (0.12-0.42)	[Reference]
70-74	0.75 (0.48-1.01)	.35	0.57 (0.37-0.78)	.02[a]
75-84	0.96 (0.80-1.11)	.02[a]	1.46 (1.23-1.69)	<.001[a]
≥85	1.38 (1.23-1.54)	<.001[a]	5.35 (4.75-5.95)	<.001[a]
Population density				
Low	1.04 (0.81-1.27)	[Reference]	1.43 (1.12-1.74)	[Reference]
Medium low	0.97 (0.76-1.17)	.64	1.31 (1.04-1.58)	.56
Medium high	1.03 (0.84-1.22)	.95	1.39 (1.14-1.65)	.86
High	1.13 (0.97-1.30)	.52	1.54 (1.31-1.77)	.57
Whites				
Sex				
Male	0.83 (0.67-0.99)	[Reference]	1.19 (0.97-1.42)	[Reference]
Female	1.16 (1.02-1.30)	.002[a]	1.51 (1.33-1.70)	.03[a]
Medicaid eligibility				
Noneligible	0.88 (0.77-1.00)	[Reference]	1.07 (0.93-1.21)	[Reference]
Eligible	1.58 (1.34-1.83)	<.001[a]	4.49 (3.81-5.17)	<.001[a]
Nonwhites				
Sex				
Male	1.03 (0.65-1.42)	[Reference]	1.52 (0.96-2.08)	[Reference]
Female	1.47 (1.12-1.82)	.01	1.80 (1.37-2.22)	.44
Medicaid eligibility				
Noneligible	1.26 (0.91-1.62)	[Reference]	1.40 (1.01-1.79)	[Reference]
Eligible	1.28 (0.90-1.66)	.94	2.21 (1.56-2.85)	.04[a]
Medicaid eligibility, males				
Noneligible	0.77 (0.61-0.93)	[Reference]	1.03 (0.82-1.24)	[Reference]
Eligible	1.32 (0.96-1.69)	.006	3.37 (2.45-4.28)	<.001[a]
Medicaid eligibility, females				
Noneligible	1.06 (0.90-1.21)	[Reference]	1.17 (1.00-1.33)	[Reference]
Eligible	1.57 (1.32-1.82)	<.001[a]	3.69 (3.12-4.26)	<.001[a]
Overall	1.05 (0.95-1.15)		1.42 (1.29-1.56)	





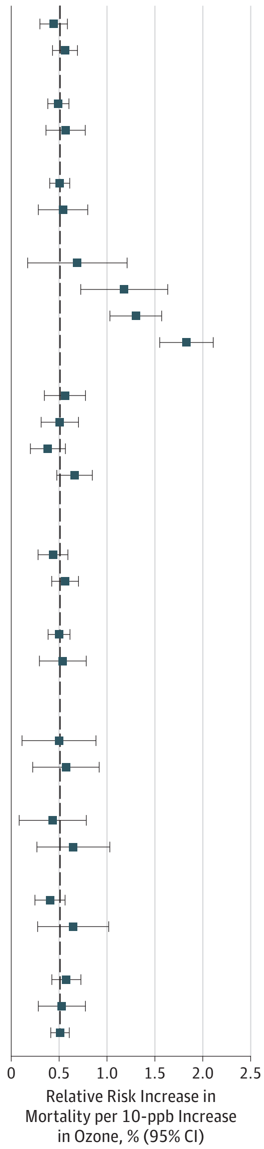
For the main analysis, subgroup analyses used a 2-pollutant analysis (with both $PM_{2.5}$ and ozone), based on the mean of daily exposure on the same day of death and 1 day prior (lag 01-day) as the exposure metric for $PM_{2.5}$, and controlled for natural splines of air and dew point temperatures (each with 3 *df*). Vertical lines indicate effects for the entire study population. Subgroup analyses were conducted for each subgroup (eg, male or female, white or nonwhite, Medicare eligible or Medicare ineligible, age groups, and quartiles of population density). For the main analysis and each subgroup, conditional logistic regressions were run to obtain relative risk increases and calculated absolute risk difference based on baseline mortality rates (eAppendix 2 in the Supplement). Numbers in the figure represent point estimates, 95% CIs, and *P* values for effect modifications. The reference groups were used when assessing effect modification.

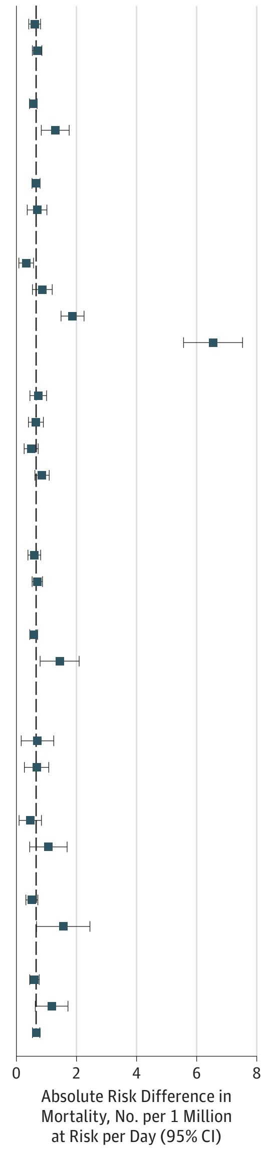
[a] Statistically significant effect estimate (at 5% level) compared with the reference group.

The Clean Air Act[1] requires the administrator of the US EPA to set NAAQS at levels that provide "protection for at-risk populations, with an adequate margin of safety."[19] In this study, Medicaid-eligible individuals, females, and elderly individuals had higher mortality rate increases associated with $PM_{2.5}$ than other groups. Previous studies have found similar results in some subgroups.[20,21] Poverty, unhealthy lifestyle, poor access to health care, and other factors may make some subgroups more vulnerable to air pollution. The exact mechanism is worth exploring in future studies.

Figure 4. Relative Risk Increase and Absolute Risk Difference of Daily Mortality Associated With 10-Parts-per-Billion (ppb) Increase in Ozone

Model	Relative Risk Increase in Mortality per 10-ppb Increase in Ozone, % (95% CI)	*P* Value for Effect Modification	Absolute Risk Difference in Mortality, No. per 1 Million at Risk per Day (95% CI)	*P* Value for Effect Modification
Sex				
Male	0.44 (0.30-0.59)	[Reference]	0.61 (0.41-0.80)	[Reference]
Female	0.56 (0.43-0.69)	.23	0.69 (0.53-0.85)	.53
Medicaid eligibility				
Noneligible	0.49 (0.38-0.60)	[Reference]	0.56 (0.44-0.69)	[Reference]
Eligible	0.57 (0.36-0.77)	.53	1.29 (0.83-1.76)	.003[a]
Race/ethnicity				
White	0.51 (0.40-0.61)	[Reference]	0.65 (0.52-0.79)	[Reference]
Nonwhite	0.54 (0.28-0.80)	.81	0.69 (0.36-1.01)	.85
Age, y				
≤69	0.69 (0.17-1.21)	[Reference]	0.33 (0.08-0.57)	[Reference]
70-74	1.18 (0.73-1.63)	.16	0.86 (0.53-1.19)	.01[a]
75-84	1.30 (1.03-1.57)	.04[a]	1.87 (1.48-2.25)	<.001[a]
≥85	1.83 (1.55-2.11)	<.001[a]	6.54 (5.56-7.52)	<.001[a]
Population density				
Low	0.56 (0.35-0.78)	[Reference]	0.73 (0.45-1.00)	[Reference]
Medium low	0.51 (0.31-0.70)	.72	0.65 (0.40-0.90)	.68
Medium high	0.38 (0.20-0.57)	.22	0.49 (0.26-0.72)	.20
High	0.66 (0.48-0.85)	.49	0.85 (0.62-1.09)	.498
Whites				
Sex				
Male	0.44 (0.28-0.59)	[Reference]	0.60 (0.38-0.81)	[Reference]
Female	0.56 (0.42-0.70)	.24	0.69 (0.52-0.87)	.48
Medicaid eligibility				
Noneligible	0.50 (0.39-0.61)	[Reference]	0.58 (0.44-0.71)	[Reference]
Eligible	0.54 (0.29-0.78)	.78	1.44 (0.79-2.09)	.01[a]
Nonwhites				
Sex				
Male	0.50 (0.11-0.89)	[Reference]	0.70 (0.16-1.24)	[Reference]
Female	0.57 (0.22-0.92)	.79	0.67 (0.26-1.08)	.93
Medicaid eligibility				
Noneligible	0.43 (0.08-0.78)	[Reference]	0.46 (0.09-0.83)	[Reference]
Eligible	0.65 (0.27-1.03)	.42	1.07 (0.44-1.69)	.10
Medicaid eligibility, males				
Noneligible	0.40 (0.25-0.56)	[Reference]	0.51 (0.31-0.71)	[Reference]
Eligible	0.65 (0.28-1.02)	.24	1.56 (0.67-2.45)	.03[a]
Medicaid eligibility, females				
Noneligible	0.58 (0.42-0.73)	[Reference]	0.60 (0.44-0.76)	[Reference]
Eligible	0.53 (0.28-0.77)	.75	1.17 (0.63-1.72)	.049[a]
Overall	0.51 (0.41-0.61)		0.66 (0.53-0.78)	



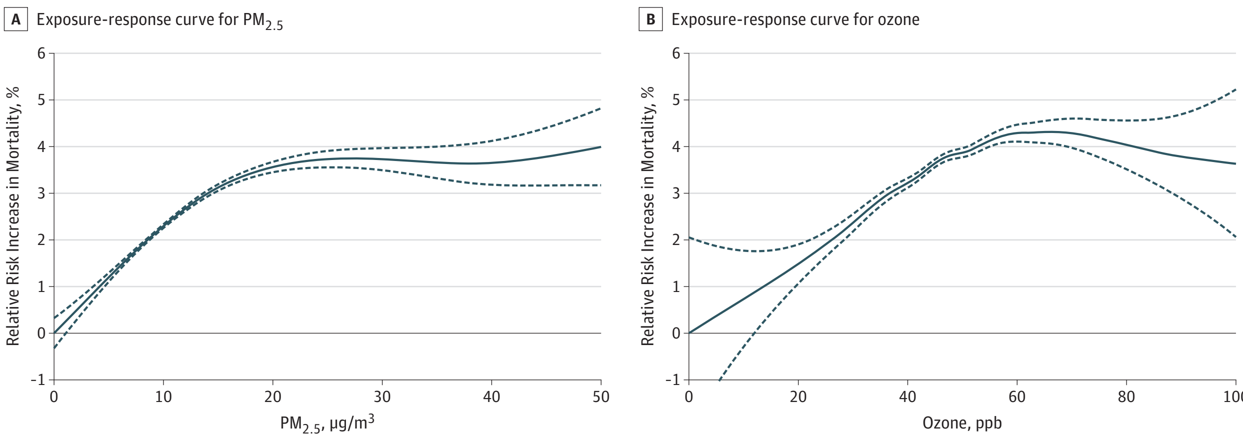


For the main analysis, subgroup analyses used a 2-pollutant analysis (with both $PM_{2.5}$ and ozone), based on the mean of daily exposure on the same day of death and 1 day prior (lag 01-day) as the exposure metric for ozone, and controlled for natural splines of air and dew point temperatures (each with 3 *df*). Vertical lines indicate effects for the entire study population. Subgroup analyses were conducted for each subgroup (eg, male or female, white or nonwhite, Medicare eligible or Medicare ineligible, age groups, and quartiles of population density). For the main analysis and each subgroup, conditional logistic regressions were run to obtain relative risk increases, and calculated absolute risk difference based on baseline mortality rates (eAppendix 2 in the Supplement). For ozone, analyses were restricted to the warm season (April to September). Numbers in the figure represent point estimates, 95% CIs, and *P* values for effect modifications. The reference groups were used when assessing effect modification.

[a] Statistically significant effect estimate (at 5% level) compared with the reference group.

The current NAAQS for daily $PM_{2.5}$ is 35 µg/m^3. When restricting the analysis to daily $PM_{2.5}$ levels below 25 µg/m^3, the association between short-term $PM_{2.5}$ exposure and mortality remained but was elevated. The current daily NAAQS for ozone is 70 ppb; when restricting the analysis to daily warm-season ozone concentrations below 60 ppb, the effect size also increased slightly. The exposure-response curves revealed a similar pattern. These results indicate

Figure 5. Estimated Exposure-Response Curves for Short-term Exposures to Fine Particulate Matter ($PM_{2.5}$) and Ozone



A 2-pollutant analysis with separate penalized splines on $PM_{2.5}$ (A) and ozone (B) was conducted to assess the percentage increase in daily mortality at various pollution levels. Dashed lines indicate 95% CIs. The mean of daily exposure on the same day of death and 1 day prior (lag 01-day) was used as metrics of exposure to $PM_{2.5}$ and ozone. Analysis for ozone was restricted to the warm season (April to September). Ppb indicates parts per billion.

that air pollution is associated with an increase in daily mortality rates, even at levels well below the current standards.

The exposure-response relationship between $PM_{2.5}$ exposure and mortality was consistent with findings of previous studies. One study combined exposure-response curves from 22 European cities and reported an almost linear relationship between $PM_{2.5}$ and mortality.[22] Another multicity study reported a linear relationship down to 2-µg/m^3 $PM_{2.5}$.[23] The present study found a similarly linear exposure-response relationship below 15-µg/m^3 $PM_{2.5}$ and a less steep slope above this level.

For ozone, the linear exposure-response curve with no threshold described in this study is consistent with earlier research. An almost linear exposure-response curve for ozone was previously reported with no threshold or a threshold at very low concentrations.[24] A study from the Netherlands also concluded that if an ozone threshold exists, it does so at very low levels.[25]

Findings from this study are also consistent with the literature regarding the observed effect sizes of both $PM_{2.5}$[5,8,16,26-28] and ozone.[7,20,29,30] This study further demonstrates that in more recent years, during which air pollution concentrations have fallen, statistically significant associations between mortality and exposures to $PM_{2.5}$ and ozone persisted.

The association of mortality and $PM_{2.5}$ exposure is supported by a large number of published experimental studies in animals[31-33] and in humans exposed to traffic air pollution,[34,35] diesel particles,[36] and unfiltered urban air.[37] Similarly, a review of toxicological studies and a recent panel study found that ozone exposure was associated with multiple adverse health outcomes.[38,39]

Strengths

This study has several strengths. First, to our knowledge, this is the largest analysis of daily air pollution exposure and mortality to date, with approximately 4 times the number of deaths included in a previous large study.[5] Second, this study assessed daily exposures using air pollution prediction models that provide accurate estimates of daily levels of $PM_{2.5}$ and ozone for most of the United States, including previously unmonitored areas. An analysis that relied only on exposure data from monitoring stations was found to result in a downward bias in estimates (Table 2). Third, the inclusion of more than 22 million deaths from 2000 to 2012 from the entire Medicare population provided large statistical power to detect differences in mortality rates in potentially vulnerable populations and to estimate mortality rates at very low $PM_{2.5}$ and ozone concentrations. Fourth, this study estimated the air pollution-mortality association well below the current daily NAAQS and in unmonitored areas, and it did not identify significant differences in the mortality rate increase between urban and rural areas. Fifth, this study used a case-crossover design that individually matched potential confounding factors by month, year, and other time-invariant variables and controlled for time-varying patterns, as demonstrated by the minimal differences in meteorological variables between case and control days.

Limitations

This study also has several limitations. First, the case-crossover design does not allow estimation of mortality rate increase associated with long-term exposure to air pollution. Long-term risks in the same study population have been estimated elsewhere.[40] Second, because this study used residential zip code to ascertain exposure level rather than exact home address or place of death, some measurement error is expected. Third, the Medicare population primarily consists of individuals older than 65 years, which limits the generalizability of findings to younger populations. However, because more than two-thirds of deaths in the United States occur in people older than 65 years of age, and air pollution–related health risk rises with age, the Medicare population in this study includes most cases of air pollution–induced mortality. Fourth, Medicare files do not report cause-specific mortality. Fifth, the most recent data used in this study are nearly 5 years old, and it is uncertain whether exposures and outcomes would be the same with more current data.

Conclusions

In the US Medicare population from 2000 to 2012, short-term exposures to $PM_{2.5}$ and warm-season ozone were significantly associated with increased risk of mortality. This risk occurred at levels below current national air quality standards, suggesting that these standards may need to be reevaluated.

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Author Contributions: Mr Di had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Mr Di and Dr Dai contributed equally to this study.
Concept and design: Di, Dai, Zanobetti, Schwartz, Dominici.
Acquisition, analysis, or interpretation of data: All authors.
Drafting of the manuscript: Di, Dai, Choirat, Dominici.
Critical revision of the manuscript for important intellectual content: All authors.
Statistical analysis: Di, Dai, Choirat, Schwartz, Dominici.
Obtained funding: Zanobetti, Schwartz, Dominici.
Administrative, technical, or material support: Wang, Choirat.
Supervision: Zanobetti, Schwartz, Dominici.

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EXHIBIT 2

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Air Pollution and Mortality in the Medicare Population

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ABSTRACT

BACKGROUND
Studies have shown that long-term exposure to air pollution increases mortality. However, evidence is limited for air-pollution levels below the most recent National Ambient Air Quality Standards. Previous studies involved predominantly urban populations and did not have the statistical power to estimate the health effects in underrepresented groups.

METHODS
We constructed an open cohort of all Medicare beneficiaries (60,925,443 persons) in the continental United States from the years 2000 through 2012, with 460,310,521 person-years of follow-up. Annual averages of fine particulate matter (particles with a mass median aerodynamic diameter of less than 2.5 μm [$PM_{2.5}$]) and ozone were estimated according to the ZIP Code of residence for each enrollee with the use of previously validated prediction models. We estimated the risk of death associated with exposure to increases of 10 μg per cubic meter for $PM_{2.5}$ and 10 parts per billion (ppb) for ozone using a two-pollutant Cox proportional-hazards model that controlled for demographic characteristics, Medicaid eligibility, and area-level covariates.

RESULTS
Increases of 10 μg per cubic meter in $PM_{2.5}$ and of 10 ppb in ozone were associated with increases in all-cause mortality of 7.3% (95% confidence interval [CI], 7.1 to 7.5) and 1.1% (95% CI, 1.0 to 1.2), respectively. When the analysis was restricted to person-years with exposure to $PM_{2.5}$ of less than 12 μg per cubic meter and ozone of less than 50 ppb, the same increases in $PM_{2.5}$ and ozone were associated with increases in the risk of death of 13.6% (95% CI, 13.1 to 14.1) and 1.0% (95% CI, 0.9 to 1.1), respectively. For $PM_{2.5}$, the risk of death among men, blacks, and people with Medicaid eligibility was higher than that in the rest of the population.

CONCLUSIONS
In the entire Medicare population, there was significant evidence of adverse effects related to exposure to $PM_{2.5}$ and ozone at concentrations below current national standards. This effect was most pronounced among self-identified racial minorities and people with low income. (Supported by the Health Effects Institute and others.)

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The adverse health effects associated with long-term exposure to air pollution are well documented.[1,2] Studies suggest that fine particles (particles with a mass median aerodynamic diameter of less than 2.5 μm [$PM_{2.5}$]) are a public health concern,[3] with exposure linked to decreased life expectancy.[4-6] Long-term exposure to ozone has also been associated with reduced survival in several recent studies, although evidence is sparse.[4,7-9]

Studies with large cohorts have investigated the relationship between long-term exposures to $PM_{2.5}$ and ozone and mortality[4,9-13]; others have estimated the health effects of fine particles at low concentrations (e.g., below 12 μg per cubic meter for $PM_{2.5}$).[14-18] However, most of these studies have included populations whose socioeconomic status is higher than the national average and who reside in well-monitored urban areas. Consequently, these studies provide limited information on the health effects of long-term exposure to low levels of air pollution in smaller cities and rural areas or among minorities or persons with low socioeconomic status.

To address these gaps in knowledge, we conducted a nationwide cohort study involving all Medicare beneficiaries from 2000 through 2012, a population of 61 million, with 460 million person-years of follow-up. We used a survival analysis to estimate the risk of death from any cause associated with long-term exposure (yearly average) to $PM_{2.5}$ concentrations lower than the current annual National Ambient Air Quality Standard (NAAQS) of 12 μg per cubic meter and to ozone concentrations below 50 parts per billion (ppb). Subgroup analyses were conducted to identify populations with a higher or lower level of pollution-associated risk of death from any cause.

METHODS

MORTALITY DATA

We obtained the Medicare beneficiary denominator file from the Centers for Medicare and Medicaid Services, which contains information on all persons in the United States covered by Medicare and more than 96% of the population 65 years of age or older. We constructed an open cohort consisting of all beneficiaries in this age group in the continental United States from 2000 through 2012, with all-cause mortality as the outcome. For each beneficiary, we extracted the date of death (up to December 31, 2012), age at year of Medicare entry, year of entry, sex, race, ZIP Code of residence, and Medicaid eligibility (a proxy for low socioeconomic status). Persons who were alive on January 1 of the year following their enrollment in Medicare were entered into the open cohort for the survival analysis. Follow-up periods were defined according to calendar years.

ASSESSMENT OF EXPOSURE TO AIR POLLUTION

Ambient levels of ozone and $PM_{2.5}$ were estimated and validated on the basis of previously published prediction models.[19,20] Briefly, we used an artificial neural network that incorporated satellite-based measurements, simulation outputs from a chemical transport model, land-use terms, meteorologic data, and other data to predict daily concentrations of $PM_{2.5}$ and ozone at unmonitored locations. We fit the neural network with monitoring data from the Environmental Protection Agency (EPA) Air Quality System (AQS) (in which there are 1928 monitoring stations for $PM_{2.5}$ and 1877 monitoring stations for ozone). We then predicted daily $PM_{2.5}$ and ozone concentrations for nationwide grids that were 1 km by 1 km. Cross-validation indicated that predictions were good across the entire study area. The coefficients of determination (R^2) for $PM_{2.5}$ and ozone were 0.83 and 0.80, respectively; the mean square errors between the target and forecasting values for $PM_{2.5}$ and ozone were 1.29 μg per cubic meter and 2.91 ppb, respectively. Data on daily air temperature and relative humidity were retrieved from North American Regional Reanalysis with grids that were approximately 32 km by 32 km; data were averaged annually.[21]

For each calendar year during which a person was at risk of death, we assigned to that person a value for the annual average $PM_{2.5}$ concentration, a value for average ozone level during the warm season (April 1 through September 30), and values for annual average temperature and humidity according to the ZIP Code of the person's residence. The warm-season ozone concentration was used to compare our results with those of previous studies.[10] In this study, "ozone concentration" refers to the average concentration during the warm season, unless specified otherwise.

As part of a sensitivity analysis, we also obtained data on $PM_{2.5}$ and ozone concentrations from the EPA AQS and matched that data with each person in our study on the basis of the nearest monitoring site within a distance of 50 km. (Details are provided in Section 1 in the Supplementary Appendix, available with the full text of this article at NEJM.org.)

STATISTICAL ANALYSIS

We fit a two-pollutant Cox proportional-hazards model with a generalized estimating equation to account for the correlation between ZIP Codes.[22] In this way, the risk of death from any cause associated with long-term exposure to $PM_{2.5}$ was always adjusted for long-term exposure to ozone, and the risk of death from any cause associated with long-term exposure to ozone was always adjusted for long-term exposure to $PM_{2.5}$, unless noted otherwise. We also conducted single-pollutant analyses for comparability. We allowed baseline mortality rates to differ according to sex, race, Medicaid eligibility, and 5-year categories of age at study entry. To adjust for potential confounding, we also obtained 15 ZIP-Code or county-level variables from various sources and a regional dummy variable to account for compositional differences in $PM_{2.5}$ across the United States (Table 1, and Section 1 in the Supplementary Appendix). We conducted this same statistical analysis but restricted it to person-years with $PM_{2.5}$ exposures lower than 12 μg per cubic meter and ozone exposures lower than 50 ppb (low-exposure analysis) (Table 1, and Section 1 in the Supplementary Appendix).

To identify populations at a higher or lower pollution-associated risk of death from any cause, we refit the same two-pollutant Cox model for some subgroups (e.g., male vs. female, white vs. black, and Medicaid eligible vs. Medicaid ineligible). To estimate the concentration-response function of air pollution and mortality, we fit a log-linear model with a thin-plate spline of both $PM_{2.5}$ and ozone and controlled for all the individual and ecologic variables used in our main analysis model (Section 7 in the Supplementary Appendix). To examine the robustness of our results, we conducted sensitivity analyses and compared the extent to which estimates of risk changed with respect to differences in confounding adjustment and estimation approaches (Sections S2 through S4 in the Supplementary Appendix).

Data on some important individual-level covariates were not available for the Medicare cohort, including data on smoking status, body-mass index (BMI), and income. We obtained data from the Medicare Current Beneficiary Survey (MCBS), a representative subsample of Medicare enrollees (133,964 records and 57,154 enrollees for the period 2000 through 2012), with individual-level data on smoking, BMI, income, and many other variables collected by means of telephone survey. Using MCBS data, we investigated how the lack of adjustment for these risk factors could have affected our calculated risk estimates in the Medicare cohort (Section 5 in the Supplementary Appendix). The computations in this article were run on the Odyssey cluster, which is supported by the FAS Division of Science, Research Computing Group, and on the Research Computing Environment, which is supported by the Institute for Quantitative Social Science in the Faculty of Arts and Sciences, both at Harvard University. We used R software, version 3.3.2 (R Project for Statistical Computing), and SAS software, version 9.4 (SAS Institute).

RESULTS

COHORT ANALYSES

The full cohort included 60,925,443 persons living in 39,716 different ZIP Codes with 460,310,521 person-years of follow-up. The median follow-up was 7 years. The total number of deaths was 22,567,924. There were 11,908,888 deaths and 247,682,367 person-years of follow-up when the $PM_{2.5}$ concentration was below 12 μg per cubic meter and 17,470,128 deaths and 353,831,836 person-years of follow-up when the ozone concentration was below 50 ppb. These data provided excellent power to estimate the risk of death at air-pollution levels below the current annual NAAQS for $PM_{2.5}$ and at low concentrations for ozone (Table 1).

Annual average $PM_{2.5}$ concentrations across the continental United States during the study period ranged from 6.21 to 15.64 μg per cubic meter (5th and 95th percentiles, respectively), and the warm-season average ozone concentrations ranged from 36.27 to 55.86 ppb (5th and 95th percentiles, respectively). The highest $PM_{2.5}$ concentrations were in California and the eastern and southeastern United States. The Mountain region and California had the highest ozone concentrations; the eastern states had lower ozone concentrations (Fig. 1).

Table 1. Cohort Characteristics and Ecologic and Meteorologic Variables.

Characteristic or Variable	Entire Cohort	Ozone Concentration		$PM_{2.5}$ Concentration	
		≥50 ppb*	<50 ppb	≥12 $\mu g/m^3$	<12 $\mu g/m^3$
Population					
Persons (no.)	60,925,443	14,405,094	46,520,349	28,145,493	32,779,950
Deaths (no.)	22,567,924	5,097,796	17,470,128	10,659,036	11,908,888
Total person-yr†	460,310,521	106,478,685	353,831,836	212,628,154	247,682,367
Median yr of follow-up	7	7	7	7	7
Average air-pollutant concentrations‡					
Ozone (ppb)	46.3	52.8	44.4	48.0	45.3
$PM_{2.5}$ ($\mu g/m^3$)	11.0	10.9	11.0	13.3	9.6
Individual covariates‡					
Male sex (%)	44.0	44.3	43.8	43.1	44.7
Race or ethnic group (%)§					
White	85.4	86.6	85.1	82.0	88.4
Black	8.7	7.2	9.2	12.0	5.9
Asian	1.8	1.8	1.8	2.1	1.6
Hispanic	1.9	2.0	1.9	1.9	1.9
Native American	0.3	0.6	0.3	0.1	0.6
Eligible for Medicaid (%)	16.5	15.3	16.8	17.8	15.3
Average age at study entry (yr)	70.1	69.7	70.2	70.1	70.0
Ecologic variables‡					
BMI	28.2	27.9	28.4	28.0	28.4
Ever smoked (%)	46.0	44.9	46.2	45.8	46.0
Population including all people 65 yr of age or older (%)					
Hispanic	9.5	13.4	8.4	8.4	10.0
Black	8.8	7.2	9.3	13.3	6.3
Median household income (1000s of $)	47.4	51.0	46.4	47.3	47.4
Median value of housing (1000s of $)	160.5	175.8	156.3	161.7	159.8
Below poverty level (%)	12.2	11.4	12.4	12.5	12.0
Did not complete high school (%)	32.3	30.7	32.7	35.3	30.6
Owner-occupied housing (%)	71.5	71.3	71.6	68.6	73.2
Population density (persons/km^2)	3.2	0.7	3.8	4.8	2.2
Low-density lipoprotein level measured (%)	92.2	92.0	92.2	92.2	92.2
Glycated hemoglobin level measured (%)	94.8	94.6	94.8	94.8	94.8
≥1 Ambulatory visits (%)¶	91.7	92.2	91.6	91.7	91.7
Meteorologic variables‡					
Average temperature (°C)	14.0	14.9	13.8	14.5	13.7
Relative humidity (%)	71.1	60.8	73.9	73.7	69.6

* Summary statistics were calculated separately for persons residing in ZIP Codes where average ozone levels were below or above 50 ppb and where $PM_{2.5}$ levels were below or above 12 μg per cubic meter. The value 12 μg per cubic meter was chosen as the current annual National Ambient Air Quality Standard (NAAQS) (e.g., the "safe" level) for $PM_{2.5}$. BMI denotes body-mass index (the weight in kilograms divided by the square of the height in meters) and ppb parts per billion.
† The number for total person-years of follow-up indicates the sum of individual units of time that the persons in the study population were at risk of death from 2000 through 2012.
‡ The average values for air pollution levels and for ecologic and meteorologic variables were computed by averaging values over all ZIP Codes from 2000 through 2012.
§ Data on race and ethnic group were obtained from Medicare beneficiary files.
¶ The variable for ambulatory visits refers to the average annual percentage of Medicare enrollees who had at least one ambulatory visit to a primary care physician.

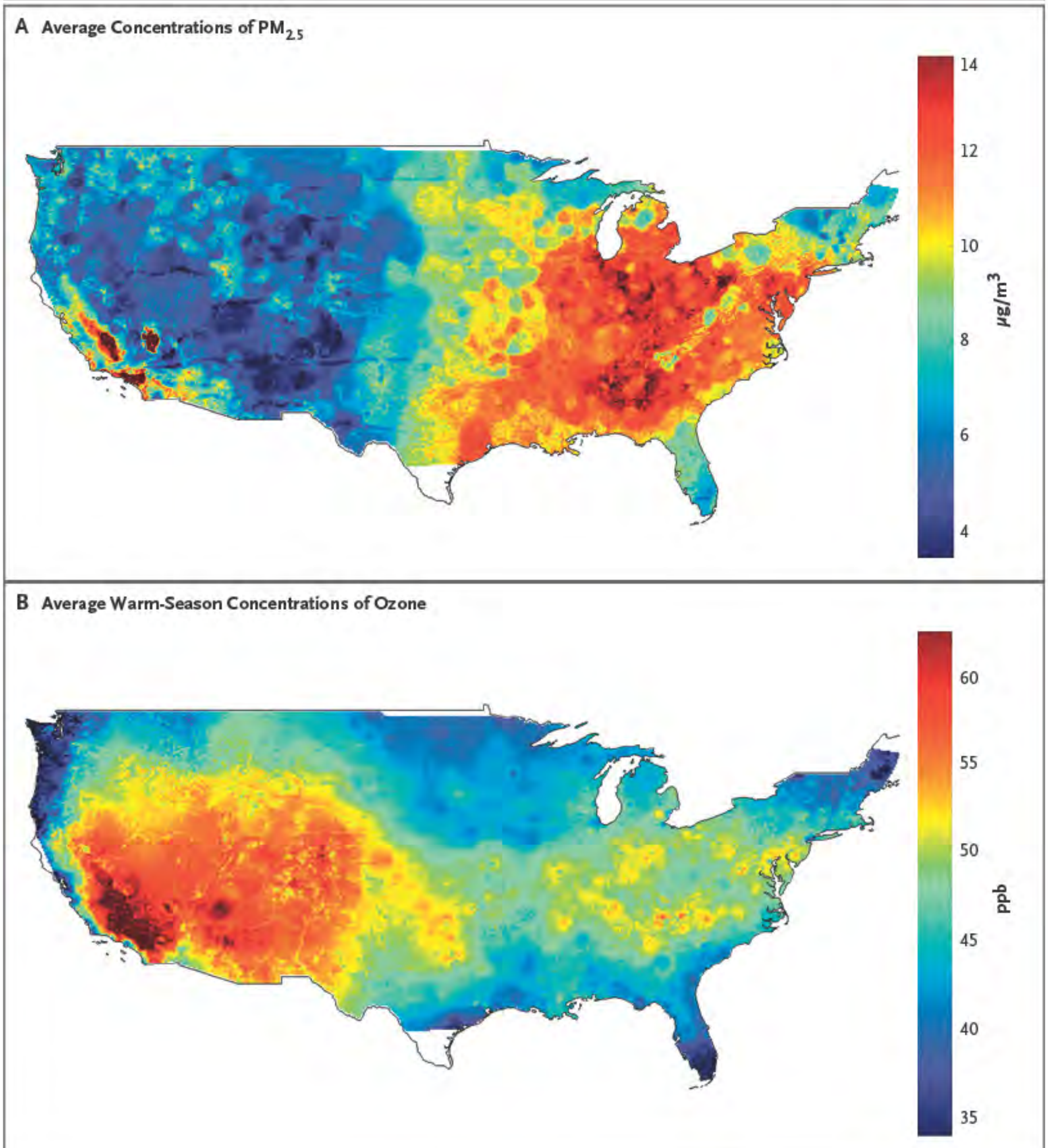

Figure 1. Average $PM_{2.5}$ and Ozone Concentrations in the Continental United States, 2000 through 2012.
Panel A shows the average concentrations of fine particulate matter (particles with a mass median aerodynamic diameter of less than 2.5 μm [$PM_{2.5}$]) in micrograms per cubic meter, as estimated on the basis of all daily predictions during the study period. Panel B shows the concentration of ozone levels in parts per billion as averaged from April 1 through September 30 throughout the study period.

In a two-pollutant analysis, each increase of 10 μg per cubic meter in annual exposure to $PM_{2.5}$ (estimated independently of ozone) and each increase of 10 ppb in warm-season exposure to ozone (estimated independently of $PM_{2.5}$) was associated with an increase in all-cause mortality of 7.3% (95% confidence interval [CI], 7.1 to 7.5) and 1.1% (95% CI, 1.0 to 1.2), respectively. Estimates of risk based on predictive, ZIP-Code–specific assessments of exposure were slightly higher than those provided by the nearest data-monitoring site (Table 2). When we restricted the $PM_{2.5}$ and ozone analyses to location-years with low concentrations, we continued to see significant associations between exposure and mortality (Table 2). Analysis of the MCBS

Table 2. Risk of Death Associated with an Increase of 10 μg per Cubic Meter in $PM_{2.5}$ or an Increase of 10 ppb in Ozone Concentration.*

Model	$PM_{2.5}$	Ozone
	hazard ratio (95% CI)	
Two-pollutant analysis		
Main analysis	1.073 (1.071–1.075)	1.011 (1.010–1.012)
Low-exposure analysis	1.136 (1.131–1.141)	1.010 (1.009–1.011)
Analysis based on data from nearest monitoring site (nearest-monitor analysis)†	1.061 (1.059–1.063)	1.001 (1.000–1.002)
Single-pollutant analysis‡	1.084 (1.081–1.086)	1.023 (1.022–1.024)

* Hazard ratios and 95% confidence intervals were calculated on the basis of an increase of 10 μg per cubic meter in exposure to $PM_{2.5}$ and an increase of 10 ppb in exposure to ozone.

† Daily average monitoring data on $PM_{2.5}$ and ozone were obtained from the Environmental Protection Agency Air Quality System. Daily ozone concentrations were averaged from April 1 through September 30 for the computation of warm-season averages. Data on $PM_{2.5}$ and ozone levels were obtained from the nearest monitoring site within 50 km. If there was more than one monitoring site within 50 km, the nearest site was chosen. Persons who lived more than 50 km from a monitoring site were excluded.

‡ For the single-pollutant analysis, model specifications were the same as those used in the main analysis, except that ozone was not included in the model when the main effect of $PM_{2.5}$ was estimated and $PM_{2.5}$ was not included in the model when the main effect of ozone was estimated.

subsample provided strong evidence that smoking and income are not likely to be confounders because they do not have a significant association with $PM_{2.5}$ or ozone (Section 5 in the Supplementary Appendix).

SUBGROUP ANALYSES

Subgroup analyses revealed that men; black, Asian, and Hispanic persons; and persons who were eligible for Medicaid (i.e., those who had low socioeconomic status) had a higher estimated risk of death from any cause in association with $PM_{2.5}$ exposure than the general population. The risk of death associated with ozone exposure was higher among white, Medicaid-eligible persons and was significantly below 1 in some racial subgroups (Fig. 2). Among black persons, the effect estimate for $PM_{2.5}$ was three times as high as that for the overall population (Table S3 in the Supplementary Appendix). Overall, the risk of death associated with ozone exposure was smaller and somewhat less robust than that associated with $PM_{2.5}$ exposure. We also detected a small but significant interaction between ozone exposure and $PM_{2.5}$ exposure (Table S8 in the Supplementary Appendix). Our thin-plate–spline fit indicated a relationship between $PM_{2.5}$, ozone, and all-cause mortality that was almost linear, with no signal of threshold down to 5 μg per cubic meter and 30 ppb, respectively (Fig. 3, and Fig. S8 in the Supplementary Appendix).

DISCUSSION

This study involving an open cohort of all persons receiving Medicare, including those from small cities and rural areas, showed that long-term exposures to $PM_{2.5}$ and ozone were associated with an increased risk of death, even at levels below the current annual NAAQS for $PM_{2.5}$. Furthermore, the study showed that black men and persons eligible to receive Medicaid had a much higher risk of death associated with exposure to air pollution than other subgroups. These findings suggest that lowering the annual NAAQS may produce important public health benefits overall, especially among self-identified racial minorities and people with low income.

The strengths of this study include the assessment of exposure with high spatial and temporal resolution, the use of a cohort of almost 61 million Medicare beneficiaries across the entire continental United States followed for up to 13 consecutive years, and the ability to perform subgroup analyses of the health effects of air pollution on groups of disadvantaged persons. However, Medicare claims do not include extensive individual-level data on behavioral risk fac-

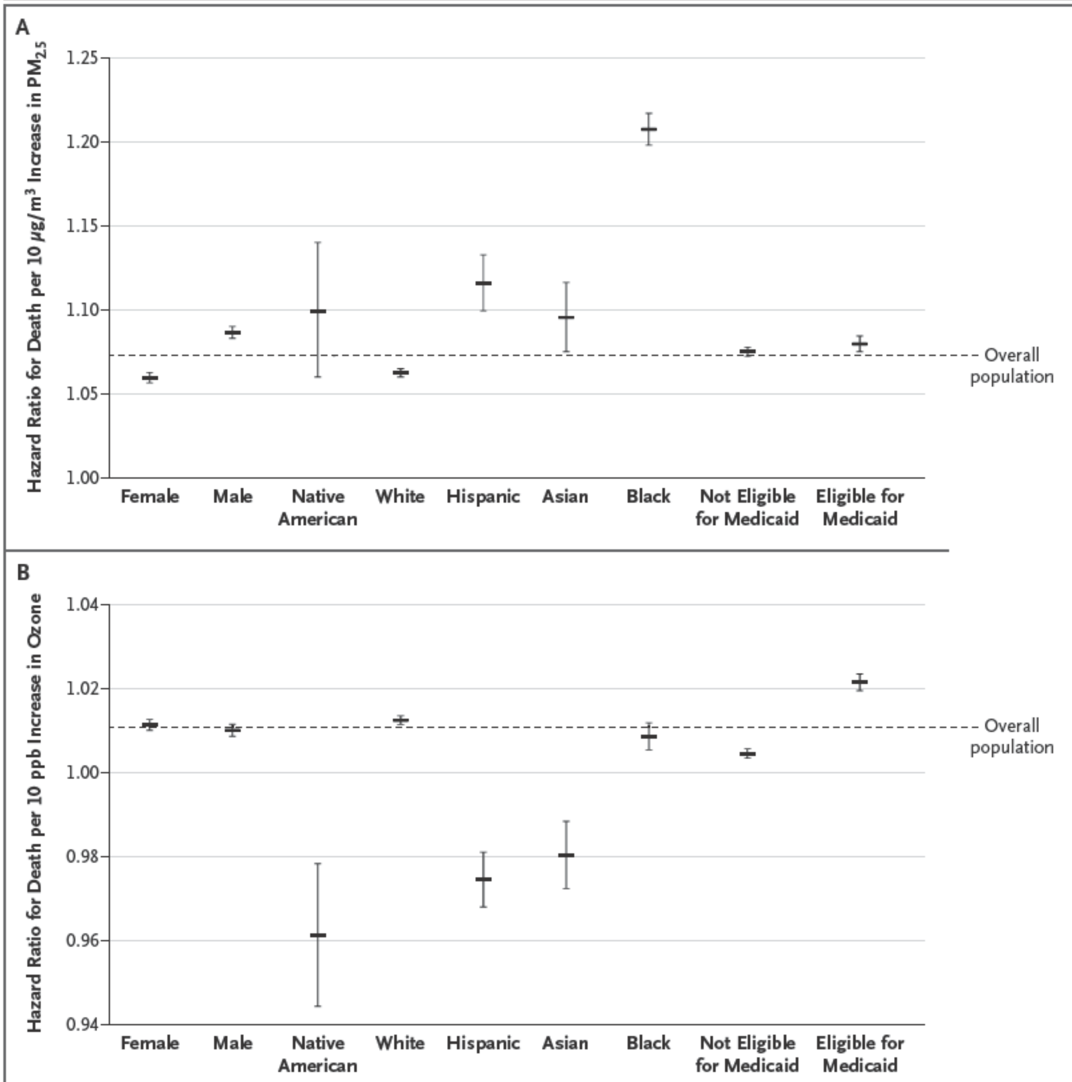

Figure 2. Risk of Death Associated with an Increase of 10 μg per Cubic Meter in $PM_{2.5}$ Concentrations and an Increase of 10 ppb in Ozone Exposure, According to Study Subgroups.

Hazard ratios and 95% confidence intervals are shown for an increase of 10 μg per cubic meter in $PM_{2.5}$ and an increase of 10 parts per billion (ppb) in ozone. Subgroup analyses were conducted by first restricting the population (e.g., considering only male enrollees). The same two-pollutant analysis (the main analysis) was then applied to each subgroup. Numeric results are presented in Tables S3 and S4 in the Supplementary Appendix. Dashed lines indicate the estimated hazard ratio for the overall population.

tors, such as smoking and income, which could be important confounders. Still, our analysis of the MCBS subsample (Table S6 in the Supplementary Appendix) increased our level of confidence that the inability to adjust for these individual-level risk factors in the Medicare cohort did not lead to biased results (Section 5 in the Supplementary Appendix). In another study, we analyzed a similar Medicare subsample with detailed individual-level data on smoking, BMI, and many other potential confounders linked to Medicare claims.[23] In that analysis, we found that for mortality and hospitalization, the risks of exposure to $PM_{2.5}$ were not sensitive to the additional control of individual-level variables that were not available in the whole Medicare population.

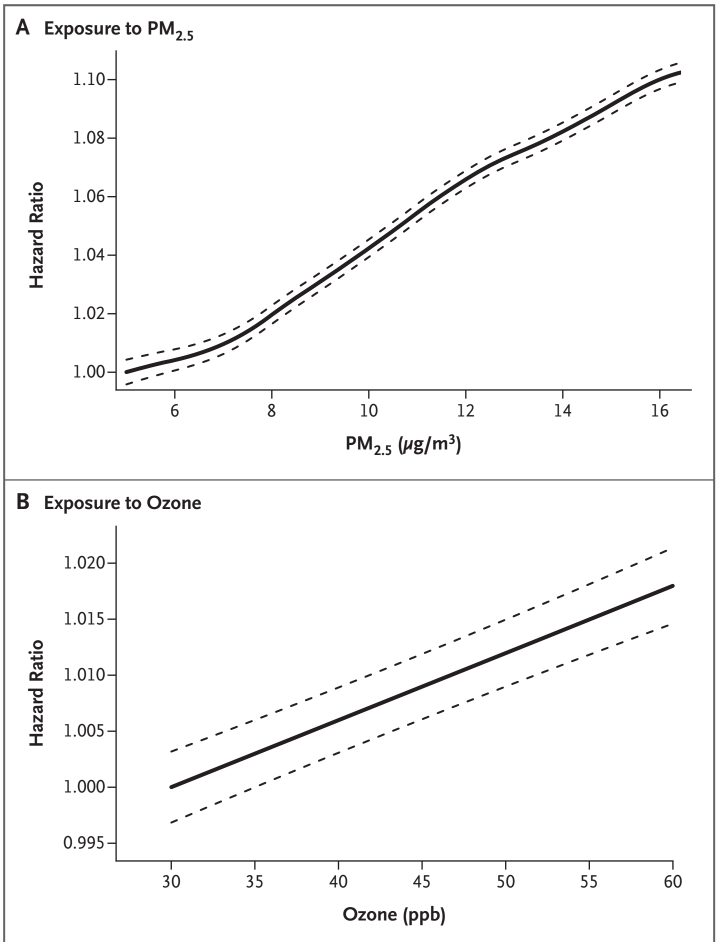

Figure 3. Concentration–Response Function of the Joint Effects of Exposure to $PM_{2.5}$ and Ozone on All-Cause Mortality.

A log-linear model with a thin-plate spline was fit for both $PM_{2.5}$ and ozone, and the shape of the concentration-response surface was estimated (Fig. S8 in the Supplementary Appendix). The concentration–response curve in Panel A was plotted for an ozone concentration equal to 45 ppb. The concentration–response curve in Panel B was plotted for a $PM_{2.5}$ concentration equal to 10 μg per cubic meter. These estimated curves were plotted at the 5th and 95th percentiles of the concentrations of $PM_{2.5}$ and ozone, respectively. The complete concentration–response three-dimensional surface is plotted in Fig. S8 in the Supplementary Appendix.

We also found that our results were robust when we excluded individual and ecologic covariates from the main analysis (Fig. S2 and Table S2 in the Supplementary Appendix), when we stratified age at entry into 3-year and 4-year categories rather than the 5 years used in the main analysis (Fig. S3 in the Supplementary Appendix), when we varied the estimation procedure (by means of a generalized estimating equation as opposed to mixed effects) (Tables S3 and S4 in the Supplementary Appendix), and when we used different types of statistical software (R, version 3.3.2, vs. SAS, version 9.4). Finally, we found that our results were consistent with others published in the literature (Section 6 in the Supplementary Appendix).[5,17,24-28]

There was a significant association between $PM_{2.5}$ exposure and mortality when the analysis was restricted to concentrations below 12 μg per cubic meter, with a steeper slope below that level. This association indicated that the health-benefit-per-unit decrease in the concentration of $PM_{2.5}$ is larger for $PM_{2.5}$ concentrations that are below the current annual NAAQS than the health benefit of decreases in $PM_{2.5}$ concentrations that are above that level. Similar, steeper concentration-response curves at low concentrations have been observed in previous studies.[29] Moreover, we found no evidence of a threshold value — the concentration at which $PM_{2.5}$ exposure does not affect mortality — at concentrations as low as approximately 5 μg per cubic meter (Fig. 3); this finding is similar to those of other studies.[18,30]

The current ozone standard for daily exposure is 70 ppb; there is no annual or seasonal standard. Our results strengthen the argument for establishing seasonal or annual standards. Moreover, whereas time-series studies have shown the short-term effects of ozone exposure, our results indicate that there are larger effect sizes for longer-term ozone exposure, including in locations where ozone concentrations never exceed 70 ppb. Unlike the American Cancer Society Cancer Prevention Study II,[9,10] our study reported a linear connection between ozone concentration and mortality. This finding is probably the result of the interaction between $PM_{2.5}$ and ozone (Section 7 in the Supplementary Appendix). The significant, linear relationship between seasonal ozone levels and all-cause mortality indicates that current risk assessments,[31-33] which incorporate only the acute effects of ozone exposure on deaths each day from respiratory mortality, may be substantially underestimating the contribution of ozone exposure to the total burden of disease.

The enormous sample size in this study, which includes the entire Medicare cohort, allowed for unprecedented accuracy in the estimation of risks among racial minorities and disadvantaged subgroups. The estimate of effect size for $PM_{2.5}$ exposure was greatest among male, black, and Medicaid-eligible persons. We also estimated risks in subgroups of persons who were eligible for Medicaid and in whites and blacks alone to ascertain whether the effect modifications according to race and Medicaid status were independent. We found that black persons who were not eligible for Medicaid (e.g., because of higher income) continued to have an increased risk of death from exposure to $PM_{2.5}$ (Fig. S4 in the Supplementary Appendix). In addition, we found that there was a difference in the health effects of $PM_{2.5}$ exposure between urban and rural populations, a finding that may be due to compositional differences in the particulates (Table S3 Supplementary Appendix).

Although the Medicare cohort includes only the population of persons 65 years of age or older, two thirds of all deaths in the United States occur in people in that age group. Although our exposure models had excellent out-of-sample predictive power on held-out monitors, they do have limitations. Error in exposure assessment remains an issue in this type of analysis and could attenuate effect estimates for air pollution.[34]

The overall association between air pollution and human health has been well documented since the publication of the landmark Harvard Six Cities Study in 1993.[25] With air pollution declining, it is critical to estimate the health effects of low levels of air pollution — below the current NAAQS — to determine whether these levels are adequate to minimize the risk of death. Since the Clean Air Act requires the EPA to set air-quality standards that protect sensitive populations, it is also important to focus more effort on estimating effect sizes in potentially sensitive populations in order to inform regulatory policy going forward.

The views expressed in this article are those of the authors and do not necessarily represent the official views of the funding agencies. Furthermore, these agencies do not endorse the purchase of any commercial products or services related to this publication.

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No potential conflict of interest relevant to this article was reported.

Disclosure forms provided by the authors are available with the full text of this article at NEJM.org.

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EXHIBIT 3

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

FEB - 3 2012

OFFICE OF
AIR AND RADIATION

The Honorable Fred Upton
Chairman
Committee on Energy and Commerce
U.S. House of Representatives
Washington, D.C. 20515

Dear Mr. Chairman:

Thank you for your letter of December 14, 2011, to Administrator Lisa Jackson, co-signed by three of your colleagues, requesting additional information regarding the Environmental Protection Agency's estimates of the public health benefits expected to result from regulatory actions. The Administrator has asked me to respond on her behalf.

Your letter raises several questions about our benefits estimates for reducing fine particle pollution. We believe the health improvements achieved by reducing fine particle exposures represent real benefits to real people, and it is appropriate to provide information to decisionmakers and the public about these expected benefits of cleaner air. These estimates are incorporated in Regulatory Impact Analyses (RIAs), which help inform decisionmakers and the public about the potential benefits and costs of our proposed and final rules. The benefits estimates and RIAs are developed and reviewed as part of the normal rulemaking process, including interagency review and public notice and comment. We prepare these estimates for all economically significant rules. Although we strive to make these analyses as complete as possible, there are often many benefits that cannot be quantified, including a number of significant benefits from reducing mercury and other air toxics.

EPA's approach for estimating benefits from reducing fine particle pollution is science-driven. Studies demonstrate an association between premature mortality and fine particle pollution at the lowest levels measured in the relevant studies, levels that are significantly below the NAAQS for fine particles. These studies have not observed a level at which premature mortality effects do not occur. The best scientific evidence, confirmed by independent, Congressionally-mandated expert panels, is that there is no threshold level of fine particle pollution below which health risk reductions are not achieved by reduced exposure. Thus, based on specific advice from scientific peer-review, we project benefits from reducing fine particle pollution below the level of the NAAQS and below the lowest levels measured in the studies.

Using a no-threshold approach to developing our primary benefits estimates for our rules, which was also the approach we took from 1997 to 2006, is warranted by the extensive scientific review reflected in the *Integrated Science Assessment on Particulate Matter* (PM ISA), the first draft of which was prepared by EPA scientists and technical staff and released in December 2008. All drafts of the PM ISA reflect this conclusion that there is no scientific evidence supporting assumption of a threshold for PM effects.

risks. The no-threshold approach, and associated projections of benefits, were also specifically reviewed and approved by the Advisory Council on Clean Air Compliance Analysis, another panel of outside experts established by Congress to review EPA studies of the benefits and costs of the Clean Air Act.

Based on the first draft PM ISA released in December 2008, EPA technical staff incorporated the no-threshold approach in benefits calculations, which were subject to intra- and inter-agency review and public notice and comment. We have followed a no-threshold approach to our primary benefits estimate since then.

Detailed responses to a number of specific questions raised in your letter are addressed in the attachment. We have also provided the key documents cited in this letter on the enclosed disc. Again, the Administrator and I thank you for your letter. If you have further questions, please contact me or your staff may call Josh Lewis in the EPA's Office of Congressional and Intergovernmental Relations at (202) 564-2095.

Sincerely,

Gina McCarthy
Assistant Administrator

Attachment

1. **In the regulatory impact analysis for the Portland Cement rule published September 9, 2010, EPA reported that it has changed its assumption concerning the concentration threshold for $PM_{2.5}$-related mortality: "EPA now estimates PM-related mortality without assuming an arbitrary threshold in the concentration-response function." (August 2010, "Regulatory Impact Analysis: Amendments to the National Emission Standards for Hazardous Air Pollutants and New Source Performance Standards (NSPS) for the Portland Cement Manufacturing Industry, Final Report", Section 6.2.1.)**

   a. Did EPA change its assumption concerning the concentration threshold at which PM is likely to cause premature mortality?

   b. If EPA changed the assumption, explain who gave ultimate direction to change the assumption, when was it changed, and what was the basis for making the change.

   c. If EPA changed the assumption, provide all analyses and briefing or decision memoranda, for the EPA Administrator or EPA Assistant Administrator for Air and Radiation, relating to the change in assumptions.

Response: EPA's approach to estimating health benefits is driven by the scientific evidence regarding the health effects associated with $PM_{2.5}$ exposure at various concentration levels. Our approach is well-established, including accounting for benefits that occur below 15 micrograms per cubic meter ($\mu g/m^3$) (the level of the current annual $PM_{2.5}$ National Ambient Air Quality Standards (NAAQS), which were issued in 2006). The Agency is committed to ensuring that its benefits analyses reflect the latest scientific evidence regarding pollution, health and the environment. As a result, the agency must periodically update its benefits assessment methodology.

From 1997 to 2006, EPA's approach for estimating benefits associated with reducing exposure to fine particles reflected the scientific literature, which indicated that health effects can occur along the entire range of potential exposures. EPA's best estimate of $PM_{2.5}$-related benefits reflected this science and assumed no level below which health effects do not occur (i.e., it assumed no threshold). For benefits analyses conducted during this time, EPA recognized the importance of this assumption and conducted various sensitivity analyses showing the impact this assumption would have on the total monetized benefits. EPA's use of the no-threshold model as the best estimate and our use of sensitivity analysis to evaluate the significance of this approach were both reviewed and supported by the outside experts, including the National Academies of Science[1] and the EPA's independent Science Advisory Board[2,3].

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[1] National Research Council (NRC). 2002. *Estimating the Public Health Benefits of Proposed Air Pollution Regulations*. Washington, DC: The National Academies Press.

[2] U.S. Environmental Protection Agency - Science Advisory Board. 1999. The Clean Air Act Amendments (CAAA) Section 812 Prospective Study of Costs and Benefits (1999): Advisory by the Health and Ecological Effects Subcommittee on Initial Assessments of Health and Ecological Effects; Part 1. EPA-SAB-COUNCIL-ADV-99-012. July. Available on the Internet at http://yosemite.epa.gov/sab/sabproduct.nsf/F64A21824D19766885257193005E51CA/$File/conadv12.pdf

[3] U.S. Environmental Protection Agency - Science Advisory Board (U.S. EPA-SAB). 2004. Advisory on Plans for Health Effects Analysis in the Analytical Plan for EPA's Second Prospective Analysis – Benefits and Costs of the Clean Air Act, 1990-2020. Advisory by the Health Effects Subcommittee of the Advisory Council on Clean Air Compliance Analysis. EPA-SAB-COUNCIL-ADV-04-002. March. Available on the Internet at <http://yosemite.epa.gov/sab%5CSABPRODUCT.NSF/08E1155AD24F871C85256E5400433D5D/$File/council_adv_04002.pdf>.

Based on an ambiguous statement in a 2005 letter from EPA's independent Clean Air Scientific Advisory Committee (CASAC)[4], EPA changed its long-standing approach and applied an assumed threshold for the benefits analysis of the 2006 PM NAAQS. As a result, all regulatory analyses of regulations reducing exposure to $PM_{2.5}$ conducted between 2006 and 2009 reflected an assumption that there were no benefits associated with reducing $PM_{2.5}$ below 10 $\mu g/m^3$.

When EPA scientists and technical experts started work on the initial draft of the *Integrated Science Assessment on Particulate Matter* (PM ISA) in 2008, these scientists and experts reached a conclusion that –based on an extensive review of the body of scientific literature— there was no scientific basis for assuming a threshold in the relationship between PM concentration levels and changes in risk of premature mortality (or other adverse PM-related health effects). This conclusion was reviewed by CASAC and incorporated in the second draft of the PM ISA submitted for CASAC review in 2009. EPA scientists and technical experts updated the approach for assessing $PM_{2.5}$-related benefits to be consistent with the scientific literature. The conclusion in all drafts of the PM ISA is that the scientific literature provides no evidence of a threshold below which health effects associated with exposure to fine particles – including premature death -- would not occur (U.S. EPA, 2009)[5,6]. Based on that review, the Agency discontinued use of an assumed threshold in the calculation of $PM_{2.5}$-related benefits and returned to the prior, peer-reviewed practice of using a no-threshold approach. The absence of an assumed threshold means that estimates of the health benefits of reductions in $PM_{2.5}$ concentrations will again be more complete and consistent with the best science by counting reductions in risk in all locations where air quality is improved, including in areas which start with less-polluted air.

EPA's no-threshold approach has been recently confirmed by two separate, independent peer review panels: the Clean Air Scientific Advisory Committee (CASAC)[7] and the Advisory Council on Clean Air Compliance Analysis (Council).[8]

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[4] The CASAC, in their 2005 consensus advisory letter on the PM staff paper, conveyed an ambiguous recommendation pertaining to assumption of a threshold. U.S. Environmental Protection Agency – Science Advisory Board. 2005. *Review of the National Ambient Air Quality Standards for Particular Matter: Policy Assessment of Scientific and Technical Information (Second Draft PM Staff Paper, January2005); and Particular Matter Health Risk Assessment for Selected Urban Areas: Second Draft Report (Second Draft PM Risk Assessment, January 2005).* U.S. Environmental Protection Agency, Washington, DC, EPA-SAB-CASAC-05-007. Available on the Internet at http://yosemite.epa.gov/sab/sabproduct.nsf/e523dd36175eb5ad8525701b007332ae/$file/sab-casac-05-007_unsigned.pdf

[5] EPA released the first draft PM ISA in December 2008, and the document was peer reviewed by the EPA's independent Science Advisory Board in April 2009. EPA released the second draft ISA in July 2009, which was peer reviewed in October 2009. The final ISA was issued in December 2009.

6 U.S. Environmental Protection Agency. 2009. *Integrated Science Assessment for Particulate Matter (Final Report).* U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F. Available on the Internet at http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546.

7 U.S. Environmental Protection Agency - Science Advisory Board. 2009a. *Review of EPA's Integrated Science Assessment for Particulate Matter (First External Review Draft, December 2008).* EPA-CASAC-09-008. May. Available at http://yosemite.epa.gov/sab/SABPRODUCT.NSF/81e39f4c09954fcb85256ead006be86e/73ACCA834AB44A10852575BD0064346B/$File/EPA-CASAC-09-008-unsigned.pdf;

U.S. Environmental Protection Agency - Science Advisory Board. 2009b. *Consultation on EPA's Particulate Matter National Ambient Air Quality Standards: Scope and Methods Plan for Health Risk and Exposure Assessment.* EPA-CASAC-09-009. May. Available on the Internet at http://yosemite.epa.gov/sab/SABPRODUCT.NSF/81e39f4c09954fcb85256ead006be86e/723FE644C5D758DF852575BD00763A32/$File/EPA-CASAC-09-009-unsigned.pdf.

In December 2009, the Health Effect Subcommittee of the Advisory Council on Clean Air Compliance Analysis (Council/HES) met to review several aspects of the draft health effects analysis supporting EPA's developing study titled, "The Benefits and Costs of the Clean Air Act from 1990 to 2020." In response to a review charge question specifically requesting advice on EPA's use of a no-threshold model for benefits analysis, the Council/HES endorsed the use of a no-threshold model. The Council's written advisory report subsequently concluded that "[t]he HES fully supports EPA's use of a no-threshold model to estimate the mortality reductions associated with reduced PM exposure."[9]

EPA began implementing this change in analytical methods with the proposed Portland cement rule, soliciting public comment on the appropriateness of both the no-threshold and threshold approaches for $PM_{2.5}$ benefits analysis in the preamble to the proposed rule:[10]

> "EPA strives to use the best available science to support our benefits analyses. We recognize that interpretation of the science regarding air pollution and health is dynamic and evolving. One of the key differences between the method used in this analysis of PM co-benefits and the methods used in recent [Regulatory Impact Analyses] RIAs is that, in addition to technical updates, we removed the assumption regarding thresholds in the health impact function. Based on our review of the body of scientific literature, we prefer the no-threshold model. EPA's draft Integrated Science Assessment (2008), which is currently being reviewed by EPA's Clean Air Scientific Advisory Committee, concluded that the scientific literature consistently finds that a no-threshold log-linear model most adequately portrays the PM-mortality concentration-response relationship while recognizing potential uncertainty about the exact shape of the concentration-response function. It is important to note that while CASAC provides advice regarding the science associated with setting the National Ambient Air Quality Standards, typically other scientific advisory bodies provide specific advice regarding benefits analysis…
>
> "The question of whether or not to assume a threshold in calculating the co-benefits associated with reductions in PM2.5 is an issue that affects the benefits calculations not only for this rule but for many future EPA rulemakings and analyses. Due to these implications, we solicit comment on appropriateness of both the no-threshold and threshold model for PM benefits analysis."

Taking into account subsequent public comments in response to the preamble, as well as advice from outside expert advisory panels, EPA technical staff then prepared the final benefits analysis for the Portland cement rule, relying on analytical results that reflected the no-threshold approach as the best estimate of benefits. The final Regulatory Impact Analysis documented the application, and the basis for, the no-threshold modeling approach.[11]

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[8] U.S. Environmental Protection Agency – Science Advisory Board (U.S. EPA-SAB). 2010. *Review of EPA's DRAFT Health Benefits of the Second Section 812 Prospective Study of the Clean Air Act*. EPA-COUNCIL-10-001. June. Available on the Internet at http://yosemite.epa.gov/sab/sabproduct.nsf/0/72D4EFA39E48CDB28525774500738776/$File/EPA-COUNCIL-10-001-unsigned.pdf.

[9] Ibid, SAB 2010. EPA-COUNCIL-10-001.

[10] 74 FR 21136- 21192

[11] U.S. Environmental Protection Agency. 2010. *Regulatory Impact Analysis: Amendments to the National Emission Standards for Hazardous Air Pollutants and New Source Performance Standards (NSPS) for the Portland Cement Manufacturing Industry*, Office of Air and Radiation, August 2010. Available on the Internet at http://www.epa.gov/ttn/ecas/regdata/RIAs/portlandcementfinalria.pdf

We have provided the key documents cited in the response to this question and throughout this letter on the enclosed disc.

2. For each final economically significant rule issued by EPA after January 1, 2007, what proportion of monetized $PM_{2.5}$ benefits represent reductions in mortality at air concentrations below 15 micrograms per cubic meter averaged annually, the level of the current $PM_{2.5}$ NAAQS?

For final economically significant rules issued after January 1, 2007, the date cited in your question, EPA has not specifically calculated the proportion of monetized $PM_{2.5}$ benefits below 15 micrograms per cubic meter ($\mu g/m^3$).

We do not believe that it is scientifically defensible to look solely at benefits above 15 $\mu g/m^3$ because there are peer-reviewed, scientific studies showing health effects below this level. While 15 $\mu g/m^3$ is the level of the current (2006) annual $PM_{2.5}$ NAAQS, it is not directly related to the studies we use to calculate benefits, which observed health effects associated with exposure to $PM_{2.5}$ concentrations below this level. This is consistent with the fact that NAAQS are not "zero risk" standards. Instead, EPA's current approach is to show the complete distribution of benefits across the entire range of $PM_{2.5}$ concentrations. We believe showing the entire distribution provides much more information than cutpoint analyses.

Below are the figures from four final RIAs that show the distribution of premature deaths across the range of $PM_{2.5}$ concentrations: the Portland Cement MACT and NSPS (8/6/10); the Cross-State Air Pollution Rule (CSAPR) (7/6/11); the 2014-2018 Heavy Duty Vehicle GHG Rule (8/9/11) and the Mercury and Air Toxics Standards (MATS) (12/16/11). These figures illustrate the proportion of benefits associated with exposure to $PM_{2.5}$ concentrations at various concentrations, including above 15 $\mu g/m^3$, even though we have not explicitly reported that proportion in the RIAs. It is important to note that these figures show the percentage of premature deaths, not the monetized benefits.

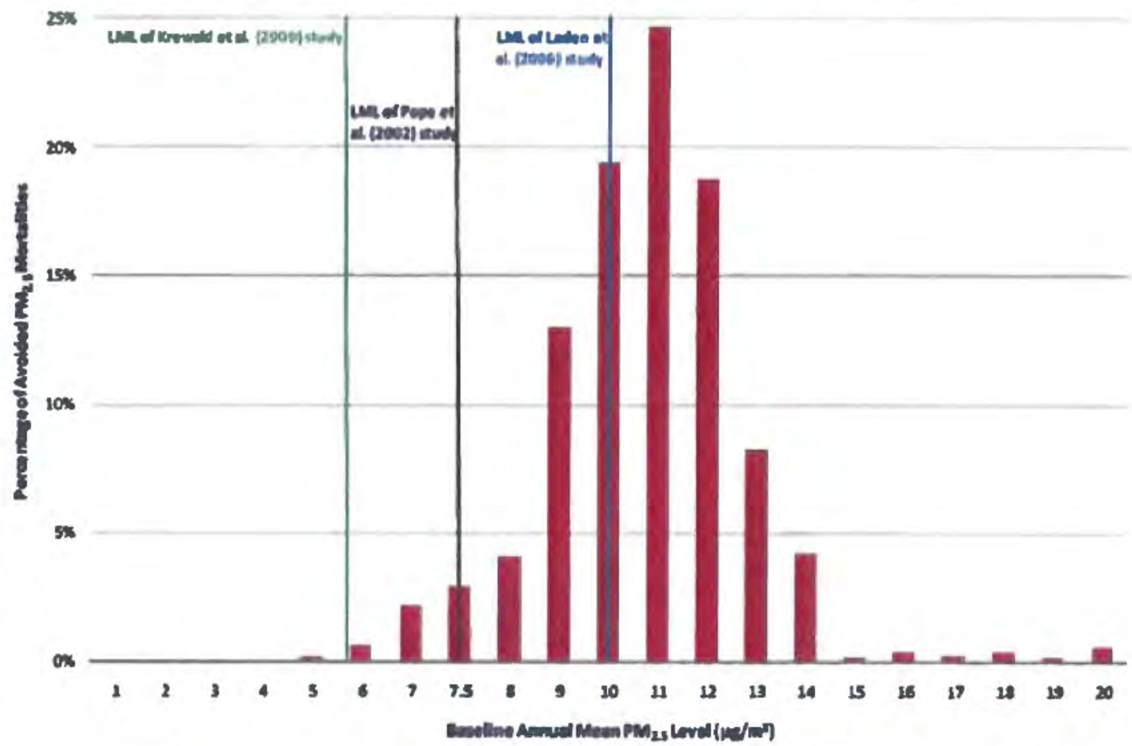
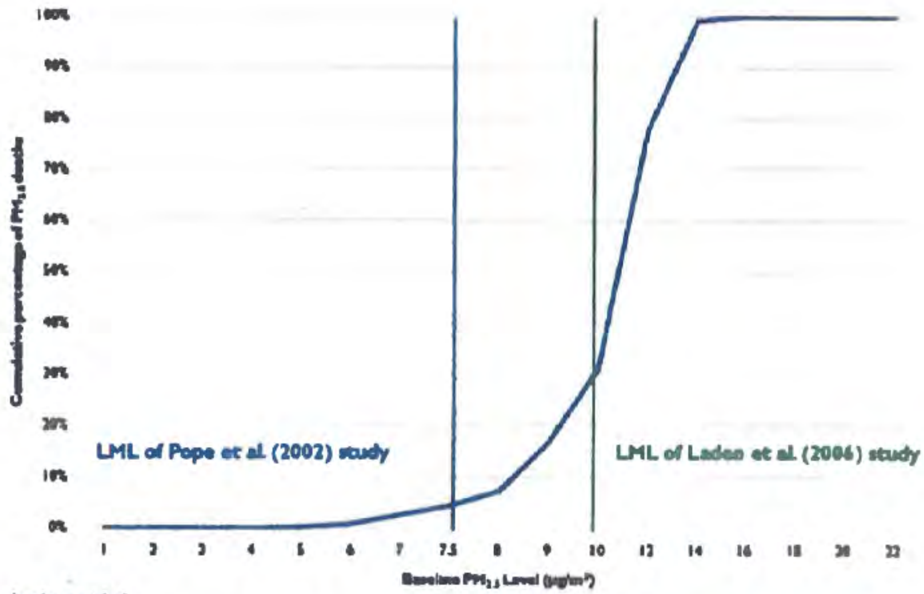


Figure 6-6. Percentage of Total PM-Related Mortalities Avoided by Baseline Air Quality Level for Final Portland Cement NESHAP and NSPS[a]

[a] Approximately 94% of the mortality impacts occur among populations with baseline exposure to annual mean $PM_{2.5}$ levels at or above 7.5 µg/m³, which is the lowest air quality level considered in the ACS cohort study by Pope et al. (2002).

Figure 5-19: Distribution of $PM_{2.5}$-related mortality impacts by baseline $PM_{2.5}$ levels, $PM_{2.5}$ epidemiology study and lowest measured level (LML) of each study

For the Final Cross-State Air Pollution Rule

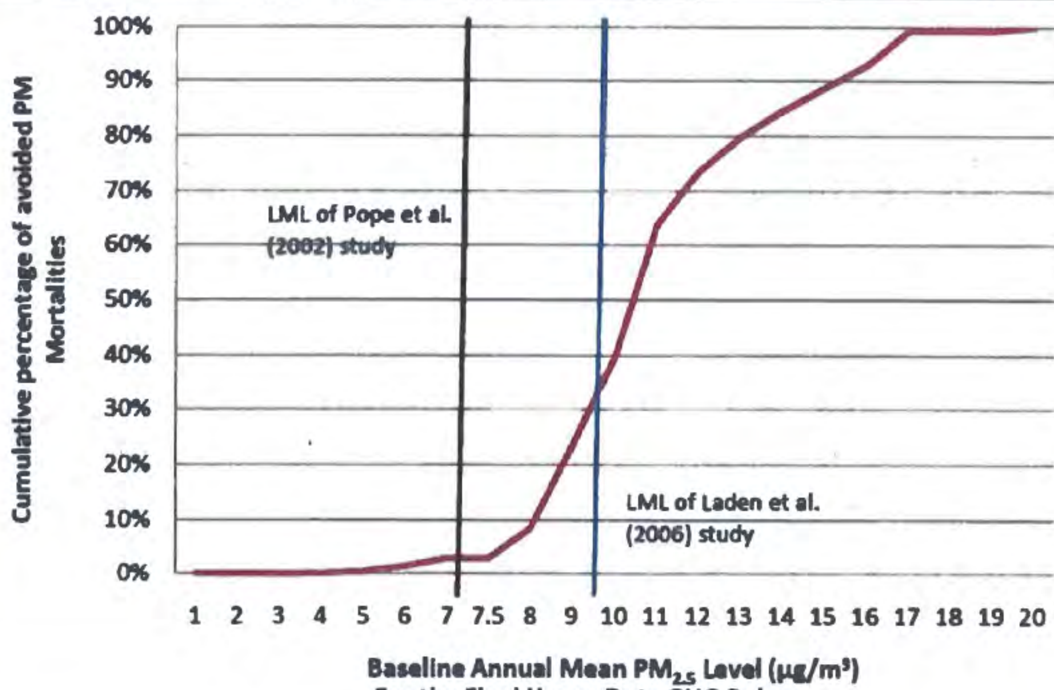


Of the deaths avoided

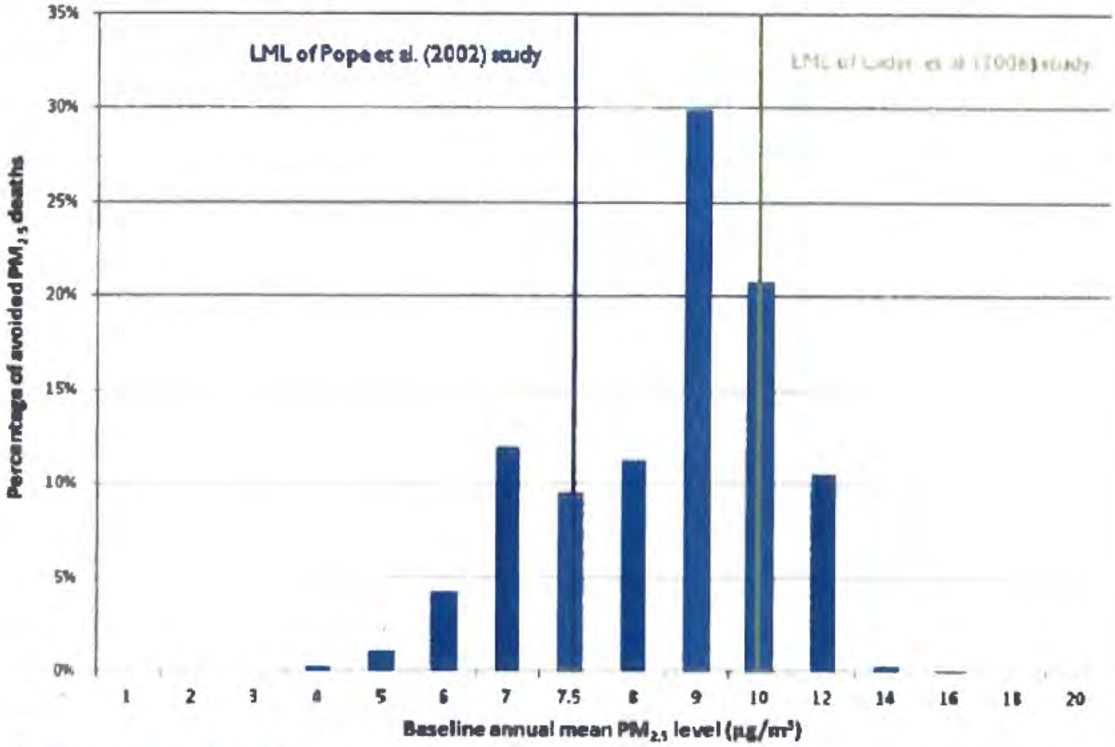
96% occur among populations exposed to PM levels at or above the LML of the Pope et al. (2002) study

69% occur among populations exposed to PM levels at or above the LML of the Laden et al (2006) study

Figure 8-20: Cumulative Percentage of Total PM-related Mortalities Avoided by Baseline Air Quality Level



For the Final Heavy Duty GHG Rule



Of the total PM-related deaths avoided:

73% occur among population exposed to PM levels at or above the LML of the Pope et al. study.

11% occur among population exposed to PM levels at or above the LML of the Laden et al. study.

Figure 5-14. Percentage of Total PM-Related Mortalities of the Mercury and Air Toxics Standards in 2016 Avoided by Baseline Air Quality Level[a]

[a] Based on the modeled interim baseline, which is approximately equivalent to the final baseline (see Appendix 5A)

3. For each final economically significant rule issued by EPA after January 1, 2007, what proportion of monetized $PM_{2.5}$ benefits represents reductions in mortality at air concentrations below Lowest Measured Level as defined by EPA in regulatory analyses using Laden, et al. 2006. "Reduction in Fine Particulate Air Pollution and Mortality" (American Journal of Respiratory and Critical Care Medicine)?

4. For each final economically significant rule issued after January 1, 2007, what proportion of monetized $PM_{2.5}$ benefits represents reductions in mortality at air concentrations below Lowest Measured Level as defined by EPA in regulatory analyses using Pope, et al. 2002. "Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution" (JAMA)?

Response to Questions 3-4:
Prior to 2006, EPA did not assume a threshold when calculating the best estimate of $PM_{2.5}$-related benefits. Between 2006 and 2009, EPA assumed a threshold when calculating the best estimate of $PM_{2.5}$-related benefits. The Agency discontinued the assumption of a threshold in April 2009, recognizing that a no-threshold approach best represents the $PM_{2.5}$ mortality concentration-response relationship, thereby providing the most accurate estimate of $PM_{2.5}$-related benefits.

EPA's no-threshold approach has been confirmed by two separate, independent peer review panels: the Clean Air Scientific Advisory Committee (CASAC)[12] and the Advisory Council on Clean Air Compliance Analysis (Council).[13]

After April 2009, EPA transitioned to an approach for characterizing uncertainty in its benefits estimate that was consistent with the scientific literature on $PM_{2.5}$ and health. This approach included returning to our prior use of a no-threshold approach to calculating the primary estimate of benefits, but the new approach also examines benefits above different cutpoints, including the lowest measured levels (LML)[14] from the underlying epidemiology studies. Information regarding these LML analyses, which examined the percent of avoided $PM_{2.5}$ exposures or $PM_{2.5}$-related deaths estimated to occur at concentrations above those cutpoints, is provided below and also is available in the Regulatory Impact Analyses for these rules.

12 U.S. Environmental Protection Agency - Science Advisory Board. 2009a. *Review of EPA's Integrated Science Assessment for Particulate Matter (First External Review Draft, December 2008).* EPA-CASAC-09-008. May. Available at http://yosemite.epa.gov/sab/SABPRODUCT.NSF/81e39f4c09954fcb85256ead006be86e/73ACCA834AB44A10852575BD0064346B/$File/EPA-CASAC-09-008-unsigned.pdf;

U.S. Environmental Protection Agency - Science Advisory Board. 2009b. *Consultation on EPA's Particulate Matter National Ambient Air Quality Standards: Scope and Methods Plan for Health Risk and Exposure Assessment.* EPA-CASAC-09-009. May. Available on the Internet at http://yosemite.epa.gov/sab/SABPRODUCT.NSF/81e39f4c09954fcb85256ead006be86e/723FE644C5D758DF852575BD00763A32/$File/EPA-CASAC-09-009-unsigned.pdf.

13 U.S. Environmental Protection Agency – Science Advisory Board (U.S. EPA-SAB). 2010. *Review of EPA's DRAFT Health Benefits of the Second Section 812 Prospective Study of the Clean Air Act.* EPA-COUNCIL-10-001. June. Available on the Internet at http://yosemite.epa.gov/sab/sabproduct.nsf/0/72D4EFA39E48CDB28525774500738776/$File/EPA-COUNCIL-10-001-unsigned.pdf.

14 An LML, or lowest measured level, refers to the lowest average ambient $PM_{2.5}$ concentration measured in key epidemiological studies evaluating the association between fine particle exposures and health effects. This is not the same as a lowest observable effects level or a no observed effects level. The science indicates, and our science advisors agree, that health effects are likely below these levels.

Analyses of rules issued between 2006 and 2009
As discussed in our response to question 2, EPA assumed a threshold of 10 $\mu g/m^3$ when calculating $PM_{2.5}$-related benefits for rules issued between 2006 and 2009. This means that all of the estimated benefits for these rules were related to exposures above 10 $\mu g/m^3$. These rules included the RICE Spark Ignition NSPS (12/20/07), the Ozone NAAQS (3/16/08), the Petroleum Refineries NSPS (4/30/08), the Locomotive and Marine Rule (3/14/08), the Small Spark Ignition & Recreational Marine Engines Rule (9/4/08), and the Lead NAAQS (10/16/08).

In 2009, EPA finalized the *Integrated Science Assessment for Particulate Matter* (US EPA, 2009), which concluded that there was no scientific foundation for assuming a threshold for $PM_{2.5}$ health effects. Indeed, the current body of scientific literature on particulate matter and health indicates that there is no evidence of a threshold below which health effects – including premature deaths – would not occur. As discussed above, to ensure that our work continues to reflect the best available science, the Agency discontinued the assumption of a threshold in the calculation of $PM_{2.5}$-related benefits, returning to the no-threshold approach used in pre-2006 rulemaking analyses. The no-threshold approach has subsequently been used in all recent rulemaking analyses.

In December 2009, the Health Effect Subcommittee of the Advisory Council on Clean Air Compliance Analysis (Council/HES) reviewed several aspects of the draft health effects analysis supporting EPA's developing study, titled "The Benefits and Costs of the Clean Air Act from 1990 to 2020." In response to a review charge question specifically requesting advice on EPA's use of a no-threshold model, the Council/HES endorsed the use of a no-threshold model. The Council's written advisory report concluded that "[t]he HES fully supports EPA's use of a no-threshold model to estimate the mortality reductions associated with reduced PM exposure." [15]

Analyses of Rules Issued Between April 2009 and June 2010: Sensitivity Analyses During Transition Period
As EPA transitioned to analyses using the no-threshold model, the Agency conducted sensitivity analyses[16] for several rules to show how changing this assumption affected the benefits estimates, especially for those rules that changed assumptions between proposal and final. Estimates from these sensitivity analyses illustrated the impact of assuming different thresholds for $PM_{2.5}$-related benefits. For the C3 Marine Rule (12/1/09), EPA's sensitivity analysis indicated that 63 percent of the total avoided $PM_{2.5}$-related premature deaths estimated in the full regulatory impact analysis (RIA) were associated with exposures above 10 $\mu g/m^3$, and 83 percent were associated with exposures above 7.5 $\mu g/m^3$. Similarly, for the 2012-2016 Light Duty Vehicle GHG Rule (4/1/10),[17] EPA's sensitivity analysis indicated that 78 percent of the avoided $PM_{2.5}$-related premature deaths estimated in the full RIA were associated with exposures above 10 $\mu g/m^3$ and 93 percent with exposures above 7.5 $\mu g/m^3$.

For the RICE Compression Ignition (CI) NESHAP (2/22/10) and the SO_2 NAAQS (6/2/10), EPA conducted sensitivity analyses that provided information regarding the percent of the $PM_{2.5}$-related benefits monetized in the full RIA that were associated with exposures below 10 $\mu g/m^3$. Assuming a threshold at 10 $\mu g/m^3$ in the sensitivity analysis for the RICE CI NESHAP, EPA estimated that 70

[15] Ibid, SAB 2010. EPA-COUNCIL-10-001.

[16] Sensitivity analyses are generally conducted to gain insights into sources of uncertainty and variability.

[17] This rule established a national program consisting of new standards for model year 2012 through 2016 light-duty vehicles that will reduce greenhouse gas emissions and improve fuel economy. The majority of projected monetized benefits are associated with greenhouse gas reductions and consumer fuel savings related to reduced oil consumption.

percent of the $PM_{2.5}$-related monetized benefits estimated in the full RIA were associated with exposures above 10 $\mu g/m^3$. In the sensitivity analysis for the SO_2 NAAQS, using that same assumption showed that 66 percent of the monetized benefits estimated in the full RIA analysis were associated with exposures above 10 $\mu g/m^3$.

Lowest Measured Level (LML) Analyses in Rules Issued After July 2010:
July 2010 marked the first time since EPA returned to using a no-threshold approach that the Agency had the data, technical tools and ambient $PM_{2.5}$ concentration information needed to conduct an LML assessment as part of the regulatory impact analyses for certain rules. An LML analysis provides us with additional insights regarding our estimates of health impacts at varying $PM_{2.5}$ concentrations: we have the highest confidence in the magnitude of our estimates of adverse health impacts at concentrations at or above the LML of the underlying epidemiology studies, and somewhat less confidence in the magnitude of our estimates of adverse health impacts at concentrations below the LML.

The final rules completed since EPA began conducting LML analyses in 2010 relied on LMLs from two studies: an LML of 10 $\mu g/m^3$ from the Harvard Six Cities study (Laden et al. 2006)[18] and an LML of 7.5 $\mu g/m^3$ from the earlier study of the American Cancer Society (Pope et al. 2002).[19] Studies from more recent years, during which $PM_{2.5}$ concentrations have fallen, continue to report strong associations with mortality. For example, based on the most recent extended analysis of the ACS study (Krewski et al., 2009),[20] we have confidence in our estimates of avoided $PM_{2.5}$-related deaths down to at least 5.8 $\mu g/m^3$, the LML in this study, and somewhat less confidence in estimates below 5.8 $\mu g/m^3$.

EPA has conducted LML assessments for seven economically significant final rules since July 2010. These assessments vary in terms of how they evaluated $PM_{2.5}$-related health impacts occurring below the LML. When we have sufficient air quality modeling data for a rule, LML analyses estimate the percentage of $PM_{2.5}$-related premature deaths avoided at or above the LML. The number of premature deaths reduced at different concentrations is a good approximation of the monetized, $PM_{2.5}$-related benefits achieved by reductions in exposure at those concentrations.

Thus far, EPA has had sufficient data to assess the proportion of $PM_{2.5}$-related premature deaths avoided in an LML analysis for four final rules. These include: the Portland Cement MACT and NSPS (8/6/10); the Cross-State Air Pollution Rule (CSAPR) (7/6/11); the 2014-2018 Heavy Duty Vehicle GHG Rule (8/9/11) and the Mercury and Air Toxics Standards (MATS) (12/16/11).

For the Portland Cement rule, for example, a very large proportion of avoided $PM_{2.5}$-related impacts in the LML analysis occur among populations exposed at or above the lowest LML of the cohort studies.[21]

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[18] Laden, F., J. Schwartz, F.E. Speizer, and D.W. Dockery. 2006. "Reduction in Fine Particulate Air Pollution and Mortality." *American Journal of Respiratory and Critical Care Medicine* 173:667-672.

[19] Pope, C.A., III, R.T. Burnett, M.J. Thun, E.E. Calle, D. Krewski, K. Ito, and G.D. Thurston.2002. "Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution." *Journal of the American Medical Association* 287:1132-1141.

[20] Krewski, D., M. Jerrett, et al. 2009. "Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality." *Res Rep Health Eff Inst* 140: 5-114.

[21] U.S. Environmental Protection Agency. 2010. *Regulatory Impact Analysis: Amendments to the National Emission Standards for Hazardous Air Pollutants and New Source Performance Standards (NSPS) for the Portland Cement Manufacturing Industry*, Office of Air and Radiation, August 2010. Available on the Internet at http://www.epa.gov/ttn/ecas/regdata/RIAs/portlandcementfinalria.pdf

That analysis showed that approximately 94 percent of the premature deaths occur among populations with baseline exposure to annual mean $PM_{2.5}$ levels at or above the LML of 7.5 μg/m^3, with approximately 40 percent occurring at or above the LML of 10 μg/m^3. Similarly, the LML analysis for the CSAPR showed 96 percent of premature deaths estimated among populations exposed to $PM_{2.5}$ occurred at concentrations at or above an LML of 7.5 μg/m^3, and 69 percent of the deaths estimated among populations exposed to $PM_{2.5}$ occurred at concentrations at or above the LML of 10 μg/m^3.[22]

For the 2014-2018 Heavy Duty Vehicle GHG Rule (8/9/11)[23], the LML analysis confirmed that the great majority of the impacts occur at or above each study's LML. The LML analysis shows that approximately 97 percent of PM2.5-related deaths occur at or above an annual mean $PM_{2.5}$ concentration of 7.5 μg/m^3, while about 60 percent of the avoided impacts occur at or above an annual mean $PM_{2.5}$ concentration of 10 μg/m^3.[24] The LML analysis for the MATS rule showed approximately 73 percent of premature deaths estimated for population exposures at or above an LML of 7.5 μg/m^3, and approximately 11 percent estimated for population exposures above an LML of 10 μg/m^3.[25]

For other rules without air quality modeling data, the LML analyses estimate the percentage of people exposed to $PM_{2.5}$ concentrations below the LML before the rule is implemented. As noted in our analyses, we did not have data to estimate the number of premature deaths occurring at different concentrations for these rules.

While illustrative of baseline air quality conditions, the proportion of people *exposed at a certain concentration before a rule is implemented* is not always a good approximation of the proportion of the *benefits* at that concentration. The reason for this difference is the location of $PM_{2.5}$ improvements that would result from a given rules. If the largest air quality improvements from a particular rule occur in locations where $PM_{2.5}$ concentrations are high before that rule is implemented, then a lot of the benefits would occur in those same areas. As a result, the percentage of benefits at or above the LML would be larger than the percentage of the population exposed to $PM_{2.5}$ at or above the LML before the rule.

Four final rules used the approach described in the preceding paragraph: the RICE Stationary Spark Ignition NESHAP (8/10/10), the Commercial and Industrial Solid Waste Incineration NSPS and Emission Guidelines (2/23/11), the Sewage Sludge Incineration NSPS and Emission Guidelines (2/23/11), the Industrial, Commercial and Institutional Boilers NESHAP (2/23/11), and the Boiler Area Source Rule (2/23/11).

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[22] U.S. Environmental Protection Agency. 2010. Regulatory Impact Analysis (RIA) for the final Transport Rule (CSAPR) Docket ID No. EPA-HQ-OAR-2009-0491, Office of Air and Radiation, June 2011. Available on the Internet at http://www.epa.gov/airtransport/pdfs/FinalRIA.pdf

[23] This rule established a national program consisting of new standards for model year 2014 through 2018 heavy-duty vehicles that will reduce greenhouse gas emissions and improve fuel economy. The majority of projected monetized benefits are associated with greenhouse gas reductions and consumer fuel savings related to reduced oil consumption.

24 U.S. Environmental Protection Agency and the National Highway Traffic Safety Administration, U.S. Department of Transportation. 2011. Final Rulemaking to Establish Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles: Regulatory Impact Analysis, August 2011. Available on the Internet at http://www.epa.gov/otaq/climate/documents/420r11901.pdf

[25] U.S. Environmental Protection Agency. 2011. *Regulatory Impact Analysis for the Final Mercury and Air Toxics Standards*, Office of Air & Radiation, December 2011. Available on the Internet at http://www.epa.gov/ttn/ecas/regdata/RIAs/matsriafinal.pdf

5. Do you consider the level of air quality that is established through the NAAQS process, including peer review by science advisors, to result in an "arbitrary" threshold; or do you believe that the NAAQS standard represents a level of air quality that is protective of public health, including sensitive populations, with an adequate margin of safety, as required by the Clean Air Act?

a. If the NAAQS standards protect the public health with an adequate margin of safety, explain how can the EPA estimate that short-term exposure to air in attainment areas would result in hundreds of thousands of deaths each year?

Response: National ambient air quality standards (NAAQS) do not represent "arbitrary" thresholds. In setting primary (health-based) standards that are requisite to protect public health with an adequate margin of safety, EPA's task is to establish standards that are neither more nor less stringent than necessary for that purpose, see Whitman v. American Trucking Assn's, 531 U.S 457, 473 (2001), recognizing that the Clean Air Act does not require the Administrator to establish a primary NAAQS at a zero risk-level, but rather at a level that reduces risk sufficiently as to protect public health with an adequate margin of safety. See *Lead Industries v. EPA*, 647 F.2d at 1156 n. 51. In addressing the requirement for an adequate margin of safety, EPA considers such factors as the nature and severity of the health effects involved, the size of at-risk populations, the strengths and limitations of the scientific evidence and related uncertainties, and whether discernible thresholds have been identified below which health effects do not occur. Standards are established to provide protection for a representative sample of persons comprising at-risk populations rather than to the most susceptible single person in such groups. Even in areas that meet the current standards, individual members of at-risk populations may at times experience health effects related to air pollution. The absence of evidence of a threshold below which health effects would not occur is one factor that the Administrator takes into consideration in selecting a NAAQS, including the level of the NAAQS, that in her judgment is sufficient to protect the public from the risks of adverse health effects, with an adequate margin of safety, but is not more stringent than necessary. The question incorrectly implies that EPA estimates that short-term exposure to air in attainment areas would result in hundreds of thousands of deaths each year. EPA has not conducted a national scale assessment of premature mortality associated with *short-term* $PM_{2.5}$ exposure to air in attainment areas. Rather, EPA has estimated the risk in a number of urban study areas associated with simulating ambient conditions to just meeting the current standards as well as alternative standards under consideration.[26] Furthermore, as discussed in the response to question 7 below, EPA conducted a national scale assessment of premature mortality related to *long-term* $PM_{2.5}$ exposure across all areas in the country.

6. Please provide any scientific studies EPA has relied upon to show a causal or associative relationship between fine particulate matter and premature mortality at levels below what EPA calls the "Lowest Measured Level" in the Pope and the Laden studies.

Response: EPA relies on the *Integrated Science Assessment (ISA) for Particulate Matter* (U.S. EPA, 2009) as the scientific basis for the determination that inhalation of $PM_{2.5}$ is causally associated with premature death. Additionally, the scientific evidence indicates that there is no evidence of a threshold below which health effects do not occur. For example, after performing an extensive analysis of the

26 U.S. Environmental Protection Agency. 2010. *Quantitative Health Risk Assessment for Particulate Matter.* Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, EPA-452/R-10-005. June 2010. Available on the Internet at http://www.epa.gov/ttn/naaqs/standards/pm/data/PM_RA_FINAL_June_2010.pdf.

Harvard Six Cities cohort, Schwartz et al. (2008)[27] were unable to discern such a population threshold between exposure to $PM_{2.5}$ and premature mortality. In addition, the recent reanalysis of the American Cancer Society cohort by Krewski et al. (2009) demonstrates mortality effects associated with long-term exposure to $PM_{2.5}$ across cities with a range of $PM_{2.5}$ concentrations, some of which were below the LMLs observed in the Pope and Laden studies.[28] Consistent with the conclusions presented in the ISA, numerous peer-review panels and nationally and internationally recognized air pollution experts have concluded that there is a lack of evidence for a threshold in the $PM_{2.5}$ mortality relationship. EPA recently summarized the scientific review statements related to the issue of thresholds in the concentration-response function for $PM_{2.5}$ mortality in a Technical Support Document appended to several recent RIAs.[29]

7. According to the most recent Particulate Matter Risk Assessment, EPA estimates that "total $PM_{2.5}$-related premature mortality ranges from 63,000 and 88,000" each year above the lowest measured level. EPA's estimate of benefits from the CSAPR rule, which involves almost all PM-related benefits, notes that mortality, ranges between 130,000 and 320,000 deaths per year.

a. Please explain how EPA came to these two different estimated mortality ranges.

b. Please explain the basis for EPA's monetization of a dramatically higher number than is identified in the peer-reviewed Risk Assessment.

c. Did you or the Assistant Administrator for Air and Radiation approve the public report of a dramatically higher number?

d. If so, please provide all documents relating to such approval.

e. If not, please explain why not.

Response: It is important to note that the CSAPR RIA estimate you reference in your question describes the overall public health burden of recent levels of $PM_{2.5}$ and ozone relative to policy relevant background levels,[30] and not the number of avoided premature deaths associated with emission reductions required by the CSAPR, which are estimated separately and reported in Table 5-17 of the CSAPR RIA.[31]

The most recent Quantitative Health Risk Assessment for Particular Matter and the CSAPR RIA provide similar estimates of the $PM_{2.5}$-related mortality. As you note in your letter, in the *Quantitative Health*

27 Schwartz J, Coull B, Laden F. (2008). "The Effect of Dose and Timing of Dose on the Association between Airborne Particles and Survival." *Environmental Health Perspectives*, 116, 64-69.

28 The lowest concentration reported by Krewski et al. (2009) was 5.8 µg/m³.

29 U.S. Environmental Protection Agency. 2010. *Technical Support Document: Summary of Expert Opinions on the Existence of a Threshold in the Concentration-Response Function for PM2.5-related Mortality.* Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, Research Triangle Park, NC June. Available on the Internet at: www.epa.gov/ttn/ecas/regdata/Benefits/thresholdstsd.pdf

30 Fann N, Lamson AD, Anenberg SC, Wesson K, Risley D, Hubbell B. 2012. "Estimating the national public health burden associated with exposure to ambient $PM_{2.5}$ and ozone." *Risk Analysis*. 32(1): 81-95. DOI: 10.1111/j.1539-6924.2011.01630.x

31 U.S. Environmental Protection Agency. 2011. *Regulatory Impact Analysis for the Federal Implementation Plans to Reduce Interstate Transport of Fine Particulate Matter and Ozone in 27 States; Correction of SIP Approvals for 22 States.* Office of Air and Radiation June 2011 Available on the Internet at http://epa.gov/airtransport/pdfs/FinalRIA.pdf.

Risk Assessment for Particulate Matter, EPA estimated that "total $PM_{2.5}$-related premature mortality [resulting from 2005 $PM_{2.5}$ levels] ranges from 63,000 (39,000—87,000) (95[th] percentile confidence interval) to 88,000 (49,000—130,000), respectively; in each case we estimated deaths per year down to the lowest measured levels (LMLs) in each epidemiological study" (pg G-2). In this same report, EPA also estimated 110,000 to 360,000 $PM_{2.5}$-related mortalities attributable to 2005 $PM_{2.5}$ levels relative to policy relevant background levels, which in most locations is well below the LML from the epidemiology studies. This estimate is comparable to the total $PM_{2.5}$–related mortality estimates cited in the CSAPR RIA of 130,000 to 320,000 premature $PM_{2.5}$-related deaths, which also are based on policy relevant background levels. The estimates reported in the CSAPR RIA are slightly different, because they were generated using more recent air quality information.

As noted in our response above, while we have higher confidence in the estimate of health impacts associated with exposure to $PM_{2.5}$ concentrations above the LML in the underlying epidemiology studies, the available evidence supports a no-threshold model. This means that it is appropriate to include estimates of mortality associated with exposure to even relatively low levels of $PM_{2.5}$, while acknowledging that there is some additional uncertainty regarding the magnitude of health effects attributable to these exposures. Thus, while we have the highest confidence that $PM_{2.5}$-related mortality impacts in 2005 were at least 63,000 to 88,000, as reported in the PM risk assessment, the best estimates for characterizing the overall public health burden of recent levels of $PM_{2.5}$ and ozone is the estimate of 130,000 to 320,000 premature deaths as summarized in the CSAPR RIA.

EXHIBIT 4

Risk and Exposure Assessment to Support the Review of the SO_2 Primary National Ambient Air Quality Standards: Final Report

EPA-452/R-09-007
July 2009

Risk and Exposure Assessment to Support the Review of the SO_2 Primary National Ambient Air Quality Standards

U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Health and Environmental Impacts Division
Research Triangle Park, North Carolina

Disclaimer

This document has been prepared by staff from the Ambient Standards Group, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency. Any opinions, findings, conclusions, or recommendations are those of the authors and do not necessarily reflect the views of the EPA. For questions concerning this document, please contact Dr. Stephen Graham (919-541-4344; graham.stephen@epa.gov), Mr. Harvey Richmond (919-541-5271; richmond.harvey@epa.gov), or Dr. Michael Stewart (919-541-7524; stewart.michael@epa.gov)

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LIST OF ACRONYMS/ABBREVIATIONS

A/C	Air conditioning
AER	Air exchange rate
AERMOD	American Meteorological Society (AMS)/EPA Regulatory Model
AHS	American Housing Survey
APEX	EPA's Air Pollutants Exposure model, version 4
ANOVA	One-way analysis of variance
AQI	Air Quality Index
ATL	Atlanta Hartsfield airport
AQS	EPA's Air Quality System
AQCD	Air Quality Criteria Document
BRFSS	Behavioral Risk Factor Surveillance System
CAA	Clean Air Act
CAMD	EPA's Clean Air Markets Division
CASAC	Clean Air Scientific Advisory Committee
CDC	Centers for Disease Control
CDF	Cumulative density function
CFR	Code of Federal Regulations
CHAD	EPA's Consolidated Human Activity Database
Clev/Cinn	Cleveland and Cincinnati, Ohio
CMSA	Consolidated metropolitan statistical area
CO	Carbon monoxide
COPD	Chronic Obstructive Pulmonary Disease
COV	Coefficient of Variation
C-R	Concentration-Response
CTPP	Census Transportation Planning Package
ED	Emergency Department
EPA	Environmental Protection Agency
EMS-HAP	Emissions Modeling System for Hazardous Pollutants model
ER	Emergency room
EOC	Exposure of Concern
FEM	Federal Equivalent Method
FEV_1	Forced expiratory volume in the first second
GM	Geometric mean
GSD	Geometric standard deviation
GST	Glutathione *S*-transferase
ISCST	Industrial Source Complex - Short Term dispersion model
ID	Identification
ISA	Integrated Science Assessment
ISH	Integrated Surface Hourly Database
JST	Jefferson Street SEARCH monitor near Georgia Tech
km	Kilometer
L95	Lower limit of the 95^{th} confidence interval

LOEL	Lowest Observed Effect Level
m	Meter
max	Maximum
ME	Microenvironment
med	Median
min	Minimum
MSA	Metropolitan statistical area
NAAQS	National Ambient Air Quality Standards
NAICS	North American Industrial Classification System
NAMS	National Ambient Monitoring Stations
NCEA	National Center for Environmental Assessment
NEI	National Emissions Inventory
NEM	NAAQS Exposure Model
NCDC	National Climatic Data Center
NHAPS	National Human Activity Pattern Study
NHIS	National Health Interview Survey
NO_2	Nitrogen dioxide
NO_x	Oxides of nitrogen
NWS	National Weather Service
NYC	New York City
NYDOH	New York Department of Health
O_3	Ozone
OAQPS	Office of Air Quality Planning and Standards
OR	Odds ratio
ORD	Office of Research and Development
ORIS	Office of Regulatory Information Systems identification code
PAMS	Photochemical Assessment Monitoring Stations
POC	Parameter occurrence code
ppb	Parts per billion
PEM	Personal exposure measurements
PEN	Penetration factor
PM	Particulate matter
PMR	Peak-to-mean ratio
ppm	Parts per million
PRB	Policy-Relevant Background
PROX	Proximity factor
R^2	R-square or the coefficient of determination
REA	Risk and Exposure Assessment
RECS	Residential Energy Consumption Survey
RIU	Rescue inhaler use
RR	Relative risk
SAF	Spatial allocation factors
SAS	Statistical Analysis Software
SB	Shortness of breath
SEARCH	Southeast Aerosol Research and Characterization study (SEARCH) monitoring
SES	Social-economic status
SIC	Standard Industrial Code

SD	Standard deviation
Se	Standard error
SLAMS	State and Local Ambient Monitoring Stations
SO_2	Sulfur dioxide
SO_3	Sulfur trioxide
SO_4^-	Sulfate
SO_x	Oxides of Sulfur
sRaw	Specific Airway Resistance
tpy	Tons per year
TRIM	EPA's Total Risk Integrated Methodology
U95	Upper limit of the 95th confidence interval
UA	Urbanized area
UC	Urban cluster
UARG	Utility Air Regulatory Group
USGS	United States Geological Survey
V_s	Ventilation rate

1. INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is presently conducting a review of the primary, health-based national ambient air quality standards (NAAQS) for sulfur dioxide (SO_2). Sections 108 and 109 of the Clean Air Act (The Act) govern the establishment and periodic review of the NAAQS. These standards are established for pollutants that may reasonably be anticipated to endanger public health and welfare, and whose presence in the ambient air results from numerous or diverse mobile or stationary sources. The NAAQS are to be based on air quality criteria, which are to accurately reflect the latest scientific knowledge useful in indicating the kind and extent of identifiable effects on public health or welfare that may be expected from the presence of the pollutant in ambient air. The EPA Administrator is to promulgate and periodically review, at five-year intervals, primary (health-based) and secondary (welfare-based) NAAQS for such pollutants. Based on periodic reviews of the air quality criteria and standards, the Administrator is to make revisions in the criteria and standards and promulgate any new standards as may be appropriate. The Act also requires that an independent scientific review committee advise the Administrator as part of this NAAQS review process, a function performed by the Clean Air Scientific Advisory Committee (CASAC).

The first step in the SO_2 NAAQS review was the development of an integrated review plan. This plan presented the schedule for the review, the process for conducting the review, and the key policy-relevant science issues that would guide the review. The final integrated review plan was informed by input from CASAC, outside scientists, and the public. This plan was presented in the *Integrated Review Plan for the Primary National Ambient Air Quality Standards for Sulfur Oxides* (EPA, 2007a). It was made available to the public in October 2007 and can be found at: http://www.epa.gov/ttn/naaqs/standards/so2/s_so2_cr_pd.html.

The second step in this review was a science assessment. A concise synthesis of the most policy-relevant science was compiled into an Integrated Science Assessment (ISA). The ISA was supported by a series of annexes that contained more detailed information about the scientific literature. The final ISA to support this review of the SO_2 primary NAAQS was presented in the *Integrated Science Assessment for Oxides of Sulfur - Health Criteria*, henceforth referred to as the ISA (EPA, 2008a). This document was made available to the public in

September 2008 and can be found at: http://www.epa.gov/ttn/naaqs/standards/so2/s_so2_cr_pd.html.

The third step in the primary SO_2 NAAQS review is a risk and exposure assessment (REA) that describes exposures and characterizes risks associated with SO_2 emissions from anthropogenic sources. The plan for conducting the risk and exposure assessment to support the SO_2 primary NAAQS review was presented in the *Sulfur Dioxide Health Assessment Plan: Scope and Methods for Exposure and Risk Assessment*, henceforth referred to as the Health Assessment Plan (EPA, 2008b). This document was made available to the public in November 2007 and can be found at: http://www.epa.gov/ttn/naaqs/standards/so2/s_so2_cr_pd.html. The first draft SO_2 REA was informed by comments from the public and CASAC on the Health Assessment Plan, as well as the first and second drafts of the ISA for SO_x. The first draft SO_2 REA developed estimates of human exposures and risks associated with recent ambient levels of SO_2 and levels that just met the current SO_2 standards. The first draft REA was presented in the *Risk and Exposure Assessment to Support the Review of the SO_2 Primary National Ambient Air Quality Standards: First Draft*. It was made available to the public in July 2008 and can be found at: http://www.epa.gov/ttn/naaqs/standards/so2/s_so2_cr_rea.html

The second draft SO_2 REA was informed by comments from CASAC and the public on the first draft REA, as well as findings and conclusions contained in the final ISA. This document developed estimates of human exposures and risks associated with: (1) recent ambient levels of SO_2, (2) levels that just met the current SO_2 standards, and (3) levels that just met potential alternative standards: defined in terms of indicator, averaging time, form, and level. This document also contained a draft policy assessment that addressed the adequacy of the current SO_2 NAAQS and potential alternative standards. More specifically, the policy assessment considered epidemiologic, human exposure, and animal toxicological evidence presented in the ISA (EPA, 2008a), as well as the air quality, exposure, and risk characterization results presented in the first draft REA, as they related to the adequacy of the current SO_2 NAAQS and potential alternative primary SO_2 standards (see Figure 1-1). The second draft REA was presented in the *Risk and Exposure Assessment to Support the Review of the SO_2 Primary National Ambient Air Quality Standards: Second Draft*. It was made available to the public in March 2009 and can be found at: http://www.epa.gov/ttn/naaqs/standards/so2/s_so2_cr_rea.html.

The final REA is this document, and has been informed by comments from CASAC and the public on the second draft REA, as well as findings and conclusions contained in the final ISA. The final REA further develops estimates of human exposures and risks associated with: (1) recent ambient levels of SO_2, (2) levels that just meet the current SO_2 standards, and (3) levels that just meet potential alternative standards. This document also contains a final policy assessment (see Chapter 10). The final policy assessment will consider epidemiologic, controlled human exposure, and animal toxicological evidence presented in the final ISA (EPA, 2008a), as well as the air quality, exposure, and risk characterization results presented in this document, as they related to the adequacy of the current SO_2 NAAQS and potential alternative primary SO_2 standards (Figure 1-1).

The final step in the review of the SO_2 NAAQS will be the rulemaking process. This process will be informed by the risk and exposure information contained in the final REA, as well the scientific evidence described in the final ISA. The rulemaking process will also take into account CASAC advice and recommendations, as well as public comment on any policy options under consideration. Notably, EPA is now under a consent decree to complete its review of the SO_2 primary NAAQS by issuing a proposed rule no later than November 16, 2009 and a final rule by June 2, 2010.

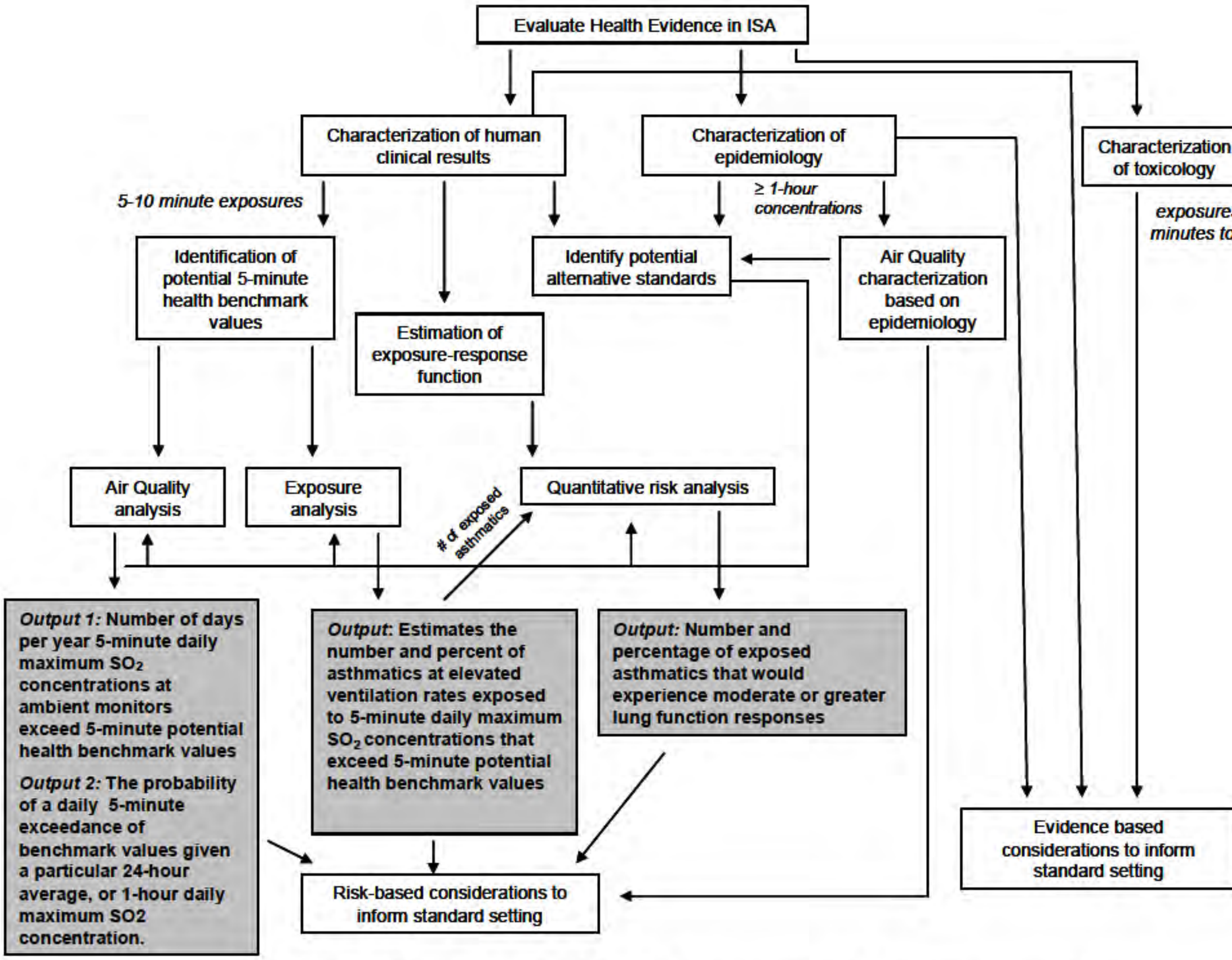

Figure 1-1. Overview of the analyses described in this document and their interconnections

As mentioned above, an initial step in the review process was the development of an integrated review plan. This plan identified policy relevant questions that would guide the review of the SO_2 NAAQS. These questions are particularly important for the REA because they provide a context for both evaluating health effects evidence presented in the ISA, as well as for selecting the appropriate analyses for assessing exposure and risks associated with current ambient SO_2 levels, SO_2 levels that just meet the current standards, and SO_2 levels that just meet potential alternative standards. These policy relevant questions are:

- Has new information altered/substantiated the scientific support for the occurrence of health effects following short- and/or long-term exposure to levels of SO_x found in the ambient air?

- Does new information impact conclusions from the previous review regarding the effects of SO_x on susceptible populations?
- At what levels of SO_x exposure do health effects of concern occur?
- Has new information altered conclusions from previous reviews regarding the plausibility of adverse health effects caused by SO_x exposure?
- To what extent have important uncertainties identified in the last review been reduced and/or have new uncertainties emerged?
- What are the air quality relationships between short-term and longer-term exposures to SO_x?

Additional questions will become relevant if the evidence suggests that revision of the current standard might be appropriate. These questions are:

- Is there evidence for the occurrence of adverse health effects at levels of SO_x different than those observed previously? If so, at what levels and what are the important uncertainties associated with that evidence?
- Do exposure estimates suggest that levels of concern for SO_x-induced health effects will occur with current ambient levels of SO_2, or with levels that just meet the current, or potential alternative standards? If so, are these exposures of sufficient magnitude such that the health effects might reasonably be judged to be important from a public health perspective? What are the important uncertainties associated with these exposure estimates?
- Do the evidence, the air quality assessment, and the risk/exposure assessment provide support for considering different standard indicators, averaging times, or forms?
- What range of levels is supported by the evidence, the air quality assessment, and risk/exposure assessment? What are the uncertainties and limitations in the evidence and assessments?

1.1 HISTORY

1.1.1 History of the SO_2 NAAQS

The first SO_2 NAAQS was established in 1971. At that time, a 24-hour standard of 0.14 ppm, not to be exceeded more than one time per year, and an annual standard of 0.03 ppm were judged to be both adequate and necessary to protect public health. The most recent review of the SO_2 NAAQS was completed in 1996 and focused on the question of whether an additional short-term standard (e.g., 5-minute) was necessary to protect against short-term, peak exposures. Based on the scientific evidence, the Administrator judged that repeated exposures to 5-minute peak SO_2 levels ($\geq$ 600 ppb) could pose a risk of significant health effects for asthmatic individuals at elevated ventilation rates. The Administrator also concluded that the likely frequency of such effects should be a consideration in assessing the overall public health risks. Based upon an exposure analysis conducted by EPA, the Administrator concluded that exposure of asthmatics to SO_2 levels that could reliably elicit adverse health effects was likely to be a rare event when viewed in the context of the entire population of asthmatics and therefore, did not pose a broad public health problem for which a NAAQS would be appropriate. On May 22, 1996, EPA's final decision not to promulgate a 5-minute standard and to retain the existing 24-hour and annual standards was announced in the Federal Register (61 FR 25566).

The American Lung Association and the Environmental Defense Fund challenged EPA's decision not to establish a 5-minute standard. On January 30, 1998, the Court of Appeals for the District of Columbia found that EPA had failed to adequately explain its determination that no revision to the SO_2 NAAQS was appropriate and remanded the decision back to EPA for further explanation. Specifically, the court gave EPA the opportunity to provide additional rationale to support the Agency judgment that 5-minute peaks of SO_2 do not pose a public health problem from a national perspective even though those peaks would likely cause adverse health impacts in a subset of asthmatics. In response, EPA has collected and analyzed additional air quality data focused on 5-minute concentrations of SO_2. These air quality analyses conducted since the last review will help inform the current review, which will answer the issues raised in the Court's remand of the Agency's last decision.

1.1.2 Health Evidence from the Previous Review

The 1982 Air Quality Criteria Document (AQCD) for Particulate Matter and Sulfur Oxides (EPA, 1982), and its subsequent addenda and supplement (EPA, 1986b, 1994a) presented an evaluation of SO_2 associated health effects primarily drawn from epidemiologic and human clinical studies. In general, these documents identified adverse health effects that were likely associated with both short- (generally hours to days), and long-term (months to years) exposures to SO_2 at concentrations present in the ambient mixture of air pollutants. Moreover, these documents presented evidence for bronchoconstriction and respiratory symptoms in exercising asthmatics following controlled exposures to 5-10 minute peak concentrations of SO_2.

Evidence drawn from epidemiologic studies supported a likely association between 24-hour average SO_2 concentrations and daily mortality, aggravation of bronchitis, and small, reversible declines in children's lung function (EPA 1982, 1994a). In addition, a few epidemiologic studies found an association between respiratory symptoms and illnesses and annual average SO_2 concentrations (EPA 1982, 1994a). However, it was noted that most of these epidemiologic studies were conducted in years and cities where particulate matter (PM) counts were also quite high, thus making it difficult to quantitatively determine whether the observed associations were the result of SO_2, PM, or a combination of both pollutants.

Evidence drawn from clinical studies exposing exercising asthmatics to <1000 ppb SO_2 for 5-10 minutes found that these types of SO_2 exposures evoked health effects that were similar to those asthmatics would experience from other commonly encountered stimuli (e.g., exercise, cold/dry air, psychological stress, etc. (EPA, 1994a). That is, there was an acute-phase response characterized by bronchoconstriction and/or respiratory symptoms that occurred within 5-10 minutes of exposure but then subsided on its own within 1 to 2 hours. This acute-phase response was followed by a short refractory period where the individual was relatively insensitive to additional SO_2 challenges. Notably, the SO_2-induced acute-phase response was found to be ameliorated by the inhalation of beta-agonist aerosol medications, and to occur without an additional, often more severe, late-phase inflammatory response.

The 1994 supplement to the AQCD noted that of particular concern was the subset of asthmatics in these clinical studies that appeared to be hyperresponsive (i.e., those experiencing greater-than-average bronchoconstriction or respiratory symptoms at a given SO_2 concentration). Thus, for a given concentration of SO_2, EPA estimated the number of asthmatics likely to experience bronchoconstriction (and/or symptoms) of a sufficient magnitude to be considered a health concern. At 600 to 1000 ppb SO_2, EPA estimated that more than 25% of mild to moderate exercising asthmatics would likely experience decrements in lung function distinctly exceeding typical daily variations in lung function, or the response to commonly encountered stimuli (EPA, 1994a). Furthermore, the AQCD concluded that the severity of effects experienced at 600-1000 ppb was likely to be of sufficient concern to cause a cessation of activity, medication use, and/or the possible seeking of medical attention. In contrast, at 200 – 500 ppb SO_2, it was estimated that at most 10 – 20% of mild to moderate exercising asthmatics were likely to experience lung function decrements larger than those associated with typical daily activity, or the response to commonly encountered stimuli (EPA, 1994a).

1.1.3 Assessment from Previous Review

The risk and exposure assessment from the previous review of the SO_2 NAAQS qualitatively evaluated both the existing 24-hour (0.14 ppm) and annual standards (0.03 ppm), but primarily focused on whether an additional standard was necessary to protect against short-term (e.g., 5-minute) peak exposures. Based on the human clinical data mentioned above, it was judged that exposures to 5-minute SO_2 levels at or above 600 ppb could pose an immediate significant health risk for a substantial proportion of asthmatics at elevated ventilation rates (e.g., while exercising). Thus, EPA analyzed existing ambient monitoring data to estimate the frequency of 5-minute peak concentrations above 500, 600, and 700 ppb, the number of repeated exceedances of these concentrations, and the sequential occurrences of peak concentrations within a given day (SAI, 1996). The results of this analysis indicated that in the vicinity of local sources, several locations in the U.S. had a substantial number of 5-minute peak concentrations at or above 600 ppb.

In addition to the ambient air quality analysis, the previous review also included several annual exposure analyses that in general, combined SO_2 emission estimates from utility and non-utility sources with exposure modeling to estimate the probability of exposure to short-term peak SO_2 concentrations. The first such analysis conducted by the Agency estimated the number of 5-minute exposures $\geq$ 500 ppb associated with four selected coal-fired power utilities (EPA, 1986a). An expanded analysis sponsored by the Utility Air Regulatory Group (UARG) considered the frequency of short-term exposure events that might result from the nationwide operation of all power utility boilers (Burton et al., 1987). Additionally, the probability of peak concentrations surrounding non-utility sources was the focus of another study conducted by the Agency (Stoeckenius et al., 1990). The resultant combined exposure estimates based on these early analyses indicated that between 0.7 and 1.8% of the total asthmatic population potentially could be exposed one or more times annually, while outdoors at exercise, to 5-minute SO_2 concentrations $\geq$ 500 ppb. It also was noted that the frequency of 5-minute exposures above the health effect benchmark of 600 ppb, while not part of the analysis, would be anticipated to be lower.

In addition to the early analyses mentioned above, two other analyses were considered in the prior review. The first was an exposure assessment sponsored by the UARG (Rosenbaum et al., 1992) that focused on emissions from fossil-fueled power plants. That study accounted for the anticipated reductions in SO_2 emissions after implementation of the acid deposition provisions (Title IV) of the 1990 Clean Air Act Amendments. This UARG-sponsored analysis predicted that these emission reductions would result in a 42% reduction in the number of 5-minute exposures to 500 ppb for asthmatic individuals (reducing the number of asthmatics exposed from 68,000 down to 40,000) in comparison with the earlier Burton et al. (1987) analysis. The second was a new exposure analysis submitted by the National Mining Association (Sciences International, Inc. 1995) that reevaluated non-utility sources. In this analysis, revised exposure estimates were provided for four of the seven non-utility source categories by incorporating new emissions data and using less conservative modeling assumptions in comparison to those used for the earlier Stoeckenius et al. (1990) non-utility analysis. Significantly fewer exposure events (i.e., occurrence of 5-minute 500 ppb or greater exposures) were estimated in this industry-sponsored revised analysis, decreasing the range of estimated exposures for these four sources by an order of magnitude (i.e., from 73,000-259,000 short-term exposure events in the original analysis to 7,900-23,100 in the revised analysis).

1.2 SCOPE OF THE RISK AND EXPOSURE ASSESSMENT FOR THE CURRENT REVIEW

1.2.1 Overview of the Risk and Exposure Assessment

The REA describes exposure and risks associated with recent ambient levels of SO_2, levels that just meet the current SO_2 standards, and levels that just meet potential alternative standards. This REA also contains a policy discussion regarding the adequacy of the current SO_2 NAAQS, and potential alternative primary standards. A concise overview of the information, analyses, and policy discussion contained in this document is presented below.

Chapters 2-4 evaluate information presented in the ISA that is relevant for conducting an exposure and risk assessment. This includes information on 1) human exposure to SO_2; 2) at-risk populations; and 3) health effects associated with short- and long-term exposures to SO_2. Chapter 5 presents the rationale for the selection of the indicator, averaging time, forms, and levels for the potential alternative standards that were assessed in the exposure and risk chapters of the document. Specifically, these potential alternative standards are 99^{th} percentile 1-hour daily maximum SO_2 levels of 50, 100, 150, 200, and 250 ppb, and 98^{th} percentile 1-hour daily maximum SO_2 levels of 200 ppb, and in some instances in the air quality analysis, 100 ppb. In brief, the rationale takes into consideration both human exposure and epidemiologic evidence from the ISA, as well as a qualitative analysis conducted by staff characterizing 98th and 99th percentile 1-hour daily maximum SO_2 levels in cities and time periods corresponding to key U.S. and Canadian hospitalization and ED visit studies for all respiratory causes and asthma (key studies are identified in Table 5-5 of the ISA). Chapter 6 is an overview of the technical analyses that are presented in the subsequent chapters of this document. This chapter also presents the rationale for the selection of specific potential health benchmark values[1] derived from the human exposure literature.

Chapters 7-9 present the analytical portion of the document. Staff considered both evidence of bronchoconstriction and respiratory symptoms from human exposure studies, as well as CASAC advice on the first and second draft REA, and judged it appropriate to conduct a series of three analyses to estimate risks associated with 5-minute SO_2 exposures ranging from 100-400 ppb in exercising asthmatics (see Figure 1-1 and Chapter 6). Chapter 7 presents an air quality characterization that uses monitored and statistically estimated 5-minute ambient SO_2 concentrations as a surrogate for exposure. This analysis estimates the number of days per year measured or statistically estimated 5-minute daily maximum SO_2 concentrations meet or exceed the potential health benchmark values of 100, 200, 300 and 400 ppb This air quality analysis is done under scenarios reflecting current air quality, air quality simulated to just meet the current standards, and air quality simulated to just meet the potential alternative standards (i.e., 99th percentile 1-hour daily maximum SO_2 levels of 50, 100, 150, 200 and 250 ppb and an 98th percentile 1-hour daily maximum SO_2 level of 200 ppb). Chapter 8 presents results from exposure analysis case studies conducted in the St. Louis modeling domain (henceforth referred to as St. Louis) and Greene County Missouri (MO). These analyses provide estimates of the number and percent of asthmatics residing within 20 kilometers (km) of major SO_2 sources experiencing 5-minute exposures to 100, 200, 300, and 400 ppb SO_2, while at elevated ventilation rates under the air quality scenarios mentioned above (i.e., recent air quality, and air quality adjusted to just meet the current and potential alternative standards). Chapter 9 is a quantitative risk assessment that produces health risk estimates for the number and percent of

[1] In general, potential health benchmark values are pollutant exposure levels that have consistently been shown to induce adverse health effects in individuals participating in free-breathing human chamber studies.

exposed asthmatics (as determined by the exposure analysis; see Figure 1-1) that would experience moderate or greater lung function responses under the air quality scenarios previously described.

In addition to the technical analyses presented in Chapters 7-9, Chapter 10 integrates the scientific evidence and the air quality, exposure, and risk information as they pertain to informing decisions about the primary SO_2 NAAQS. More specifically, Chapter 10 considers the epidemiologic, controlled human exposure, and animal toxicological evidence presented in the ISA (EPA, 2008a), as well as the air quality, exposure, and risk characterization results presented in this document, as they relate to the adequacy of the current SO_2 NAAQS and potential alternative primary SO_2 standards.

1.2.2 Species of Sulfur Oxides Included in Analyses

The sulfur oxides include multiple gaseous (e.g., SO_2, SO_3) and particulate (e.g., sulfate) species. In considering what species of sulfur oxides are relevant to the current review of the SO_2 NAAQS, we note that the health effects associated with particulate species of sulfur oxides have been considered within the context of the Agency's review of the primary NAAQS for particulate matter (PM). In the most recent review of the NAAQS for PM, it was determined that size-fractionated particle mass, rather than particle composition, remains the most appropriate approach for addressing ambient PM. This conclusion will be re-assessed in the parallel review of the PM NAAQS; however, at present it would be redundant to also consider effects of particulate sulfate in this review. Therefore, the current review of the SO_2 NAAQS will focus on gaseous species of sulfur oxides and will not consider health effects directly associated with particulate sulfur oxide species. Additionally, of the gaseous species, EPA has historically determined it appropriate to specify the indicator of the standard in terms of SO_2 because other gaseous sulfur oxides (e.g., SO_3) are likely to be found at concentrations many orders of magnitude lower than SO_2 in the atmosphere, and because most all of the health effects and exposure information is for SO_2. The ISA has again found this to be the case, and therefore this REA will use SO_2 as a surrogate for all gaseous sulfur oxides.

2. OVERVIEW OF HUMAN EXPOSURE

In order to help inform the air quality, exposure, and risk analyses presented in Chapters 7-9, staff has briefly summarized relevant human exposure information from the ISA. After defining the concept of "integrated exposure," this chapter discusses major sources of SO_2 emissions. Characterizing these SO_2 sources helps identify the most relevant locations for conducting air quality, exposure, and health risk analyses. This chapter then presents a description of the SO_2 monitoring network, and discusses ambient levels of SO_2 associated with 1-hour, 24-hour, and annual averaging times. SO_2 concentrations associated with these averaging times are relevant to the air quality, exposure, and risk analyses because the current SO_2 standards have 24-hour and annual averaging times, and EPA is considering potential alternative 1-hour averaging time standards (see section 5.3). Next, this chapter describes the small subset of SO_2 monitors that report 5-minute SO_2 concentrations, as well as a broad characterization of ambient 5-minute SO_2 levels (a more thorough discussion of these topics can be found in Chapters 6 and 7). This discussion is particularly relevant to the analyses described in this document because the potential health effect benchmarks and the outputs of the air quality, exposure, and risk assessments are presented with respect to a 5-minute averaging time (see section 6.2). More specifically, as previously described in section 1.2.1, an output of the air quality analysis presented in Chapter 7 is the number of days per year measured, or statistically estimated (see Chapter 6) 5-minute daily maximum SO_2 concentrations exceed 5-minute potential health effect benchmark levels. Similarly, the output of the exposure analysis in Chapter 8 is the number of exercising asthmatics exposed to 5-minute SO_2 concentrations above benchmark levels. Outputs of the exposure analysis (i.e., the number of exercising asthmatics exposed to 5-minute SO_2 concentrations above benchmark levels) are then used as inputs into the quantitative risk assessment in Chapter 9 to estimate the number and percent of exposed exercising asthmatics expected to experience a moderate or greater lung function response (see Figure 6-1).

In addition to providing information relevant to the air quality, exposure, and risk analyses, this Chapter also provides information relevant to the Chapter 4 health discussion and the Chapter 10 policy assessment. That is, the current chapter highlights uncertainties involved with using ambient SO_2 concentrations as a surrogate for personal exposure in epidemiologic studies, as well as the ISA's conclusions on this topic.

2.1 BACKGROUND

The integrated exposure of a person to a given pollutant is the sum of the exposures over all time intervals for all environments in which the individual spends time. People spend different amounts of time in different microenvironments and each microenvironment is characterized by different pollutant concentrations. There is a large amount of variability in the time that individuals spend in different microenvironments, but on average people spend the majority of their time (about 87%) indoors. Most of this time is spent at home with less time spent in an office/workplace or other indoor locations (ISA, Figure 2-36). In addition, people spend on average about 8% of their time outdoors and 6% of their time in vehicles. A potential consequence of multiple sources of exposure or microenvironments is the exposure misclassification that may result when total human exposure is not disaggregated between these various microenvironments. In epidemiologic studies that rely on ambient pollutant levels as a surrogate for exposure to ambient SO_2, such misclassification may obscure the true relationship between ambient air pollutant exposures and health outcomes.

In addition to accounting for the times spent in different microenvironments, it is also important to note the duration of exposure experienced. This is important because health effects caused by long-term, low-level exposures may differ from those caused by relatively higher shorter-term exposures.

2.2 SOURCES OF SO_2

In order to estimate risks associated with SO_2 exposure, principle sources of the pollutant must first be characterized because the majority of human exposures are likely to result from the release of emissions from these sources. Anthropogenic SO_2 emissions originate chiefly from point sources, with fossil fuel combustion at electric utilities (~66%) and other industrial facilities (~29%) accounting for the majority of total emissions (ISA, section 2.1). Other anthropogenic sources of SO_2 include both the extraction of metal from ore as well as the burning of high sulfur containing fuels by locomotives, large ships, and non-road diesel equipment. Notably, almost the entire sulfur content of fuel is released as SO_2 or SO_3 during combustion. Thus, based on the sulfur content in fuel stocks, oxides of sulfur emissions can be calculated to a higher degree of accuracy than can emissions for other pollutants such as PM and NO_2 (ISA, section 2.1).

The largest natural sources of SO_2 are volcanoes and wildfires. Although SO_2 constitutes a relatively minor fraction (0.005% by volume) of total volcanic emissions, concentrations in volcanic plumes can be in the range of several to tens of ppm (thousands of ppb). Volcanic sources of SO_2 in the U.S. are limited to the Pacific Northwest, Alaska, and Hawaii. Emissions of SO_2 can also result from burning vegetation. The amount of SO_2 released from burning vegetation is generally in the range of 1 to 2% of the biomass burned and is the result of sulfur from amino acids being released as SO_2 during combustion.

2.3 BACKGROUND ON THE SO_2 MONITORING NETWORK

The following section provides general background on the SO_2 monitoring network. A more detailed description of this network can be found in Watkins (2009). The SO_2 monitoring network was originally deployed to support implementation of the SO_2 NAAQS established in 1971. Despite the establishment of an SO_2 standard, uniform minimum monitoring requirements for SO_2 monitoring did not appear until May 1979. From the time of the implementation of the 1979 monitoring rule through 2008, the SO_2 network has steadily decreased in size from approximately 1496 sites in 1980 to the approximately 488 sites operating in 2008.

The 1979 monitoring rule established two categories of SO_2 monitoring sites: State and Local Ambient Monitoring Stations (SLAMS) and the smaller set of National Ambient Monitoring Stations (NAMS). No minimum requirements were established for SLAMS. Minimum requirements (described below) were established for NAMS. The 1979 rule also required that SO_2 only be monitored using Federal Reference Methods (FRMs) or Federal Equivalent Methods (FEMs). The 1979 monitoring rule called for a range of number of sites in a metropolitan statistical area (MSA) based both on population size and known concentrations relative to the NAAQS (at that point in time; see Watkins, 2009).

In October 2006, EPA revised the monitoring requirements for SO_2 in light of the fact that there was not an SO_2 non-attainment problem (Watkins, 2009). The 2006 rule eliminated the minimum requirements for the number of SO_2 monitoring sites. The current SO_2 monitoring rule, 40 CFR Part 58, Appendix D, section 4.4 states:

Sulfur Dioxide (SO_2) Design Criteria.

(a) There are no minimum requirements for the number of SO_2 monitoring sites. Continued operation of existing SLAMS SO_2 sites using FRM or FEM is required until discontinuation is approved by the EPA Regional Administrator. Where SLAMS SO_2 monitoring is ongoing, at least one of the SLAMS SO_2 sites must be a maximum concentration site for that specific area.
(b) The appropriate spatial scales for SO_2 SLAMS monitoring are the microscale, middle, and possibly neighborhood scales. The multi-pollutant NCore sites can provide for metropolitan area trends analyses and general control strategy progress tracking. Other SLAMS sties are expected to provide data that are useful in specific compliance actions, for maintenance plan agreements, or for measuring near specific stationary sources of SO_2.

(1) Micro and middle scale – Some data uses associated with microscale and middle scale measurements for SO_2 include assessing the effects of control strategies to reduce concentrations (especially for the 3-hour and 24-hour averaging times) and monitoring air pollution episodes.

(2) Neighborhood scale – This scale applies where there is a need to collect air quality data as part of an ongoing SO_2 stationary source impact investigation. Typical locations might include suburban areas adjacent to SO_2 stationary sources for example, or for determining background concentrations as part of these studies of population responses to exposure to SO_2.

(c) Technical guidance in reference 1 of this appendix should be used to evaluate the adequacy of each existing SO_2 site, to relocate an existing site, or to locate new sites.

To ascertain what the current SO_2 network is addressing or characterizing, and in light of the relatively recent removal of a specific SO_2 monitoring requirement, EPA reviewed some of the SO_2 network meta-data (Watkins, 2009). The data reviewed are those available from AQS for calendar year 2008, for any monitors reporting data at any point during the year. The meta-data fields are usually created by state and locals whenever a monitor or site is opened, moved, or has a certain characteristic re-characterized. Often, EPA Regions consult with states and locals on some of these metadata characteristics, but it is the responsibility of the state or local to classify their own sites. With that, it should be noted that EPA must caveat such a review due to the fact the AQS meta-data may have missing or 'old' meta-data field entries, as states and locals do not have a routine or enforced process by which they must update or correct meta-data fields (Watkins, 2009).

Monitoring Objective:

The monitoring objective meta-data field describes what the data from the monitor are intended to characterize. The focus of the data presented is to show the nature of the network in terms of its attempt to generally characterize health effects, source impacts, transport, or welfare effects. In 2008, there were 488 SO_2 monitors reporting data to AQS at some point during the year. Any particular monitor can have multiple monitor objectives, however for this analysis (see Watkins, 2009) we have selected one reported objective based on a hierarchy to represent an individual monitor. The hierarchy used was to select, in order of priority: 1) source oriented, 2) high concentration, 3) population exposure, or 4) general background, if they existed at a site with multiple monitoring objectives. Table 2-1 presents the monitor objective distribution across all SO_2 sites from the available AQS data. There are 12 categories of monitor objective for any pollutant monitor within AQS. The "other" category is for sites likely addressing a state or local need outside of the routine objectives, and the "unknown" category represents missing meta-data. The six primary categories appropriate for use with SO_2 monitoring efforts stem directly from categorizations of site types within the CFR. In 40 CFR Part 58 Appendix D, they are defined as:

1. Sites located to determine the highest concentration expected to occur in the area covered by the network (Highest Concentration).
2. Sites located to measure typical concentrations in areas of high population (Population Exposure).
3. Sites located to determine the impact of significant sources or source categories on air quality (Source Oriented).
4. Sites located to determine general background concentration levels (General Background).
5. Sites located to determine the extent of regional pollutant transport among populated areas; and in support of secondary standards (Regional Transport).
6. Sites located to measure air pollution impacts on visibility, vegetation damage, or other welfare-based impacts (Welfare Related Impacts).

The remaining four categories available are a result of updating the AQS database. In the more recent upgrade to AQS, the data handlers inserted the available site types for Photochemical Assessment Monitoring Stations (PAMS) network as options for monitoring site objectives. In our metadata review, three SO_2 monitors have a listed monitoring objective that EPA intended to be applied only to NO_X or O_3 sites. As a result these three sites are presumably co-located with a NO_X or O_3 monitor with the same objective.

Measurement Scales

The spatial (measurement) scales are laid out in 40 CFR Part 58, Appendix D, Section 1 "Monitoring Objectives and Spatial Scales." This part of the regulation spells out what data from a monitor can represent in terms of air volumes associated with area dimensions:

Microscale - 0 to 100 meters

Middle Scale - 100 to 500 meters

Neighborhood Scale - 500 meters to 4 kilometers

Urban Scale - 4 to 50 kilometers

Regional Scale - 50 kilometers up to 1000km

There are meta-data records for the SO_2 network to indicate what the measurement scale of a particular monitor represents. In addition to the scales presented above, "industrial" scale sites are an available option for characterizing SO_2 monitor sites in AQS. These "industrial" scale sites are typically operated by industry, and are likely representative of the same scales that are associated with sites having source oriented and high concentration monitoring objectives, but we are unable to determine what spatial scale these monitors actually represent through AQS. It is also noted that a monitor can only have one measurement scale, as opposed to the possibility of a single monitor having multiple monitor objectives. Table 2-2 shows the measurement scale distribution across all SO_2 sites from the available data in AQS of monitors reporting data in 2008.

Table 2-1. SO_2 network monitoring objective distribution.

SO_2 Monitoring Objective	Number of Monitoring Objective Records	Percent Distribution
Population Exposure	208	42.6 %
Source Oriented	88	18.0 %
Highest Concentration	83	17.0 %
General Background	55	11.3 %
Regional Transport	12	2.5 %
Other	5	1.0 %
Max Precursor Impact (PAMS Type 2 Site)	3	0.6 %
Welfare Related Impacts	1	0.2 %
Unknown	33	6.8 %
Totals:	**488**	**100 %**

Table 2-2. SO_2 network distribution across measurement scales.

Measurement Scale	Number of Measurement Scale Records	Percent Distribution
Microscale	1	0.2 %
Middle Scale	35	7.2 %
Neighborhood	309	63.3 %
Urban Scale	61	12.5 %
Regional Scale	41	8.4 %
Industrial Scale	6	1.2 %
Unknown	35	7.2 %
Totals:	**488**	**100%**

Urban/Rural Location Analysis

The US Census Bureau (http://www.census.gov/geo/www/ua/ua_2k.html) defines the term "urban" as all territory, population, and housing units located within an urbanized area (UA) or an urban cluster (UC). The Census bureau uses UA and UC boundaries to encompass densely settled territory, which consists of:

- core census block groups or blocks that have a population density of at least 1,000 people per square mile and
- surrounding census blocks that have an overall density of at least 500 people per square mile
- Conversely, the Census Bureau's classification of "rural" consists of all territory, population, and housing units located outside of UAs and UCs. Counties, metropolitan areas, and the territory outside metropolitan areas, often are "split" between "urban" and "rural" territory. A spatial analysis of the SO_2 monitors against the Census Bureau's defined UAs and UCs shows that 63% of SO_2 monitors are in an "urban" setting and 37% are in a "rural" setting.

2.4 AMBIENT LEVELS OF SO_2

Since the integrated exposure to a pollutant is the sum of the exposures over all time intervals for all environments in which the individual spends time, understanding the temporal and spatial patterns of SO_2 levels across the U.S is an important component of conducting air quality, exposure, and risk analyses. SO_2 emissions and ambient concentrations follow a strong east to west gradient due to the large numbers of coal-fired electric generating units in the Ohio River Valley and upper Southeast regions. In the 12 CMSAs that had at least 4 SO_2 regulatory monitors from 2003-2005, 24-hour average concentrations in the continental U.S. ranged from a reported low of ~1 ppb in Riverside, CA and San Francisco, CA to a high of ~12 ppb in

Pittsburgh, PA and Steubenville, OH (ISA, section 2.4.4). In addition, inside CMSAs from 2003-2005, the annual average SO_2 concentration was 4 ppb (ISA, Table 2-8). However, spikes in hourly concentrations occurred; the mean 1-hour maximum concentration was 130 ppb, with a maximum value of greater than 700 ppb (ISA, Table 2-8).

In addition to considering 1-hour, 24-hour, and annual SO_2 levels in this document, examining the temporal and spatial patterns of 5-minute peaks of SO_2 is also important given that human clinical studies have demonstrated exposure to these peaks can result in adverse respiratory effects in exercising asthmatics (see Chapter 4). Although the total number of SO_2 monitors across the continuous U.S. can vary from year to year, in 2006 there were approximately 500 SO_2 monitors in the NAAQS monitoring network (ISA, section 2.5.2). State and local agencies responsible for these monitors are required to report 1-hour average SO_2 concentrations to the EPA Air Quality System (AQS). However, a small number of sites, only 98 total from 1997 to 2007, and not the same sites in all years, voluntarily reported 5-minute block average data to AQS (ISA, section 2.5.2). Of these, 16 reported all twelve 5-minute averages in each hour for at least part of the time between 1997 and 2007. The remainder reported only the maximum 5-minute average in each hour. When maximum 5-minute concentrations were reported, the absolute highest concentration over the ten-year period exceeded 4000 ppb, but for all individual monitors, the 99^{th} percentile was below 200 ppb (ISA, section 2.5.2). Medians from these monitors reporting data ranged from 1 ppb to 8 ppb, and the average for each maximum 5-minute level ranged from 3 ppb to 17 ppb. Delaware, Pennsylvania, Louisiana, and West Virginia had mean values for maximum 5-minute data exceeding 10 ppb (ISA, section 2.5.2). Among aggregated within-state data for the 16 monitors from which all 5-minute average intervals were reported, the median values ranged from 1 ppb to 5 ppb, and the means ranged from 3 ppb to 11 ppb (ISA, section 2.5.2). The highest reported concentration was 921 ppb, but the 99th percentile values for aggregated within-state data were all below 90 ppb (ISA, section 2.5.2).

EPA has generally conducted NAAQS risk assessments that focus on the risks associated with levels of a pollutant that are in excess of policy relevant background (PRB). Policy relevant background levels are defined as concentrations of a pollutant that would occur in the U.S. in the absence of anthropogenic emissions in continental North America (defined here as the United

States, Canada, and Mexico). However, throughout much of the United States, SO_2 PRB levels are estimated to be at most 30 parts per trillion and contribute less than 1% to present day SO_2 concentrations (ISA, section 2.5.3). We note that in the Pacific Northwest and Hawaii, PRB concentrations can be considerably higher due to geogenic activity (e.g., volcanoes); in these areas, PRB can account for 70-80% of total SO_2 concentrations (ISA, section 2.5.3). Since we do not plan on conducting SO_2 risk assessments in areas with high background SO_2 levels due to natural sources, and the contribution of PRB is negligible in all other areas, EPA is addressing the risks associated with monitored and/or modeled ambient SO_2 levels without regard to PRB levels.

2.5 RELATIONSHIP OF PERSONAL EXPOSURE TO AMBIENT CONCENTRATIONS

To help inform the evaluation of the epidemiologic evidence in Chapter 4 and the evidence-based considerations presented in Chapter 10, this section discusses the relationship of personal SO_2 exposure to ambient SO_2 concentrations. Many epidemiologic studies rely on measures of ambient SO_2 concentrations as surrogates for personal exposure to ambient SO_2. Thus, it is important to consider the potential sources of error that are associated with using SO_2 measured by ambient monitors as a surrogate for personal exposure to ambient SO_2. Key aspects related to this issue include: (1) ambient and personal sampling issues, (2) the spatial variability of ambient SO_2 concentrations, and (3) the relationship between ambient concentrations and personal exposures as influenced by exposure factors (e.g., indoor sources).

Only a limited number of studies have focused on the relationship between personal exposure and ambient concentrations of SO_2, in part because ambient SO_2 levels have declined markedly over the past few decades. Indoor and outdoor SO_2 concentrations are often below detection limits for personal samplers[2] and in these situations, the ISA notes that associations between ambient concentrations and personal exposures are inadequately characterized (ISA, section 2.6.3.2). However, in studies with personal measurements above detection limits, the ISA states that a reasonably strong association was observed between personal SO_2 exposure and ambient concentrations (Brauer et al., 1989; Sarnat et al., 2006; described in ISA section 2.6.3.2).

[2] The lower limit of detection of personal samplers is ~60 ppb for 1-hour and ~5 ppb for 24-hour. A discussion of personal sampler detection limits can be found in section 2.6.2 of the ISA.

In addition, the ISA notes that no study has examined the relationship between concentrations measured at ambient monitors and the community average exposure: a relationship that is more relevant than that of ambient concentration to personal exposure for community time-series studies (ISA, section 5.3).

Because epidemiologic studies rely on ambient SO_2 measurements at fixed site monitors, there is concern about the extent to which instrument error could influence the results of these studies. That is, the SO_2 monitoring network was designed and put into place when SO_2 concentrations were considerably higher, and thus, well within the standard monitor's limits of detection. However, SO_2 concentrations have fallen considerably over the years and are currently at, or very near these monitors' lower limit of detection (~3 ppb). As a result, greater relative error is most often observed at lower ambient concentrations compared to less frequent higher concentrations. Notably, the ISA states that it is unclear how instrument error will influence the effect estimates of epidemiologic studies relying on these measurements (ISA, section 2.6.4.1). As an additional matter, staff notes that the lower detection limit of these monitors is not considered problematic with respect to determining attainment of SO_2 NAAQS because the current 24-hour and annual standards, as well as the potential alternative 1-hour daily maximum standards, are all well within the detection limits of the SO_2 monitoring network.

Uncertainty in epidemiologic studies is also associated with the spatial and temporal variation of SO_2 across communities. The ISA finds that site-to-site correlations of SO_2 concentrations among monitors in U.S. cities ranges from very low to very high (ISA, section 2.6.4.1; ISA, Table 2-9). This suggests that at any given time, SO_2 concentrations at individual monitoring sites may not highly correlate with the average SO_2 concentration in the community. This could be the result of local sources (e.g., power plants) causing an uneven spatial distribution of SO_2, monitors being sited to represent concentrations near local sources, or effects related to terrain or weather (ISA, section 2.6.4.1). However, this type of error is not thought to bias community time-series results in a positive direction because it generally tends to reduce, rather than increase, effect estimates.

In epidemiologic studies, since people spend most of their time indoors, there is also uncertainty in the relationship between ambient concentrations measured by local monitors and actual personal exposure related to ambient sources. That is, the presence of indoor or nonambient sources of SO_2 could complicate the interpretation of associations between personal exposure and ambient SO_2 in exposure studies. Sources of indoor SO_2 are associated with the use of sulfur-containing fuels, with higher levels expected when emissions are poorly vented. In the U.S., the contribution of indoor sources is not thought to be a major contributor to overall SO_2 exposure because the only known indoor source is kerosene heaters and their use is not thought to be widespread (ISA, section 2.6.4.1).

The ISA concludes that exposure error caused by using ambient concentrations of SO_2 as a surrogate for exposure to ambient SO_2 is a source of uncertainty for epidemiologic studies. However, in community time-series and short-term panel epidemiologic studies, exposure error would tend to bias the effect estimate towards the null (ISA, section 2.6.4.4. and 5.3).

2.6 KEY OBSERVATIONS

- SO_2 emissions and ambient concentrations follow a strong east to west gradient due to the large numbers of coal-fired electric generating units in the Ohio River Valley and upper Southeast regions.
- In the 12 CMSAs that had at least 4 SO_2 regulatory monitors from 2003-2005, 24-hour average concentrations in the continental U.S. ranged from a reported low of ~1 ppb in Riverside, CA and San Francisco, CA to a high of ~12 ppb in Pittsburgh, PA and Steubenville, OH.
- Inside CMSAs from 2003-2005, the annual average SO_2 concentration was 4 ppb.
- Inside CMSAs from 2003-2005, the mean 1-hour maximum concentration was 130 ppb, with a maximum value of greater than 700 ppb.
- A small number of sites, only 98 total from 1997 to 2007, and not the same sites in all years—voluntarily reported 5-minute block average data to AQS. Of these, 16 reported all twelve 5-minute averages in each hour, while the remainder reported only the maximum 5-minute average in each hour.
- Throughout much of the United States, SO_2 PRB levels are estimated to be at most 30 parts per trillion and contribute less than 1% to present day SO_2 concentrations.
- The ISA concludes that exposure error caused by using ambient concentrations of SO_2 as a surrogate for exposure to ambient SO_2 is a source of uncertainty for epidemiologic studies. However, in community time-series and short-term panel epidemiologic studies, exposure error would tend to bias the effect estimate towards the null. Thus, results of these studies can be used, in part, to evaluate the adequacy of the current and potential alternative SO_2 standards (see Chapter 10)

3. AT RISK POPULATIONS

3.1 OVERVIEW

Interindividual variation in human responses to air pollutants indicates that some subpopulations are at increased risk for the detrimental effects of ambient exposure to SO_2. The NAAQS are intended to provide an adequate margin of safety for both general populations and sensitive subpopulations, or those subgroups potentially at increased risk for health effects in response to ambient air pollution. To facilitate the identification of subpopulations at the greatest risk for SO_2-related health effects, studies have identified factors that contribute to the susceptibility and/or vulnerability of an individual to SO_2. Susceptible individuals are broadly defined as those with a greater likelihood of an adverse outcome given a specific exposure in comparison with the general population (American Lung Association, 2001). The susceptibility of an individual to SO_2 can encompass a multitude of factors which represent normal developmental phases (e.g., age) or biologic attributes (e.g., gender); however, other factors (e.g., socioeconomic status (SES)) may influence the manifestation of disease and also increase an individual's susceptibility (American Lung Association, 2001). In addition, subpopulations may be vulnerable to SO_2 in response to an increase in their exposure during certain windows of life (e.g., childhood or old age) or as a result of external factors (e.g., SES) that contribute to an individual being disproportionately exposed to higher concentrations than the general population. It should be noted that in some cases specific factors may affect both the susceptibility and vulnerability of a subpopulation to SO_2. For example, a subpopulation that is characterized as having low SES may have less access to healthcare resulting in the manifestation of a disease, which increases their susceptibility to SO_2, but they may also reside in a location that results in exposure to higher concentrations of SO_2, increasing their vulnerability to SO_2.

To examine whether SO_2 differentially affects certain subpopulations, stratified analyses are often conducted in epidemiologic investigations to identify the presence or absence of effect modification. A thorough evaluation of potential effect modifiers may help identify subpopulations that are more susceptible and/or vulnerable to SO_2. These analyses require the proper identification of confounders and their subsequent adjustment in statistical models, which helps separate a spurious, from a true causal association. Although the design of toxicological and human clinical studies does not allow for an extensive examination of effect modifiers, the use of animal models of disease and the study of individuals with underlying disease or genetic polymorphisms do allow for comparisons between subgroups. Therefore, the results from these studies, combined with those results obtained through stratified analyses in epidemiologic studies, contribute to the overall weight of evidence for the increased susceptibility and vulnerability of specific subpopulations to SO_2. Those groups identified in the ISA to be potentially at greater risk of experiencing an adverse health effect from SO_2 exposure are described in more detail below.

3.2 PRE-EXISTING RESPIRATORY DISEASE

In human clinical studies, asthmatics have been shown to be more responsive to the respiratory effects of SO_2 exposure than healthy non-asthmatics. While SO_2-attributable decrements in lung function have generally not been demonstrated at concentrations $\leq$ 1000 ppb in non-asthmatics, statistically significant increases in respiratory symptoms and decreases in lung function have consistently been observed in exercising asthmatics following 5 to 10 minute SO_2 exposures at concentrations ranging from 400-600 ppb (ISA, section 4.2.1.1). Moderate or greater SO_2-induced decrements in lung function have also consistently been observed at SO_2 concentrations ranging from 200-300 ppb in some asthmatics. The ISA also notes that a number of epidemiologic studies have reported respiratory morbidity in asthmatics associated with SO_2 exposure (ISA 4.2.1.1). For example, numerous epidemiologic studies have observed positive associations between ambient SO_2 concentrations and ED visits and hospitalizations for asthma (ISA section 4.2.1.1). Overall, the ISA concludes that epidemiologic and controlled human exposure studies indicate that individuals with pre-existing respiratory diseases, particularly asthma, are at greater risk than the general population of experiencing SO_2-associated health effects (ISA, section 4.2.1.1).

3.3 GENETICS

The ISA notes that a consensus now exists among scientists that the potential for genetic factors to increase the risk of experiencing adverse health effects due to ambient air pollution merits serious consideration. Several criteria must be satisfied in selecting and establishing useful links between polymorphisms in candidate genes and adverse respiratory effects. First, the product of the candidate gene must be significantly involved in the pathogenesis of the effect of interest, which is often a complex trait with many determinants. Second, polymorphisms in the gene must produce a functional change in either the protein product or in the level of expression of the protein. Third, in epidemiologic studies, the issue of effect modification by other genes or environmental exposures must be carefully considered (ISA section 4.2.2).

While many studies have examined the association between genetic polymorphisms and susceptibility to air pollution in general, only one study has specifically examined the effects of SO_2 exposure on genetically distinct subpopulations. Winterton et al. (2001) found a significant association between SO_2-induced decrements in Forced Expiratory Volume in the first second (FEV_1) and the homozygous wild-type allele in the promoter region of Tumor Necrosis Factor-α (TNF- α; AA, position -308). However, the ISA concluded that the overall body of evidence was too limited to reach a conclusion regarding the effects of SO_2 exposure on genetically distinct subpopulations at this time.

3.4 AGE

The ISA identifies children (i.e., <18 years of age) and older adults (i.e., >65 years of age) as groups that are potentially at greater risk of experiencing SO_2-associated adverse health effects. In children, the developing lung is prone to damage from environmental toxicants as it continues to develop through adolescence. The biological basis for increased risk in the elderly is unknown, but one hypothesis is that it may be related to changes in antioxidant defenses in the fluid lining the respiratory tract. The ISA found a number of epidemiologic studies that observed increased respiratory symptoms in children associated with increasing SO_2 concentrations. In addition, several studies have reported that the excess risk estimates for ED visits and hospitalizations for all respiratory causes, and to a lesser extent asthma, associated with a 10-ppb increase in 24-hour average SO_2 concentrations were higher for children and older adults than for all ages together (ISA, section 4.2.3). However, the ISA also notes that the evidence from controlled human exposure studies does not suggest that adolescents are either more or less at risk than adults to the respiratory effects of SO_2, but rather adolescents may experience similar respiratory effects at a given exposure concentration (ISA, sections 3.1.3.5 and 4.2.3). Overall, the ISA finds that compared to the general population, there is limited evidence to suggest that children and older adults are at greater risk of experiencing SO_2-associated health effects (ISA, section 4.2.3).

3.5 TIME SPENT OUTDOORS

Outdoor SO_2 concentrations are generally much higher than indoor concentrations. Thus, the ISA notes that individuals who spend a significant amount of time outdoors are likely at greater risk of experiencing SO_2-associated health effects than those who spend most of their time indoors (ISA section 4.2.5).

3.6 VENTILLATION RATE

Controlled human exposure studies have demonstrated that decrements in lung function and respiratory symptoms occur at significantly lower SO_2 exposure levels in exercising subjects compared to resting subjects. As ventilation rate increases, breathing shifts from nasal to oronasal, thus resulting in greater uptake of SO_2 in the tracheobronchial airways due to the diminished absorption of SO_2 in the nasal passages. Therefore, individuals who spend a significant amount of time at elevated ventilation rates (e.g. while playing, exercising, or working) are expected to be at greater risk of experiencing SO_2-associated health effects (ISA section 4.2.5).

3.7 SOCIOECONOMIC STATUS

There is limited evidence that increased risk to SO_2 exposure is associated with lower SES (ISA section 4.2.5). Finkelstein et al. (2003) found that among people with below-median income, the relative risk for above-median exposure to SO_2 was 1.18 (95% CI: 1.11, 1.26); the corresponding relative risk among subjects with above-median income was 1.03 (95% CI: 0.83, 1.28). However, the ISA concludes that there is insufficient evidence to reach a conclusion regarding SES and exposure to SO_2 at this time (ISA section 4.2.5).

3.8 NUMBER OF AT RISK INDIVIDUALS

Considering the size of the groups mentioned above, large proportions of the U.S. population are likely to have a relatively high risk of experiencing SO_2-related health effects. In the United States, approximately 10% of adults and 13% of children have been diagnosed with asthma. Notably, the prevalence and severity of asthma is higher among certain ethnic or racial groups such as Puerto Ricans, American Indians, Alaskan Natives, and African Americans (ISA for NO_x, section 4.4). Furthermore, a higher prevalence of asthma among persons of lower SES and an excess burden of asthma hospitalizations and mortality in minority and inner-city communities have been observed. In addition, population groups based on age comprise substantial segments of individuals that may be potentially at risk for SO_2-related health impacts. Based on U.S. census data from 2000, about 72.3 million (26%) of the U.S. population are under 18 years of age, 18.3 million (7.4%) are under 5 years of age, and 35 million (12%) are 65 years of age or older. There is also concern for the large segment of the population that is potentially at risk to SO_2-related health effects because of increased time spent outdoors at elevated ventilation rates (those who work or play outdoors). Overall, the considerable size of the population groups at risk indicates that exposure to ambient SO_2 could have a significant impact on public health in the United States.

3.9 KEY OBSERVATIONS

- The susceptibility of an individual to SO_2 can encompass a multitude of factors which represent normal developmental phases (e.g., age) or biologic attributes (e.g., gender); however, other factors (e.g., SES) may influence the manifestation of disease and also increase an individual's susceptibility.
- Subpopulations may be vulnerable to SO_2 in response to an increase in their exposure during certain windows of life (e.g., childhood or old age) or as a result of external factors (e.g., SES) that contribute to an individual being disproportionately exposed to higher concentrations than the general population.
- In some cases specific factors may affect both the susceptibility and vulnerability of a subpopulation to SO_2.
- The ISA concludes that individuals with pre-existing respiratory disease are likely at greater risk than the general population of experiencing SO_2-associated health effects.
- Epidemiologic studies suggest that children and older adults may be at greater risk of experiencing SO_2-associated health effects. However, the evidence from controlled human exposure studies suggests that adolescents are neither more nor less at risk than adults.
- People who spend extended periods of time outdoors and/or at elevated ventilation rates are likely at increased risk of experiencing adverse health effects from SO_2 exposure.
- Large proportions of the U.S. population are likely to be at increased risk of experiencing SO_2-related health effects. Thus, exposure to ambient SO_2 could have a significant impact on public health in the United States

4. INTEGRATION OF HEALTH EVIDENCE

4.1 INTRODUCTION

The ISA, along with its annexes, integrates newly available epidemiologic, human clinical, and animal toxicological evidence with consideration of key findings and conclusions from prior reviews to draw conclusions about the relationship between short- and long-term exposure to SO_2 and numerous human health categories. For these health effects, the ISA characterizes judgments about causality with a hierarchy (for discussion see ISA section 1.3.7) that contains the following five levels:

- Sufficient to infer a causal relationship
- Sufficient to infer a likely causal relationship (i.e., more likely than not)
- Suggestive but not sufficient to infer a causal relationship
- Inadequate to infer the presence or absence of a causal relationship
- Suggestive of no causal relationship

The ISA notes that these judgments about causality are informed by a series of aspects of causality that are based on those set forth by Sir Austin Bradford Hill in 1965 (ISA section 1.3.6). These aspects include strength of the observed association, availability of experimental evidence, consistency of the observed association, biological plausibility, coherence of the evidence, temporal relationship of the observed association, and the presence of an exposure-response relationship. A summary of each of the five levels of the hierarchy is provided in Table 1-2 of the ISA, which has also been included below (Table 4-1).

Table 4-1. Weight of evidence for causal determination.

RELATIONSHIP	DESCRIPTION
Causal relationship	Evidence is sufficient to conclude that there is a causal relationship between relevant pollutant exposures and the health outcome. That is, a positive association has been observed between the pollutant and the outcome in studies in which chance, bias, and confounding could be ruled out with reasonable confidence. Evidence includes, for example, controlled human exposure studies; or observational studies that cannot be explain by plausible alternatives or are supported by other lines of evidence (e.g. animal studies or mechanism of action information). Evidence includes replicated and consistent high-quality studies by multiple investigators.
Likely to be a causal relationship	Evidence is sufficient to conclude that a causal relationship is likely to exist between relevant pollutant exposures and the health outcome but important uncertainties remain. That is, a positive association has been observed between the pollutant and the outcome in studies in which chance and bias can be ruled out with reasonable confidence but potential issues remain. For example: a) observational studies show positive associations but copollutant exposures are difficult to address and/or other lines of evidence (controlled human exposure, animal, or mechanism of action information) are limited or inconsistent; or b) animal evidence from multiple studies, sex, or species is positive but limited or no human data are available. Evidence generally includes replicated and high-quality studies by multiple investigators.
Suggestive of a causal relationship	Evidence is suggestive of a causal relationship between relevant pollutant exposures and the health outcome, but is limited because chance, bias and confounding cannot be ruled out. For example, at least one high-quality study shows a positive association but the results of other studies are inconsistent.
Inadequate to infer a causal relationship	Evidence is inadequate to determine that a causal relationship exists between relevant pollutant exposures and the health outcome. The available studies are of insufficient quantity, quality, consistency or statistical power to permit a conclusion regarding the presence or absence of an association between relevant pollutant exposure and the outcome.
Suggestive of no causal relationship	Evidence is suggestive of no causal relationship between relevant pollutant exposures and the health outcome Several adequate studies, covering the full range of levels of exposure that human beings are known to encounter and considering sensitive subpopulations, are mutually consistent in not showing a positive association between exposure and the outcome at any level of exposure. The possibility of a very small elevation in risk at the levels of exposure studied can never be excluded.

Considering the framework presented in Table 4-1, the ISA concludes that there is sufficient evidence to infer a causal relationship between respiratory morbidity and short-term exposure to SO_2 (ISA, section 5.2). The ISA bases this conclusion on the consistency, coherence, and plausibility of findings observed in controlled human exposure studies of 5-10 minutes, epidemiologic studies mostly using 24-hour average concentrations, and animal toxicological studies using exposures of minutes to hours (ISA, section 5.2). The evidence of an association between SO_2 exposure and other health categories is judged to be less convincing, at most suggestive but not sufficient to infer a causal relationship. Key conclusions from the ISA are summarized below and are described in greater detail in Table 5-3 of the ISA.

- **Sufficient to infer a causal relationship:**
  - Short-Term Exposure to SO_2 and Respiratory Morbidity
- **Suggestive but not sufficient to infer a causal relationship:**
  - Short-Term Exposure to SO_2 and Mortality
- **Inadequate to infer the presence or absence of a causal relationship**
  - Short-Term Exposure to SO_2 and Cardiovascular Morbidity;
  - Long-Term Exposure to SO_2 and Respiratory Morbidity;
  - Long-Term Exposure to SO_2 and Other Morbidity;
  - Long-Term Exposure to SO_2 and Mortality

The integrated health discussion in this chapter will focus on health effect categories for which the ISA finds a causal or likely causal relationship, as these effect categories are the basis for the potential health effect benchmarks and quantitative health risk assessment included in Chapters 7 through 9 of this document. As a result, this chapter will present an integrated discussion of the health evidence related to respiratory morbidity following short-term exposure to SO_2. This is because respiratory morbidity is the only health effect category found by the ISA to have either a causal or likely causal association with SO_2. The focus on health effect categories with the strongest evidence for purposes of the quantitative evaluation is consistent with prior NAAQS reviews, including the recent NO_2 REA. However, we note that other health endpoints will be considered as part of the policy discussion in Chapter 10 and during the rulemaking process.

In addition to an integrated discussion of the respiratory morbidity health evidence, section 4.3 of this chapter will discuss whether SO_2-associated health effects can reasonably be considered adverse. Briefly, this discussion will integrate: 1) respiratory morbidity health evidence; 2) conclusions from previous NAAQS reviews regarding adversity of effect; 3) ATS guidelines on what constitutes an adverse health effect of air pollution; and 4) CASAC views regarding the impact of moderate decrements in lung function or respiratory symptoms on individuals with pre-existing lung disease.

4.2 RESPIRATORY MORBIDITY FOLLOWING SHORT-TERM SO_2 EXPOSURE

4.2.1 Overview

The ISA concludes that there is sufficient evidence to infer a causal relationship between respiratory morbidity and short-term (5-minutes to 24-hours) exposure to SO_2 (ISA, section 5.2). In large part, this determination is based on the results of controlled human exposure studies in exercising asthmatics demonstrating a relationship between 5-10 minute peak SO_2 exposures and decrements in lung function that are frequently accompanied by respiratory symptoms. In fact, the ISA describes the controlled human exposure studies as being the “definitive evidence” for its causal determination between short-term SO_2 exposure and respiratory morbidity (ISA, section 5.2). In addition to the controlled human exposure evidence, the ISA finds supporting evidence for its causal determination from a large body of epidemiologic studies observing positive associations between ambient SO_2 levels and respiratory symptoms, as well as ED visits and hospital admissions for all respiratory causes and asthma (ISA, section 5.2). An integrated discussion of the controlled human exposure and epidemiologic evidence from the ISA is presented below. In addition, section 4.2.3 discusses the effect of medication on SO_2-induced respiratory morbidity.

4.2.2 Integration of Respiratory Morbidity Health Evidence

As previously mentioned, the ISA’s finding of a causal relationship between respiratory morbidity and short-term SO_2 exposure is based in large part on results from controlled human exposure studies involving exercising asthmatics. In general, these studies demonstrate that asthmatic individuals exposed to SO_2 concentrations as low as 200-300 ppb for 5-10 minutes during exercise experience moderate or greater bronchoconstriction, measured as a decrease in FEV_1 of $\geq$ 15% or an increase in specific airway resistance (sRaw) of $\geq$ 100% after correction for exercise-induced responses in clean air (Bethel et al., 1983; Linn et al., 1983, 1984, 1987; 1988;

1990; Magnussen et al., 1990; Roger et al., 1985; Gong et al., 1995; Trenga et al., 1999). In addition, the ISA finds that among asthmatics, both the percentage of individuals affected, and the severity of the response increases with increasing SO_2 concentrations. That is, at concentrations ranging from 200-300 ppb, the lowest levels tested in free breathing chamber studies[3] , 5-30% percent of exercising asthmatics experience moderate or greater decrements in lung function (ISA, Table 3-1). At concentrations ≥ 400 ppb, moderate or greater decrements in lung function occur in 20-60% of exercising asthmatics, and compared to exposures at 200-300 ppb, a larger percentage of asthmatics experience severe decrements in lung function (i.e., ≥ 200% increase in sRaw, and/or a ≥ 20% decrease in FEV_1) (ISA, Table 3-1). Moreover, at SO_2 concentrations ≥ 400 ppb, moderate or greater decrements in lung function are frequently accompanied by respiratory symptoms (e.g., cough, wheeze, chest tightness, shortness of breath) (Balmes et al., 1987; Gong et al., 1995; Linn et al., 1983; 1987; 1988; 1990; ISA, Table 3-1). Further analysis and discussion of the individual studies leading to the conclusions presented above can be found in Sections 3.1.1 to 3.1.3.5 of the ISA.

Supporting the human clinical evidence is a relatively larger body of epidemiologic studies published since the last review. In general, these studies observed positive associations between ambient SO_2 concentrations and respiratory symptoms, as well as ED visits and hospitalizations for all respiratory causes (particularly among children and older adults) and asthma. Moreover, although copollutant adjustment had varying degrees of influence on the SO_2 effect estimate in ED visit and hospitalization studies, the effect of SO_2 appeared to be generally robust and independent of gaseous copollutants, including NO_2 (Anderson et al., 1998; Lin et al., 2004a; Sunyer et al., 1997) and O_3 (Anderson et al., 1998; Hajat et al., 1999; Tsai et al., 2006; Yang et al., 2003; 2005). With respect to potential confounding by PM_{10}, the evidence of an independent SO_2 effect on respiratory health was less consistent, with some positive associations with ED visit and hospitalization results becoming negative (although the negative results were not statistically significant) after inclusion of PM_{10} in regression models (Galan et al., 2003; Schwartz, 1995 [in New Haven, CT]; Tsai et al., 2006). However, several other ED visit and hospitalization studies found the SO_2 effect estimate to be generally robust after inclusion of

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[3] The ISA cites one chamber study with intermittent exercise where healthy and asthmatic children were exposed to 100 ppb SO_2 in a mixture with ozone and sulfuric acid. The ISA notes that compared to exposure to filtered air, exposure to the pollutant mix did not result in statistically significant changes in lung function or respiratory symptoms (ISA section 3.1.3.4)

PM_{10} in regression models (Burnett et al., 1997; Hagen et al., 2000; Hajat et al., 1999; Schwartz, 1995 [in Tacoma, WA]). Furthermore, in most (Van der Zee et al., 1999; Mortimer et al., 2002 and Schildcrout et al., 2006), but not all (Schwartz et al., 1994) studies of respiratory symptoms, the SO_2 effect estimate remained robust and relatively unchanged after inclusion of PM_{10} in multipolutant models (although the effect estimate may have lost statistical significance). In addition, SO_2-effect estimates generally remained robust in the limited number of studies that included $PM_{2.5}$ and/or $PM_{10-2.5}$ in multipolutant models (Burnett et al., 1997; Ito et al., 2007; Lin et al., 2003; NY DOH, 2006). Taken together, the ISA ultimately concludes that studies employing multipollutant models suggest that SO_2 has an independent effect on respiratory morbidity outcomes (ISA, section 5.2).

The ISA further characterizes the epidemiologic results of increases in respiratory symptoms as well as increases in hospital admissions and ED visits as being consistent and coherent. The evidence is consistent in that associations are reported in studies conducted in numerous locations and with a variety of methodological approaches (ISA, section 5.2). Epidemiologic results are coherent in that respiratory symptoms results from epidemiologic studies with short-term (≥ 1-hour) exposures are generally in agreement with respiratory symptom results from controlled human exposure studies of 5-10 minutes. However, the ISA notes the differences in averaging times associated with respiratory effects in human exposure and epidemiologic studies. That is, while adverse respiratory effects are observed following 5-10 minute exposures in human clinical studies, the majority of positive respiratory results from epidemiologic studies are associated with a 24-hour averaging time- the only averaging time evaluated in the vast majority of these studies. As a potential explanation for the difference in averaging times employed across study designs, the ISA suggests that it is possible that results from epidemiologic studies are being driven, at least in part, by shorter-term peak SO_2 concentrations (ISA section 5.2). More specifically, with respect to epidemiologic studies of respiratory symptoms, the ISA states “that it is possible that these associations are determined in large part by peak exposures within a 24-hour period” (ISA, section 5.2). Similarly, the ISA states that the respiratory effects following peak SO_2 exposures in controlled human exposure studies provides a basis for a progression of respiratory morbidity that could result in increased ED visits and hospital admissions (ISA, section 5.2). Also, it should be noted there is epidemiologic evidence to suggest that shorter-term peak SO_2 concentrations can result in adverse respiratory effects. That is, there are a relatively small number of epidemiologic studies demonstrating positive associations between 1-hour daily maximum SO_2 concentrations and respiratory symptoms, as well ED visits and hospitalizations (ISA, Tables 5-4 and 5-5). While these studies are not limiting the exposure to a defined 1-hour period, they provide additional evidence that the shorter term peaks result in adverse respiratory effects.

The ISA also finds that the respiratory effects of SO_2 are consistent with the mode of action as it is currently understood from animal toxicological and human exposure studies (ISA, section 5.2). The immediate effect of SO_2 on the respiratory system is bronchoconstriction. This response is mediated by chemosensitive receptors in the tracheobronchial tree. Activation of these receptors triggers central nervous system reflexes that result in bronchoconstriction and respiratory symptoms that are often followed by rapid shallow breathing (ISA, section 5.2). The ISA notes that asthmatics are likely more sensitive to the respiratory effects of SO_2 due to preexisting inflammation associated with the disease. For example, pre-existing inflammation may lead to enhanced release of inflammatory mediators, and/or enhanced sensitization of the chemosensitive receptors (ISA, section 5.2).

Taken together, the ISA concludes that the controlled human exposure, epidemiologic, and toxicological evidence support its determination of a causal relationship between respiratory morbidity and short-term (5-minutes to 24-hours) exposure to SO_2. Results from controlled human exposure studies provide the definitive evidence for this conclusion, while supporting evidence is found in numerous epidemiologic studies of respiratory symptoms and ED visits and hospitalizations (ISA, section 5.2). The ISA further notes that both lines of evidence are consistent with the SO_2 mode of action as it is currently understood (ISA, section 5.2).

4.2.3 Medication as an Effect Modifier

As mentioned above, the immediate effect of SO_2 on the respiratory system is bronchoconstriction. Thus, we note that quick-relief and long-term-control asthma medications have been shown to provide varying degrees of protection against SO_2-induced bronchoconstriction in mild and moderate asthmatics (ISA section 3.1.3.2 and Annex Table D-1). More specifically, while no therapy has been shown to completely eliminate SO_2-induced respiratory effects in exercising asthmatics, some short- and long-acting asthma medications are capable of significantly reducing SO_2-induced bronchoconstriction (Gong et al., 1996; 2001; Koenig et al., 1987; Linn et al., 1990). However, the ISA notes that asthma is often poorly controlled even among severe asthmatics due to inadequate drug therapy or poor compliance among those who are on regular medication (Rabe et al., 2004). Moreover, the ISA also notes that mild asthmatics, who constitute the majority of asthmatic individuals, are much less likely to use asthma medication than asthmatics with more severe disease (O'Byrne, 2007; Rabe et al., 2004). Therefore, the ISA finds that it is reasonable to conclude that all asthmatics (i.e., mild, moderate, and severe), are at high risk of experiencing adverse respiratory effects from SO_2 exposure (ISA section 3.1.3.2).

4.3 WHAT CONSTITUTES AN ADVERSE HEALTH IMPACT FROM SO_2 EXPOSURE?

In making judgments as to when various SO_2 -related health effects become regarded as adverse to the health of individuals, staff has relied upon the guidelines published by the American Thoracic Society (ATS), conclusions from previous NAAQS reviews, and the advice of CASAC. Taken together, staff concludes that for asthmatics, SO_2-induced respiratory effects are adverse. The rationale for this conclusion is presented below.

The ATS has previously defined adverse respiratory health effects as "medically significant physiologic changes generally evidenced by one or more of the following: (1) interference with the normal activity of the affected person or persons, (2) episodic respiratory illness, (3) incapacitating illness, (4) permanent respiratory injury, and/or (5) progressive respiratory dysfunction" (ATS 1985). The ATS has also recommended that transient loss in lung function with accompanying respiratory symptoms, or detectable effects of air pollution on clinical measures (e.g., medication use) be considered adverse (ATS 1985). We also note that during the last O_3 NAAQS review, the CD and Staff Paper indicated that for many people with lung disease (e.g., asthma), even moderate decrements in lung function (e.g., FEV_1 decrements > 10% but < 20% and/or ≥100% increases in sRaw) or respiratory symptoms would likely interfere with normal activities and result in additional and more frequent use of medication (EPA 2006, EPA 2007e). In addition, CASAC has previously indicated that in the context of standard setting, a focus on the lower end of the range of moderate functional responses is most appropriate for estimating potentially adverse lung function decrements in people with lung disease (73 FR16463). Finally, we note that in the current SO_2 NAAQS review, clinicians on the CASAC Panel again advised that moderate or greater decrements in lung function can be clinically significant in some individuals with respiratory disease (CASAC transcripts, July 30-31 2008, pages 211-213)

Considering the advice and recommendations described above, as well as key conclusions in the ISA, staff finds that for asthmatics, SO_2-induced respiratory effects are adverse. Human exposure studies are described in the ISA as being the "definitive evidence" for a causal association between short-term SO_2 exposure and respiratory morbidity (ISA, section 5.2). These studies have consistently demonstrated that exposure to SO_2 concentrations as low as 200-300 ppb for 5-10 minutes can result in moderate or greater decrements in lung function, evidenced by a ≥15% decline in FEV_1 and/or ≥ 100% increase in sRaw in a significant percentage of exercising asthmatics (see section 4.2.2). It is highly likely that these decrements in lung function will result in increased medication use and a disruption of normal activities for a significant percentage of these asthmatics. This expectation is supported by a number of human exposure studies reporting that some exercising asthmatics required the use of medication to treat the respiratory effects that followed a 5-10 minute SO_2 exposure (EPA 1994a). It is also supported by CASAC views during the previous O_3 review that moderate declines in FEV_1can be clinically significant in some individuals (Henderson 2006). As an additional matter, we note that human exposure studies have also reported that at SO_2 concentrations ≥ 400 ppb, lung function decrements (i.e., ≥ 15% decline in FEV_1 and/or ≥ 100% increase in sRaw) are frequently accompanied by respiratory symptoms. Taken together, staff concludes that human exposure studies demonstrate that adverse respiratory effects occur in exercising asthmatics following 5-10 minute SO_2 exposures as low as 200 ppb. However, we also note that the subjects participating in these exposure studies do not represent the most sensitive asthmatics (i.e., severe asthmatics), and therefore, it is possible that adverse respiratory effects could occur at lower SO_2 concentrations in these individuals.

Epidemiologic studies also indicate that adverse respiratory morbidity effects are associated with SO_2. In reaching the conclusion of a causal relationship between respiratory morbidity and short-term SO_2 exposure, the ISA generally found positive associations between ambient SO_2 concentrations and ED visits and hospitalizations for all respiratory causes and asthma (see section 4.2.2). Notably, ED visits and hospitalizations attributable to air pollution are considered adverse effects under ATS guidelines. These studies also indicate that SO_2 is associated with episodic respiratory illness and aggravation of respiratory diseases, which under ATS guidance, would also be considered adverse effects of air pollution.

In 2000, the ATS published updated guidelines on what constitutes an adverse health effect of air pollution (ATS, 2000). These guidelines expanded those released in 1985 (ATS 1985). Among other considerations, the 2000 guidelines stated that measurable negative effects of air pollution on quality of life should be considered adverse (ATS 2000). These updated guidelines also indicated that exposure to air pollution that increases the risk of an adverse effect to the entire population is adverse, even though it may not increase the risk of any individual to an unacceptable level (ATS 2000). For example, a population of asthmatics could have a distribution of lung function such that no individual has a level associated with significant impairment. Exposure to air pollution could shift the distribution to lower levels that still do not bring any individual to a level that is associated with clinically relevant effects. However, this would be considered adverse because individuals within the population would have diminished reserve function, and therefore would be at increased risk if affected by another agent (ATS 2000).

The 2000 ATS guidelines further strengthen the conclusion that SO_2-induced respiratory effects are adverse. As previously mentioned, human clinical studies have consistently demonstrated that SO_2 exposure can result in moderate or greater decrements in FEV_1 and sRaw at levels as low as 200-300 ppb in a significant percentage of exercising asthmatics. Staff finds that these results could reasonably indicate an SO_2-induced shift in these lung function measurements for this population. As a result, a significant percentage of exercising asthmatics exposed to SO_2 concentrations as low as 200 ppb would have diminished reserve lung function and would be at greater risk if affected by another respiratory agent (e.g., viral infection). Importantly, diminished reserve lung function in a population that is attributable to air pollution is an adverse effect under ATS guidance.

Staff finds multiple lines of evidence indicating that exposure to SO_2 concentrations at least as low as 200 ppb can result in adverse respiratory effects. We note that this is in agreement with CASAC comments offered on the first draft SO_2 REA. The CASAC letter to the

Administrator states: "CASAC believes strongly that the weight of clinical and epidemiology evidence indicates there are detectable clinically relevant health effects in sensitive subpopulations down to a level at least as low as 0.2 ppm SO_2 (Henderson 2008)." Thus, when examining the adequacy of the current and potential alternative standards (see Chapter 10), staff finds it appropriate to consider the degree of protection these standards provide, or would provide, against moderate or greater decrements in lung function and/or respiratory symptoms in asthmatics at elevated breathing ventilation rates.

4.4 KEY OBSERVATIONS

- The ISA concludes that there is sufficient evidence from human exposure, epidemiologic, and toxicological studies to infer a causal relationship between respiratory morbidity and short-term exposure to SO_2
- The ISA characterizes no other health endpoints as having a causal or likely causal association with short or long-term exposure to SO_2.
- Human exposure studies demonstrate that at SO_2 concentrations ranging from 200-300 ppb, the lowest levels tested in free breathing chamber studies, 5-30% percent of exercising asthmatics experience moderate or greater decrements in lung function (i.e., ≥ 100% increase in sRaw, and/or a ≥ 15% decrease in FEV_1). At concentrations ≥ 400 ppb, moderate or greater decrements in lung function occur in 20-60% of exercising asthmatics, and compared to exposures at 200-300 ppb, a larger percentage of asthmatics experience severe decrements in lung function (i.e., ≥ 200% increase in sRaw, and/or a ≥ 20% decrease in FEV_1).
- At SO_2 concentrations ≥ 400 ppb, moderate or greater decrements in lung function are frequently accompanied by respiratory symptoms.
- In general, epidemiologic studies observed positive associations between ambient SO_2 concentrations and respiratory symptoms, as well as ED visits and hospitalizations for all respiratory causes and asthma. In studies using multipollutant models, the effects of SO_2 were generally independent of effects of other ambient air pollutants
- No medication regimen has been shown to completely eliminate SO_2-induced respiratory effects in exercising asthmatics.
- Staff finds multiple lines of evidence indicating that SO_2 exposure can result in respiratory effects that can reasonably be considered adverse to the health of asthmatics.

5. SELECTION OF POTENTIAL ALTERNATIVE STANDARDS FOR ANALYSIS

5.1 INTRODUCTION

The primary goals of the SO_2 risk and exposure assessment described in this document are to estimate short-term exposures and potential human health risks associated with 1) recent levels of ambient SO_2; 2) SO_2 levels associated with just meeting the current standards; and 3) SO_2 levels associated with just meeting potential alternative standards. This section presents the rationale for the selection of the potential alternative standards that are assessed in the quantitative analyses discussed in Chapters 7 through 9. These potential alternative standards are defined in terms of indicator, averaging time, form, and level.

5.2 INDICATOR

The SO_x include multiple gaseous (e.g., SO_2, SO_3) and particulate (e.g., sulfate) species. In considering the appropriateness of different indicators, we note that the health effects associated with particulate species of SO_x have been considered within the context of the health effects of ambient particles in the Agency's review of the PM NAAQS. Thus, as discussed in the Integrated Review Plan (2007a), the current review of the SO_2 NAAQS is focused on the gaseous species of SO_x and will not consider health effects directly associated with particulate species of SO_x. Of the gaseous species, EPA has historically determined it appropriate to specify the indicator of the standard in terms of SO_2 because other gaseous sulfur oxides (e.g., SO_3) are likely to be found at concentrations many orders of magnitude lower than SO_2 in the atmosphere, and because most all of the health effects evidence and exposure information is related to SO_2. The final ISA has again found this to be the case. Therefore, staff concluded that SO_2 remains the most appropriate indicator for the alternative standards that are analyzed in this document.

5.3 AVERAGING TIME

Staff concluded that the most robust evidence for SO_2-induced respiratory morbidity exists for exposure durations ≤ 1-hour. The strongest evidence for this conclusion comes from controlled human exposure studies that have consistently demonstrated that exposure to SO_2 for 5-10 minutes can result in significant bronchoconstriction and/or respiratory symptoms in exercising asthmatics (see section 4.2). In fact, the ISA describes the controlled human exposure studies as being the "definitive evidence" for its causal determination between SO_2 exposure and short-term respiratory morbidity (ISA, section 5.2). In addition to these controlled human exposure studies, there is a relatively small body of epidemiologic evidence describing positive associations between 1-hour maximum SO_2 levels and respiratory symptoms as well as hospital admissions and ED visits for all respiratory causes and asthma (ISA, Tables 5.4 and 5.5). In addition to the epidemiologic evidence for effects related to the 1-hour maximum concentration in a 24-hour period, there is a considerably larger body of epidemiologic studies reporting associations between 24-hour average SO_2 levels and respiratory symptoms, as well as hospitalizations and ED visits; however, the ISA notes that it is possible that associations observed in these 24-hour studies are being driven, at least in part, by short-term SO_2 peaks of duration < 24-hours. More specifically, when describing epidemiologic studies observing associations between ambient SO_2 and respiratory symptoms, the ISA states "that it is possible that these associations are determined in large part by peak exposures within a 24-hour period" (ISA, section 5.2). The ISA also states that the respiratory effects following peak SO_2 exposures in controlled human exposure studies provides a basis for a progression of respiratory morbidity that could result in increased ED visits and hospital admissions (ISA, section 5.2). It should also be noted that epidemiologic studies conducted in Paris, France (Dab et al., 1996) and in Manhattan and Bronx, NY (NY DOH, 2006) used both 24-hour average and 1-hour daily maximum air quality levels and found similar effect estimates with regard to hospital admissions for all respiratory causes (Dab et al., 1996) and asthma ED visits (NY DOH, 2006). Finally, in addition to the controlled human exposure and epidemiologic evidence, the ISA describes key toxicological studies with exposures ranging from minutes to hours resulting in decrements in lung function, airway inflammation, and/or hyperresponsiveness in laboratory animals (ISA, Table 5-2).

The scientific evidence described above suggests that at a minimum, averaging time(s) selected for further risk and exposure analyses should address respiratory effects associated with SO_2 exposures of ≤ 1-hour. We note that analyses conducted in the ISA demonstrate that at monitors measuring all twelve 5-minute SO_2 levels in an hour (n=16), there is a high Pearson correlation between the 5-minute maximum level and the corresponding 1-hour average SO_2 concentration, with only one monitor observing a correlation ≤ 0.9 (ISA, section 2.5.2; ISA,

Table 2-12). Thus, for the purpose of conducting quantitative exposure and risk analyses, staff concluded that the focus should be on potential alternative SO_2 standards with an averaging time of 1-hour. Staff believes that alternative standards with an averaging time of 1-hour will limit both 5-minute peak concentrations within an hour, as well as other peak SO_2 concentrations (≥ 1-hour) that are likely in part, driving the respiratory outcomes described in epidemiologic studies.

Staff also considered examining alternative 5-minute standards in the risk and exposure assessment, but concluded for several reasons that such an analysis would be of questionable utility in the decision-making process. We note that EPA historically conducts air quality, exposure, and risk analyses of alternative standards by adjusting measured, not modeled air quality data. This is an issue in evaluating alternative 5-minute standards for SO_2 because there were, and continue to be relatively few locations reporting 5-minute SO_2 concentrations. As described in Appendix A, from 1997-2007, there were a total of 98 monitors in 13 states and the District of Columbia measuring maximum 5-minute SO_2 concentrations in an hour. In comparison, there were 933 monitors in 49 states, the District of Columbia, Puerto Rico and the Virgin Islands measuring 1-hour SO_2 concentrations. Moreover, it is important to consider that those monitors reporting 5-minute concentrations do not represent data from a dedicated 5-minute monitoring network, but rather a voluntary submission of 5-minute values from monitors placed for the purpose of evaluating attainment of 24-hour and annual average SO_2 NAAQS. Thus, staff has little confidence that this limited set of data, from monitors sited for a different purpose, can provide the input required for a comprehensive air quality, exposure, and risk analysis of a much shorter averaging time standard. In fact, given the spatial heterogeneity of 5-minute peaks, and the aforementioned issues with monitor siting, staff is not confident (based on 5-minute monitoring data alone) that even in the 13 locations reporting 5-minute concentrations, that those reported values adequately reflect the extent to which 5-minute peaks are occurring in those areas.

While we have chosen to evaluate alternative 1-hour averaging time standards in the air quality, exposure, and risk chapters of this document, this choice did not preclude the possibility of considering 5-minute standards as part of the policy assessment discussion in Chapter 10, or during the rulemaking process. Consideration of potential alternative 5-minute standards could be based on evidence-based considerations, drawn from the discussion of the scientific evidence related to 5-10 minute exposures from the ISA, and presented below in Chapter 10.

5.4 FORM

Staff recognizes that the adequacy of the public health protection provided by a 1-hour daily maximum potential alternative standard will be dependent on the combination of form and level (see section 5.5). It is therefore important that the particular form selected for a 1-hour daily maximum potential alternative standard reflect the nature of the health risks posed by increasing SO_2 concentrations. That is, the form of the standard should reflect results from human exposure studies demonstrating that the percentage of asthmatics affected, and the severity of the respiratory response (i.e., decrements in lung function, respiratory symptoms) increases as SO_2 concentrations increase (see section 4.2.2). Taking this into consideration, staff concluded that a concentration-based form is more appropriate than an exceedance-based form. This is because a concentration-based form averaged over three years (see below) would give proportionally greater weight to 1-hour daily maximum SO_2 concentrations that are well above the level of the standard, than to 1-hour daily maximum SO_2 concentrations that are just above the level of the standard. In contrast, an expected exceedance form would give the same weight to 1-hour daily maximum SO_2 concentrations that are just above the level of the standard, as to 1-hour daily maximum SO_2 concentrations that are well above the level of the standard. Therefore, a concentration-based form better reflects the continuum of health risks posed by increasing SO_2 concentrations (i.e., the percentage of asthmatics affected and the severity of the response increases with increasing SO_2 concentrations). Concentration-based forms also provide greater regulatory stability than a form based on allowing only a single expected exceedance.

Staff also recognizes that it is important to have a form that achieves a balance between limiting the occurrence of peak concentrations and providing a stable and robust regulatory target. The most recent review of the PM NAAQS (completed in 2006) judged that using a 98^{th} percentile form averaged over 3 years provides an appropriate balance between limiting the occurrence of peak concentrations and providing a stable regulatory target (71 FR 61144). In that review, staff also considered other forms within the range of the 95^{th} to the 99^{th} percentiles. In making recommendations regarding the form, staff considered the impact on risk of different forms, the year-to-year stability in the air quality statistic, and the extent to which different forms of the standard would allow different numbers of days per year to be above the level of the standard in areas that achieve the standard. Based on these considerations, staff recommended either a 98th percentile form or a 99th percentile form. We have made similar judgments in selecting appropriate forms for the potential alternative 1-hour daily maximum SO_2 standards assessed in this REA. As a result of these judgments, we decided to consider both 98th and 99th percentile SO_2 concentrations, averaged over 3 years. We have judged that the 98th and 99th percentile, when combined with the selected range of alternative levels of a 1-hour daily maximum standard (see below), will likely offer a sufficient range of options to balance the objective of providing a stable regulatory target against the objective of limiting the occurrence of peak 5-minute concentrations.

Notably, for a given 1-hour standard level, staff's initial judgment is that a 99th percentile form will be appreciably more protective against 5-minute peaks than a 98th percentile form. Staff finds this is likely the case because compared to a standard with a 98th percentile form, a standard with a 99th percentile form (at the same level) will limit a greater number of peak 1-hour concentrations, and thus, a greater number of peak 5-minute concentrations. Therefore, all potential alternative standard levels (see section 5.5) were assessed with a 99th percentile form in the air quality, exposure and risk analyses. However, as a comparison between forms, one alternative standard level was examined with a 98th percentile form in the exposure and risk analyses, and two alternative standard levels were examined with a 98th percentile form in the air quality analysis.

5.5 LEVEL

When considering the appropriate range of levels for alternative 1-hour daily maximum standards to analyze in the exposure and risk analyses, staff examined both the controlled human exposure and epidemiologic evidence evaluated in the ISA. Controlled human exposure evidence demonstrates that there is a continuum of SO_2-related health effects following 5-10 minute peak SO_2 exposures in exercising asthmatics. That is, the ISA finds that the percentage of asthmatics affected and the severity of the response increases with increasing SO_2 concentrations. At concentrations ranging from 200-300 ppb, approximately 5-30% percent of exercising asthmatics are likely to experience moderate or greater bronchoconstriction (ISA, Table 3-1). At concentrations $\geq$ 400 ppb, moderate or greater bronchoconstriction occurs in approximately 20-60% of exercising asthmatics, and compared to exposures at 200-300 ppb, a larger percentage of subjects experience severe bronchoconstriction (ISA, Table 3-1). Moreover, at concentrations $\geq$ 400 ppb, moderate or greater bronchoconstriction was frequently accompanied with respiratory symptoms (ISA, Table3-1).

In addition to the controlled human exposure evidence, we also considered the epidemiologic evidence, as well as an air quality analysis conducted by staff characterizing 1-hour daily maximum SO_2 air quality levels in cities and time periods corresponding to key U.S. and Canadian ED visit and hospital admission studies for all respiratory causes and asthma[4] (key studies are identified in Table 5-5 of the ISA). Figures 5-1 to 5-5 show standardized effect estimates and the 98th and 99th percentile 1-hour daily maximum SO_2 levels for locations and time periods corresponding to these key U.S. (Figures 5-1 to 5-4) and Canadian[5] (Figure 5-5) studies**.** In general, staff concluded that the results presented in these figures demonstrate that most of these epidemiologic studies show positive, although frequently not statistically significant associations with SO_2. Furthermore, we concluded that Figures 5-1 to 5-5 demonstrate that positive effect estimates, including some that are statistically significant, are found in locations that span a broad range of 98th and 99th percentile 1-hour daily maximum SO_2 concentrations (98th percentile range: 19- 401 ppb; 99th percentile range: 21-457 ppb). Thus, staff decided to utilize the 1-hour daily maximum air quality data presented in these figures to help inform both the upper and lower ranges of alternative SO_2 standards for analysis in this REA (see Chapters 7-9).

[4] Authors of relevant U.S. and Canadian studies were contacted and air quality statistics from the study monitor that recorded the highest SO_2 levels were requested. In some cases, U.S. authors provided the AQS monitor IDs used in their studies and the statistics from the highest reporting monitor were calculated by EPA. In cases where U.S. authors were unable to provide the requested data (Schwartz 1995, Schwartz 1996, and Jaffe 2003), EPA identified the maximum reporting monitor from all monitors located in the study area and calculated the 98th and 99th percentile statistics (see Thompson and Stewart 2009).

[5] The Canadian statistics presented in Figure 5-5 were calculated from a data set provided by Dr. Richard Burnett and were used for all relevant single city studies on which he was an author. Note that air quality statistics presented for Canadian studies are likely not directly comparable to those presented for U.S. studies. This is because SO_2 concentrations presented for Canadian studies represent the 98th and 99th percentile 1-hour daily maximum SO_2 concentrations across a given city, rather than concentrations from the single monitor that recorded the highest 98th and 99th percentile SO_2 levels in a given city (see Thompson and Stewart, 2009).

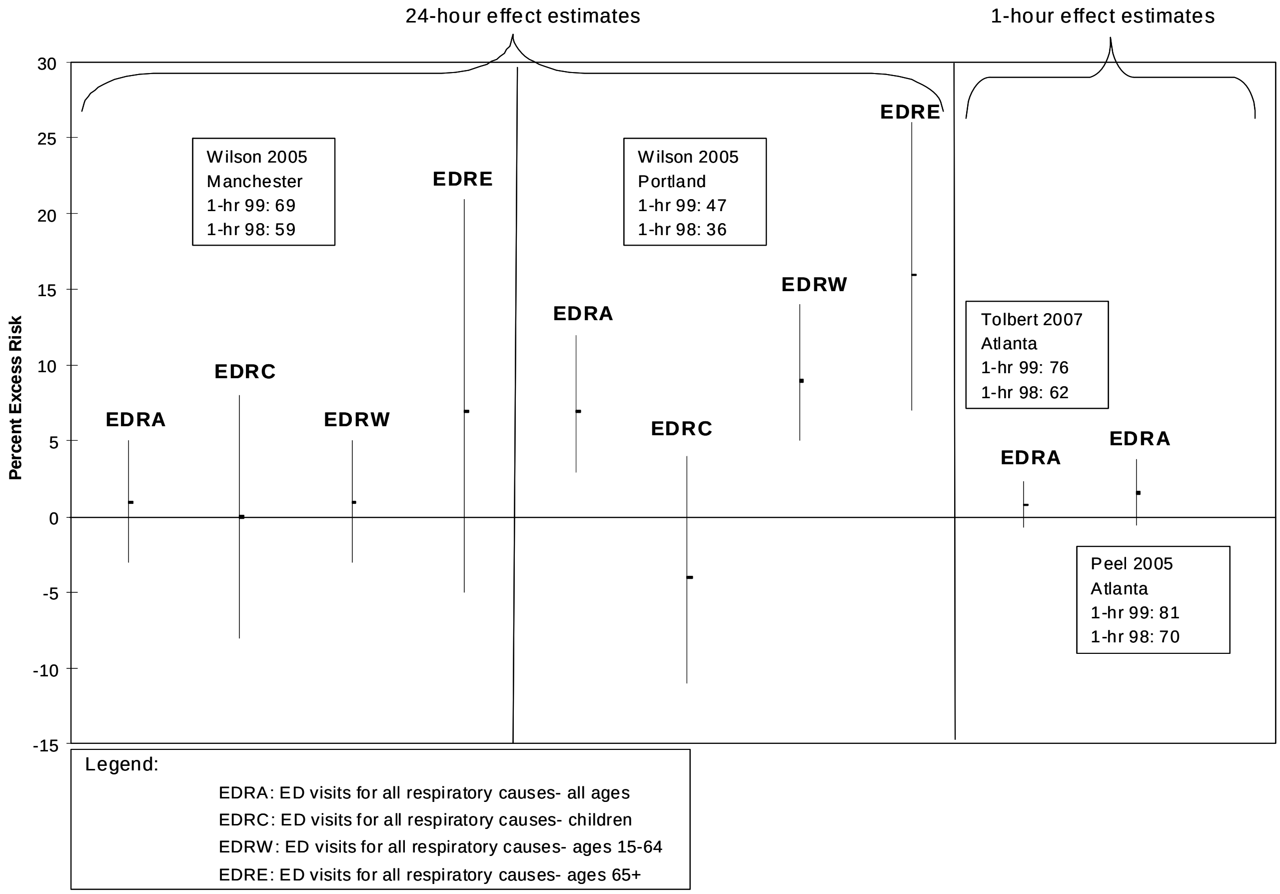

Figure 5-1. Effect estimates for U.S. all respiratory ED visit studies and associated 98th and 99th percentile 1-hour daily maximum SO_2 levels.

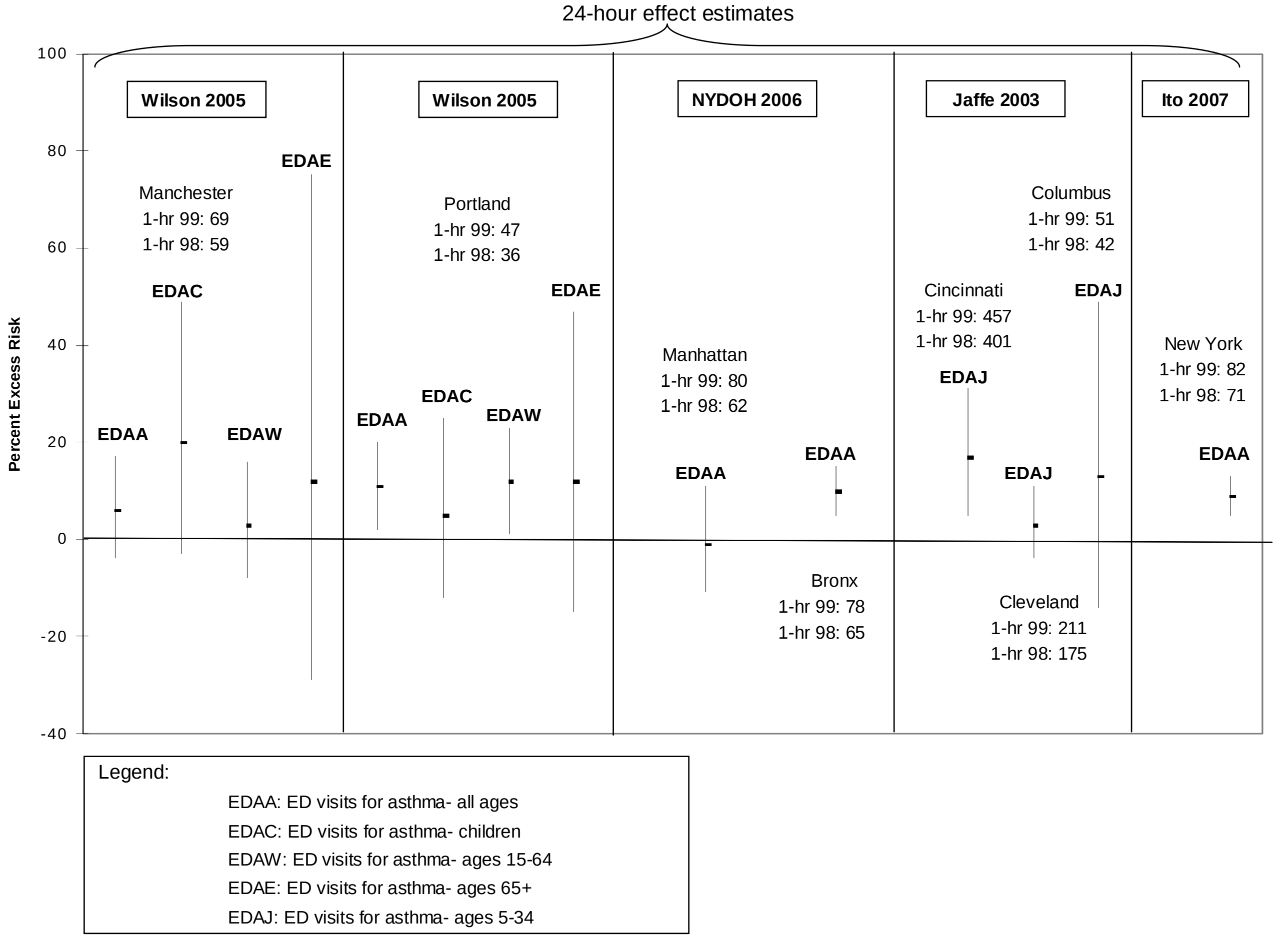

Figure 5-2. 24-hour effect estimates for U.S. asthma ED visit studies and associated 98th and 99th percentile 1-hour daily maximum SO_2 levels.

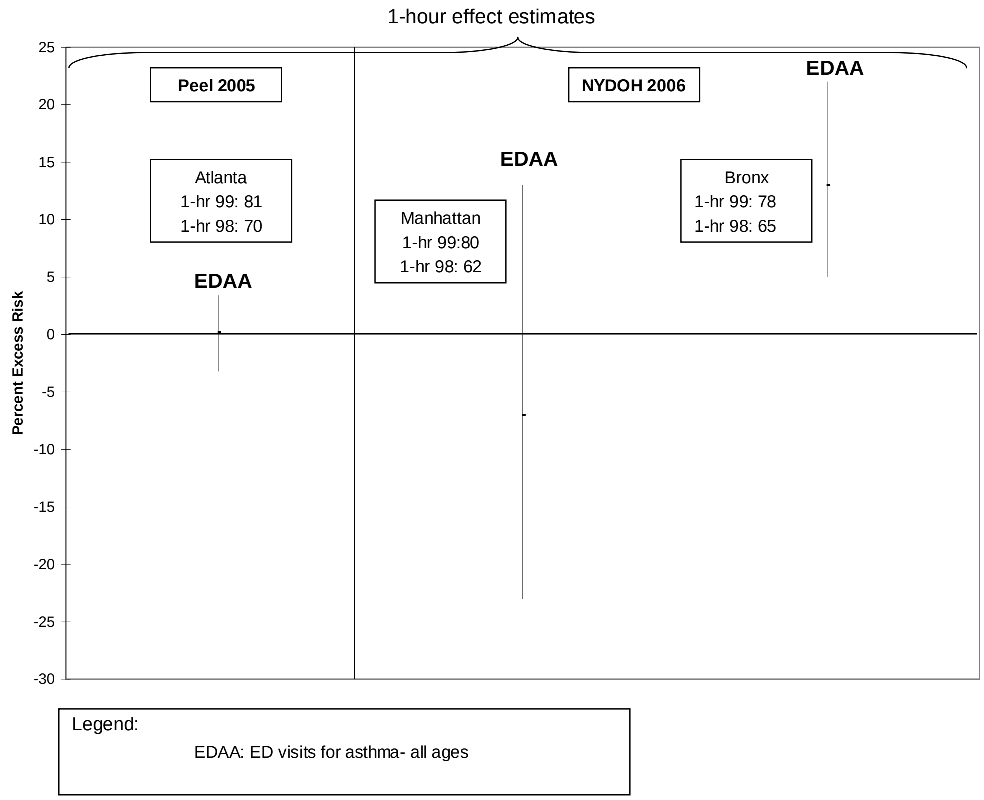

Figure 5-3. 1-hour effect estimates for U.S. asthma ED visit studies and associated 98th and 99th percentile 1-hour daily maximum SO_2 levels.

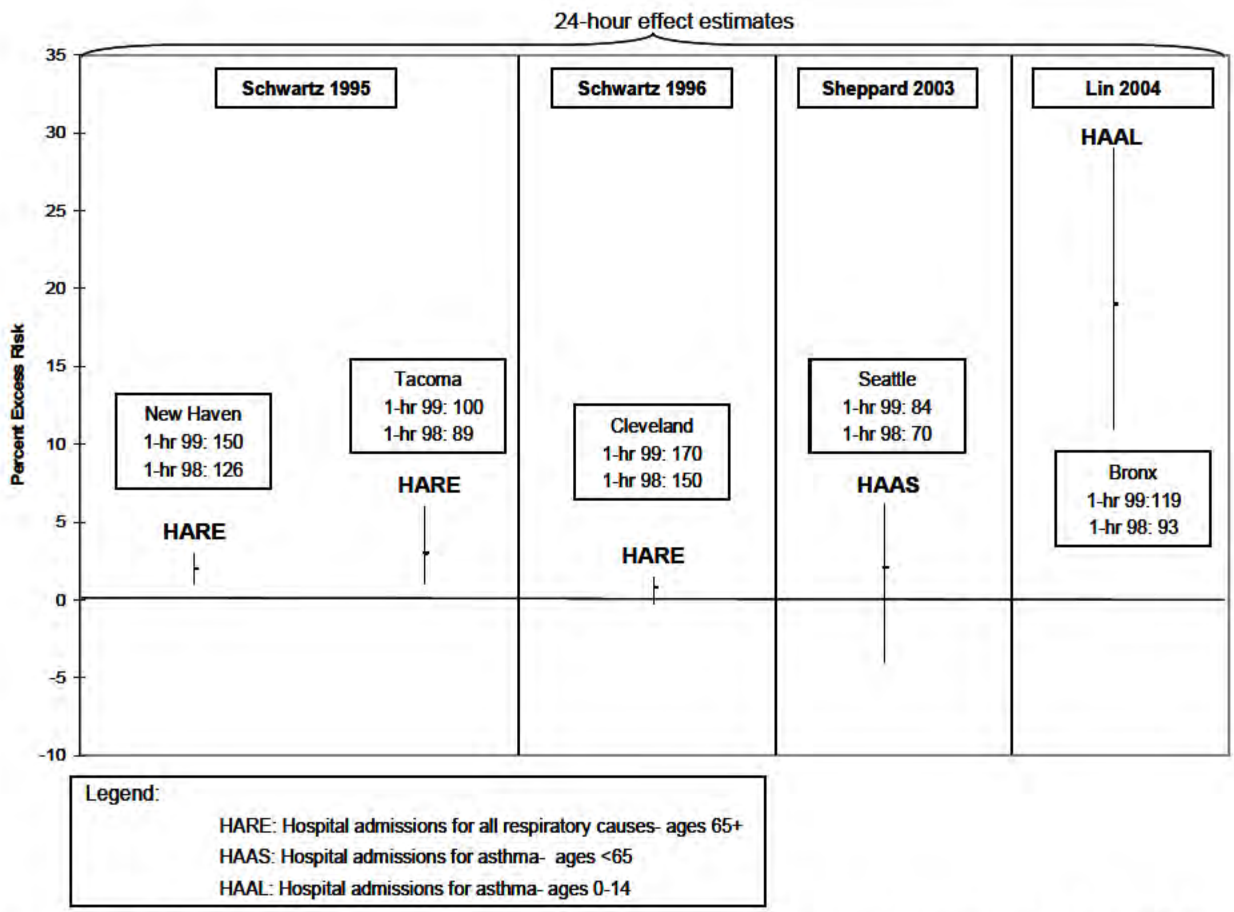

Figure 5-4. 24-hour effect estimates for U.S. hospitalization studies and associated 98th and 99th percentile 1-hour daily maximum SO_2 levels.[6]

[6] There were no key U.S. hospitalization studies with 1-hour effect estimates identified in Table 5-5 of the ISA

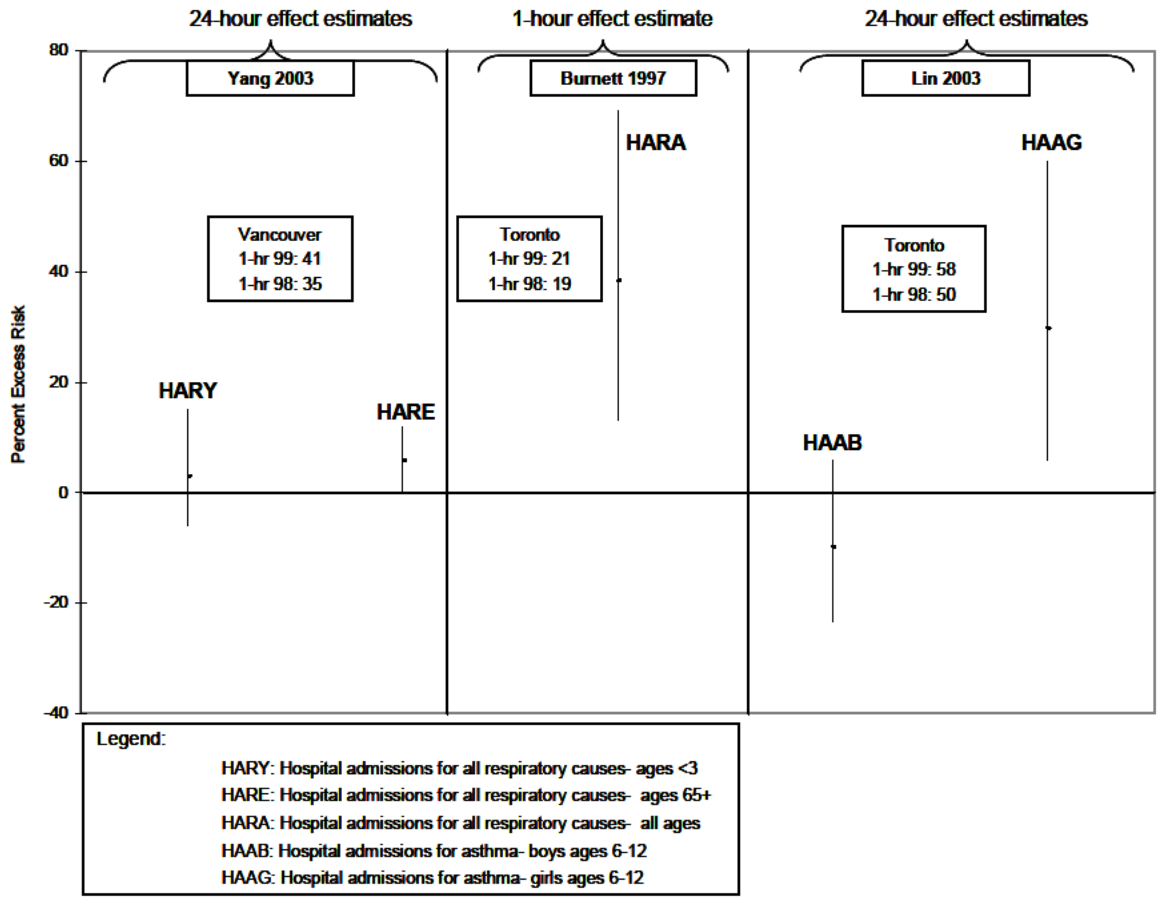

Figure 5-5. Effect estimates for Canadian ED visits and hospitalization studies and associated 98th and 99th percentile 1-hour daily maximum SO_2 levels.

The highest 98th and 99th percentile 1-hour daily maximum air quality levels were found in analyses conducted in the cities of Cincinnati (Figure 5-2), Cleveland (Figures 5-2 and 5-4) and New Haven (Figure 5-4). These studies showed positive associations[7] with respiratory-related hospital admissions or ED visits during time periods when 98th and 99th percentile 1-hour daily maximum SO_2 concentrations ranged from 126 ppb to 457 ppb. Notably, this range of 1-hour daily maximum SO_2 levels overlaps considerably with 5-10 minute SO_2 concentrations ($\geq$ 200 ppb) that have consistently been shown in controlled human exposure studies to result in lung function responses in exercising asthmatics. Of particular concern are the air quality levels that were found in Cincinnati (Jaffe et al., 2003). The 98th and 99th percentile 1-hour daily maximum SO_2 concentrations were in excess of 400 ppb. Levels $\geq$ 400 ppb have consistently been shown in human exposure studies to result in moderate or greater bronchoconstriction in the

[7] Results in Cincinnati (Jaffe et al., 2003) and New Haven (Schwartz et al., 1996) were statistically significant.

presence of respiratory symptoms in a considerable percentage of exercising asthmatics. As a result, staff decided to analyze alternative standard levels up to 250 ppb. We concluded that a 98th or 99th percentile 1-hour daily maximum standard at this level had the potential to substantially limit the number of days when the 1-hour daily maximum SO_2 concentration is $\geq$ 200 ppb, while also potentially limiting the number of 5-10 minute SO_2 peaks $\geq$ 400 ppb.

In selecting the lower end of the range of alternative standards to be analyzed, staff again considered controlled human exposure and epidemiologic evidence. However, with regard to the controlled human exposure evidence, several additional factors were considered. First, we considered that the subjects in human exposure studies do not represent the most SO_2 sensitive asthmatics; that is, these studies included mild and moderate, but not severe asthmatics. Also, while human clinical studies have been conducted in adolescents, younger children have not been included in these exposure studies, and thus, it is possible asthmatic children represent a population that is more sensitive to the respiratory effects of SO_2 than the individuals who have been examined to date. Moreover, we considered that approximately 5-30% of asthmatics who engaged in moderate or greater exertion experienced bronchoconstriction following exposure to 200-300 ppb SO_2, which are the lowest levels tested in free breathing chamber studies (ISA, Table 3-1). Thus, we concluded that it was highly likely that a subset of the asthmatic population would also experience bronchoconstriction following exposure to levels lower than 200 ppb.

As an additional consideration, we noted that Figure 5-5 contains two epidemiologic analyses observing positive associations between ambient SO_2 concentrations and hospital admissions in Canadian cities when 99th percentile 1-hour daily maximum SO_2 levels were < 47 ppb. More specifically, positive associations between SO_2 and hospital admissions were found in Toronto, (Burnett al., 1997) and Vancouver (Yang et. al., 2003) when 99th percentile 1-hour daily maximum SO_2 levels were approximately 21 ppb and 41 ppb, respectively. However, as previously noted, the 99th percentile 1-hour daily maximum SO_2 concentrations reported for Canadian studies are not directly comparable to those reported for U.S. studies. That is, the concentrations reported for Canadian studies represent the average 98th or 99th percentile 1-hour daily maximum levels across multiple monitors in a given city (Figure 5-5), rather than 98th or 99th percentile concentrations from the single monitor that recorded the highest SO_2 levels

(Figures 5-1 to 5-4; see Thompson and Stewart, 2009). As a result, the SO_2 concentrations presented in Figure 5-5 for Canadian studies would be relatively lower (potentially significantly lower) than those levels presented in Figures 5-1 to 5-4 for U.S. epidemiologic studies. In addition to these Canadian studies, we also noted that a U.S. study, Delfino et al. (2003), observed a statistically significant association between ambient SO_2 and respiratory symptoms in Hispanic children when the 1-hour daily maximum SO_2 concentration in Los Angeles was 26 ppb (ISA Table 5-4). However, this epidemiologic study was very small (n=22), and did not examine potential confounding by co-pollutants. Thus, staff concluded that these three studies alone do not provide sufficient evidence for considering alternative 1-hour daily maximum SO_2 standards below 50 ppb.

Staff noted that numerous studies reported positive associations between ambient SO_2 and hospital admissions and ED visits in cities and time frames when 98^{th} and/or 99^{th} percentile 1-hour daily maximum SO_2 concentrations ranged from approximately 50 to 100 ppb (Figures 5-1 to 5-5). Moreover, although most of these positive effect estimates were not statistically significant, there were some statistically significant results in single pollutant models (Portland, Wilson, 1995; Bronx, NYDOH, 2006; NYC, Ito, 2006; and Schwartz, 1995), as well as some evidence of statistically significant associations in multi-pollutant models with PM[8] (Bronx, NYDOH, 2006 and NYC, Ito, 2007). Given these epidemiologic and air quality results, as well as the considerations mentioned above regarding the controlled human exposure evidence, staff concluded it was appropriate to examine a range of alternative standards in the air quality, exposure, and risk analyses that include a level of 50 ppb as the lower bound. We judged that a 98^{th} or 99^{th} percentile 1-hour daily maximum standard at this level would both limit the number of days when 1-hour daily maximum SO_2 levels are $\geq$ 50 ppb, while also limiting 5-10 minute peaks of $SO_2 \geq$ 100 ppb. Moreover, we noted that a level of 50 ppb is substantially below the 98^{th} and 99^{th} percentile 1-hour daily maximum SO_2 levels observed in the Bronx during the NYDOH analysis and in NYC during the period analyzed by Ito et al., (2006): two studies where

[8] In the NYDOH study (2006), the Bronx positive effect estimate remained statistically significant in the presence of $PM_{2.5}$. In Ito et al., (2007), the NYC positive effect estimate was statistically significant in the presence of $PM_{2.5}$ during the warm season. We also note that in Schwartz et al., (1995), the positive effect estimate in New Haven, but not Tacoma remained statistically significant in the presence of PM_{10} when the 99^{th} percentile 1-hour daily maximum SO_2 concentration in New Haven was 150 ppb.

the SO_2 effect estimate remained robust and statistically significant in multi-pollutant models with $PM_{2.5}$ (ISA, Table 5-5).

5.6 KEY OBSERVATIONS

- Staff concluded that SO_2 remains the most appropriate indicator for the potential alternative standards to be analyzed in the air quality, exposure, and risk analyses described in this document.
- For the purpose of conducting quantitative air quality, exposure, and risk analyses, staff concluded that the focus should be on potential alternative SO_2 standards with an averaging time of 1-hour.
- Staff also considered examining alternative 5-minute standards in the risk and exposure assessment, but concluded that there was insufficient data to do so. However, this did not preclude the possibility of considering 5-minute standards as part of the policy assessment discussion in Chapter 10, or during the rulemaking process.
- With regard to the form of the potential alternative standards to be analyzed in the air quality, exposure, and risk analyses, staff concluded that it was appropriate to consider the annual 98^{th} and 99^{th} percentile SO_2 concentrations averaged over a 3 year period. Staff found that a concentration-based form better reflected the continuum of health risks posed by increasing SO_2 concentrations, and provided greater regulatory stability than a form based on allowing only a single expected exceedance.
- Based on findings from controlled human exposure and epidemiologic studies, and evaluation of air quality information from key U.S. and Canadian studies of ED visits and hospitalizations, staff concluded that it was appropriate to examine alternative 1-hour daily maximum standards in the air quality, exposure, and risk analyses in the range of 50-250 ppb.

6. OVERVIEW OF RISK CHARACTERIZATION AND EXPOSURE ASSESSMENT

6.1 INTRODUCTION

The assessments presented in the subsequent chapters of this document characterize short-term exposures (i.e., 5-minutes) and potential health risks associated with: (1) recent ambient levels of SO_2, (2) levels associated with just meeting the current SO_2 NAAQS, and (3) levels associated with just meeting several potential alternative standards (see Chapter 5 of this document for the discussion of potential alternative standards). To characterize health risks, we employed three approaches (Figure 6-1). With each approach, we characterize health risks associated with the air quality scenarios mentioned above (i.e., recent air quality unadjusted, air quality adjusted to simulate just meeting the current standards, and air quality adjusted to simulate just meeting several potential alternative standards). In the first approach, SO_2 air quality levels are compared to potential health effect benchmark values (see section 6.2) derived from the controlled human exposure literature (Chapter 7). In the second approach, modeled estimates of human exposure are compared to the same potential health effect benchmark values derived from the human exposure literature (Chapter 8). In the third approach, outputs from the exposure analysis are combined with exposure-response functions derived from the human clinical literature to estimate the number and percent of exposed asthmatics that would experience moderate or greater lung function responses under the different air quality scenarios (Chapter 9). A more detailed overview of each of these approaches to characterizing health risks is provided below (section 6.3), and each approach is described in more detail in their respective chapters and associated appendices. In addition, this chapter also describes important methodologies used throughout these analyses. This includes the approach used to estimate 5-minute SO_2 concentrations from 1-hour data (section 6.4), how recent air quality was adjusted to simulate alternative air quality standards scenarios (section 6.5), and an overview of how uncertainty was characterized in each of the analyses performed (section 6.6).

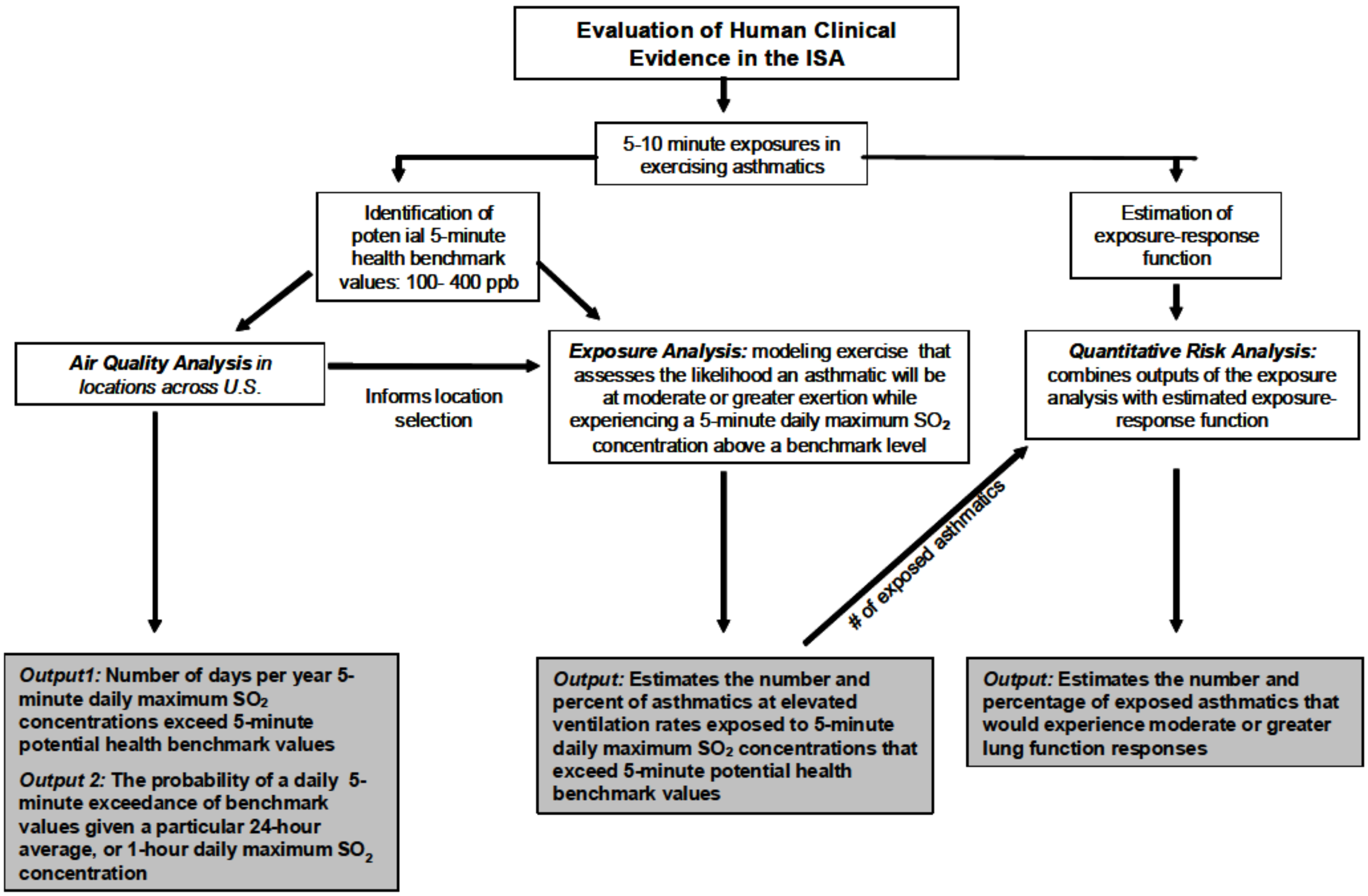

Figure 6-1. Overview of analyses addressing exposures and risks associated with 5-minute peak SO_2 exposures. All three outputs are calculated considering current air quality, air quality just meeting the current standards, and air quality just meeting potential alternative standards. Note: this schematic was modified from Figure 1-1.

6.2 POTENTIAL HEALTH EFFECT BENCHMARK LEVELS

Potential health benchmark values used in the air quality, exposure, and risk analyses were derived solely from the human exposure literature. This is primarily because concentrations used in human clinical studies represent actual personal exposures rather than concentrations measured at fixed site ambient monitors. In addition, human exposure studies can examine the health effects of SO_2 in the absence of co-pollutants that can confound results in epidemiological analyses; thus, health effects observed in clinical studies can confidently be attributed to a defined exposure level of SO_2.

The ISA presents human exposure evidence demonstrating decrements in lung function in approximately 5-30% of exercising asthmatics exposed to 200-300 ppb SO_2 for 5-10 minutes.

However, it is important to note: (1) subjects in human exposure studies do not include individuals who may be most susceptible to the respiratory effects of SO_2, (e.g., severe asthmatics and children) and (2) given that 5-30% of exercising asthmatics experienced bronchoconstriction following exposure to 200-300 ppb SO_2 (the lowest levels tested in free-breathing chamber studies), it is likely that a percentage of asthmatics would also experience bronchoconstriction following exposure to levels lower than 200 ppb. That is, there is no evidence to suggest that 200 ppb represents a threshold level below which no adverse respiratory effects occur. We also noted that small SO_2-induced lung function decrements have been observed in asthmatics at concentrations as low as 100 ppb when SO_2 is administered via mouthpiece[9] (ISA, section 3.1.3). Considering this information, staff concluded it was appropriate to examine potential 5-minute benchmark values in the range of 100-400 ppb. The lower end of the range considers the factors mentioned above, while the upper end of the range recognizes that 400 ppb represents the lowest concentration at which statistically significant decrements in lung function are seen in conjunction with statistically significant respiratory symptoms. Moreover, we note that this range of benchmark values is in general agreement with consensus CASAC comments on earlier drafts of this document.

As an additional matter, we note that in the outputs of the air quality and exposure analyses (see section 6.3), staff considered the number of days with a 5-minute maximum SO_2 concentration above benchmark levels rather than all 5-minute exceedances of benchmark levels in a given day. This is because human exposure studies have suggested that after an initial SO_2 exposure, there is approximately a 5-hour period of time when asthmatics are less sensitive to subsequent SO_2 challenges (ISA, section 3.1.3.2). As a result, there is uncertainty as to whether an additional SO_2 exposure(s) on a given day would be associated with an additional adverse respiratory outcome(s) (i.e., moderate decrements in lung function and/or respiratory symptoms). On the other hand, we recognize that not counting multiple exceedances in a day could possibly

[9] Studies utilizing a mouthpiece exposure system cannot be directly compared to studies involving freely breathing subjects, as nasal absorption of SO_2 is bypassed during oral breathing, thus allowing a greater fraction of inhaled SO_2 to reach the tracheobronchial airways. As a result, individuals exposed to SO_2 through a mouthpiece are likely to experience greater respiratory effects from a given SO_2 exposure. In addition, the two mouthpiece studies cited in the ISA as exposing exercising asthmatics to 100 ppb SO_2 (Koenig et al., 1990 and Sheppard et al., 1981) had a small number of exposures at this concentration (e.g., Sheppard et al., exposed two subjects to 100 ppb SO_2) and observed very small changes in FEV_1 or sRaw. Nonetheless, these studies do provide very limited evidence for SO_2-induced respiratory effects at 100 ppb.

lead to an underestimate in the number of asthmatics experiencing an SO_2 concentration above a benchmark level, and thus, an adverse respiratory outcome. Therefore, there is further discussion and/or analysis of this topic and its relevance to uncertainty in each of the air quality, exposure, and risk analysis outputs (see sections 7.4, 8.11 and 9.3).

6.3 APPROACHES FOR ASSESSING EXPOSURE AND RISK ASSOCIATED WITH 5-MINUTE PEAK SO_2 EXPOSURES

In the first approach (i.e., the air quality characterization), we have compared SO_2 air quality with the potential health effect benchmark levels for SO_2. Scenario-driven air quality analyses were performed using ambient SO_2 concentrations for the years 1997 though 2006. All U.S. monitoring sites where 1-hour SO_2 data have been collected are represented by this analysis and, as such, the results generated are considered a broad characterization of national air quality and potential human exposures that might be associated with these concentrations.[10] The output of the air quality characterization is an estimate of the number of exceedances of the potential health effect benchmark levels for several air quality scenarios. An advantage of this approach is its relative simplicity; however, there is uncertainty associated with the assumption that SO_2 air quality can adequately serve as an indicator of exposure to ambient SO_2. Actual exposures will be influenced by factors not considered by this approach, such as the spatial and temporal variability in human activities.

In the second approach (i.e., the exposure assessment), we have used an inhalation exposure model to generate estimates of personal SO_2 exposures. The estimates of personal exposure have also been compared to the potential health benchmark levels as was done in the air quality characterization. This results in estimates of the number of individuals that are likely to experience exposures exceeding these benchmark levels. For this exposure analysis, a probabilistic approach was used to model individual exposures considering the time people spend in different microenvironments and the variable SO_2 concentrations that occur within these microenvironments across time, space, and microenvironment type. The exposure model also accounts for activities that individuals perform within the microenvironments, allowing for estimation of exposures that coincide with varying activity levels. As such, this approach to

[10] Two additional subsets of the broader SO_2 monitoring network were also used in detailed analyses, thus by definition are not representative of the full set of monitors in the U.S.

assessing exposures was more resource intensive than evaluating ambient air quality; therefore, staff has included the analysis of two specific locations in the U.S. (Greene County, MO. and St. Louis, MO.)[11] Although the geographic scope of this analysis is restricted, the approach provides realistic estimates of SO_2 exposures, particularly those exposures associated with important emission sources of SO_2 and serves to complement the broad air quality characterization.

Staff used a range of short-term potential health effect benchmarks to characterize risk in both the air quality and the exposure modeling analyses described above. The levels of potential benchmarks are based on SO_2 exposure levels that have been associated with respiratory symptoms and decrements in lung function in exercising asthmatics during controlled human exposure studies (ISA, section 5.2; see above section 6.2 for discussion). Benchmark values of 100, 200, 300, and 400 ppb have been compared to both SO_2 air quality (measured and modeled 5-minute SO_2 concentrations) and to estimates of SO_2 exposures. In characterizing the SO_2 air quality using ambient monitors, the output of the analysis is an estimate of the number of days per year specific locations experience 5-minute daily maximum levels of SO_2 above a particular benchmark. When personal exposures are simulated, the output of the analysis is an estimate of the number of individuals at risk for experiencing daily maximum 5-minute levels of SO_2 of ambient origin that exceed a particular benchmark.

In the third approach (i.e., the quantitative risk assessment), we combine outputs from the exposure analysis with exposure-response functions derived from controlled human exposure studies. This analysis estimates the percentage and number of asthmatics likely to experience a given decrement in lung function associated with recent air quality and SO_2 levels adjusted to simulate just meeting the current and potential alternative standards. Staff concluded that it was appropriate to limit the scope of the quantitative risk assessment to lung function responses based on findings from the controlled human exposure studies and the basis for this decision is described below.

[11] In the 1st draft REA, staff presented the results of an exposure analysis for Greene County (or Springfield, MO.) and several other source-based modeling domains in Missouri. Based on CASAC comments received on that exposure analysis, staff refined the modeling approach and applied those refinements to the Greene County analysis presented in the 2nd draft REA and completed the exposure assessment in St. Louis which had been started at the time of the 1st draft REA.

As discussed above in Chapter 4, the ISA concludes that the overall weight of the evidence supports a causal relationship between short-term SO_2 exposure and respiratory morbidity. The ISA states that the "definitive evidence" for its causal determination is from controlled human exposure studies demonstrating decrements in lung function and/or respiratory symptoms in exercising asthmatics exposed to $\geq$ 200 ppb SO_2 (ISA, section 5.2). The ISA further notes that supporting this causal determination is a larger body of U.S and international epidemiological studies examining respiratory symptoms and ED visits and hospitalizations for all respiratory causes and asthma (ISA, section 5.2).

As previously described, staff is utilizing both the epidemiological evidence in the ISA, and an air quality analysis based on U.S. and Canadian ED visit and hospitalization studies for all respiratory causes and asthma (Figures 5-1 to 5-5), to qualitatively inform: (1) the selection of potential 1-hour daily maximum alternative standards to be analyzed in the air quality, exposure, and risk chapters of this document (see Chapter 5), and (2) the adequacy of the current standard and consideration of potential alternative standards (Chapter 10). However, staff did not find the overall breadth of the epidemiological evidence was robust enough to support a quantitative assessment of risk.

We first note that for purposes of conducting a quantitative risk assessment for locations in the U.S., staff concludes that only U.S. studies should be considered given differences in monitoring networks, levels of co-pollutants, and other factors across different locations that may well alter SO_2-concentration-response relationships. Taking this into account, we reviewed the available epidemiological literature and found relatively few studies that focused on these endpoints were conducted in U.S. cities. In those U.S. cities where epidemiological studies had been conducted, many of the SO_2 effect estimates were positive, but not statistically significant in single pollutant models. Moreover, in the relatively few studies that employed multi-pollutant models, inclusion of PM_{10} in the model resulted in a loss of statistical significance for the SO_2 effect estimate in about half of these studies (although the effect estimate may have remained positive). Overall, we conclude that these factors would make it particularly difficult to quantify with confidence the magnitude of respiratory health effects related to SO_2 exposures and therefore, we judge that the results of a quantitative risk assessment based on concentration-response functions from epidemiological studies for these health outcomes would be of limited utility in the decision-making process given the nature of the uncertainties associated with these studies.

6.4 APPROACH FOR ESTIMATING 5-MINUTE PEAK SO_2 CONCENTRATIONS

Health effects evaluated in this REA include those associated with 5-10 minute peak concentrations of SO_2. While there are 98 ambient monitors that have reported 5-minute SO_2 concentrations some time during 1997-2007, the spatial and temporal representation is limited to a few states and often only a few years of monitoring. Most of these monitors report the 5-minute maximum SO_2 concentration occurring within an hour, though there were some that reported all twelve continuous 5-minute SO_2 concentrations measured within the hour. The ambient monitors reporting continuous SO_2 values are limited to fewer locations and number of monitoring years, with sixteen monitors deployed within six US states and Washington DC, ten of which operated only during one year. The overwhelming majority of the SO_2 ambient monitoring data are for 1-hour average concentrations (upwards to 935 monitors), comprising a broad monitoring network that includes most U.S. states and territories. Because the health effects of greatest interest were associated with short-term exposures (5-10 minutes) and a greater number of monitors and monitor-years were available for the 5-minute maximum SO_2 concentrations than 10-minute maximum concentrations, a model was developed to estimate 5-minute maximum SO_2 concentrations from the comprehensive 1-hour SO_2 ambient monitoring data.

Staff first reviewed the air quality characterization conducted in the prior SO_2 NAAQS review and supplementary analyses. In these prior analyses, relationships between maximum 5-minute SO_2 concentrations and the 1-hour average SO_2 concentrations, or peak-to-mean ratios (PMRs) were evaluated and used to approximate 5-minute maximum SO_2 concentrations from 1-hour values (EPA, 1986a; EPA, 1994b; SAI, 1996; Thompson, 2000). While the relationship between the two metrics is not expected to be linear, the temporal patterns in the two averaging times are consistent. Five-minute maximum SO_2 concentrations are often much greater than that of the corresponding 1-hour SO_2 concentrations, and observed increases in a given 1-hour SO_2 concentration often coincide with increases in the 5-minute maximum SO_2 concentration. As an example of this pattern, the time-series of 1-hour average and 5-minute maximum SO_2

concentrations measured at an ambient monitor across a 3-day period in 2005 is illustrated in Figure 6-2.

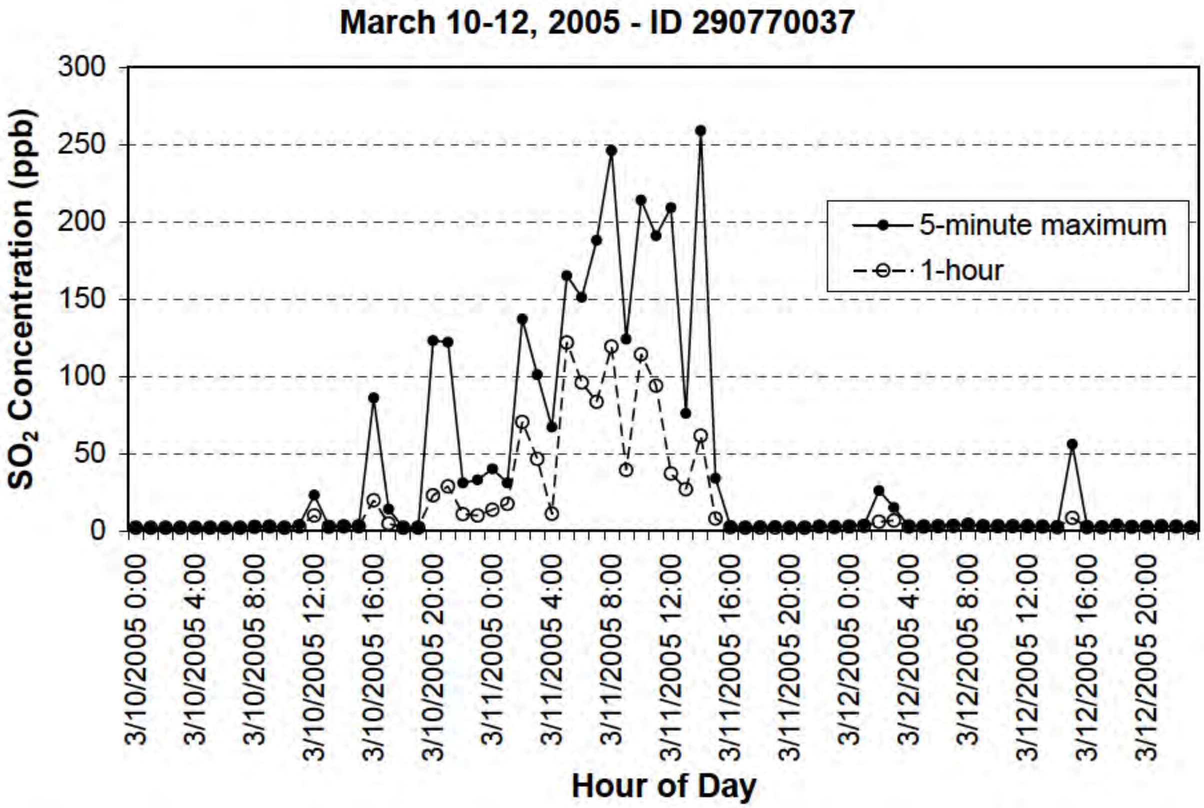

Figure 6-2. Example of an hourly time-series of measured 1-hour and measured 5-minute maximum SO_2 concentrations.

In general, PMRs were determined to be approximately two in some of the earlier studies when used in estimating 5-minute peak SO_2 concentrations; though for the exposure analyses conducted for the last NAAQS review, a distribution of PMRs was used with values of up to eleven (EPA, 1994b). In each of the analyses conducted previously, estimates of PMRs were derived using ambient monitoring data (i.e., where both 5-minute maximum and 1-hour average SO_2 were measured) and then used to estimate the occurrence of peak 5-minute SO_2 concentrations given a 1-hour ambient SO_2 concentration. The approach was generally as follows:

$$C_{\max-5} = PMR \times C_{1-hour} \qquad \text{equation (6-1)}$$

where,

$C_{max\text{-}5}$ = estimated 5-minute maximum SO_2 concentration (ppb)

PMR = peak-to-mean ratio (PMR)

$C_{1\text{-}hour}$ = measured 1-hour average SO_2 concentration

At the time of the last NAAQS review, there were very few monitors reporting 5-minute SO_2 data. In fact, distributions of PMRs from ambient monitors surrounding a single coal-fired power utility served as the primary source used in estimating 5-minute peak concentrations used in the exposure analyses (EPA, 1994b). As mentioned above, the PMRs were determined to be approximately two in these earlier studies; however, the ratio can vary depending on a several factors. It has been shown that there can be increased variability in the ratio with decreasing 1-hour average SO_2 concentrations, that is, there is a greater likelihood of values greater than two at low hourly average concentrations than expected at high hourly average concentrations (EPA, 1986a). It has also been argued that the occurrence of short-term peak concentrations at ambient monitors may be influenced by particular SO_2 emission sources (EPA, 1994b). Different sources have variable emission amounts, temporal operating patterns (e.g., seasonal, time-of-day), facility maintenance, and other physical parameters (e.g., stack height, area terrain) that likely contribute to variability in 5-minute maximum SO_2 concentrations. In addition, a sensitivity analysis conducted for copper-smelters determined that distance from the source was inversely proportional to the PMR in all three of the 1-hour mean stratifications evaluated (i.e., ≤ 0.04 ppm, 0.04 to ≤ 0.15 ppm, and >0.15 ppm), with the highest 1-hour category having the lowest range of PMR (Sciences International, 1995).[12]

There are some data available for the current SO_2 monitoring network regarding the type of sources that may be near the ambient monitors, the magnitude of emissions, the temporal variation in emissions, and distance from specific sources; however, staff determined that there was no practical way to define every ambient monitor as being exclusively influenced by a single source or a defined mix of sources. Given other conditions that may vary within a specific source category (monitor-to-source distances, local meteorology, operating conditions, etc.), staff also determined that there was no practical way to use such data quantitatively in the

[12] In that analysis, normalized 1-hour SO_2 concentrations were obtained by dividing by the maximum hourly concentration.

construction of the PMR statistical model and apply such a model to the 1-hour SO_2 ambient monitor data.

In recognizing the limited geographic span of the monitors reporting the 5-minute maximum SO_2 concentrations and the overall uncertainty regarding the amount of influence of a specific source on any given monitor, staff developed an approach based on hourly SO_2 concentration levels and the variability observed at the monitors reporting both the 5-minute maximum and 1-hour average SO_2 concentrations. The main assumption in the approach is that the temporal and spatial pattern in SO_2 source emissions is influenced by the type of source(s) present, its operating conditions, and that the emission pattern(s) is reflected in the ambient SO_2 concentration distribution measured at the monitor. Thus, measures of concentration level and associated variability at each monitor were used as a surrogate for the variability in the source characteristics that may impact concentrations at a particular monitor. Each monitor reporting 5-minute maximum SO_2 concentrations was categorized based on the coefficient of variation (COV) of 1-hour average SO_2 concentrations and then used to estimate distribution of PMRs for range of 1-hour SO_2 concentrations. This approach, that fully utilizes all of the available 5-minute maximum SO_2 data, is detailed in section 7.2.3.

6.5 APPROACH FOR SIMULATING THE CURRENT AND ALTERNATIVE AIR QUALITY STANDARD SCENARIOS

A primary goal of the risk and exposure assessments described in this document is to evaluate the ability of the current SO_2 primary standards (30 ppb annual average, 140 ppb 24-hour average)[13] and potential alternative standards (99^{th} percentile 1-hour daily maximum SO_2 levels of 50, 100, 150, 200, and 250 ppb, and 98^{th} percentile 1-hour daily maximum SO_2 levels: 200 ppb; see Chapter 5 of this document) to protect public health. To evaluate the ability of a specific standard to protect public health, ambient SO_2 concentrations need to be adjusted such that they simulate levels of SO_2 that just meet that standard. Such adjustments allow for comparison of the level of public health protection that could be associated with just meeting the current and potential alternative standards.

[13] For consistency, the concentration units in this chapter are reported as ppb, even though the SO_2 NAAQS have units of ppm.

All areas of the United States currently have ambient SO_2 levels below the current annual standard (EPA, 2007c). One site in Northampton County, Pa., measured concentrations above the level of the 24-hour standard in 2006. Therefore, to evaluate whether the current standards adequately protect public health, nearly all SO_2 concentrations need to be adjusted upwards in all areas included in our assessment to simulate levels of SO_2 that would just meet the current standard levels. Similarly, to simulate a potential air quality standard that is below current air quality standards, those current levels must be adjusted downward.

Ambient SO_2 concentrations and exposures were characterized by considering *as is* air quality (unadjusted concentrations) and several hypothetical air quality scenarios. Each of the hypothetical air quality scenarios had an ambient concentration target, derived from the form and level of the current NAAQS or from potential alternative standards. Staff chose a proportional approach to adjust the SO_2 concentrations to simulate each of the current and alternative air quality standard scenarios.[14] A proportional approach was selected based on the mostly linear relationship between older high concentration years of air quality when compared with recent low concentration years at several locations (Rizzo, 2009). Briefly, for each location of interest (i) and year (j), SO_2 concentration adjustment factors (F) were derived by the following equation:

$$F_{ij} = S / C_{\max,ij} \qquad \text{equation (6-2)}$$

where,

F_{ij}	=	Adjustment factor derived from the air quality standard target concentration in location *i* and year *j* (unitless)
S	=	concentration values allowed that would just meet the air quality standard level (ppb)
$C_{max,ij}$	=	maximum measured SO_2 concentration given particular form of standard at a monitor in location *i* and year *j* (ppb)

[14] The particular equation used to derive each of the adjustment factors is dependent on the form and level of the standard considered, however the equations all share proportionality between the target level and ambient concentration. To evaluate the current and alternative air quality scenarios in the exposure assessment (Chapter 8), a mathematically equivalent proportional approach was used to adjust the benchmark levels rather than adjusting the ambient concentrations as done for the air quality characterization (Chapter 7).

In these cases where staff simulated a proportional adjustment in ambient SO_2 concentrations using equation (6-2), it was assumed that the current temporal and spatial distribution of air concentrations (as characterized by the current air quality data) is maintained and increased SO_2 emissions contribute to increased SO_2 concentrations. All the hourly SO_2 concentrations in a location were multiplied by the same constant value *F*, whereas the highest monitor (in terms of concentration) is adjusted such that it just meets the standard target level.

This procedure for adjusting either the ambient concentrations (i.e., in the air quality characterization) or health effect benchmark levels (i.e., in the exposure assessment) was necessary to provide insight into the degree of exposure and risk which would be associated with an increase in ambient SO_2 levels such that the levels were just at the current standards in the areas analyzed. Staff recognizes that it is extremely unlikely that SO_2 concentrations in any of the selected areas where concentrations have been adjusted would rise to meet the current NAAQS and that there is considerable uncertainty associated with the simulation of conditions that would just meet the current standards. Nevertheless, this procedure was necessary to assess the ability of the current standards, not current ambient SO_2 concentrations, to protect public health. This process of adjusting SO_2 concentrations to simulate just meeting a specific standard is described in more detail in sections 7.2.4 and 8.8.1.

6.6 APPROACHES FOR CHARACTERIZING VARIABILITY AND UNCERTAINTY

An important issue associated with any population exposure or risk assessment is the characterization of variability and uncertainty. *Variability* refers to the inherent heterogeneity in a population or variable of interest (e.g., residential air exchange rates) and cannot be reduced through further research, only better characterized with additional measurement. *Uncertainty* categorically refers to the lack of knowledge regarding the values of model input variables (i.e., *parameter uncertainty*), the physical systems or relationships used (i.e., use of input variables to estimate exposure or risk or *model uncertainty*), and in specifying the scenario that is consistent with purpose of the assessment (i.e., *scenario uncertainty*). Uncertainty is, ideally, reduced to the maximum extent possible through improved measurement of key parameters and iterative model refinement. The approaches used to assess variability and characterize uncertainty in this REA are discussed in the following two sections.

6.6.1 Characterization of Variability

The purpose for addressing variability in this REA is to ensure that the characterization of air quality and the estimates of exposure and risk reflect the variability of ambient SO_2 concentrations and associated SO_2 exposure and health risk across the study locations and population. In this REA, there are several algorithms that account for variability of input data when generating the number of estimated benchmark exceedances or health risk outputs. For example, variability may result from the number of monitors operating in an area and their associated temporal and spatial heterogeneity in ambient SO_2 concentrations. Variability may also arise from differences in the population residing within a census block (e.g., age distribution) and the activities that may affect SO_2 population exposure (e.g., time spent outdoors), and/or the influential risk factors (e.g., the fraction of the population responding to an SO_2 exposure). A complete range of potential exposure levels and associated risk estimates can be generated when appropriately addressing variability in exposure and risk assessments; note however that the range of values obtained would be within the constraints of the algorithm or modeling system used, not the complete range of the true exposure or risk values.

Where possible, staff identified and incorporated any observed variability in input data sets and estimated parameters within each of the analyses performed in Chapters 7-9 rather than employing standard default assumptions and/or using point estimates to describe model inputs. The details regarding variability distributions used in data inputs are described in the methods sections of each assessment and summarized in sections 7.4, 8.11, and 9.3 for the air quality characterization, the exposure assessment, and the risk characterization, respectively.

6.6.2 Characterization of Uncertainty

While it may be possible to capture a full range of exposure or risk values by accounting for variability inherent to influential factors, the true exposure or risk for any given individual is largely unknown. To characterize health risks, exposure and risk assessors commonly use an iterative process of gathering data, developing models, and estimating exposures and risks, given the goals of the assessment, scale of the assessment performed, and the limitations of the input data available. However, significant uncertainty often remains and emphasis is then placed on characterizing the nature of that uncertainty and its impact on exposure and risk estimates.

The characterization of uncertainty can include either qualitative or quantitative evaluations, or a combination of both. The approach can also be tiered, that is, the analysis can begin with a simple qualitative uncertainty characterization then progress to a complex probabilistic analysis. This could follow when a lower tier analysis indicates a high degree of uncertainty for certain identified sources, the sources are highly influential to exposure and risk estimates, and sufficient information and resources are available to conduct a quantitative uncertainty assessment. This is not to suggest that quantitative uncertainty analyses should always be performed in all exposure and risk assessments. The decision regarding the type of uncertainty characterization performed is also be informed by the intended scope and purpose of the assessment, whether the selected analysis will provide additional information to the overall decision regarding health protection, whether sufficient data are available to conduct a complex quantitative analysis, and if time and resources are available for higher tier characterizations (EPA, 2004b; WHO, 2008).

The primary purpose of the uncertainty characterization approach selected in this REA is to identify and compare the relative impact important sources of uncertainty may have on the potential health effect benchmarks and/or respiratory effects endpoints estimated in Chapters 7-9. The approach used to evaluate uncertainty was adapted from guidelines outlining how to conduct a qualitative uncertainty characterization (WHO, 2008), though staff also performed several quantitative sensitivity analyses to iteratively inform both model development and the qualitative uncertainty characterization, where possible. While it may be considered ideal to follow a tiered approach in the REA to quantitatively characterize all identified uncertainties, staff selected the mainly qualitative approach given the limited data available to inform probabilistic analyses, and time and resource constraints.

The qualitative approach used in this REA varies from that of WHO (2008) in that a greater focus of the characterization performed was placed on evaluating the direction and the magnitude[15] of the uncertainty; that is, qualitatively rating how the source of uncertainty, in the presence of alternative information, may affect the estimated air quality, exposure, and health risk assessment results. In addition and consistent with the WHO (2008) guidance, staff discuss the uncertainty in the knowledge-base (e.g., the accuracy of the data used, acknowledgement of

[15] This is synonymous with the "level of uncertainty" discussed in WHO (2008), section 5.1.2.2.

data gaps) and decisions made (e.g., selection of particular model forms), though qualitative ratings were assigned only to uncertainty regarding the knowledge-base.

First, staff identified the key sources of the assessment that may contribute to uncertainty in the air quality, exposure, and risk estimates and provide the rationale for their inclusion. Then, staff characterized the magnitude and direction each identified source of uncertainty influences the assessment results. Consistent with the WHO (2008) guidance, staff subjectively scaled the overall impact of the uncertainty by considering the degree of severity of the uncertainty as implied by the relationship between the source of the uncertainty and the output of the air quality characterization. Where the magnitude of uncertainty was rated *low*, it was judged that large changes within the source of uncertainty would have only a small effect on the assessment results. A designation of *medium* implies that a change within the source of uncertainty would likely have a moderate (or proportional) effect on the results. A characterization of *high* implies that a small change in the source would have a large effect on results. Staff also included the direction of influence, indicating how the source of uncertainty was judged to affect estimated benchmark exceedances or risk estimates; either the estimated values were likely *over*- or *under-estimated*. In the instance where the component of uncertainty can affect the assessment endpoint in either direction, the influence was judged as *both*. Staff characterized the direction of influence as *unknown* when there was no evidence available to judge the directional nature of uncertainty associated with the particular source. Staff also subjectively scaled the knowledge-base uncertainty associated with each identified source using a three level scale: *low* indicated significant confidence in the data used and its applicability to the assessment endpoints, *medium* implied that there were some limitations regarding consistency and completeness of the data used or scientific evidence presented, and *high* indicated the knowledge-base was extremely limited.

The output of the uncertainty characterization was a summary describing, for each identified source of uncertainty, the magnitude of the impact and the direction of influence the uncertainty may have on the air quality, exposure, and risk characterization results. And finally, an evaluation of the uncertainties presented in Chapters 7-9 is discussed in Chapter 10, providing the overall implications in informing staff’s evaluation of exposures and risks associated with level, form, and averaging time related to judging the adequancy of the current standard and consideration of potential alternative primary SO_2 standards.

6.7 KEY OBSERVATIONS

- Potential health effect benchmark values were derived from the controlled human exposure literature.
- Staff concluded that there is no evidence from human exposure studies to suggest that 200 ppb represents a threshold level below which no adverse respiratory effects occur.
- Staff concluded that it was appropriate to consider 5-minute benchmark levels in the range of 100 to 400 ppb in the air quality and exposure analyses.

7. AMBIENT AIR QUALITY AND BENCHMARK HEALTH RISK CHARACTERIZATION FOR 5-MINUTE PEAK SO_2 EXPOSURES

7.1 OVERVIEW

Ambient monitoring data for each of the years 1997 through 2007 were used in this chapter to characterize SO_2 air quality across the U.S. The measured air quality, as well as additional SO_2 concentrations derived from the measured air quality data, were used as an indicator of potential human exposure. While an ambient monitor measures SO_2 concentrations at a stationary location, the monitor may well represent the concentrations to which persons residing nearby are exposed. The quality of the extrapolation of ambient monitor concentration to personal exposure depends upon the spatial representativeness of the monitoring network, the corresponding spatial distribution of important emission sources, local meteorological conditions and geographical features, and a consideration of places that persons visit. Staff considers the analyses presented in this chapter to be a broad characterization of national air quality and potential human exposures that might be associated with a variety of scenario-driven concentrations. This is because many of the SO_2 ambient monitoring sites used in this analysis target public health monitoring objectives and some of the analysis results were separated by the population density surrounding the ambient monitors.

As previously discussed in Chapter 4, the ISA finds the evidence for an association between respiratory morbidity and SO_2 exposure to be “sufficient to infer a causal relationship” (ISA, section 5.2). The ISA states that the “definitive evidence” for this conclusion comes from the results of human exposure studies demonstrating decrements in lung function and/or respiratory symptoms in exercising asthmatics following exposure to SO_2 levels as low as 200 to 300 ppb for 5-10 minutes (ISA, section 5.2). Accordingly, 5-minute potential health effect benchmark levels ranging from 100-400 ppb were derived from the human exposure literature (see section 6.2 for benchmark level rationale) and compared to measured and statistically modeled 5-minute ambient concentrations. A broad analysis is first presented that evaluates the potential health risk at all ambient monitors, and then for more detailed analyses, at monitors located within selected U.S. counties (see section 7.2.4). Staff estimated the number of days in a year with 5-minute benchmark exceedances and the probability of benchmark exceedances given the occurrence of 1-hour daily maximum or 24-hour average SO_2 concentrations at ambient monitors.

All ambient SO_2 monitors report hourly concentrations; a subset of those report 5-minute maximum SO_2 concentrations as well, with a subset of these reporting continuous 5-minute SO_2 concentrations. Because there were two distinct sample averaging times reported for the available ambient monitoring data (i.e., ambient monitors reporting 1-hour SO_2 concentration measurements alone and monitors reporting both 5-minute and 1-hour average SO_2 concentrations), the data used in the analyses were separated by staff as follows.

The first set of ambient air quality data was from monitors reporting both 5-minute and 1-hour SO_2 concentrations. Staff 1) analyzed the ambient monitoring data for trends in 1-hour and 5-minute SO_2 concentrations, 2) counted the number of measured daily 5-minute maximum SO_2 concentrations above the potential health effect benchmark levels given the annual average SO_2 concentrations, 3) estimated the probability of benchmark exceedances given the 24-hour average and 1-hour daily maximum SO_2 concentrations, 4) developed a statistical model to estimate 5-minute maximum SO_2 concentrations from 1-hour SO_2 concentrations, and 5) evaluated the performance of the statistical model by comparing the model's predicted versus measured numbers of exceedances (see section 7.2.3).

The second set of ambient data was comprised of 1-hour SO_2 concentrations from the broader SO_2 monitoring network; therefore this set also included 1-hour SO_2 concentrations from those monitors where 5-minute SO_2 data were reported, though the vast majority of the 1-hour data were from monitors that did not report 5-minute concentration measurements. Staff applied the statistical model that related 5-minute to 1-hour SO_2 measurements to this second set of ambient monitoring data to estimate 5-minute maximum SO_2 concentrations. As was done with the 5-minute SO_2 ambient measurement data, staff 1) evaluated trends in SO_2 concentrations, 2) counted the number of statistically modeled potential health effect benchmark exceedances in a day using the same longer-term averaging times, and 3) estimated the probability of peak concentrations associated with 1-hour daily maximum and 24-hour average SO_2 concentrations.

Staff considered three data analysis groups to characterize the ambient SO_2 air quality. In the first group, we evaluated the combined 5-minute and 1-hour SO_2 measurement data as they were reported, representing the conditions at the time of monitoring (termed in this assessment "*as is*"). The second group also considered the *as is* air quality; however staff analyzed the statistically modeled 5-minute SO_2 concentrations that were generated from *as is* 1-hour SO_2 measurements. This second data analysis group expanded the geographic scope of the 5-minute air quality characterization by using the broader SO_2 monitoring network. The third data analysis group considered 1-hour SO_2 concentrations adjusted to just meeting the current NAAQS[16] and each of the potential alternative 1-hour daily maximum standard levels of 50, 100, 150, 200 and 250 ppb (see Chapter 5 for details). The data used to simulate the current and alternative standard scenarios were limited to the most recent and comprehensive ambient monitoring data available (i.e., 2001-2006) in forty selected U.S. counties.[17] Due to the form of the potential alternative standards considered here (98th and 99th percentiles of the 1-hour daily maximum concentrations averaged over 3 years), the recent ambient monitoring data set was evaluated using two three-year periods, 2001-2003 and 2004-2006.[18] Whereas the first analysis group used entirely 1-hour and 5-minute SO_2 measurement data, the second and third analysis groups used statistically modeled 5-minute SO_2 concentrations that were generated from 1-hour SO_2 concentrations. The third data analysis group also included an adjustment of the 1-hour SO_2 concentrations to evaluate several air quality standard scenarios in 40 selected counties.

Staff expected that there would be variability in the number of persons living within close proximity of each monitor (both the 5-minute and 1-hour SO_2 monitors) given the particular siting characteristics of the ambient monitors (e.g., either source- or population-oriented monitoring objectives). Therefore, we separated some of the air quality results within each scenario by using the population density surrounding each ambient monitor. First, each monitor was characterized by having one of three population densities (i.e., *low*, *medium*, and *high*), groupings defined by the three characteristic regions of the population distribution generated from the broader SO_2 monitoring network (section 7.2.2). Then, staff counted the number days

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[16] Just meeting the current NAAQS levels could either be meeting a 30 ppb annual average or the 140 ppb 24-hour average concentration (one allowed exceedance), whichever is the controlling standard at that ambient monitor (see section 7.2.4).

[17] At the time of the initial data download from the AQS data mart, many of the monitors did not have complete years of data available for 2007, therefore the most recent data for most monitors was from 2006. These complete site-year data are a subset of the broader ambient monitoring data set available.

[18] A number of 3-year groups are within 2001-2006 (e.g., 2001-2003, 2002-2004, etc.) and a number of years of monitoring data are outside the 2001-2006 time frame that could have been used in an extended 3-year grouping of 2001-2006 air quality (e.g., 2000-2002). For convenience, the upper and lower groupings were chosen by staff to represent 3-year air quality within the 6-year period when considering just meeting the potential alternative standards.

with 5-minute benchmark exceedances per year at each monitor, either measured or estimated depending on the data analysis group considered, and aggregated the results by the population density group. Rather than count the total number of 5-minute SO_2 concentrations above a particular benchmark, staff calculated the number of days in a year with a 5-minute SO_2 concentration above a potential health effect benchmark.[19]

One output of this air quality characterization is an estimate of the number of days per year a monitor experienced 5-minute SO_2 concentration above those that may cause adverse health effects in susceptible individuals (i.e., benchmark level exceedances). These counts are a useful metric in comparing one ambient monitor or monitoring location to another and in identifying where and when frequent benchmark exceedances could occur. However, earlier analyses indicated that the relationship between the annual average SO_2 concentration and the number of 5-minute benchmark exceedances was generally weak (1st draft SO_2 REA). Therefore, a comparison of the number of days/year with benchmark exceedances to the annual average SO_2 concentration is of limited use. This absence of a strong relationship highlights the ineffectiveness of long-term averaged concentrations in controlling short-term peak concentrations. Furthermore, while there was an improved relationship between the number of 5-minute maximum SO_2 concentrations and 24-hour average concentrations, it was also shown that the number of benchmark exceedances in a day was variable given a specific 24-hour average concentration.[20] For example, there could be as many as five 5-minute maximum SO_2 concentrations above a selected benchmark levels at a particular 24-hour average SO_2 concentration, while in other instances there may be no benchmark exceedances at the same 24-hour concentration.

Given that there is variability in the number of 5-minute peak SO_2 concentrations associated with concentrations of longer-term averaging times, that a daily maximum 5-minute SO_2 concentration was the metric of interest, and that the potential alternative standards

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[19] In the 1st draft SO_2 REA, as well as the early draft NO_2 REAs, all benchmark exceedances for any hour of the day were reported. The use of the daily maximum exceedance was selected in the final NO_2 REA as well in the 2nd draft and final SO_2 REA to improve the temporal perspective for the metric in the air quality analysis (i.e., the number of daily maximum exceedances also gives the number of days in a year with an exceedance of a selected benchmark), and to be consistent with the exposure and risk analyses. The implication of not counting multiple exceedances is discussed further in sections 7.4, 8.11, and 10.3.3.1.

[20] In the 1st draft SO_2 REA, multiple exceedances within a day (if any) were counted. In the 2nd draft and final SO_2 REA, there is only one counted maximum exceedance per day. Additional analysis of multiple exceedances within the day is given in section 8.11.211.

investigated use 1-hour daily maximum SO_2 concentrations, staff decided that an appropriate comparison would be between the frequency of peak 5-minute SO_2 concentrations given 1-hour daily maximum SO_2 concentrations. Thus, the second output of this air quality characterization is presented as the probability of a benchmark exceedance given a daily maximum 1-hour SO_2 concentration. In addition, the probability of a 5-minute benchmark exceedance given a 24-hour average concentration is also provided to offer additional perspective on this averaging time.

7.2 APPROACH

There were five broad steps to characterize the SO_2 air quality. The first step involved compiling and screening the ambient air quality data collected since 1997 to ensure consistency with the SO_2 NAAQS requirements and for usefulness in this air quality characterization. Next, due to potential variable influence of SO_2 emission sources on ambient monitor concentrations, the monitors from each of the two data sets (i.e., combined 5-minute and 1-hour, broader 1-hour only) were categorized and evaluated according to their monitoring site attributes, including land use characteristics, location type, monitoring objective, distance to emissions sources, and population density. In addition, the variability in 5-minute and 1-hour SO_2 concentrations was evaluated and used to categorize each ambient monitor. Staff used concentration variability in the development and application of a statistical model used to estimate 5-minute maximum SO_2 concentrations. Then, a concentration adjustment approach was developed and applied in selected locations to evaluate several air quality scenarios. And finally, air quality metrics of interest (i.e., the number and probability of potential health effect benchmark exceedances) were calculated using the air quality data from each scenario.

The following provides an overview of the five steps used to characterize air quality and summarizes key portions of the analysis. Briefly, the five steps include: 1) screening of air quality data; 2) evaluation of site characteristics of ambient SO_2 monitors; 3) development of a statistical model to estimate 5-minute maximum SO_2 concentrations; 4) adjustment of air quality; and 5) generation of air quality metrics. Details regarding the ambient monitors used for characterizing air quality and associated descriptive meta-data are provided in Appendix A.1.

7.2.1 Screening of Air Quality Data

SO_2 air quality data and associated documentation from the years 1997 through 2007 were downloaded from EPA's Air Quality System for this analysis (EPA, 2007c, h). Data obtained were used as reported by these sources; there were no substitutions performed for any missing or zero concentration data. The total available SO_2 ambient monitoring data, reported for either 5-minute or 1-hour averaging times, are summarized in Table 7-1. The 5-minute SO_2 monitoring data existed in either one of two forms; the single highest 5-minute concentration occurring in a 1-hour period (referred to here as max-5 data set), or all twelve 5-minute concentrations within a 1-hour period (referred to here as continuous-5 data set).

Table 7-1. Summary of all available 5-minute and 1-hour SO_2 ambient monitoring data, years 1997-2007, pre-screened.

Sample Type	Number of Monitors	Number of States[1]	Years in Operation	Number of Measurements[2]
Max-5	104	13 + DC	1997-2007	3,457,057
Continuous-5	16	6 + DC	1999-2007	3,328,725
1-hour	935	49 + DC, PR, VI	1997-2007	47,206,918

Notes:
[1] DC=District of Columbia, PR=Puerto Rico, VI=Virgin Islands.
[2] For the max-5 and 1-hour data sets, this number represents the number of hours a sample was collected/reported. The number for the continuous-5 data set is the number of 5-minute samples. The total number of hours where measurements for the continuous-5 set were collected is 283,202 (see Table 7-2).

Staff evaluated the data for inconsistencies and duplication. The reported measurement units varied within each of the data sets, therefore the staff converted all concentrations to parts per billion (ppb). Next staff screened each of the three data sets listed in Table 7-1 for where monitor IDs had multiple parameter occurrence codes (POCs) and identical monitoring times. These duplicate measures could either result from co-location of ambient monitors (i.e., more than one measurement instrument) or from duplicate reporting of ambient concentrations (i.e., the 5-minute maximum concentration in the max-5 data set is the same as the maximum 5-minute concentration reported from the continuous-5 data set). As a result of this evaluation and additional concentration level screening (see below), staff constructed several data sets for analysis in this REA. These data sets are summarized in Table 7-2 and are described in detail below.

Table 7-2. Analytical data sets generated using the continuous-5, max-5, and 1-hour ambient SO_2 monitoring data, following screening.

<table>
<tr><th>Sample Type</th><th>Within Set Duplicates (n)</th><th>Available Data (n)</th><th colspan="2">Combined Set Duplicates (n)</th><th>Final Combined Max-5 Data (n)</th><th>Final Combined 1-hour (n)</th><th>Final Combined Max-5 & 1-hour (n)</th></tr>
<tr><td>Max-5</td><td>300,438</td><td>3,156,619</td><td rowspan="2">29,058</td><td></td><td rowspan="2">3,410,763</td><td></td><td rowspan="3">2,367,686[4]</td></tr>
<tr><td>Continuous-5 with 1-hour[1]</td><td>0</td><td>283,202[2]</td><td rowspan="2">258,457</td><td rowspan="2">47,213,385[3]</td></tr>
<tr><td>1-hour</td><td>0</td><td>47,188,640</td><td></td><td></td></tr>
</table>

Notes:
[1] 1-hour concentrations from continuous-5 data were calculated from all 5-minute values within the hour.
[2] The number of 5-minute maximum SO_2 samples.
[3] There were a total of 24,745 unique 1-hour values added from the continuous-5 monitors.
[4] There were a total of 2,408,351 values where the 5-minute maximum and 1-hour measurements were reported at the same time at the same monitor. Of these, a total of 40,665 were screened out for not meeting the peak-to-mean (PMR) criterion.

Boxes spanning two rows are comprised of data from the two sample types. For example, there were 29,058 duplicate values when considering the max-5 and continuous-5 data sets. Therefore, in creating the "Final Combined Max-5 Data" (n= 3,410,763), this was the sum of the max-5 (n=3,156,619) and continuous-5 (n=283,202) minus the duplicates (n=29,058).

1. Simultaneously reported/measured ambient SO_2 data

Two separate data sets were constructed that had multiple 5-minute SO_2 measurements collected at the same monitoring location and time for:

- max-5 duplicates (i.e., simultaneous measurements of 5-minute maximum SO_2 concentrations from co-located max-5 monitors; n=300,438)
- max-5 and continuous-5 duplicates (i.e., simultaneous 5-minute maximum SO_2 concentrations reported in max-5 and continuous-5 datasets; n=29,058)

A third data set was constructed that had simultaneous 1-hour SO_2 measurements collected at the same monitoring location and time for:

- 1-hour duplicates (i.e., from 1-hour SO_2 monitors and from averaging the continuous-5 monitors; n=258,457)

Each of these duplicate data sets were used for quality assurance purposes only, the evaluation of which is presented in Appendix A.2. The duplicate values were not used in the statistical model development or for any other 5-minute or 1-hour SO_2 concentration analysis.

2. Combined 5-minute and 1-hour ambient SO_2 data

A complete set of 5-minute maximum SO_2 concentrations,[21] generated from the max-5 data set and from the maximum 5-minute concentrations reported by the continuous-5 monitors, was then combined with their corresponding measured 1-hour SO_2 concentrations (see below). Then, the combined data were screened for validity, recognizing that the combined max-5 and 1-hour SO_2 data set may have certain anomalies (e.g., 5-minute maximum SO_2 concentrations < 1-hour mean SO_2 concentration). A value of 1 was selected as the lower bound peak-to-mean ratio (PMR),[22] accepting the possibility that the 5-minute maximum concentrations (and all other 5-minute concentrations within the same hour) may be identical to the 1-hour average concentration. A PMR of <12 was selected as the upper bound since it would be a mathematical impossibility to generate a value at or above 12 given there are twelve 5-minute measurements within any 1-hour period.[23] This screening resulted in a total of nearly 2.4 million values comprising the combined 5-minute maximum and 1-hour SO_2 concentration dataset. The locations of these 98 monitoring sites comprising this dataset are illustrated in Figure 7-1. Staff used this data set to develop a statistical model (section 7.2.3) and to characterize the measured 5-minute maximum ambient air quality. Details on the monitors used and site attributes (e.g., latitude, longitude, operating years, monitoring objective) are provided in Appendix A.1.

[21] A single 5-minute and 1-hour SO_2 concentration was used in each of data set 2 and 3. The criteria for selection of a particular value was first based on whether the 1-hour concentration was calculated from the continuous-5 data (where present) followed by the monitor ID POC that had the greatest overall number of samples.
[22] The peak-to-mean ratio is the maximum 5-minute SO_2 concentration within an hour divided by the 1-hour average SO_2 concentration.
[23] As the 5-minute maximum concentration approaches infinity, the other 11 concentrations measured in the hour comparatively tend towards zero, giving a maximum PMR = Peak/Mean = $C_{max}/[(C_{max} + (C_{others} \rightarrow 0) \times 11)/12] < 12$.

Figure 7-1. Location of the 98 monitors that reported 5-minute maximum SO_2 concentrations and comprising the first data analysis group.

3. Broader 1-hour ambient SO_2 data

This data set was comprised of all 1-hour SO_2 data, whether obtained from the 1-hour ambient monitoring data set or from averaging 5-minute concentrations from the continuous-5 data set. The raw 1-hour data from a total of 935 ambient monitors were first screened for negative concentrations (n=3,555) and for where concentrations were less than 0.1 ppb (n=14,723). The screened data were not used in any analyses. The refined 1-hour data (n=47,188,640) were then combined with the 1-hour average concentrations obtained from the continuous 5-monitors. Staff retained the 1-hour average concentrations from the continuous-5 monitors where duplicate values existed. This was done to better maintain the relationship between the 5-minute maximum and 1-hour SO_2 concentrations. As described above for data set 1, staff removed duplicate 1-hour values identified at each monitoring location originating from the 1-hour and continuous-5 monitors for separate analysis (Appendix A-2). The remaining 1-hour SO_2 data set (with duplicate 1-hour values removed) was then combined with the complete 5-minute maximum data set described above for data set 2 (with duplicate 5-minute maximum

SO_2 values removed). Staff used data set 2 in developing the statistical model to estimate 5-minute maximum SO_2 concentrations (section 7.2.3).

Additional screening of the 1-hour SO_2 data set was performed using a 75% completeness criterion. This monitoring data requirement is used in demonstrating attainment of the SO_2 NAAQS (61 FR 25579).[24] For an ambient monitor to have a valid year of data, first, valid days were selected as those with at least 18 hours of data. Then, each monitor was required to have 75% of each calendar quarter with complete days (either 68 or 69 days per quartile). This 75% completeness criterion was applied to the available monitoring data to generate a total of 4,692 valid site-years of data obtained from 809 ambient monitors. The number of valid monitoring site-years available as a result of this screening is presented in Table 7-3, effectively encompassing ambient SO_2 monitoring in 48 US States, Washington DC, Puerto Rico and the US Virgin Islands over years 1997 through 2006.[25] The locations of the 809 monitors comprising the broader SO2 monitoring network are illustrated in Figure 7-2. This data set was used in the second data air quality characterization scenario that considered the measured *as is* 1-hour SO_2 concentrations with statistically modeled 5-minute maximum concentrations. Details on the monitors used and site attributes (e.g., latitude, longitude, operating years, monitoring objective) are provided in Appendix A.1.

7.2.2 Site Characteristics of Ambient SO_2 Monitors

The siting of the monitors is of particular importance, recognizing that proximity to local sources could have an influence on the measured SO_2 concentration data and subsequent interpretation of the air quality characterization. Staff evaluated the attributes of monitors within each of the two data sets; the first data set was comprised of monitors that reported 5-minute maximum SO_2 concentrations, and the second was generated from monitors within the broader SO_2 monitoring network and having valid 1-hour SO_2 concentrations. Two points are worth mentioning for this analysis; the first being the number of monitors and the second being the potential for differences in types of sources influencing each monitor. While there is overlap in

[24] See http://www.epa.gov/air/oaqps/greenbook/40cfr50_2001.pdf

[25] Based on the version date of the files downloaded from EPA's AQS data mart (6/20/2007), all 1-hour SO_2 data from 2007 were less than complete. In addition, two monitors located in Hawaii County, HI were identified in the 1st draft REA as having concentrations influenced by natural sources. Therefore, monitor IDs 150010005 and 150010007, while meeting the completeness criteria, were removed from the valid 1-hour SO_2 data set due to the influence of volcanic activity on measured SO_2 concentrations at these locations. Alaska had no SO_2 monitors during the period of analysis.

Table 7-3. Counts of complete and incomplete site-years of 1-hour SO_2 ambient monitoring data for 1997-2006.

State		Number of Site-Years		Percent Valid	Number of Valid Monitors per year	
Abbr.	Code	Complete	Incomplete		Minimum	Maximum
AL	01	36	15	71	1	5
AZ	04	44	24	65	1	6
AR	05	17	14	55	1	2
CA	06	308	136	69	7	41
CO	08	33	13	72	1	6
CT	09	69	18	79	6	12
DE	10	27	16	63	2	4
DC	11	10	1	91	1	1
FL	12	223	76	75	3	28
GA	13	65	34	66	5	9
HI	15	31	19	62	2	4
ID	16	17	10	63	1	3
IL	17	235	30	89	18	30
IN	18	276	80	78	13	34
IA	19	110	33	77	8	14
KS	20	28	27	51	2	4
KY	21	104	42	71	2	13
LA	22	57	11	84	5	6
ME	23	25	18	58	1	7
MD	24	10	7	59	1	3
MA	25	102	33	76	6	15
MI	26	84	28	75	5	15
MN	27	74	23	76	5	12
MS	28	25	11	69	1	4
MO	29	166	40	81	11	21
MT	30	121	50	71	2	18
NE	31	9	13	41	1	2
NV	32	16	6	73	1	4
NH	33	63	26	71	3	11
NJ	34	117	21	85	12	14
NM	35	56	24	70	3	9
NY	36	229	72	76	21	24
NC	37	61	29	68	4	9
ND	38	155	45	78	10	18
OH	39	309	74	81	28	35
OK	40	59	32	65	3	9
OR	41	0	4	0	0	0
PA	42	398	97	80	33	51
RI	44	21	2	91	2	3
SC	45	90	34	73	5	11
SD	46	7	4	64	1	3
TN	47	175	70	71	12	23

State		Number of Site-Years		Percent Valid	Number of Valid Monitors per year	
Abbr.	Code	Complete	Incomplete		Minimum	Maximum
TX	48	172	71	71	10	21
UT	49	33	14	70	3	4
VT	50	11	4	73	1	2
VA	51	94	28	77	8	11
WA	53	18	24	43	1	7
WV	54	203	28	88	14	25
WI	55	39	18	68	2	7
WY	56	3	8	27	1	1
PR	72	33	32	51	1	6
VI	78	24	23	51	1	5
Total or Average[1]		**4692**	**1612**	**68**	**6**	**12**

Notes:
[1] Columns of complete and incomplete site years were summed. The percent valid site-years and the monitors in operation per year with valid data were averaged.

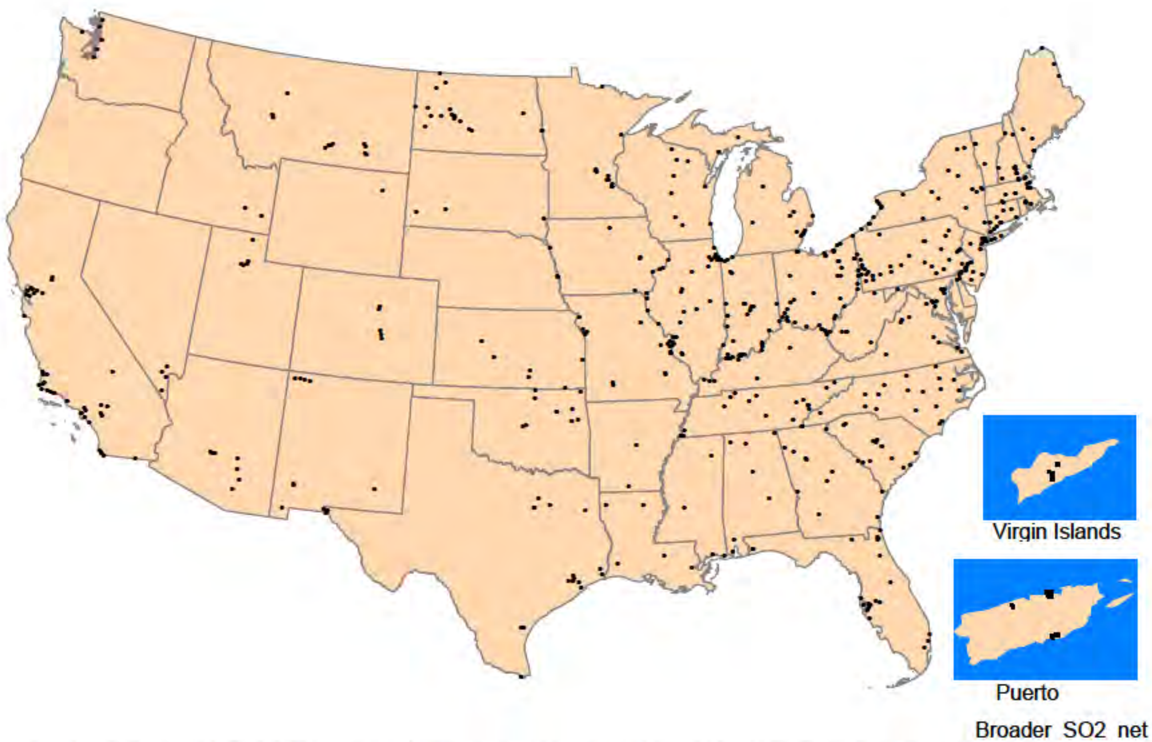

Figure 7-2. Location of the 809 monitors comprising the broader SO_2 ambient monitoring network (i.e., the second data analysis group).

the measurement of 5-minute maximum and its associated 1-hour SO_2 concentration at some locations (n=98), the remainder of SO_2 monitors with valid data (n=711) are sited in other locations where 5-minute SO_2 measurements have not been reported. Staff evaluated the ambient monitor attributes within each data set because there may be influential attributes in the subset of data used to develop the statistical model (i.e., monitors reporting 5-minute maximum SO_2 concentrations) that are not applicable to the broader SO_2 monitoring network. Staff acknowledges that the information available and the monitoring site characteristics considered can limit how well the monitoring data serve as an indicator of human exposure.

First, staff evaluated the specific monitoring site characteristics provided in AQS, including the monitoring objective, measurement scale, and predominant land-use. Additional features such as proximity to SO_2 emission sources and the population residing within various distances of each monitor were estimated using monitoring site and emission source geographic coordinates and U.S Census data. Each of these attributes is summarized here to provide perspective on the attributes of where 5-minute maximum SO_2 concentrations were reported versus the attributes of the broader SO_2 monitoring network. A more thorough discussion of the purpose of the existing ambient SO_2 monitoring network is provided in Chapter 2. Individual monitor site characteristics are given in Appendix A.1.

The monitoring objective meta-data field describes the nature of the monitor in terms of its attempt to generally characterize health effects, the presence of point sources, regional transport, or welfare effects. In recognizing that there were variable numbers of ambient monitors in operation and variation in the number of valid site-years available for each data set, staff weighted the monitoring objectives by the number of site-years. This was done to provide perspective on the air quality characterization results that are based on the total site-years of data available, not just the number of ambient monitors. In addition, the monitors can have more than one objective. Where multiple objectives were designated, staff selected a single objective to characterize each monitor using the following order: population exposure, source-oriented, high concentration, general/background, unknown.[26] All other objectives (whether known or indicated as "none") were grouped by staff into an "Other" category. Figure 7-3 summarizes the

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[26] This order was selected to characterize the monitors with a specific objective. Most of the time where there were multiple objectives at a monitor, there was a specific objective (e.g., population exposure) and a non-specific objective (e.g., unknown).

objectives for the monitors comprising each data set. Each of the data sets had a large proportion of site-years that would target public health objectives through the population exposure and highest concentration categories, though the monitors in the broader SO_2 monitoring network had a greater percentage than the monitors reporting both 5-minute maximum and 1-hour SO_2 concentrations. The monitors reporting 5-minute concentrations had approximately twice the percentage of site-years from source-oriented monitors when compared with the broader SO_2 monitoring network.

Similarly, the overall measurement scale of the monitors used for the air quality characterization in each location was evaluated based on the weighting of valid site-years of data. The measurement scale represents the air volumes associated with the monitoring area dimensions. While a monitor can have multiple objectives, each monitor typically has only one measurement scale. Figure 7-3 also summarizes the measurement scales for the monitoring site-years comprising each data set. Both data sets had their greatest proportion of monitoring site-years associated with neighborhood measurement scales (500 m to 4 km), though monitors recording 1-hour concentrations had about 22 percentage points greater than the monitors reporting 5-minute maximum concentrations. Furthermore, monitors reporting 5-minute values had a larger proportion of site-years of data characterized at an urban (4 to 50 km) and regional scale (50 km to 1,000 km) compared with the broader SO_2 monitoring network.

The land-use meta-data indicate the prevalent land-use within ¼ mile of the monitoring site. Figure 7-4 summarizes the land-use surrounding monitors that reported 5-minute maximum concentrations and the monitors in the broader 1-hour SO_2 monitoring network. Over half of the site-years are from residential and industrial areas and are of similar proportions for both data sets considered. The greatest difference in the surrounding land-use was for the percent of site-years associated with monitors sited in agricultural and commercial areas. The monitors reporting 5-minute maximum SO_2 concentrations had about 10 percentage points more site-years from monitors within agricultural areas and 10 percentage points less in commercial areas when compared to the respective land use of the broader SO_2 monitoring network.

The setting is a general description of the environment within which the site is located. Figure 7-4 also summarizes the setting of the monitors comprising each data set. For monitors reporting 5-minute concentrations, the greatest proportion of site-years is from ambient monitors with a rural setting (49%). Most of the site-years in the broader SO_2 monitoring network were from monitors within a suburban setting (40%).

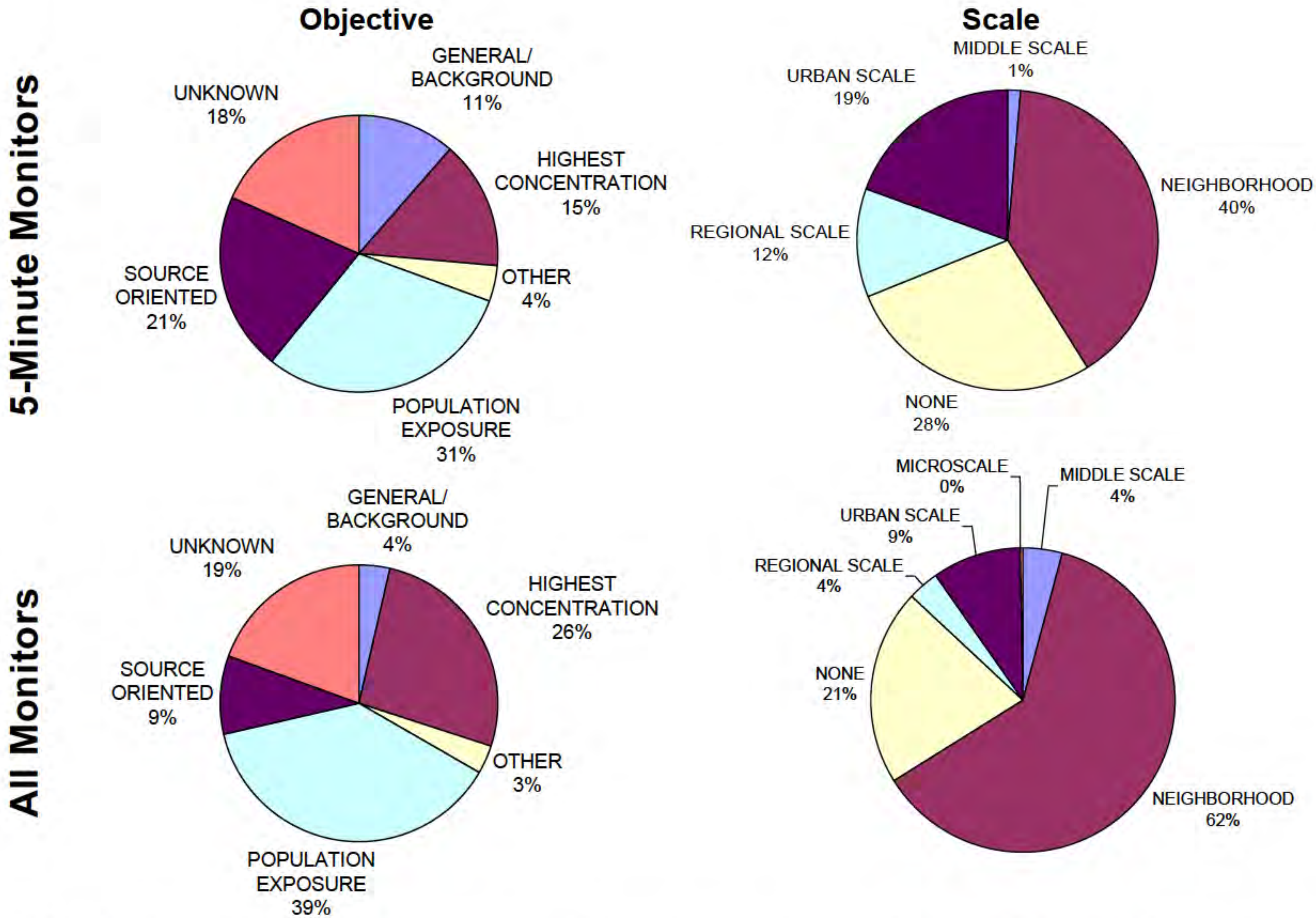

Figure 7-3. Distribution of site-years of data considering monitoring objectives and scale: monitors that reported 5-minute maximum SO_2 concentrations (top) and the broader SO_2 monitoring network (bottom).

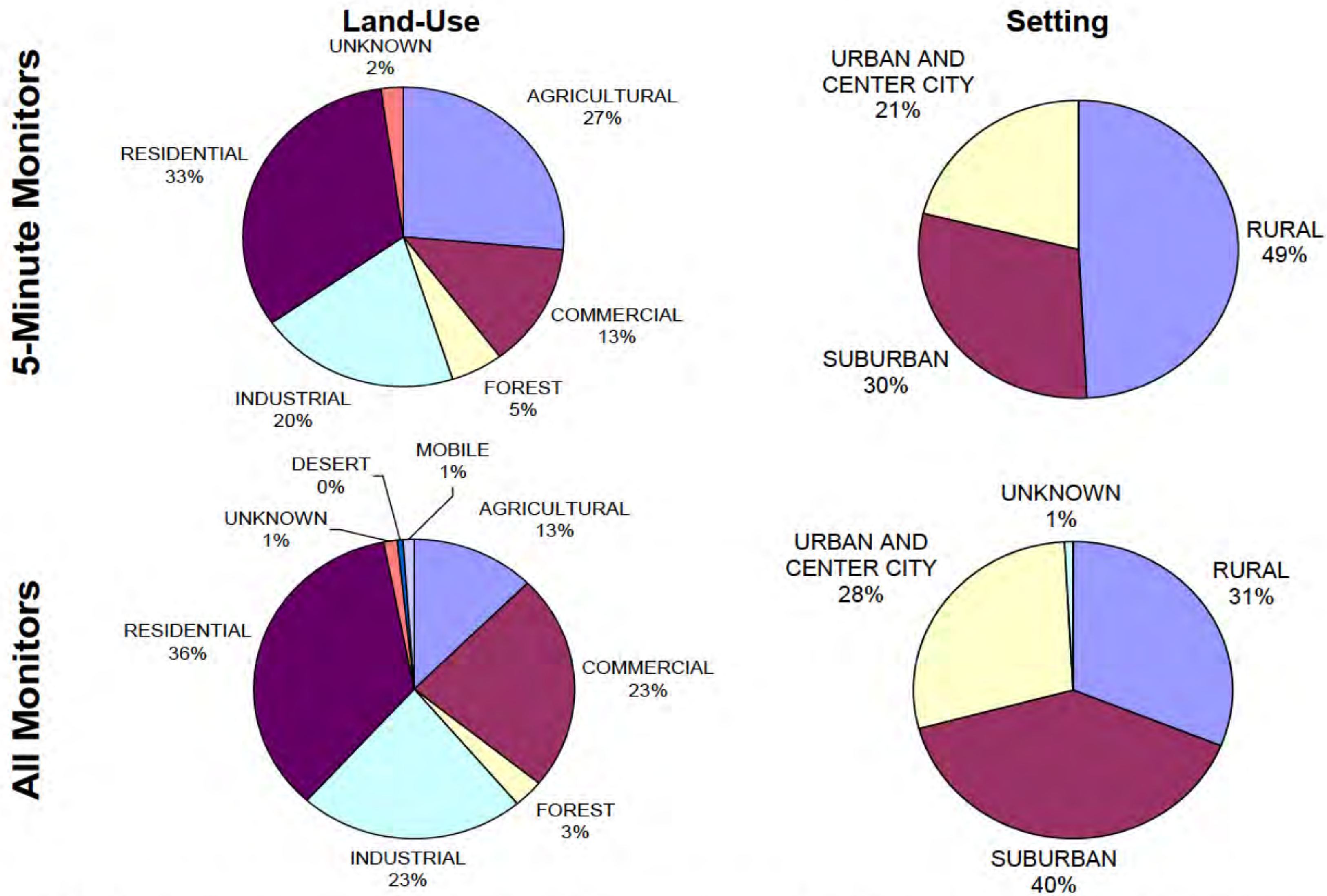

Figure 7-4. Distribution of site-years of data considering land-use and setting: monitors that reported 5-minute maximum SO_2 concentrations (top) and the broader SO_2 monitoring network (bottom).

Stationary sources (in particular, power generating utilities using fossil fuels) are the largest contributor to SO_2 emissions in the U.S. (ISA, section 2.1). First, staff determined the distances, amounts of, and types of stationary source emissions associated with each of the ambient SO_2 monitors. Then, staff selected the sources in close proximity of each monitor to identify whether there are differences in the distribution of emission sources that could affect the monitored concentrations. Stationary sources emitting > 5 tons per year (tpy) SO_2 and within 20 km of each monitor were identified using data from the 2002 National Emissions Inventory (NEI).[27] Details on the number of sources, the distribution of emissions, and the method for determining the distances to each individual ambient monitor are provided in Appendix A.1.

The total SO_2 source emissions within 20 km of every monitor were summed by their source descriptions; the top eight source types were selected for evaluation followed by a summing of all other remaining source types in a final source description group ("other").[28] These emission results are presented in Figure 7-5 for the monitors reporting 5-minute maximum SO_2 concentrations and for the broader SO_2 monitoring network. A comparison of the sources located within 20 km of monitors comprising both data sets indicates strong similarity in the types of sources present. Approximately 70% of the stationary source emissions local to monitors comprising either data set originate from fossil fuel power generation.[29] Similarity in emission contributions from several other source categories is also evident (i.e., petroleum refineries, iron and steel mills, cement manufacturing). One of the largest distinctions between the sources surrounding the two data sets is the emission contribution from primary smelters. There were greater source emissions from smelters located within 20 km of the monitors reporting 5-minute maximum SO_2 concentrations (8.8%) than within 20 km of the broader SO_2 monitoring network (1.1%). A second difference between the two sets of data existed in the emission contribution from a combined power generation, transmission and distribution description; this source category contributes approximately 11% to emissions proximal monitors

[27] 2002 National Emissions Inventory Data & Documentation. Office of Air Quality Planning and Standards, Research Triangle Park, NC. Available at: http://www.epa.gov/ttn/chief/net/2002inventory html.

[28] Details for the number of sources and emissions surrounding each monitor are given in Appendix A.1.1 and A.1.2

[29] This emission category was summed from fossil fuel power generation (NEI code 221112) and hydroelectric utilities (NEI code 221111). Hydroelectric utility SO_2 emissions arise from power generating facility operations that require fossil fuel combustion (e.g., diesel-fueled backup generators).

in the broader SO_2 monitoring network compared with only 2% at monitors measuring 5-minute SO_2 concentrations.

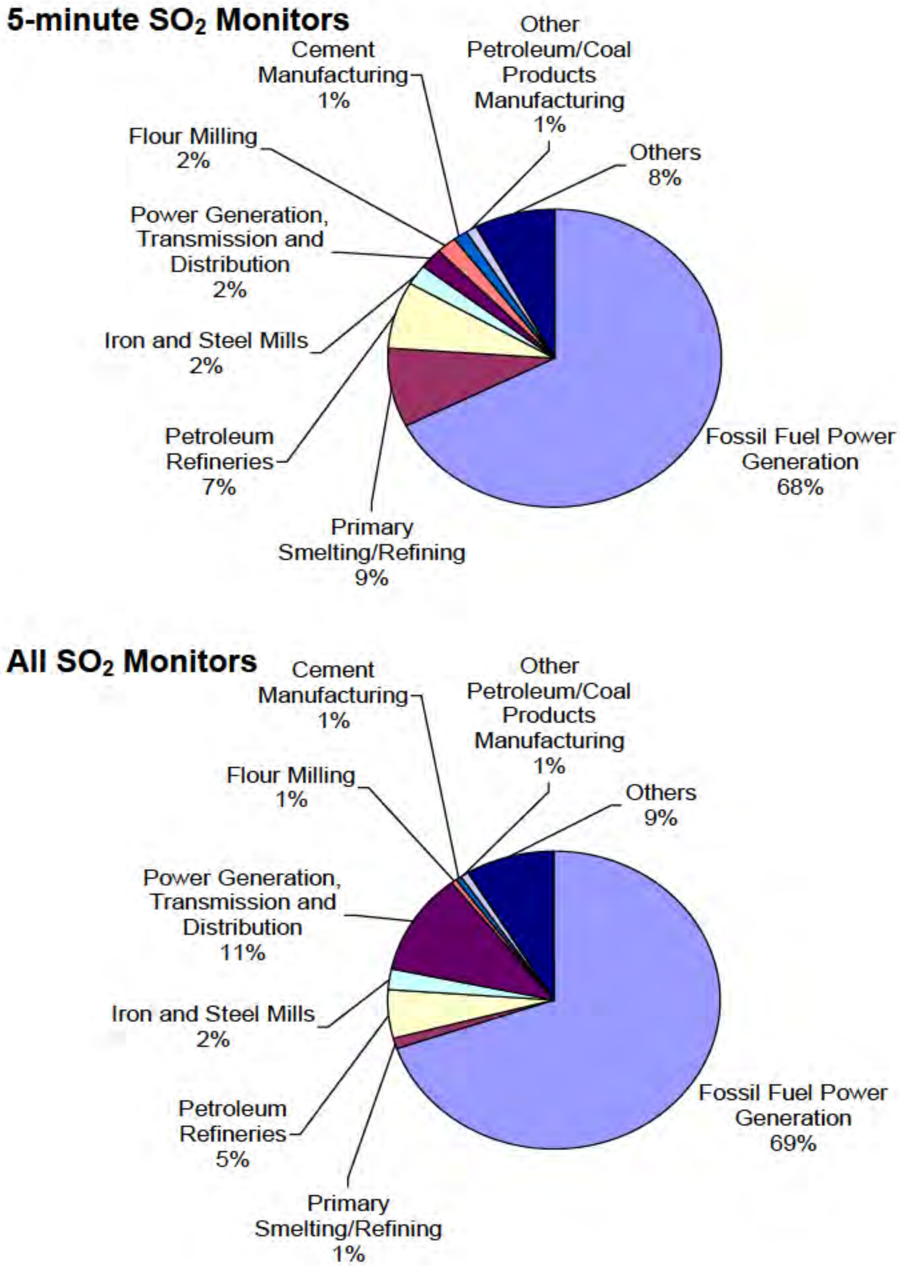

Figure 7-5. The percent of total SO_2 emissions of sources located within 20 km of ambient monitors: monitors reporting 5-minute maximum SO_2 concentrations (top) and the broader SO_2 monitoring network (bottom).

The population residing within four buffer distances of each ambient monitor was estimated using ArcView. First, staff obtained block group population data from the US Census and converted the location of each block group polygon to single central point. Then buffers were created around each monitor location at progressive 5 km distances to a final buffer distance of 20 km. The total population was estimated by summing the population of all block group centroids that fell within the monitor buffers. We then created population distribution functions (across monitors) for the monitors reporting 5-minuute maximum SO_2 concentrations and for the broader SO_2 monitoring network. An example of the population distribution represented by the monitors comprising each data set is given by Figure 7-6, with the population within each of the buffer distances given in Appendix A.1.[30] In general, the shape of the population distribution was similar for each data set, though as a whole, the monitors reporting 5-minute SO_2 concentrations tended to be sited in locations with lower population density when considering any of the population buffers. Staff created population density groups of *low*, *mid*, and *high* to categorize all ambient monitors using the population distribution within 5 km, by apportioning each data set into three sample size groupings. The low-population density group included those monitors with populations under 10,000 persons. Mid-population density included those monitors with between 10,000 and 50,000 persons, while the high-population density group was assigned to monitors with greater than 50,000 persons within a 5 km buffer. These population density groups of low, mid, and high were used in separating some of the air quality characterization results.

The population density surrounding each monitor was compared with its monitoring objective. The descriptive statistics for each monitoring objective, separately considering those monitors that reported 5-minute maximum SO_2 concentrations and the broader SO_2 monitoring network, are provided in Table 7-4. The calculated population statistics generally support expectations given the designated monitoring objectives. There are similarities in the population density around monitors characterized as having *highest concentration* and *population exposure* monitor objectives, both of which having the greatest number of persons residing within 5 km of the monitors. *Source-oriented* monitors had consistently lower population densities, though monitors assigned the *general/background* objective had the lowest population densities.

[30] If the estimated population was zero, then the monitor value was not plotted in the figure.

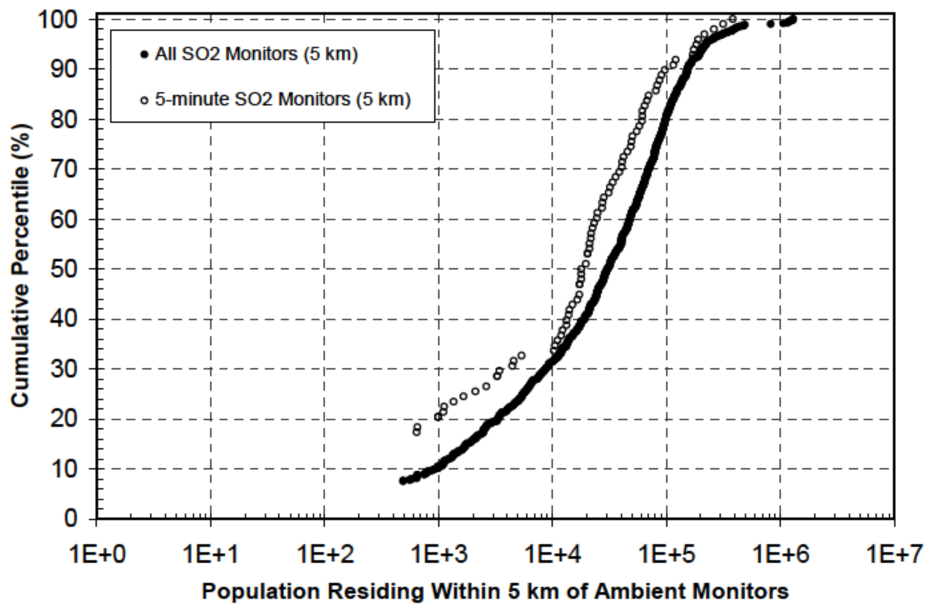

Figure 7-6. Distribution of the population residing within a 5 km radius of ambient monitors: monitors reporting 5-minute maximum SO_2 concentrations and the broader SO_2 monitoring network.

Table 7-4. Descriptive statistics of the population residing within a 5 km radius of ambient monitors by monitoring objective: monitors reporting 5-minute maximum SO_2 concentrations and the broader SO_2 monitoring network.

Data Source	Objective[1]	n	Population residing within 5 km of Ambient Monitor[2]							
			mean	max	p95	p75	p50	p25	p5	min
5-minute monitors	GEN	10	8537	28224	28224	17957	1330	0	0	0
	OTH	6	8881	35872	35872	11967	2396	655	0	0
	SRC	15	9216	42208	42208	17925	1103	0	0	0
	UNK	18	40177	262592	262592	33774	20360	4587	0	0
	HIC	19	59958	316944	316944	90863	17963	13314	0	0
	POP	30	67886	382995	216129	70221	49283	21784	3280	2118
All SO_2 Monitors	GEN	45	18096	378415	78376	7883	1947	492	0	0
	SRC	68	20594	136288	76896	30070	9844	1112	0	0
	UNK	179	58477	1215989	200253	59772	16676	3403	0	0
	OTH	30	61878	1205886	320320	11205	4270	787	0	0
	HIC	202	86485	1301071	222716	94449	48179	14142	905	0
	POP	285	87406	1173879	276378	105796	54986	21336	1865	0

Notes:
[1] Objectives are POP=Population Exposure; HIC=Highest Concentration; SRC=Source Oriented; GEN=General/Background; OTH=Other; UNK=Unknown.
[2] p5, p25, p50, p75, and p95 are the 5th, 25th, 50th, 75th, and 95th percentiles, respectively. The minimum (min), maximum (max), and arithmetic average (mean) are also provided.

7.2.3 Statistical model to estimate 5-minute maximum SO_2 concentrations

As described earlier, staff noted there were a limited number of ambient monitors that reported 5-minute maximum SO_2 concentrations. The majority of the SO_2 monitoring network reports 1-hour average SO_2 concentrations. Staff developed a statistical model to extend the 5-minute SO_2 air quality characterization to locations where 5-minute concentrations were not reported. This statistical model was briefly introduced in section 6.4; this section details the development of the statistical model designed to estimate 5-minute maximum SO_2 concentrations from 1-hour SO_2 concentrations, using the combined 5-minute maximum and 1-hour SO_2 measurement data set (see section 7.2.1).

Fundamental to the statistical model are the peak-to-mean ratios or PMRs. Peak-to-mean ratios are derived by dividing the 5-minute maximum SO_2 concentration by the 1-hour average SO_2 concentration. These derived PMRs can be useful in estimating 5-minute maximum SO_2 concentrations when only the 1-hour SO_2 concentration is known. The values of PMRs derived from the monitoring data can be variable and are likely dependent on local source emissions, site meteorology, and other influential factors. Each of these factors will have variable influence on the measured 1-hour and 5-minute SO_2 concentrations at the ambient monitors. Therefore, to develop a useful tool for extrapolating from the measurement data, at a minimum, the approach needed to account for variability in ambient concentrations. It is within this context that the statistical model was developed.

Staff selected the variability in SO_2 concentrations at each individual ambient monitor as a surrogate for source emissions, source types, and/or distance to sources to allow for a purposeful application of the statistical model to the broader 1-hour SO_2 measurement data. Many of the meta-data described earlier in section 7.2.2, while useful for qualitatively describing characteristics of monitors in the SO_2 monitoring network, were not considered robust in quantifying how sources might influence monitored concentrations. The utility of the meta-data is also diminished when the monitor attributes were reported as unknown, missing entries, or possibly mischaracterized. In addition, while individual source types, emissions, and distances to the monitors are presented as quantitative measures, the use of this data can be problematic. This is because 1) source characteristics can change over time, 2) it is largely unknown what source(s) influence many of the ambient monitors and by how much, 3) there is uncertainty in source emission estimates, and 4) even similar source types will not have the same emission characteristics. Staff considered several ways to link the statistical model developed from monitors reporting 5-minute maximum concentrations to the broader SO_2 ambient monitoring network, including the use of the ambient monitoring site characteristics. Staff decided that the measured concentrations had the most to offer in efficiently designing such a linkage given the strong relationships between averaging times, concentration variability, and the frequency of peak concentrations. Where possible, staff compared the relevant monitor attributes described in section 7.2.2 with selected variability metrics used in developing and applying the statistical model.

The purpose of the first analysis that follows is to determine an appropriate variable to reasonably connect the statistical model derived from 5-minute and 1-hour concentrations to any 1-hour SO_2 concentration data set where there are no 5-minute SO_2 measurements. Staff first evaluated variability metrics associated with 5-minute and 1-hour SO_2 ambient monitoring concentrations as a basis for linking the statistical model to 1-hour concentrations. Next, staff generated distributions of PMRs for use in estimating 5-minute concentrations. Then the statistical model was applied to where 5-minute measurements were reported and evaluated using cross-validation.

7.2.3.1 Relationship Between 5-minute and 1-hour SO_2 Concentrations

Because the statistical model employs 5-minute and 1-hour SO_2 concentrations, staff evaluated the relationship between the concentrations for the two averaging times. The monitors reporting all twelve 5-minute concentrations within the hour were used for this analysis (n=16). First, all of the continuous-5 minute data available for each monitor were averaged to generate a single 5-minute mean concentration (both in an arithmetic and geometric mean form) and their respective standard deviations, yielding a total of 16 monitor-specific 5-minute SO_2 values.[31] Staff performed a second calculation to generate similar statistics using the continuous 5-minute data, though a 1-hour averaging time was of interest. To obtain the 1-hour statistics, the 5-minute SO_2 concentrations within an hour were averaged to generate 1-hour mean SO_2 concentrations for each monitor, which were then averaged to generate a single 1-hour mean SO_2

[31] Each of the 16 continuous-5 monitors was characterized by four statistics, arithmetic and geometric means and their respective standard deviations.

concentration (both in an arithmetic and geometric mean form) and their corresponding standard deviations, yielding a total of 16 monitor-specific 1-hour SO_2 values.

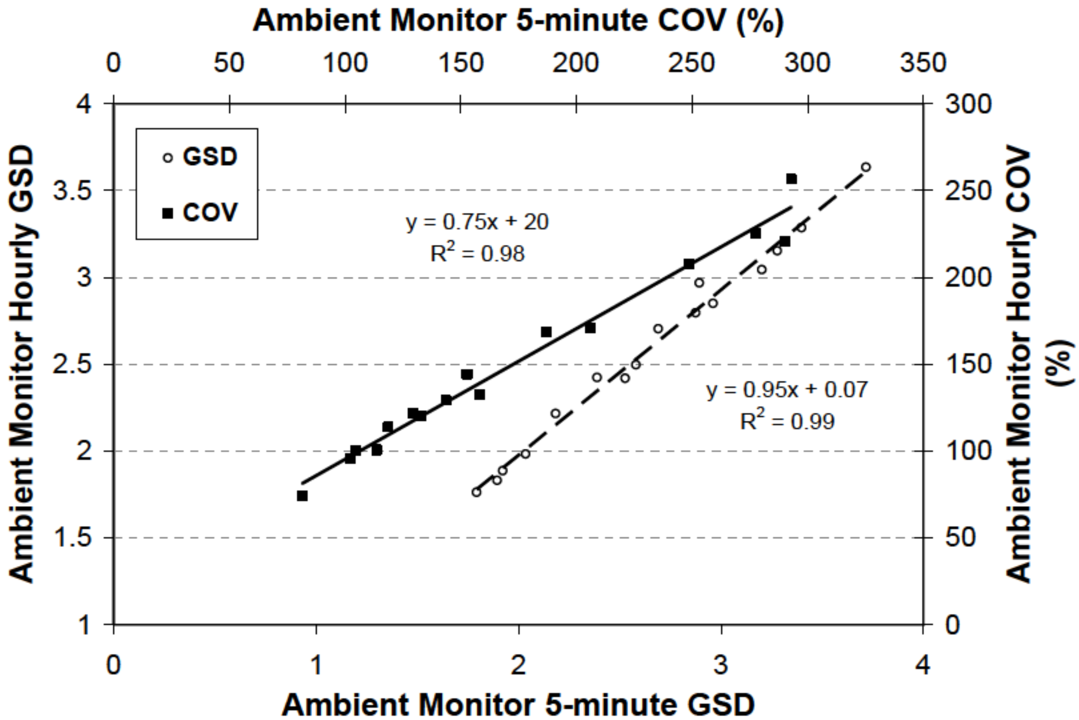

Figure 7-7. Comparison of hourly and 5-minute concentration COVs and GSDs at sixteen monitors reporting all twelve 5-minute SO_2 concentrations over multiple years of monitoring.

Staff selected the coefficient of variation (COV)[32] and geometric standard deviation (GSD) as metrics to compare concentration variability in both 1-hour and 5-minute averaging times, each of which are illustrated in Figure 7-7. As expected, a strong direct linear relationship exists between the variability in 5-minute and 1-hour SO_2 concentrations at each monitor. Even with the limited geographic representation (these monitors are from only six U.S. States and Washington DC), there is a wide range in the observed concentration variability for both the 5-minute and associated hourly measurements (i.e., COVs range from about 75 – 300%, GSDs range from about 1.7 – 3.7). In general, this analysis demonstrates that variability in 5-minute

[32] The COV used here is calculated by dividing the standard deviation by the arithmetic mean, then multiplying by 100. The statistic gives a relative measure of variation, to better facilitate the comparison of data having different mean concentrations or units of measure.

SO_2 concentrations is directly related to the variability in 1-hour SO_2 concentrations, and these measures of variability may be used to describe the potential variability in concentrations measured at any ambient SO_2 monitor, similarly for either the 1-hour or 5-minute measured concentrations. Note that there is a difference in the slope of the two lines, indicating that there is not a constant relationship between the COV and GSD. This means that in characterizing the variability at any ambient monitor, an identified COV (e.g., either low or high COV) does not necessarily correspond to the same GSD characterization.

Next, staff compared the variability in 1-hour SO_2 concentrations using data from the monitors reporting 5-minute maximum SO_2 concentrations (n=98) to variability observed for the broader SO_2 monitoring network (n=809). The objective of this evaluation was to determine if the distribution of the observed hourly concentration variability was similar for the two sets of data. As done above for the monitors reporting 5-minute maximum SO_2 concentrations, four statistics were generated for each ambient monitor within the broader SO_2 monitoring network using the 1-hour concentrations, with the variability at each monitor represented by its COV and GSD. Figure 7-8 illustrates the cumulative density functions (CDFs) for the hourly COVs and GSDs at each of the 98 monitors that reported 5-minute maximum SO_2 concentrations (i.e., the data set used for developing the statistical model) and the 809 monitors from the broader SO_2 monitoring network (i.e., the final 1-hour SO_2 data set having valid site-years). While the subset of monitors reporting the 5-minute maximum SO_2 concentrations exhibit greater variability in hourly concentration at most percentiles of the distribution, the overall shape and span of the distribution is very similar to that of the monitors within the broader SO_2 monitoring network using either variability metric. The similarity in variability distributions could indicate that the monitor proximity to sources, the magnitude and temporal profile of source emissions, and the types of sources affecting concentrations at either set of data (i.e., the monitors reporting 5-minute SO_2 concentrations versus the broader SO_2 monitoring network) are similar. This, combined with the meta-data evaluation and the source type, distance, and emissions analysis that indicated similar source type emission proportions between the two sets of ambient monitoring data (7.2.2), provides support for using concentration variability as a variable to extrapolate information from the 5-minute SO_2 monitors to the 1-hour SO_2 monitors.

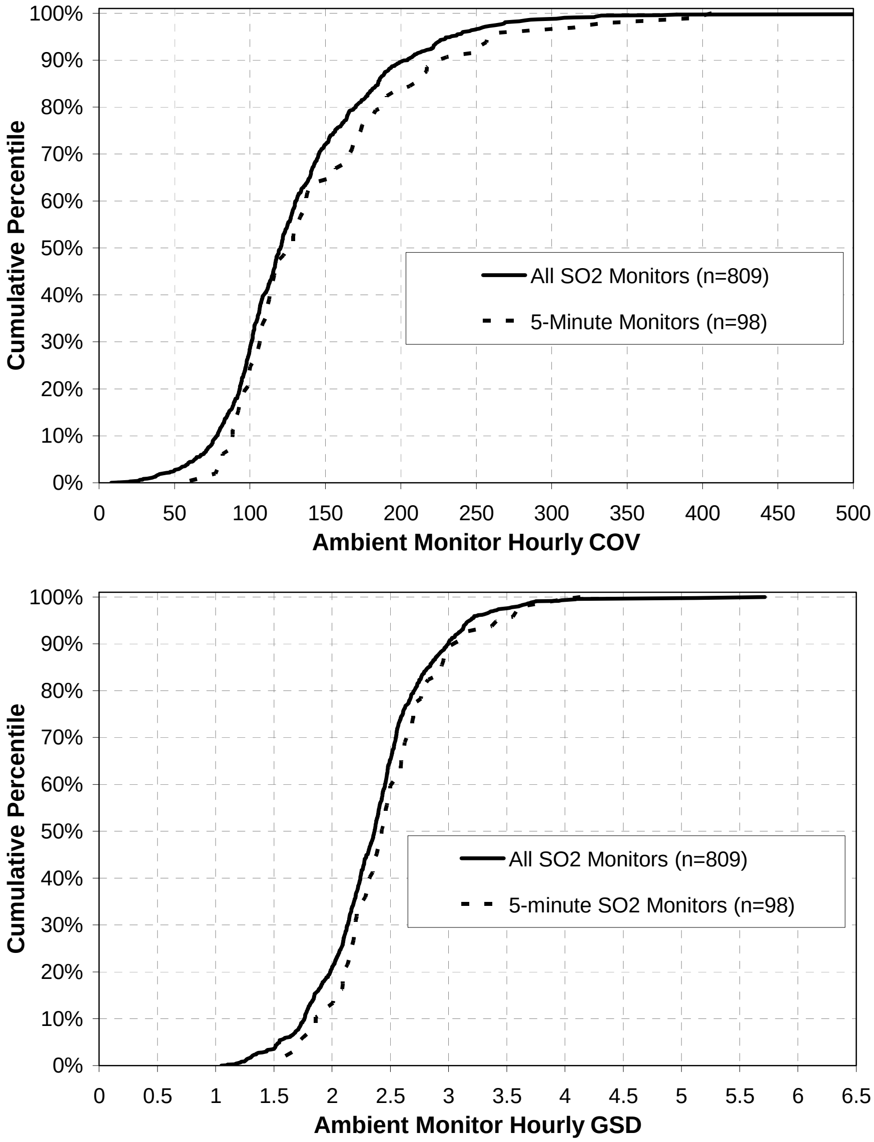

Figure 7-8. Cumulative density functions (CDFs) of hourly COVs (top) and GSDs (bottom) at ambient monitors: monitors reporting 5-minute maximum SO_2 concentrations and the broader SO_2 monitoring network.

7.2.3.2 Development of Peak-to-Mean Ratio (PMR) Distributions

A key variable in the statistical model to estimate the 5-minute maximum SO_2 concentrations where only 1-hour average SO_2 concentrations were measured is the peak-to-mean ratio (PMR). Peak-to-mean ratios are obtained by dividing the 5-minute maximum SO_2 concentration occurring within an hour by the 1-hour SO_2 concentration. The use of a PMR or distributions of PMRs in estimating 5-minute maximum SO_2 concentrations is not new to the current NAAQS review. Both individual PMRs and distributions of PMRs were used in the previous NAAQS review in characterizing 5-minute SO_2 air quality (Thrall et al, 1982; EPA, 1986a; 1994b; Thompson 2000) and in estimating human exposures to 5-minute SO_2 concentrations (Burton et al. 1987; EPA, 1986a, 1994b; Stoeckenius et al. 1990; Rosenbaum et al., 1992; Science International, 1995). In this review, staff generated distributions of PMRs to estimate 5-minute maximum SO_2 concentrations at ambient monitors (this chapter) and at air quality modeled census block centroid receptors (chapter 8). The distributions of PMRs used here build upon recent PMR analyses conducted by Thompson (2000).[33] In the current PMR analysis, staff developed several distributions of PMRs using more recent 5-minute SO_2 monitoring data (through 2007) and used concentration level and variability as categorical variables in defining the distributions of PMRs.

Concentration variability has been identified as a potential attribute in characterizing sources affecting concentrations measured at the ambient monitors (section 7.2.3.1). Instead of designing a continuous function from the variability distribution, staff chose to use categorical variables to describe the monitors comprising each data set. The approach involved the creation of variability bins, such that PMR data from several monitors would comprise each bin. Staff decided this approach would better balance the potential number of PMRs available in generating the distributions of PMR given the variable number of samples collected and years of monitoring at monitors that reported the 5-minute maximum SO_2 concentrations (Appendix A-2). Using the hourly COV or GSD distributions in illustrated Figure 7-8, staff assigned one of three COV or GSD bins to each of the 98 monitors reporting the 5-minute maximum SO_2 concentrations: for COV, the bins were defined as low (COV ≤ 100%), mid (100% < COV ≤ 200%), and high (COV > 200%). These three COV bins were selected to capture the upper and lower tails of the variability distribution and a mid-range area.[34] Similarly and based on the same percentile ranges selected for binning the COV, three GSD bins were selected as follows: low (GSD ≤ 2.17), mid (2.17 < GSD ≤ 2.94), and high (GSD > 2.94).

In addition, the level of the 1-hour mean SO_2 concentration has been identified as an important consideration in defining an appropriate PMR distribution to use in estimating 5-minute maximum SO_2 concentrations (EPA, 1986a). Therefore, staff further stratified the PMRs

[33] In the Thompson (2000) analysis, a single distribution of PMRs was employed based on 6 ratio bins and assumed independence between the ratio and the 1-hour SO_2 concentration.
[34] For monitors reporting the 5-minute maximum SO_2 concentrations, these groupings corresponded to approximately the 25th and the 84th percentile of the variability distribution.

by seven 1-hour mean concentration ranges: 1-hour mean < 5 ppb, 5 ≤ 1-hour mean < 10 ppb, 10 ≤ 1-hour mean < 25 ppb, 25 ≤ 1-hour mean < 75 ppb, 75 ≤ 1-hour mean < 150 ppb, 150 ≤ 1-hour mean < 250 ppb, and 1-hour mean > 250 ppb.[35] Staff selected these 1-hour concentration stratifications to maximize any observed differences in the PMR distributions within a given variability and concentration bin and to limit the total possible number of PMR distributions for computational manageability.

Based on the concentration variability and 1-hour concentration bins, staff generated a total of 19 separate PMR distributions.[36] Due to the large number of PMRs available for several of the variability and concentration bins (the number of samples ranged from 100 to 800,000), all of the empirical data were summarized into distributions using the cumulative percentiles ranging from 0 to 100, by increments of 1. Figure 7-9 illustrates two patterns in the PMR distributions when comparing the different stratification bins. First, the monitors with the highest COVs or GSDs contain the highest PMRs at each of the percentiles of the distribution (bottom graph of each variability bin in Figure 7-9) when compared with monitors from the other two variability bins (top and middle graphs), while the mid-range variability bins (middle graph) had a greater proportion of high PMRs than the low variability bin (top graph). These distinctions in the PMR distributions are consistent with the results illustrated in Figure 7-7, that is, the variability in the hourly average concentrations is directly related to the variability in the 5-minute concentrations as summarized across monitors.

Second, differences were observed in the PMR distributions within each variability bin when stratified by 1-hour SO_2 concentration. This is most evident in the highest variability bin (bottom graph of Figure 7-9); the highest 1-hour concentration category (> 250 ppb) had lower PMRs at each of the distribution percentiles compared with the PMR distributions derived for the lower concentration categories, most prevalent at the upper percentiles of the distribution. In fact, the maximum PMRs for the > 250 ppb concentration bin were only 5.4 and 3.6 for the COV and GSD high variability bin, respectively, compared with maximum PMRs of about 11.5 at

[35] While PMR distributions were generated for 1-hour SO_2 concentrations < 5 ppb, it should be noted that any estimated 5-minute maximum SO_2 concentration would be below that of the lowest potential health effect benchmark level of 100 ppb.

[36] Although there were a total of 21 PMR distributions possible (i.e., 3 × 7), the COV < 100% and GSD <2.17 categories had only three 1-hour concentrations above 150 ppb. Therefore, the two highest concentration bins do not have a distribution, and concentrations > 75 ppb constituted the highest concentration bin in the low COV or low GSD bins. All PMR distributions are provided in Appendix A-3.

many of the other concentration bins. Again, this inverse relationship between the PMR and concentration level has been shown by other researchers (EPA, 1986a). The stratification of PMRs by the 1-hour concentration was done to avoid applying high PMRs calculated from low hourly concentrations to high hourly concentrations. The observed patterns in the PMR distributions support the staff selection of variability bins and 1-hour concentration stratifications in controlling for the aberrant assignment of PMRs to particular 1-hour concentrations.

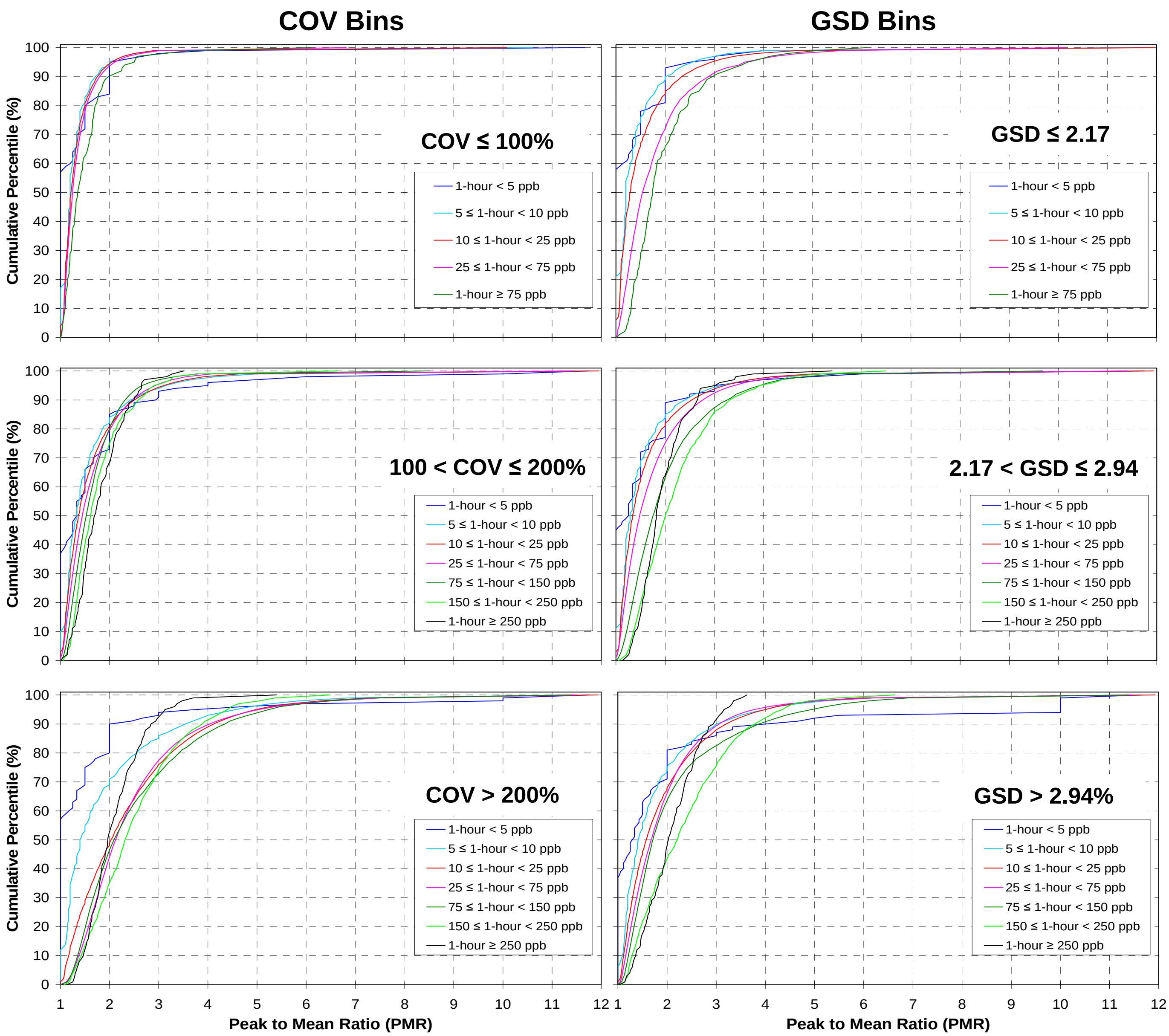

Figure 7-9. Peak-to-mean ratio (PMR) distributions for three COV and GSD variability bins and seven 1-hour SO_2 concentration stratifications.

Staff then evaluated the assigned concentration variability bin using two ambient monitoring site characteristics described in section 7.2.2 and using the observed number of benchmark exceedances at each monitor. The purpose of this analysis was to determine to what extent the selected variability bins were representing variability local source characteristics and the likelihood of benchmark exceedances. First, staff compared the total emissions within 20 km of each monitor with the assigned concentration variability bin using the monitors reporting 5-minute maximum SO_2 concentrations and the broader SO_2 monitoring network (Figure 7-10). The purpose of this comparison was to determine whether increased emissions were associated with greater variability in monitoring concentrations. In general, a pattern of increased emissions was associated with an increase in the concentration variability bin, though the pattern was more prominent when considering the COV bins. This indicates the variability bins may be useful as a surrogate for local source emission characteristics.

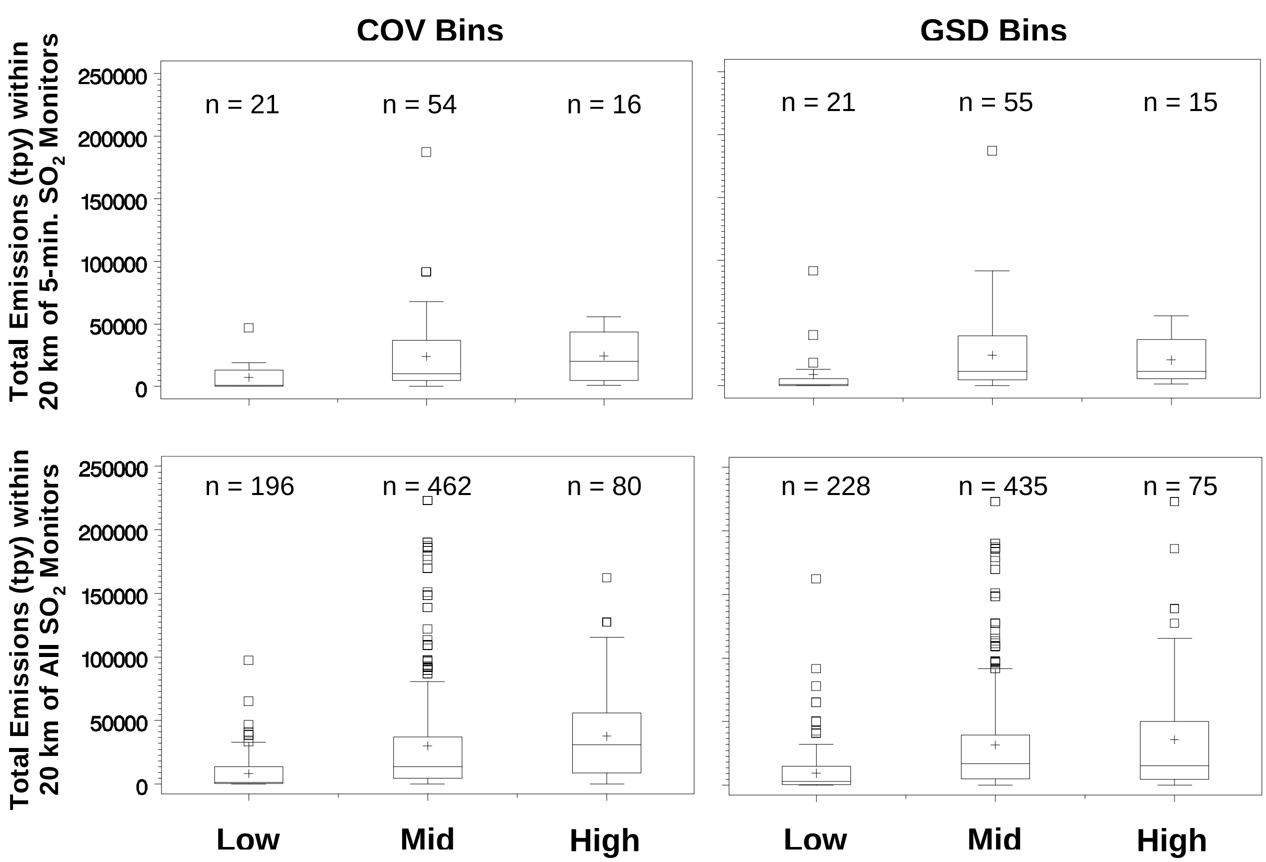

Figure 7-10. Distribution of total SO_2 emissions (tpy) within 20 km of monitors by COV (left) and GSD (right) concentration variability bins: monitors reporting 5-minute maximum SO_2 concentrations (top) and the broader SO_2 monitoring network (bottom).

The second ambient monitoring site characteristic evaluated using the selected concentration variability bins was the monitoring objective, principally when it was noted as source-oriented. The purpose of this analysis was to determine whether high variability in SO_2 concentration was related to source-oriented monitor siting. Staff calculated the percent of source-oriented monitors in each variability bin for the two sets of data; the set comprised of monitors that reported 5-minute maximum SO_2 concentrations and those within the broader SO_2 monitoring network. In general, there is an increasing percent of source-oriented monitors in the higher concentration variability bins when using either the COV or GSD metrics (Figure 7-11), though the pattern is more consistent with the COV metric than with the GSD metric. This comparison also indicates that the concentration variability metric may be useful as a surrogate for local source emission characteristics.

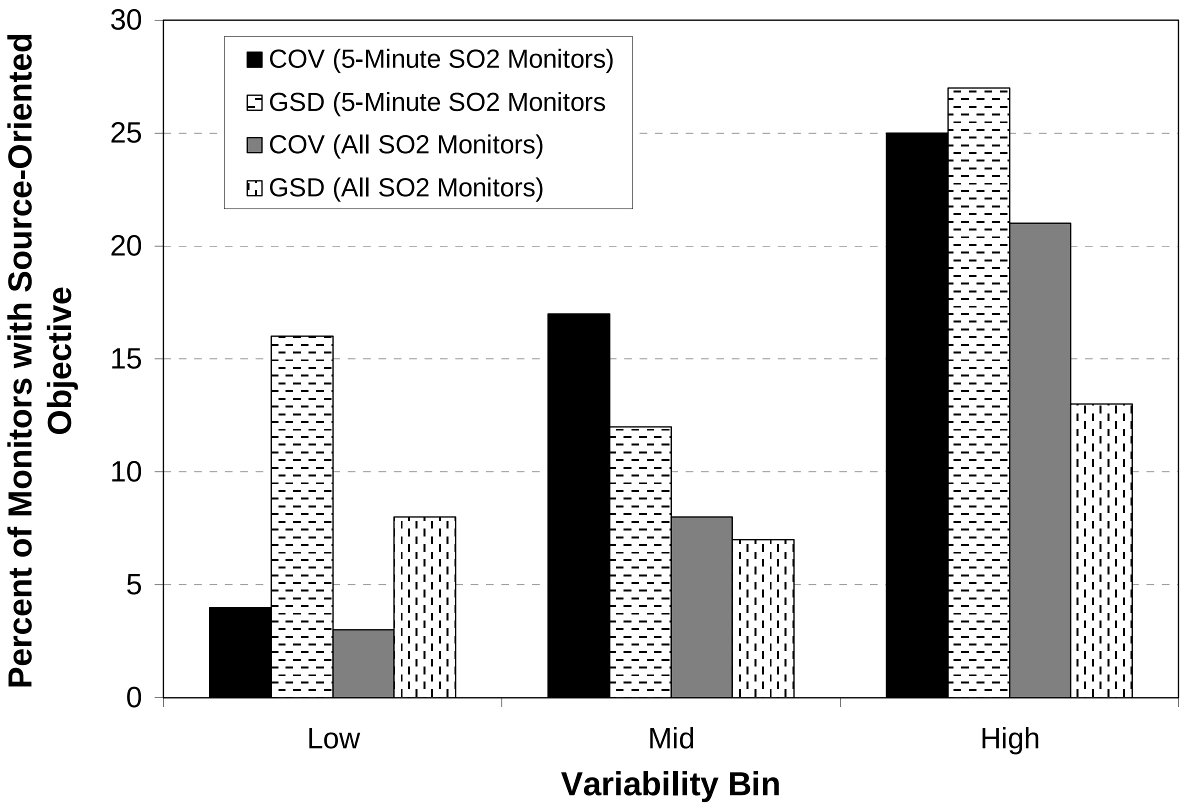

Figure 7-11. Percent of monitors within each concentration variability bin where the monitoring objective was source-oriented: monitors reporting 5-minute maximum SO_2 concentrations (solid) and the broader SO_2 monitoring network (slotted).

Staff evaluated the number of measured benchmark exceedances in a site-year given the variability bins used to characterize the ambient monitors. The purpose of this analysis was to determine whether monitors exhibiting greater variability in SO_2 concentration also have a greater number of benchmark exceedances. Figure 7-12 summarizes the distribution of exceedances of the 200 and 400 ppb benchmark level by each of the COV and GSD variability bins (patterns for the 100 ppb and 300 ppb benchmarks were similar). Clearly, monitors having the greatest variability in 1-hour SO_2 concentration are the monitors most likely to have 5-minute SO_2 benchmark exceedances and a greater number of exceedances per year. This analysis provides further support to the binning of monitors by concentration variability to appropriately extrapolate the relationships derived from monitors reporting 5-minute maximum concentrations to monitors reporting only 1-hour SO_2 concentrations (and at the dispersion model receptors).

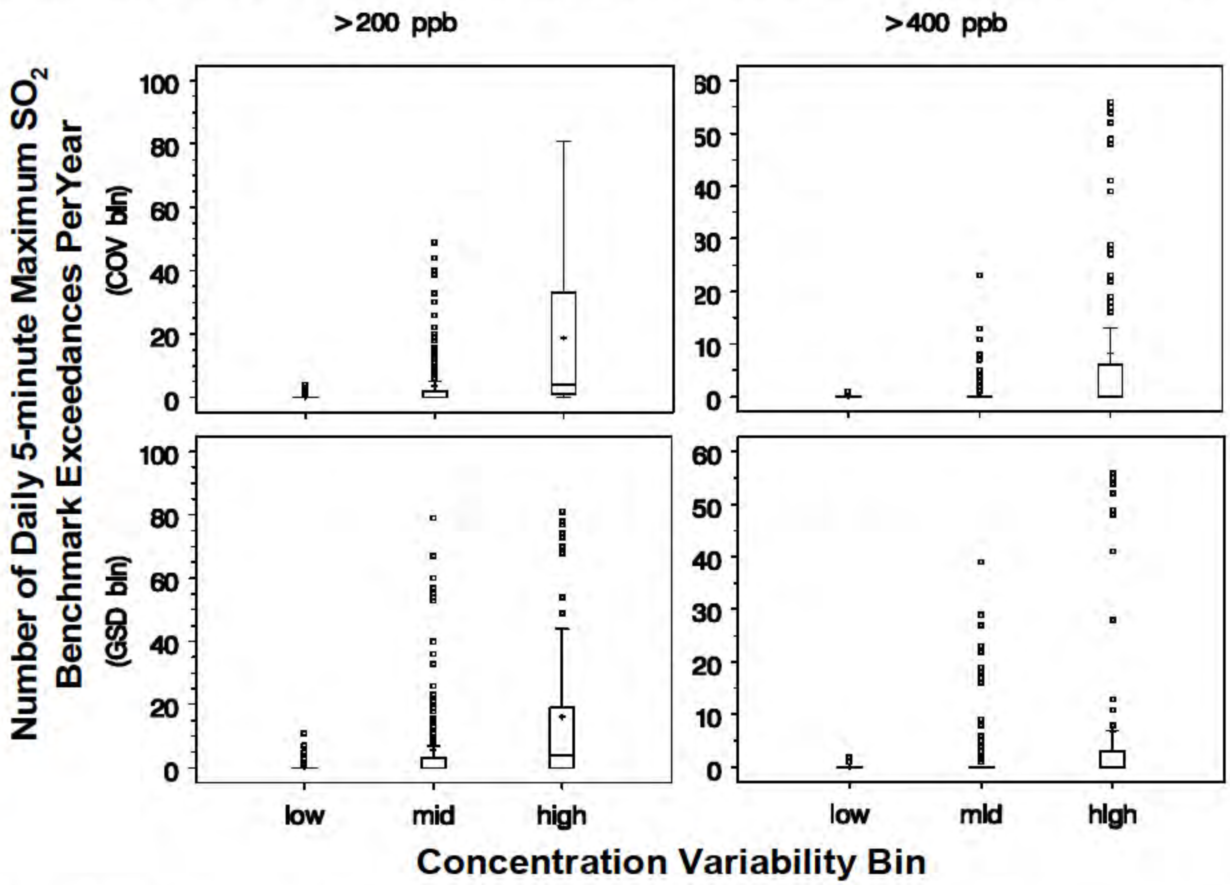

Figure 7-12. Distribution of the measured number of daily 5-minute maximum SO_2 concentrations above 200 ppb (left) and 400 ppb (right) in a year by hourly concentration COV (top) and GSD (bottom) variability bins. Data were from the 98 ambient monitors reporting 5-minute maximum concentrations (471 site-years).

7.2.3.3 Application of Peak to Mean Ratios (PMRs)

As described above in section 7.2.3.2 regarding the monitors reporting 5-minute maximum SO_2 concentrations, staff characterized the monitors within the broader SO_2 monitoring network (n=809) by their respective hourly concentration variability and assigned to one of the three COV bins (COV ≤ 100%, 100% < COV ≤ 200%, and COV > 200%) and GSD bins (GSD ≤ 2.17, 2.17 < GSD ≤ 2.94, and GSD > 2.94). Based on the monitor's assigned concentration variability bin (either from the COV or GSD, not mixed) and the 1-hour SO_2 concentration, PMRs can be randomly sampled[37] from the appropriate PMR distribution to estimate a 5-minute maximum SO_2 concentration using the following equation:

$$C_{\max-5} = PMR_{ij} \times C_{i,1-hour} \qquad \text{equation (7-1)}$$

where,

C_{max-5} = estimated 5-minute maximum SO_2 concentration (ppb) for each hour

PMR_{ij} = peak-to-mean ratio (PMR) randomly sampled from the *i* concentration variability and *j* 1-hour mean SO_2 concentration distribution

$C_{i,1-hour}$= measured 1-hour average SO_2 concentration at an *i* concentration variability monitor

As a result of this calculation, every 1-hour ambient SO_2 concentration has an estimated 5-minute maximum SO_2 concentration.[38] These statistically modeled 5-minute maximum SO_2 concentrations were then summarized using the output metrics described in section 7.2.5.

7.2.3.4 Evaluation of Statistical Model Performance

Staff evaluated the performance of the statistical model using cross-validation (Stone, 1974). Details of the evaluation are provided by Langstaff (2009). Briefly, PMR distributions were estimated using 97 of the 98 monitors that reported both the 1-hour and 5-minute maximum SO_2 concentrations. All ambient monitors were characterized using the same variability bins described in section 7.2.3.2. The 1-hour concentrations were also characterized using the same

[37] The random sampling was based selection of a value from a uniform distribution {0,100}, whereas that value was used to select the PMR from the corresponding distribution percentile value.

[38] When the 1-hour SO_2 concentration was > 0, otherwise the 5-minute maximum SO_2 concentration was estimated as zero).

stratifications discussed earlier. Then staff used the newly constructed PMR distributions from the 97 monitors and equation 7-1 to predict the 5-minute maximum SO_2 concentrations at the single monitor not included in developing the PMR distributions. This modeling was performed 98 times, i.e., removing every single monitor (one monitor at a time), generating new PMR distributions, and predicting 5-minute maximum SO_2 concentrations at the removed monitor. Staff then compared the predicted and measured daily 5-minute maximum SO_2 concentrations to generate a distribution of model prediction errors (e.g., median errors, median absolute errors) and general model statistics (i.e., the root mean square error or RMSEs, and R^2, a measure of the amount of variance explained by the model).

Four statistical models were evaluated: two models constructed from the variability bins (either COV or GSD) using all percentiles of the PMR distributions, and two similar models constructed without the minimum and maximum percentiles of the PMR distributions. The models were evaluated at the benchmark concentration levels as well as at selected percentiles in the 5-minute SO_2 concentration distribution. In comparing the model predictions, the model using variability bins defined by the COV and excluding the minimum and maximum percentiles had the lowest prediction errors (e.g., see Table 7-5).[39] Based on these results, staff used this COV model (excluding the 0^{th} and 100^{th} percentiles of the PMR distribution) to estimate 5-minute maximum SO_2 concentrations from 1-hour SO_2 concentrations.

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[39] Table 7-5 presents a few of the prediction error statistics used to compare each of the models, though several other prediction errors were evaluated (e.g., the 75^{th} and 99^{th}). Results for the other percentiles were consistent with median results discussed in the text, that is the alt. COV model had the lowest error when compared with the other models evaluated. See Langstaff (2009) for the additional percentile comparisons for each of the models.

Table 7-5. Comparison of prediction errors and model variance parameters for the four models evaluated.

Benchmark Level (ppb)	Model[1]	Median Prediction Error[2]	RMSE	R^2
100	COV	2.6	18.9	0.72
	alt. COV	0.4	14.1	0.81
	GSD	2.5	24.8	0.48
	alt. GSD	0.3	19.8	0.63
200	COV	1	10.7	0.66
	alt. COV	0.1	8.6	0.74
	GSD	1.3	12.8	0.49
	alt. GSD	0.4	10.2	0.64
300	COV	0.6	6.5	0.73
	alt. COV	0	5.6	0.78
	GSD	0.6	8.2	0.55
	alt. GSD	0.1	7.1	0.64
400	COV	0.3	4.5	0.76
	alt. COV	0	3.9	0.8
	GSD	0.3	6	0.55
	alt. GSD	0	5.5	0.61

Notes:
[1] The "alt." abbreviation denotes the alternative model was used: the minimum and maximum percentiles of the PMR distributions were not used.
[2] The absolute value of the prediction differences is calculated (predicted minus the observed number of exceedances in a year), generating a distribution of prediction errors. The value reported here is the (50^{th} percentile) of that distribution.

Staff performed supplementary evaluations using the prediction errors associated with the selected statistical model. Additional percentiles of the prediction error distribution were calculated to estimate the magnitude and direction of the statistical model bias. Table 7-6 summarizes the prediction errors for each benchmark level. When considering paired percentiles (e.g., the 25^{th} and the 75^{th} or prediction intervals) and the 50^{th} percentile as a pivot point there appears to be an over-estimation bias at each of the benchmark levels. For example, there is a greater overestimation of the 400 ppb benchmark level at the 95^{th} percentile (i.e., 5 exceedances), than compared with the under estimation at the 5^{th} percentile (i.e., one exceedance). However, there is good agreement in the predicted versus observed number of exceedances, whereas 90% of the predicted exceedances of 400 ppb were within -1 to 5 exceedances per year. There is a wider range in the prediction intervals at the lower benchmark levels, partly a function of the greater number of exceedances at the lower benchmark levels rather than the degree of agreement (Table 7-6). At the extreme ends of the distribution for each of the benchmarks, the agreement between the predicted and observed exceedances widens, indicating that for some site-years (approximately 2%), the number of days with a benchmark exceedance can be over- or under-estimated by 20 to 50 in a year.

Table 7-6. Prediction errors of the statistical model used in estimating 5-minute maximum SO_2 concentrations above benchmark levels.

Percentile	Prediction Error at Benchmark Level[1]			
	100	**200**	**300**	**400**
1	-31	-17	-18	-19
5	-15	-7	-3	-1
25	-1	0	0	0
50	0	0	0	0
75	7	1	1	0
95	32	20	10	5
99	48	43	26	14
	Mean Number of Benchmark Exceedances[2]			
Benchmark	**100**	**200**	**300**	**400**
Observed	148	81	69	56
Predicted	150	100	67	45

Notes:
[1] The percentiles are based on the distribution of predicted minus the observed values for each benchmark. Units are the number of exceedances per year.
[2] This is the average of all site-years. Units are the number of exceedances per year.

7.2.4 Adjustment of Ambient Concentrations to Evaluate the Current and Potential Alternative Air Quality Scenarios

Staff evaluated multiple hypothetical air quality scenarios in this assessment, each defined by the form and level of a selected standard. Collectively, the purpose of these air quality scenarios was to estimate the relative level of public health protection associated with just meeting the current and potential alternative standards. The measured ambient SO_2 concentrations needed adjustment to reflect concentrations that might be observed given the hypothetical air quality scenarios. To maintain a computationally manageable data set given the number of air quality scenarios (i.e., eight) and potential health effect benchmark levels investigated (i.e., four), staff used the recent ambient monitoring data from 40 counties, specifically years 2001 through 2006.[40] The following two sections discuss the concentration adjustment approach and the selection criteria used for selecting counties for analysis.

7.2.4.1 Approach

There are two important considerations in developing an approach to adjust air quality concentrations. One is the relative contribution of policy-relevant background (PRB) to ambient concentrations and the other is in understanding how the distribution of ambient concentrations measured at a particular monitor has changed over time.

In developing a simulation approach to adjust air quality to meet a particular standard level, PRB levels in the U.S. were first considered. As described in section 2.3, PRB is well below concentrations that might cause potential health effects and constitutes a small percent (<1%) of the total ambient SO_2 concentrations at most locations. Based on the small contribution, PRB will not be considered separately in any characterization of health risk associated with *as is* air quality or air quality just meeting the current or potential alternative standards. In monitoring locations where PRB is expected to be of particular importance however (e.g., Hawaii County, HI), data were noted by staff as influenced by significant natural sources rather than anthropogenic sources and were not used in any of the air quality analyses.

While annual average concentrations have declined significantly over time, the variability in the SO_2 concentrations (both the 5-minute and 1-hour concentrations) has remained relatively constant. This trend is present when considering ambient concentration data collectively (section 7.4.2.3) and when considering monitors individually (Rizzo, 2009). For example, Figure 7-13 compares the distribution of daily maximum SO_2 1-hour concentration percentiles at the two ambient monitors in Beaver County, Pa. that were in operation as far back as 1978 and are currently part of the broader SO_2 monitoring network. Staff selected a recent year of data (2007) to constitute a low concentration year along with an historical year of data (1992) constituting a high concentration year, with each year of ambient monitoring common to both monitors. As shown in Figure 7-13, the relationships between the low and high concentration years at each of the daily maximum concentration percentiles are mostly linear, with regression coefficients of determination (R^2 values) greater than 0.98. Where deviation

[40] As described in the section 7.2.1, at the time the 1-hour concentrations were downloaded, none of the monitors had a complete year of data for 2007. All data from 2007 were excluded from the 1-hour monitor simulations.

from linearity did occur (as was observed in many of the other low-to-high concentration comparisons performed), it occurred primarily at the extreme upper or lower portions of the distribution, often times at the maximum daily maximum or the minimum daily maximum 1-hour SO_2 concentration (Rizzo, 2009). In addition, the absolute values for the simple linear regression intercepts were typically 1-3 ppb (Rizzo, 2009). This indicates that the rate of decrease in ambient air quality concentrations at the mean value for the monitors evaluated is consistent with the rate of change at the lower and upper daily maximum 1-hour concentration percentiles. This evaluation provides support for the use of a proportional approach to adjust current ambient concentrations to represent air quality under both the current and alternative standard scenarios.

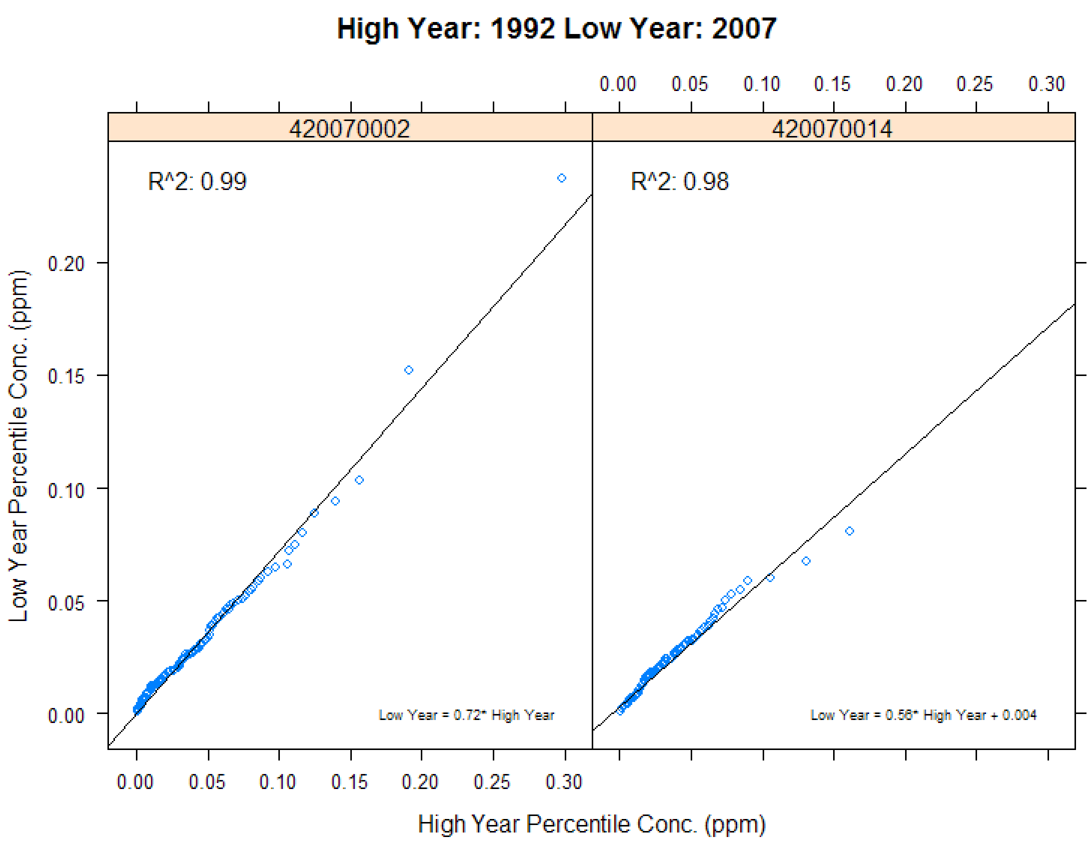

Figure 7-13. Comparison of measured daily maximum SO_2 concentration percentiles in Beaver County, PA for a high concentration year (1992) versus a low concentration year (2007) at two ambient monitors (from Rizzo, 2009).

The current deterministic form of each standard was used to approximate concentration adjustment factors to simulate just meeting the current 24-hour and annual SO_2 NAAQS. The

24-hour standard of 140 ppb is not to be exceeded more than once per year, therefore, the 2nd highest 24-hour average observed at each monitor was used as the target for adjustment. The rounding convention, which is part of the form of the standard, defines values up to 144 ppb as just meeting the 24-hour standard. The form of the current annual standard requires that a level of 30 ppb is not to be exceeded; therefore, with a rounding convention to the fourth decimal, annual average concentrations of up to 30.4 ppb would just meet the current annual standard.

Staff limited the analysis of alternative air quality scenarios to particular locations using designated geographic boundaries (not just the monitors individually). Counties were used to define the locations of interest in the alternative air quality standard scenarios. Use of a county is consistent with current policies on the designation of appropriate boundaries of non-attainment areas (Meyers, 1983).

For each location (i) and year (j), 24-hour and annual SO_2 concentration adjustment factors (F) were derived by the following equation:

$$F_{ij} = S / C_{\max,ij} \qquad \text{equation (7-2)}$$

where,

F_{ij} = Adjustment factor derived from either the 24-hour or the annual average concentrations at monitors in location i for year j (unitless)

S = concentration values allowed that would just meet the current NAAQS (either 144 ppb for 24-hour or 30.4 ppb for annual average)

$C_{max,ij}$ = the maximum 2nd highest 24-hour average SO_2 concentration at a monitor in location i and year j or the maximum annual average SO_2 concentration at a monitor in location i and year j (ppb)

In adjusting concentrations to just meet the current standard, the highest monitor (in terms of concentration) within a county was adjusted so that it just meets either a 30.4 ppb annual average or a 144 ppb 24-hour average (2nd highest), whichever was the controlling standard.[41] For monitors in each county and calendar year, all hourly SO_2 concentrations were

[41] The controlling standard by definition would be the standard that allows air quality to just meet either the annual concentration level of 30.4 ppb (i.e., the annual standard is the controlling standard) or the 2nd highest 24-hour concentration level of 144 ppb (i.e., the 24-hour standard is the controlling standard). The factor selected is derived

multiplied by the same constant value F, though only one monitor would have an annual mean equal to 30.4 ppb or the 2nd highest 24-hour average equal to 144 ppb for that county and year.

For example, of five monitors measuring hourly SO_2 in Cuyahoga County for year 2001 (Figure 7-14, top), the maximum annual average concentration was 7.5 ppb (ID 390350060), giving an adjustment factor of $F = 30.4/7.5 = 4.06$ for that year. The 2nd highest 24-hour SO_2 concentration at a monitor in a year was 35.5 (ID 390350038), giving an adjustment factor of F = 144/35.5 = 4.05 for year 2001. Because the adjustment factor derived from the 24-hour average concentration was lower, the 24-hour average concentration was the controlling standard. All 1-hour concentrations measured at all five monitoring sites in Cuyahoga County were multiplied by 4.05, resulting in an upward scaling of hourly SO_2 concentrations to simulate air quality just meeting the current standard for that year. Therefore, one monitoring site in Cuyahoga County for year 2001 would have a 2nd highest 24-hour average concentration of 144 ppb, while all other monitoring sites would have a 2nd highest 24-hour average concentration below that value, although still proportionally scaled up by 4.05 (Figure 7-14, bottom).

Proportional adjustment factors were also derived considering the form, averaging time, and levels of the potential alternative standards under consideration. Discussion regarding the staff selection of each of these components of the potential alternative standards is provided in Chapter 5 of this document. The 98th and 99th percentile 1-hour daily maximum SO_2 concentrations averaged across three years of monitoring were used in calculating the adjustment factors at each of five standard levels as follows:

$$F_{ikl} = S_l / \left(\frac{\sum_{j=1}^{3} C_{ijk}}{3} \right)_{\max,i} \qquad \text{equation (7-3)}$$

where,

F_{ikl} = SO_2 concentration adjustment factor in location i given alternative standard percentile form k and standard level l across a 3-year period (unitless)

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from a single monitor within each county (even if there is more than one monitor in the county) for a given year. A different (or the same) monitor in each county could be used to derive the factor for other years; the only requirement for selection is that it be the lowest factor, whether derived from the annual or 24-hour standard level.

S_l = Standard level l (i.e., 50, 100, 150, 200, and 250 ppb 1-hour SO_2 concentration) (ppb)

C_{ijk} = Selected percentile k (i.e., 98th or 99th) 1-hour daily maximum SO_2 concentration at a monitor in location i for each year j (ppb)

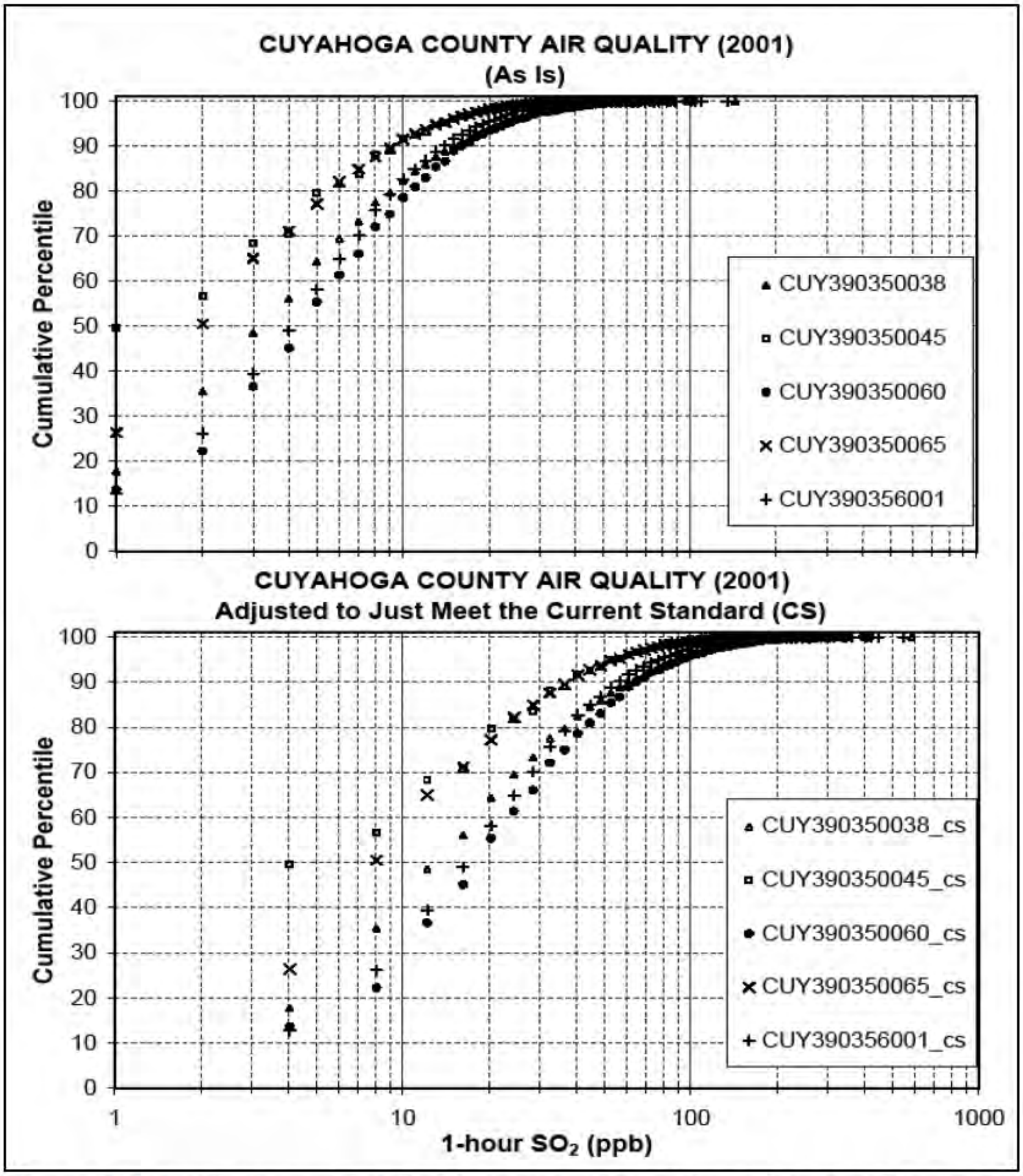

Figure 7-14. Distributions of hourly SO_2 concentrations at five ambient monitors in Cuyahoga County, *as is* (top) and air quality adjusted to just meet the current 24-hour SO_2 standard (bottom), Year 2001.

As described above for adjustments made in simulating just meeting the current standards, the highest monitor (in terms of the 3-year average at the 98th or 99th percentile) was adjusted so that it just meets the level of the particular 1-hour alternative standard. All other monitor concentrations in that location were adjusted using the same factor, only resulting in concentrations at those monitors below the level of the selected 1-hour alternative standard. Since the alternative standard levels range from 50 ppb through 250 ppb, both proportional upward and downward adjustments were made to the 1-hour ambient SO_2 concentrations. Due to the form of the alternative standards, the expected utility of such an analysis, and the limited time available to conduct the analysis, only the more recent air quality data were used (i.e., years 2001-2006). The 1-hour ambient SO_2 concentrations were adjusted in a similar manner described above for just meeting the current standard, however, due to the form of these standards, only one factor was derived for two 3-year periods (i.e., 2001-2003, 2004-2006), rather than one factor for each calendar year.

7.2.4.2 Selection of Locations

The first criterion used to select locations for the alternative air quality analyses was whether monitors had a high number of daily 5-minute maximum SO_2 concentrations at or above the potential health effect benchmark levels. Ambient monitors located in two counties in Missouri (Iron and Jefferson) had the most frequently measured daily 5-minute maximum SO_2 concentrations above the potential health effect benchmarks (see Appendix A-5). While there were limited data available from these ambient monitors (4 and 2 years out of 8 total site-years did not met the completeness criteria for each of Jefferson and Iron counties, respectively), it was decided by staff that lack of a complete year should not preclude their use in this focused analysis given the high number of measured daily 5-minute maximum SO_2 concentrations at these monitors. All other monitoring data used in this focused analysis were selected from where 1-hour ambient monitoring met the completeness criteria described in section 7.2.1.

Staff selected an additional 38 counties based on the relationship of the ambient SO_2 concentrations within the county to the current annual and 24-hour NAAQS to expand the number of counties investigated to a total of 40.[42] An additional criterion to be met for county selection included having at least two monitors operating in the county for at least five of the six

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[42] In the 1st draft SO_2 REA, a total of 20 counties were selected to evaluate the current standard scenario only.

possible years of monitoring.[43] First, the 24-hour and annual concentration adjustment factors were derived by equation 7-2 for each county and year. Then the mean 24-hour and mean annual factor for each county was calculated by averaging the site-years available at each monitor, with the selection of the lowest mean factor retained to characterize the county. Each county was then ranked in ascending order based on this selected mean factor. The 38 counties were selected from the top 38 values, that is, those counties having the lowest mean adjustment factors and having at least two monitors.

The complete list of the 40 counties selected and the mean factors used to select each location given the above selection criteria are provided in Table 7-7. In addition, Table 7-7 gives the number of monitors in each COV bin that were used to characterize the air quality in the 40 counties. The locations of ambient monitors comprising the 40 county dataset (i.e., the third data analysis group) are illustrated in Figure 7-15. Compared with the two other data analysis groups, the 40 county data set has a greater number of mid and high COV bin monitors and notably fewer low COV bin monitors (Figure 7-16). This is not unexpected given the concentration-based selection criteria used in identifying the 40 counties.

Following the selection of the 40 counties, staff retained the adjustment factors calculated for each monitoring site-year (not simply the mean factor that was used for the county selection) to simulate air quality just meeting the current standard (either the daily or annual factor, whichever was lower). These adjustment factors are given in Appendix A, Table A.4-1. Then using equation 7-3, staff calculated the adjustment factors needed for evaluating the potential alternative standards. Each of these alternative air quality scenarios were used as an input to the statistical model to estimate 5-minute maximum SO_2 concentrations (equation 7-1). Then, air quality characterization metrics of interest were estimated for each site and year as described in section 7.2.5.

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[43] In the 1st draft SO_2 REA, having at least three monitors for all six years of the monitoring period was required. These earlier criteria were relaxed in the 2nd draft and in this final REA to allow for additional locations that may have ambient concentrations close to the current annual and daily standard levels.

Table 7-7. Counties selected for evaluation of air quality adjusted to just meeting the current and potential alternative SO_2 standards and the number of monitors in each COV bin.

State	County[1]	Mean Factor	Closest Standard[2]	# of Monitors in COV bin[4]		
				Low	Mid	High
Arizona	Gila	3.44	A		1	1
Delaware	New Castle	2.80	D		5	
Florida	Hillsborough	3.81	D		4	2
Iowa	Linn	3.58	D		3	2
	Muscatine	3.46	D		1	2
Illinois	Madison	3.78	D		4	
	Wabash	3.39	D			2
Indiana	Floyd	4.38	D		2	1
	Gibson	2.60	D			2
	Lake	4.41	D		2	
	Vigo	4.80	D		2	
Michigan	Wayne	3.13	D		3	
Missouri	Greene	4.47	D	2	1	2
	Iron[3]	5.49	A			2
	Jefferson[3]	3.53	D			4
New Hampshire	Merrimack	2.98	D		3	1
New Jersey	Hudson	3.90	A	2		
	Union	3.81	A	2		
New York	Bronx	3.09	A	2		
	Chautauqua	4.19	D		1	1
	Erie	3.17	D		1	1
Ohio	Cuyahoga	4.51	A		5	
	Lake	2.99	D		2	
	Summit	3.13	D		2	
Oklahoma	Tulsa	4.61	A		3	
Pennsylvania	Allegheny	2.65	D	2	5	
	Beaver	2.39	D		3	
	Northampton	3.26	A	1	1	
	Warren	1.74	D		2	
	Washington	3.19	A	2	1	
Tennessee	Blount	1.86	D		2	
	Shelby	4.08	D	1	2	
	Sullivan	3.45	D		2	
Texas	Jefferson	4.38	D		3	
Virginia	Fairfax	4.80	A	3		
US Virgin Islands	St Croix	4.60	D		2	3
West Virginia	Brooke	2.32	A		2	
	Hancock	2.32	A		9	
	Monongalia	2.93	D		2	
	Wayne	3.07	D	1	3	

Notes:
[1] Listed counties were selected based on lowest mean concentration adjustment factor, derived from at least 2 monitors per year for years 2001-2006 and ≥5 years of data.
[2] Ambient concentrations were closest to either the annual (A) or daily (D) NAAQS level.
[3] County selected based on frequent 5-minute benchmark level exceedances.
[4] COV bins were low (COV≤100%); mid (100%<COV≤200%); high (COV>200%).

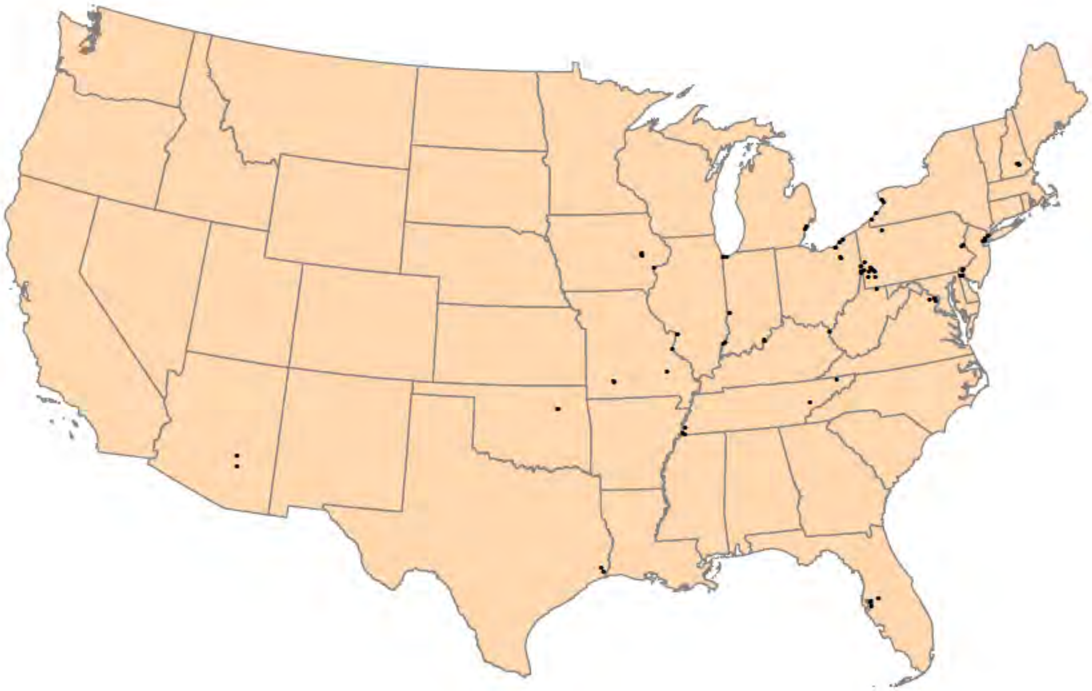

Figure 7-15. Locations of the 128 ambient monitors comprising the 40 County data set (i.e., the third data analysis group).

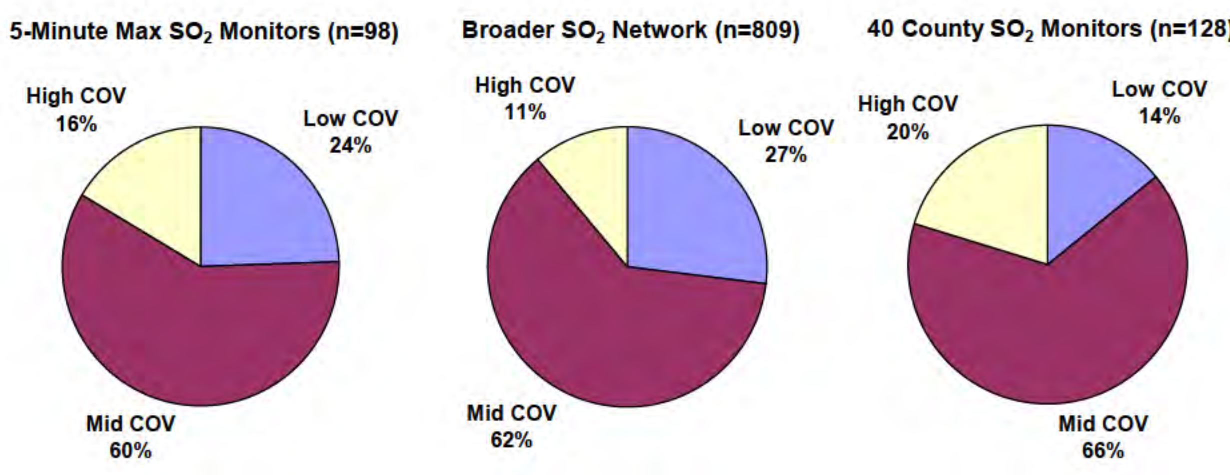

Figure 7-16. Percent of monitors in each COV bin for the three data analysis groups: monitors reporting 5-minute maximum SO_2 concentrations, the broader SO_2 monitoring network, and SO_2 monitors selected for detailed analysis in 40 counties.

7.2.5 Air Quality Concentration Metrics

For each of the data analysis groups and air quality scenarios considered, several concentration metrics were calculated; these included the annual average, 24-hour, and 1-hour daily maximum SO_2 concentrations for each site-year of data and the number of exceedances of the potential health effect benchmark levels. The numbers of daily maximum 5-minute concentration exceedances in a year were counted (i.e., either 1 or none per day) rather than total number of exceedances (i.e., which confounds numbers of exceedances and days with exceedances). To characterize the relationship between the number of days with a 5-minute benchmark exceedance and the ambient concentration levels, staff generated two additional outputs given the different concentration averaging times.

The first output was a comparison of the annual average SO_2 concentration and the number of daily 5-minute maximum SO_2 concentrations above the benchmark levels in a year. The output of this is the number of days per year a monitor had a measured or modeled exceedance, given an annual average SO_2 concentration. In general, these results are graphically depicted in this REA, though most of the individual results displayed in the figures are provided in Appendix A-5. When considering the 40 counties used for detailed analysis, the results are presented at the county-level, some of which had multiple ambient monitors. Therefore, the results for the monitors within counties were aggregated to generate mean values representing the central tendency of the county's annual average concentrations and the numbers of days in a year with benchmark exceedances.

The second output was the probability of potential health effect benchmark exceedances given concentrations of short-term averaging times. It was proposed in Chapter 5 that the 1-hour daily maximum SO_2 concentration would be of an appropriate averaging time in controlling the number of daily 5-minute maximum SO_2 concentrations. Staff evaluated such a relationship using the measured 5-minute and 1-hour ambient SO_2 concentrations to determine if this indeed was the case. A tally was made every time a daily 5-minute maximum SO_2 concentration occurred during the same hour of the day as the 1-hour daily maximum SO_2 concentration. The results of this analysis, separated by benchmark exceedance level, are given in Table 7-8. The co-occurrence of the daily 5-minute maximum and the 1-hour daily maximum SO_2

concentrations is greater than 70% at each of the benchmark levels indicating a strong relationship between the two concentration averaging times.

Table 7-8. The co-occurrence of daily 5-minute maximum and 1-hour daily maximum SO_2 concentrations using measured ambient monitoring data.

Concentration/Level	Co-occurring 5-minute and 1-hour daily maximums[1] (n)	Total Paired Samples[2] (n)	Percent Co-occurring (%)
All concentrations	106,115	130,296	81.4
> 100 ppb	6,192	8,817	70.2
> 200 ppb	2,030	2,793	72.7
> 300 ppb	1,067	1,476	72.3
> 400 ppb	700	961	72.8

Notes:
[1] the number of events the 5-minute maximum occurred in the same hour as the 1-hour daily maximum.
[2] total events with both a 5-minute maximum and 1-hour SO_2 concentration measurement.

Given the form of the current 24-hour standard, the form of the potential alternative standards (1-hour daily maximum), and the frequency of 5-minute SO_2 benchmark exceedances (i.e., either one or none per concentration), staff generated probability functions to estimate the likelihood of a 5-minute benchmark exceedance. These functions are useful in estimating the probability of a 5-minute benchmark exceedance given a range of SO_2 concentrations at alternative averaging times (i.e., either a 24-hour average or 1-hour daily maximum concentration). Two approaches were used to generate the probability functions: the first was empirically-based while the second employed a logistic regression model.

To generate the empirically-based probability functions, concentration data were first stratified into bins using concentration midpoints, with each bin separated by 10 ppb. For example a concentration of 53 ppb would be included in the 50 ppb bin, while a concentration of 55 ppb would fall within the 60 ppb bin. Then, the presence or absence of a daily 5-minute benchmark exceedance given the number of values in each concentration bin (that originate from all monitored concentrations within the bin range) was used to estimate the probability of an exceedance. For example, if there were 105 exceedances of the 200 ppb benchmark level out of

239 instances of a 1-hour daily maximum binned concentration of 110 ppb[44], the probability of a 200 ppb benchmark exceedance would be 105/239 = 0.44 or 44 % given a 1-hour daily maximum concentration of around 110 ppb. An example of an output from this empirically-based probability function is illustrated in Figure 7-17 for each of the four benchmark levels.

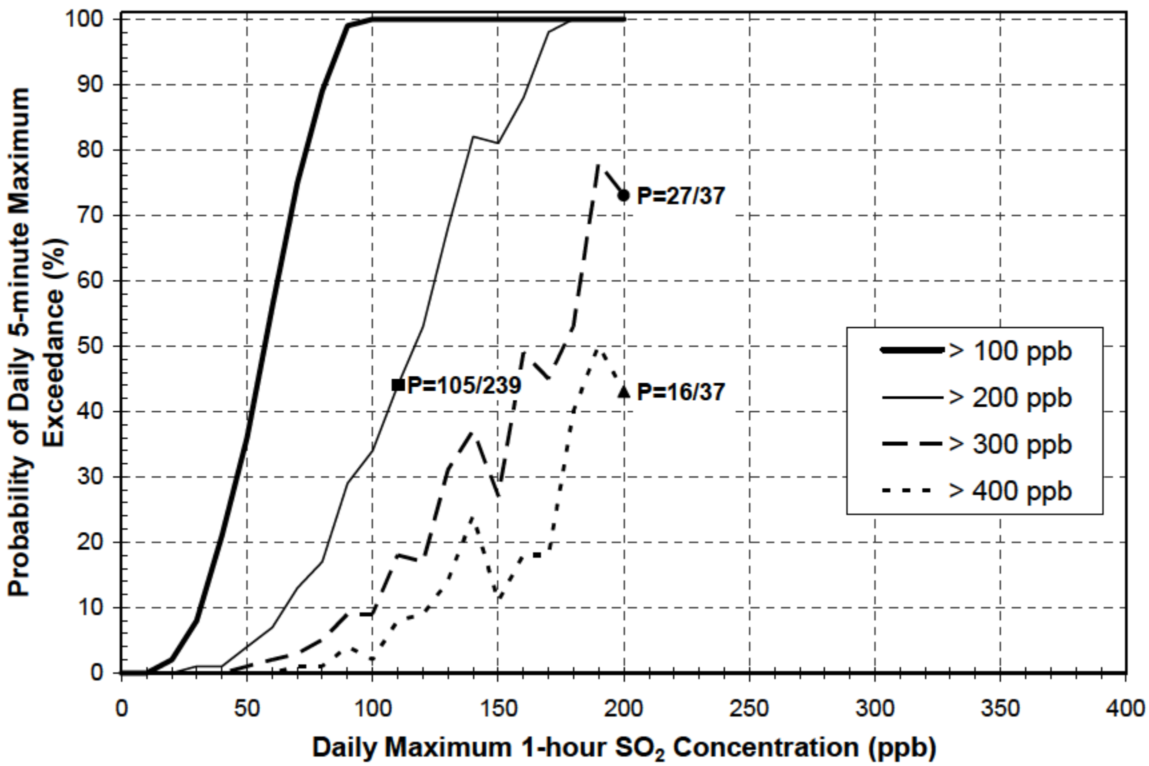

Figure 7-17. Example of empirically-based probability curves. The probability of a 5-minute SO_2 benchmark exceedance (P) was estimated by dividing the number of days with an exceedance by the total number of days within each 1-hour daily maximum SO_2 concentration bin.

In constructing the empirical probability curves, staff noted there were fewer samples with increasing concentrations (either 1-hour daily maximum or 24-hour average). Having too few samples generated instability in the empirically-based probability curves at the highest 1-hour daily maximum or 24-hour average concentrations. For example, there were very few measured 1-hour daily maximum SO_2 concentrations above the 130 ppb bin considering the high

[44] Therefore, there were 134 instances whereby the 1-hour daily maximum of 110 ppb did not correspond to a 5-minute maximum concentration above 200 ppb.

population density group (Table 7-9). A total of 116 1-hour daily maximum SO_2 concentrations out of 26,983 were scattered across the bins of 140 through 620 ppb, concentrations associated with the presence or absence of a 300 ppb 5-minute benchmark exceedance. There were increasing probabilities of 5-minute benchmark exceedances with increasing 1-hour daily maximum SO_2 concentration starting at 100 ppb; however, at 170, 210, and 230 ppb there were lower estimated probabilities of exceedances than the preceding lower 1-hour daily maximum SO_2 concentration. If using the probability data alone in Table 7-9, this would imply that at 1-hour daily maximum concentrations of about 210–230 ppb, the likelihood of an exceedance is less than that when considering 1-hour daily maximum concentrations between 190–200 ppb. This is likely not the case, and in this instance, the wide range in estimated probabilities are more a function of the small sample sizes (no more than 3 samples per bin in this case) rather than the 1-hour daily maximum SO_2 concentrations. Therefore, in viewing the occurrence of this issue at small sample sizes, staff selected concentration bins having at least thirty 1-hour daily maximum (or 24-hour average) concentrations (whether it was all, none, or a mixture of exceedances) for inclusion in the empirically-based probability curves. As a result, the sample size limits compressed the range of predictability offered by the empirically-based probability curves. As an example, Figure 7-17 indicates that there were fewer than 30 samples available for concentration bins above a 1-hour daily maximum SO_2 concentration of 200 ppb (note the 200 ppb bin contained 37 samples).

Table 7-9. Example of how the probability of exceeding a 400 ppb 5-minute benchmark would be calculated given 1-hour daily maximum SO_2 concentration bins.

Daily Maximum 1-hour bin	Number of times: With no exceedances	With one exceedance	Probability of Exceedance (%)
100	71	0	0
110	45	2	4
120	43	1	2
130	34	1	3
140	17	1	6
150	15	2	12
160	11	4	27
170	10	2	**→ 17 ←**
180	8	3	27
190	1	4	80
200	1	3	75
210	1	0	**→ 0 ←**
220	1	2	67
230	2	0	**→ 0 ←**
240	0	2	100
250	0	2	100

Notes:
→ % ← notes sharp decrease in probability from prior concentration bin.
Data used in this table is from the high population density monitors reporting 5-minute concentrations.

In the second approach, we generated probability curves for each of the four benchmark levels and the time-averaged SO_2 concentrations (i.e., 1-hour daily maximum or 24-hour average concentration) using *proc logistic* and a probit link function (SAS, 2004). The probit link function used can be described with the following:

$$y(x;\beta,\gamma) = \frac{1}{(2\pi)^{1/2}} \int_{-\infty}^{\beta+\gamma(x)} e^{-t^2/2} dt \qquad \text{equation (7-4)}$$

where *x* denotes the time averaged SO_2 concentration (either 1-hour daily maximum or the 24-hour average in ppb), *y* denotes the corresponding probability of a 5-minute exceedance, and β and γ are two model estimated parameters used to generate predicted values. The logistic-modeled predictions were then used to generate probability curves using all available measurements, thereby extending the range of predictability beyond that of the empirically-based curves. Figure 7-18 illustrates an example of logistic-modeled probability curves using the same data used in generating the probability curves shown in Figure 7-17. Note that predictions for the modeled curves extend beyond the 1-hour daily maximum limits of 200 ppb when using the empirical curves.

Prior to estimating either the empirically-based or logistic-modeled probability curves, staff separated the monitors within each data analysis group by the population density groups; either *low* (≤ 10,000 persons within 5 km), *mid* (10,001 to ≤ 50,000 persons within 5 km), or *high* (> 50,000 persons within 5 km). Staff hypothesized that there may be different exceedance probabilities in dense population areas compared with locations having fewer residents given the siting characteristics of the monitors with regard to the presence of emission sources. This separation of the monitoring results by the surrounding population should be useful in appropriately characterizing the air quality because the monitoring data are used as indicators of potential human exposure; the results from monitors sited within greater population densities should be more representative of potential population exposure.

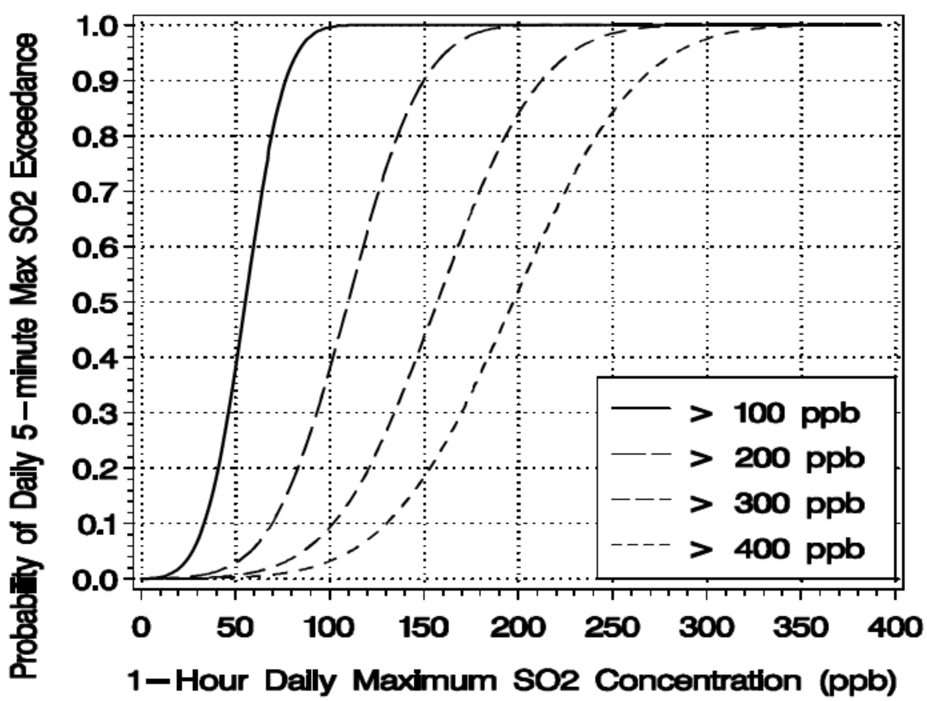

Figure 7-18. Example of logistic-modeled probability curves. The data used to generate these modeled curves were the same used in generating the empirically-based curves in Figure 7-17.

7.3 RESULTS

7.3.1 Measured 5-minute Maximum and Measured 1-Hour SO_2 Concentrations at Ambient Monitors – *As Is* Air Quality

In this first data analysis group, staff analyzed the *as is* air quality data solely based on the SO_2 ambient monitor measurements. Ambient monitoring data were evaluated at the 98 locations where both the 1-hour and 5-minute maximum SO_2 concentrations were reported for years 1997 through 2007. Due to the large size of the data set (i.e., 471 site-years), staff summarized the number of potential health effect benchmark exceedances in a series of figures. This analysis centered on the relationship between various concentration averaging times and the daily 5-minute maximum SO_2 concentration exceedances. Descriptive statistics for the measured daily 5-minute maximum and the 1-hour SO_2 concentrations are provided in Appendix A-5 and in the SO_x ISA (ISA, section 2.5.2), the latter of which includes additional discussion of the spatial and temporal variability of the 5-minute maximum and continuous 5-minute SO_2 concentrations. Staff performed two broad analyses using this data analysis group; first staff evaluated the relationship between annual average concentrations and number of days per year with at least one 5-minute concentration above benchmark levels and then estimated the probability of having at least one 5-minute concentration above benchmark levels given short-term averaging times (i.e., 1-hour daily maximum and 24-hour average).

First, staff evaluated the occurrence of the daily 5-minute maximum SO_2 concentration exceedances in a year. Figure 7-19 compares the number of days with 5-minute maximum SO_2 concentrations above the potential health effect benchmark levels along with the corresponding annual average SO_2 concentration from each max-5 monitor. Overall, there are few days in a year with 5-minute maximum SO_2 concentrations above each of the potential health effect benchmark levels. Given the data in Table 7-8, no more than 7% of the total days with measurements had 5-minute maximum SO_2 concentrations above the 100 ppb benchmark, while approximately 2%, 1%, and 0.7% of days had daily 5-minute maximum SO_2 concentrations above the 200, 300, and 400 ppb levels, respectively. None of the monitors in this data set had annual average SO_2 concentrations above the current annual NAAQS of 30 ppb. However, several of the monitors in several years frequently had daily 5-minute maximum SO_2 concentrations above the potential health effect benchmark levels. Many of those monitors where frequent 5-minute benchmark exceedances occurred had annual average SO_2

concentrations between 5 and 15 ppb, with little to no correlation between the annual average SO_2 concentration and the number of daily 5-minute maximum SO_2 concentrations above the potential health effect benchmark levels. These data are useful in determining the number of days in a year a particular monitor had a daily maximum exceedance of a selected benchmark level, however from a practical perspective, the annual average concentration would be ineffective at controlling daily 5-minute maximum SO_2 concentrations given the observed weak relationships.

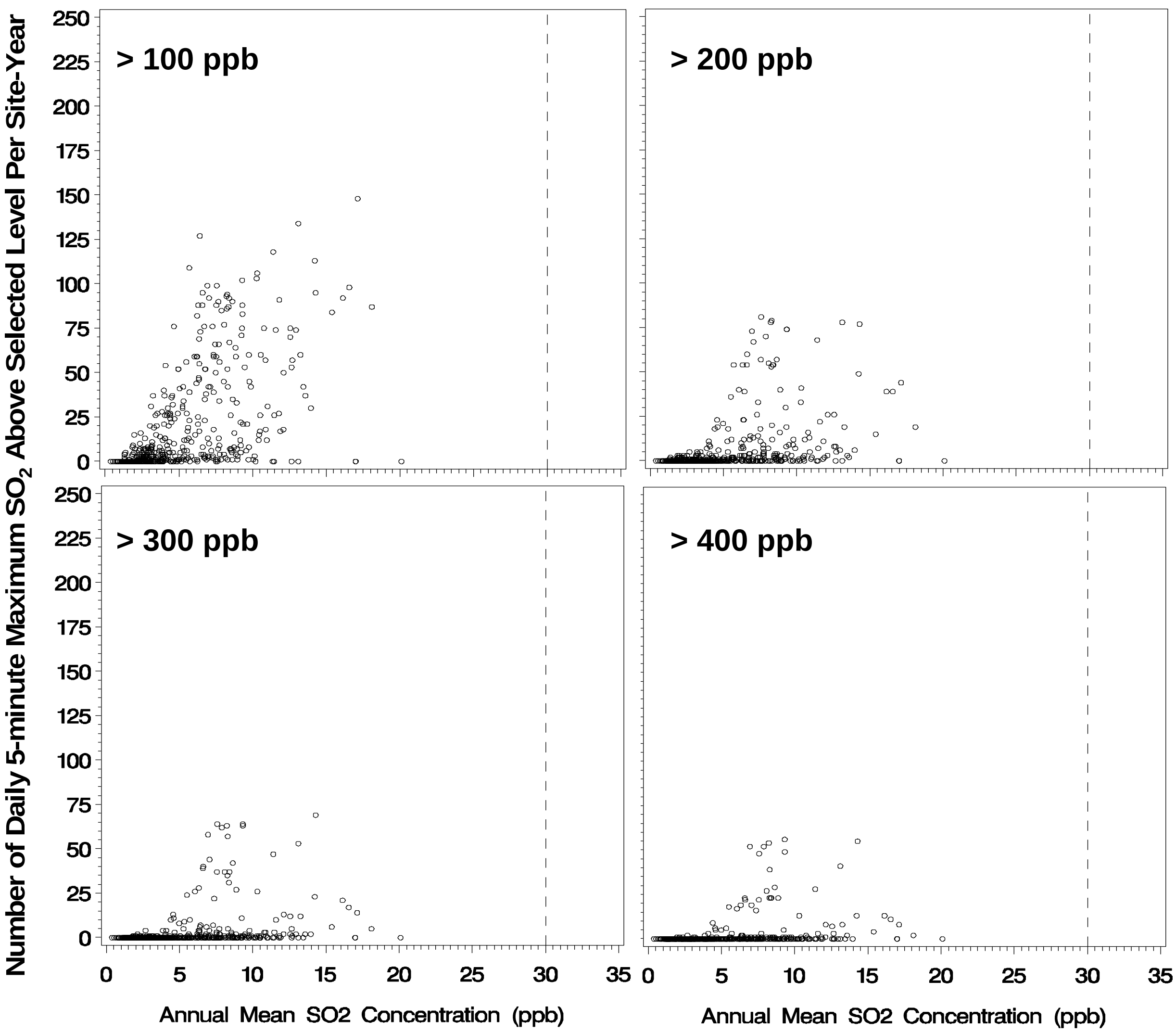

Figure 7-19. The number of days per year with measured 5-minute maximum SO_2 concentrations above potential health effect benchmark levels at 98 monitors given the annual average SO_2 concentration, 1997-2007 air quality *as is*. The level of the annual average SO_2 NAAQS of 30 ppb is indicated by the dashed line.

Second, the probability of potential health effect benchmark exceedances was estimated given the 24-hour average and 1-hour daily maximum SO_2 concentrations. Figure 7-20 presents the empirically-based and logistic-modeled probability curves given the 24-hour average SO_2 concentrations and separated by the three population densities. There is an increasing probability of a daily 5-minute maximum SO_2 concentration exceedance with increasing 24-hour average concentrations at each of the potential health effect benchmark levels and for each of the population density groups. Some deviation from increasing probability occurs near the end of the empirically-based curves derived from the mid-population density monitors. As discussed earlier, this observed behavior is likely a function of the small sample size rather than variability in 24-hour SO_2 concentrations. The logistic-modeled curves are consistent with the empirically-based curves; however, the modeled curves illustrate an extended concentration range and a consistent pattern of increasing probability of 5-minute benchmark exceedances with increasing 24-hour concentration.

Probability curves generated from monitors sited in low-population density areas exhibit a steeper slope when compared with the other population density groups, indicating a greater probability of a 5-minute SO_2 benchmark exceedance given the same 24-hour SO_2 concentration. For example, the probability of exceeding a daily 5-minute maximum concentration of 200 ppb using the empirically-based curves is 30% at the low-population density monitors given a 24-hour average concentration of about 20 ppb. In comparison, empirically-based curves generated from the mid- and high-population density monitors indicate that the probability of a 5-minute benchmark exceedance at the same 24-hour concentration of 20 ppb is only about 14% and 3%, respectively. There is a small probability (about 10%) of exceeding the 300 and 400 ppb in the high-population density areas given a 24-hour average concentration of about 40 ppb (using either the empirical or modeled curves), though at monitors sited in the low-population areas this probability is greater than 50%.

The empirically-based curves are limited to estimating exceedance probabilities at or below 24-hour concentrations of 60 ppb, with mostly unknown probabilities associated with many of the benchmark levels and at concentrations approaching the current 24-hour standard. For example, while the estimated probability of a daily 5-minute maximum SO_2 concentration above 100 ppb is at or near 100% considering any of the population density groups, little can be construed from the other empirically-based curves at 24-hour concentrations above 60 ppb, particularly at monitors sited in mid- to high-population density areas. The logistic-modeled curves however provide the probability of benchmark exceedances at higher 24-hour concentrations. For example, according to Figure 7-20 there would be a 100% probability of exceeding all benchmark levels at about a 24-hour concentration of 100-120 ppb, when considering monitors in either the mid- or high-population density areas.

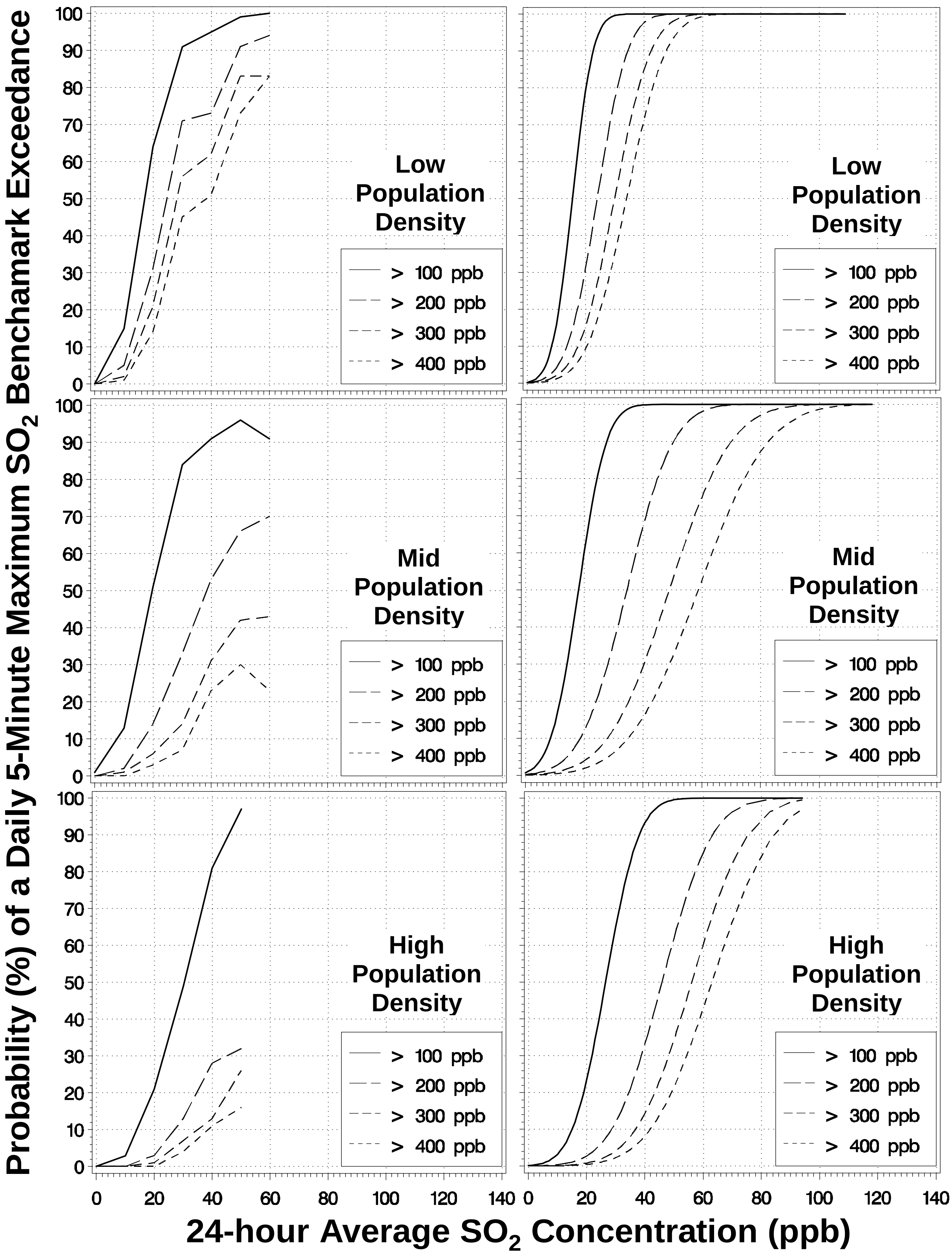

Figure 7-20. Probability of daily 5-minute maximum SO_2 concentrations above potential health effect benchmark levels given 24-hour average SO_2 concentration, using empirical data (left) and a fitted log-probit model (right), 1997-2007 air quality *as is*. Both the 5-minute maximum and 24-hour SO_2 concentrations were from measurements collected at 98 ambient monitors and separated by population density.

Figure 7-21 presents similar probability curves generated from the 5-minute and 1-hour ambient measurement data, but the probabilities of benchmark exceedances are associated with the 1-hour daily maximum SO_2 concentrations instead of 24-hour average concentrations. At each of the benchmark levels and population densities, Figure 7-21 shows increasing probabilities of exceedances with increasing 1-hour daily maximum SO_2 concentrations. Further, the probability curves have steeper slopes associated with the low-population density group compared to the slopes of the higher population density groups. Note that while there is uncertainty regarding the extrapolation beyond the limits imposed on the empirically-based curves (i.e., 30 or greater samples per bin), one can be assured that the probability of an exceedance of a daily 5-minute maximum SO_2 concentration of 400 ppb is 100% given a 1-hour daily maximum SO_2 concentration of 400 ppb (and so on for the other 5-minute benchmark/1-hour daily maximum SO_2 concentration combinations).[45] As observed using the 24-hour average concentrations, the shape of the curves beyond the imposed limits of the empirical data can be informed by the logistic regression modeling (right column, Figure 7-21). In using the logistic-modeled benchmark curves, a 100% probability of an exceedance is estimated to occur at about a 1-hour daily maximum concentration 50-100 ppb less that of the respective 5-minute benchmark level.

It also should be noted that when comparing any of the 24-hour average probability curves with corresponding 1-hour daily maximum probability curves (e.g., Figure 7-20 and Figure 7-21) the relative slopes of the 24-hour curves are steeper. Therefore, changes in 24-hour average SO_2 concentration (either higher or lower) will effectively result in greater changes in the probability of exceedances when compared to a similar 1-hour daily maximum concentration shift. For example, to reduce the likelihood of a 200 ppb benchmark exceedance from about 90% to 10%, 24-hour average concentrations would need to go from a level of about 50 to 20 ppb using the logistic-modeled mid-population curves. This same reduction in probability would correspond to a 1-hour daily maximum concentration reduction of about 150 ppb to 70 ppb.

[45] Technically, if all 5-minute concentrations were exactly 400 ppb, the 1-hour average concentration would be 400 ppb and the 5-minute maximum would not actually exceed 400 ppb. However, note that probability of exceeding the 100 or 200 ppb benchmarks approaches 100% at less than a 1-hour daily maximum of 100 an 200 ppb, respectively (Figure 7-18).

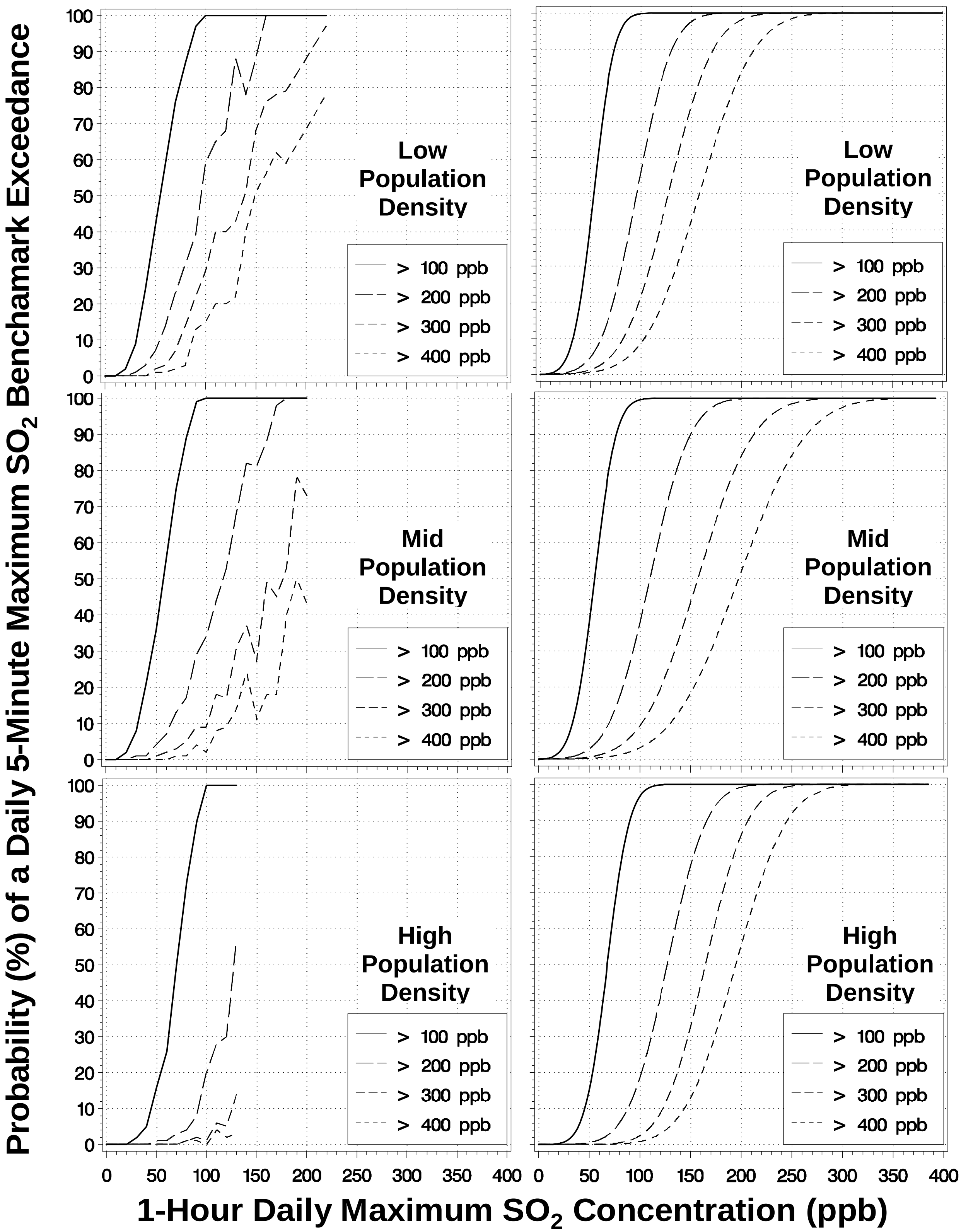

Figure 7-21. Probability of daily 5-minute maximum SO_2 concentrations above potential health effect benchmark levels given 1-hour daily maximum SO_2 concentration, using empirical data (left) and a fitted log-probit model (right), 1997-2007 air quality *as is*. Both the 5-minute maximum and 1-hour SO_2 concentrations were from measurements collected at 98 ambient monitors and separated by population density.

7.3.2 Measured 1-Hour and Modeled 5-minute Maximum SO_2 Concentrations at All Ambient Monitors – *As Is* Air Quality

In the second data analysis group, staff analyzed the *as is* air quality using a combination of measurement and modeled data. As described in section 7.2.3, a statistical model was applied to 1-hour ambient SO_2 measurements to estimate 5-minute maximum SO_2 concentrations. This was done because there are a greater number of monitors in the broader SO_2 monitoring network compared to subset of monitors reporting the 5-minute maximum SO_2 concentrations (section 7.3.1). This larger monitoring data set included 809 ambient monitors in operation at some time during the years 1997 through 2006 that met the completeness criteria described in section 7.2.1. This data set included 4,692 site-years of data, and combined with the estimated 5-minute SO_2 concentrations using the measured 1-hour values, allowed for a comprehensive characterization of the hourly and 5-minute SO_2 air quality at ambient monitors located across the U.S. Descriptive statistics for the measured 1-hour SO_2 concentrations are provided in the SO_x ISA (ISA, section 2.5.1) including additional discussion of the spatial and temporal variability in 1-hour SO_2 concentrations.

Staff performed twenty separate model simulations to estimate the 5-minute maximum SO_2 concentration associated with each 1-hour measurement. The individual simulation results at each monitor were averaged to generate a mean number of days per year with a 5-minute benchmark exceedance. The modeled (5-minute maximum) and measurement (1-hour) data were analyzed in a similar manner as performed on the measured 5-minute maximum and 1-hour SO_2 concentrations described in section 7.3.1. The results provided in this section were generated using the modeled daily 5-minute maximums and the measured hourly SO_2 concentrations considering 1-hour, 24-hour, and annual averaging times. Staff performed two broad analyses; first staff evaluated the relationship between annual average concentrations and number of days per year with at least one 5-minute concentration above benchmark levels and then estimated the probability of having at least one 5-minute concentration above benchmark levels given short-term averaging times (1-hour daily maximum and 24-hour average).

First, Figure 7-22 shows the number of days per year with a 5-minute SO_2 concentration above benchmark levels versus the annual average SO_2 concentration. Fewer than 5% of total days per year had a 5-minute SO_2 concentration above the 100 ppb benchmark, while approximately 1%, 0.5%, and 0.2% of days had at least one 5-minute concentration above the

200, 300, and 400 ppb benchmark levels, respectively. None of the site-years of data had annual average SO_2 concentrations at or above the level of the current annual NAAQS (30 ppb). However as described above, several site-years had predicted 5-minute SO_2 concentrations above the potential health effect benchmark levels. Many of the monitors with frequent 5-minute benchmark exceedances had annual average SO_2 concentrations between 10 and 20 ppb, with a pattern of increasing number of days per year with at least one 5-minute concentration above the benchmark levels with increasing annual average concentrations. This pattern was most prominent at the 100 ppb benchmark level, with progressively weaker relationships between the number of 5-minute benchmark exceedances and annual average concentrations at each of the higher benchmark levels.

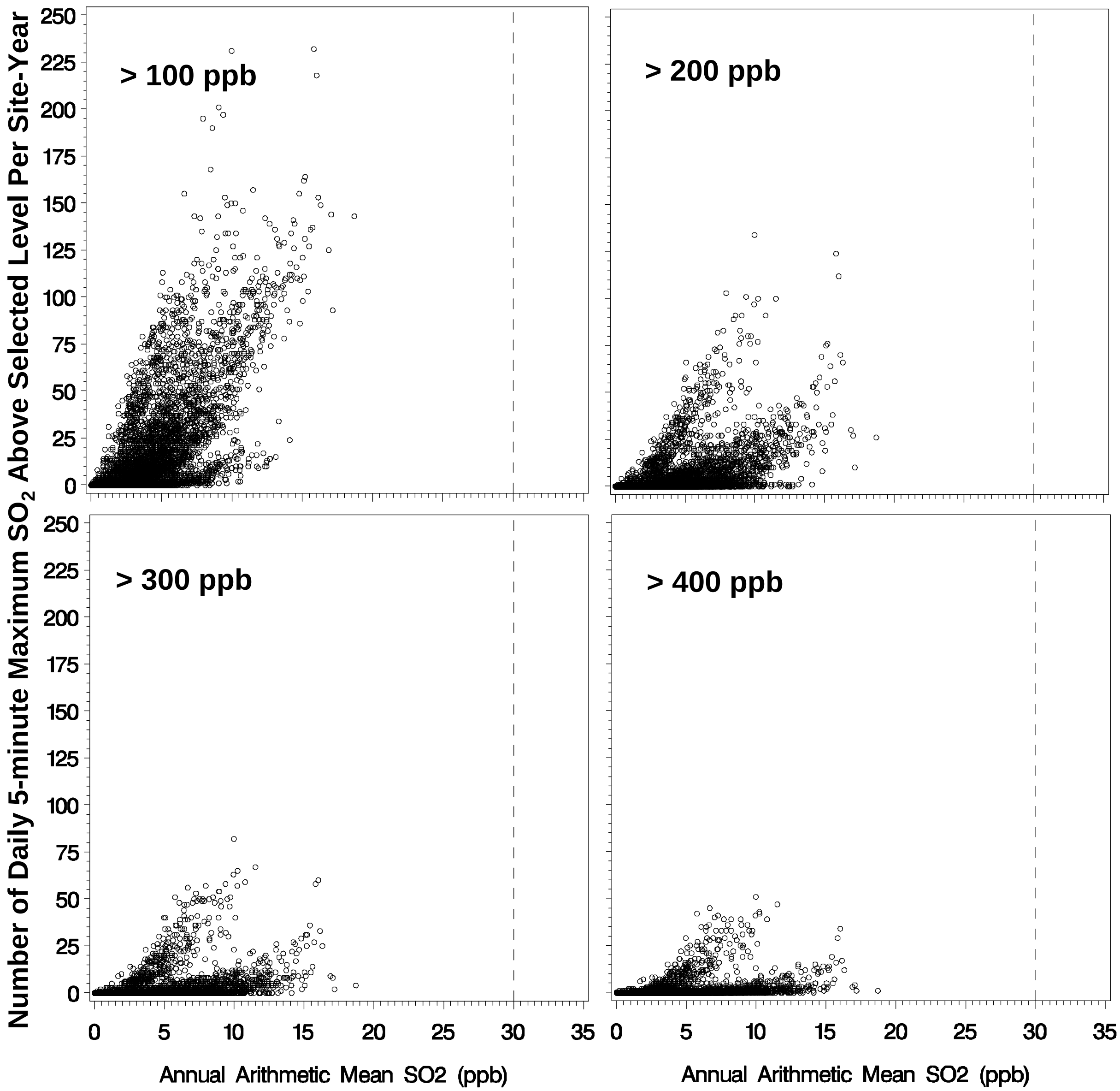

Figure 7-22. The number of days per year with modeled daily 5-minute maximum SO_2 concentrations above potential health effect benchmark levels at 809 ambient monitors given the annual average SO_2 concentration, 1997-2006 air quality *as is*. The level of the annual average SO_2 NAAQS of 30 ppb is indicated by the dashed line.

Next, empirical and logistic-modeled probability curves were generated for this second data analysis group. Figure 7-23 illustrates the probability of benchmark exceedances using the modeled daily 5-minute maximum SO_2 concentrations and 24-hour average concentrations. These probability curves exhibit patterns similar to that described using the pure measurement data (Figure 7-20). For example, the probability curves generated from low-population density area monitors are steeper than those generated using the higher population density monitors at each of the benchmark levels considered. In addition, the slopes of the probability curves are generally consistent between the measured and modeled 5-minute maximum data, where comparable 24-hour average concentrations exist.

The broader SO_2 monitoring network to estimate daily 5-minute maximum SO_2 concentrations provides insight as to the potential shape of each empirically-based probability curve at greater 24-hour average concentrations. The upper range of 24-hour concentrations extends to around 70-100 ppb (Figure 7-23), while at the monitors reporting 5-minute maximum SO_2 concentrations the maximum 24-hour average concentrations extends to at most between 50 and 60 ppb (Figure 7-20). The extended range of 24-hour concentrations in the empirically-based curves provides additional support to what was stated earlier using the pure measurement data, that is, there is a strong likelihood of 5-minute peak concentrations above the benchmark levels at 24-hour average concentrations well below the level of the current standard. This is further confirmed by the logistic-modeled probability curves that estimate all benchmark levels would be exceeded at about a 24-hour concentration of 60-100 ppb, the level of which dependent on where the monitor is sited.

The probability curves generated using the modeled 5-minute maximum and 1-hour daily maximum SO_2 concentrations (Figure 7-24) also exhibit patterns consistent with those patterns observed using the pure measurement data (Figure 7-21). Again, a wider range of 1-hour daily maximum concentrations is observed in using the broader monitoring network when compared with the results using the monitors reporting the 5-minute maximum SO_2 concentrations, giving greater ability to discern the probability of benchmark exceedances at higher 1-hour daily maximum SO_2 concentrations. When using either the empirically-based or logistic modeled curves, a 100% probability of exceeding the 100, 200, 300, and 400 ppb benchmarks is estimated to occur at 1-hour daily maximum concentrations of about 80, 150, 225, and 300 ppb, respectively.

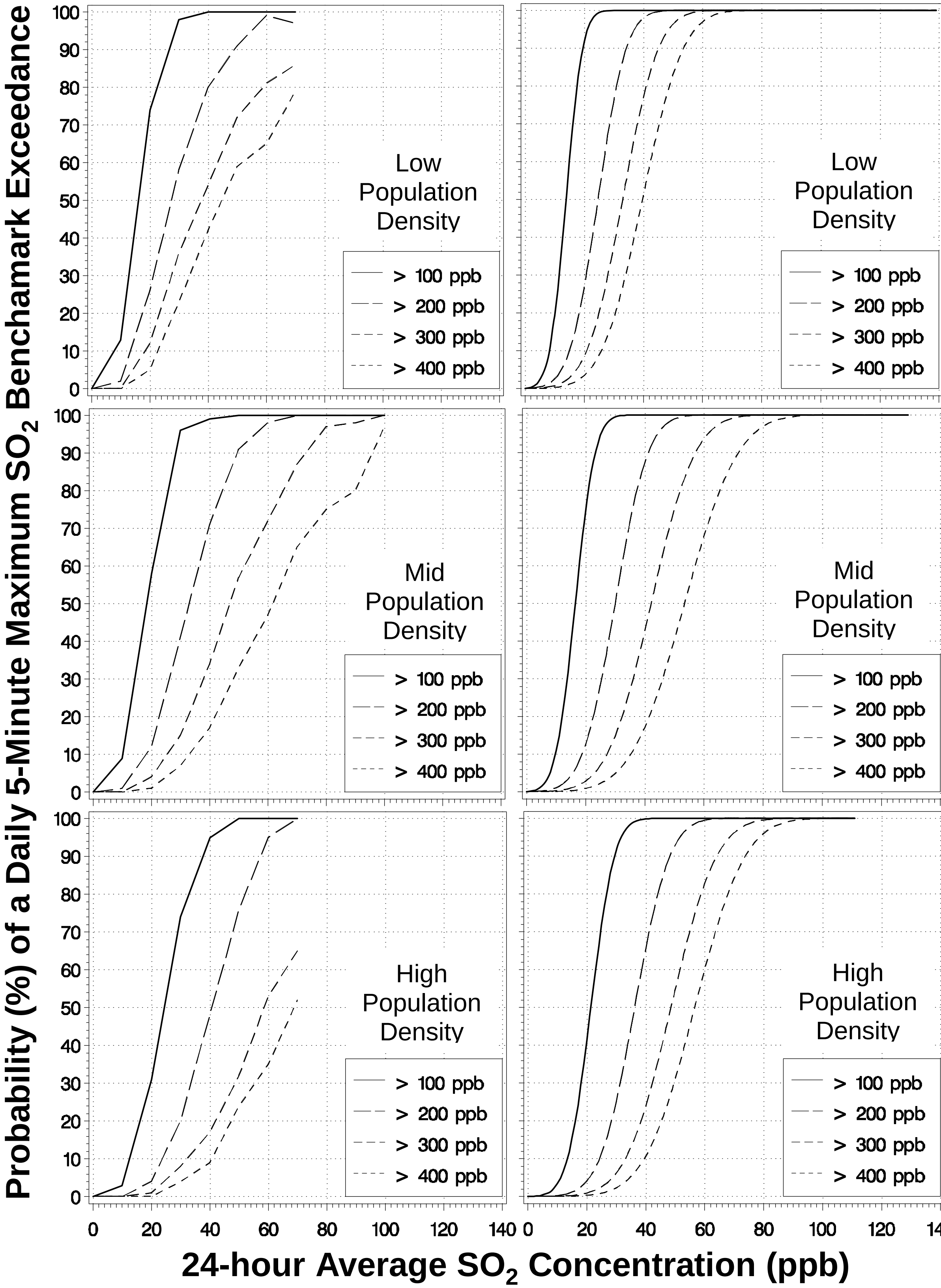

Figure 7-23. Probability of daily 5-minute maximum SO_2 concentrations above potential health effect benchmark levels given 24-hour average SO_2 concentrations, using empirical data (left) and a fitted log-probit model (right), 1997-2006 air quality *as is*. The 5-minute maximum SO_2 concentrations were modeled from 1-hour measurements collected at 809 ambient monitors and then separated by population density.

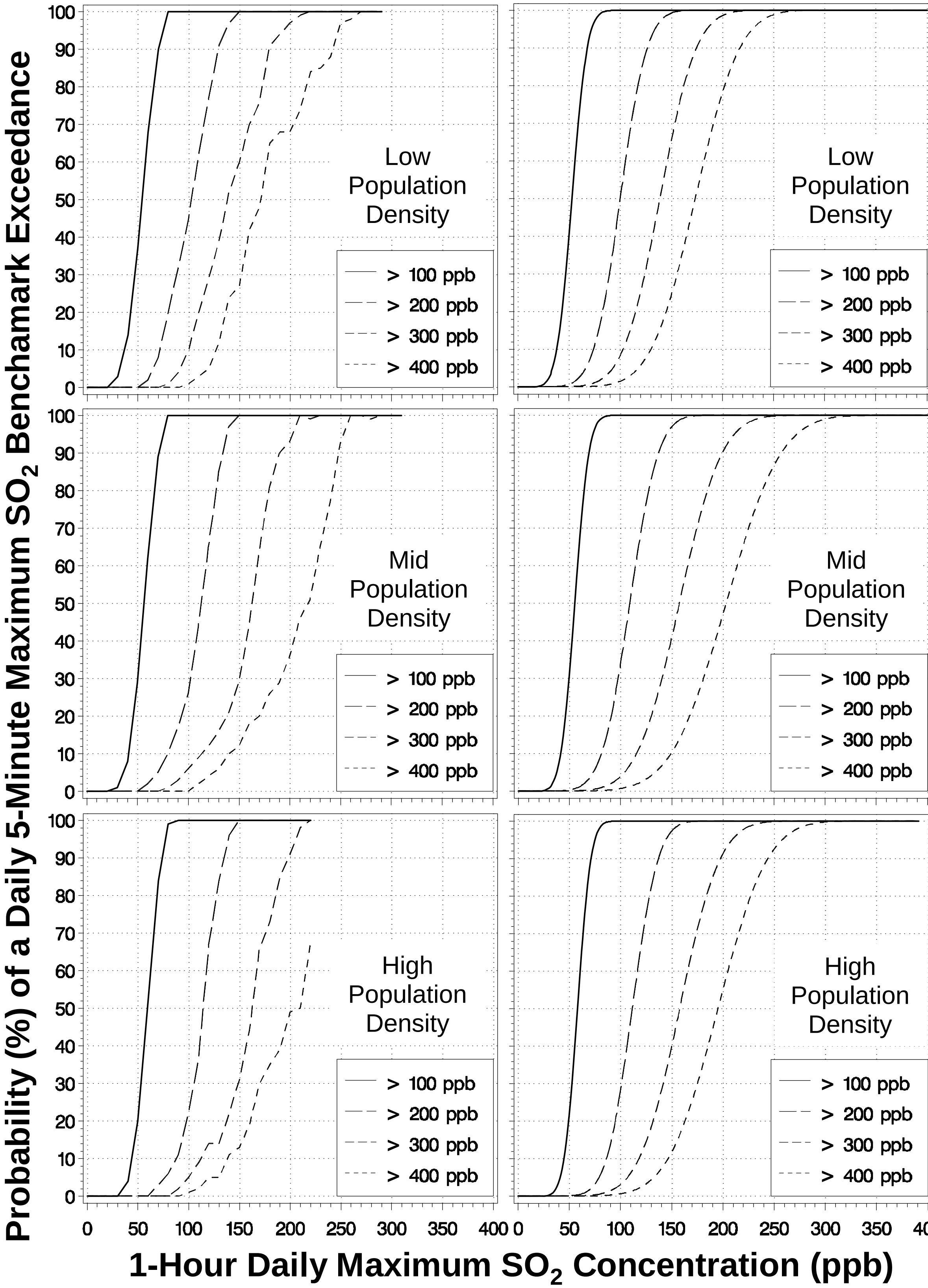

Figure 7-24. Probability of daily 5-minute maximum SO_2 concentrations above potential health effect benchmark levels given 1-hour daily maximum SO_2 concentrations, using empirical data (left) and a fitted log-probit model (right), 1997-2006 air quality *as is*. The 5-minute maximum SO_2 concentrations were modeled from 1-hour measurements collected at 809 ambient monitors and then separated by population density.

7.3.3 Modeled 1-Hour and Modeled 5-minute Maximum SO_2 Concentrations at Ambient Monitors in 40 Counties – Air Quality Adjusted to Just Meet the Current and Potential Alternative Standards

Staff selected forty counties to analyze 5-minute benchmark exceedances under several air quality scenarios: *as is* air quality and air quality adjusted to just meeting the current and alternative standards. The forty counties were selected using criteria discussed in section 7.2.4. Specifically, we chose the 38 counties with 1-hour ambient monitor SO_2 concentrations nearest the current NAAQS levels and two counties with a high frequency of measured daily 5-minute maximum SO_2 concentrations above the potential health effect benchmark levels. The 1-hour SO_2 measurement data were from 128 ambient monitors and totaled 610 site-years of monitoring, a subset of data from the broader SO_2 monitoring network (see section 7.3.2). Staff evaluated multiple alternative air quality scenarios by first adjusting the 1-hour ambient monitoring concentrations to just meet a particular standard level (section 7.4). Then, as was done in section 7.3.2, staff performed twenty simulations to estimate the 5-minute maximum SO_2 concentration associated with each 1-hour adjusted concentration using the statistical model described in section 7.2.3. These simulation results were combined to generate a mean estimate for each of the metrics of interest (e.g., the number of days in a year with 5-minute maximum SO_2 concentrations > 200 ppb) selected here as the best estimate from the twenty simulations. Staff 1) evaluated the relationship between annual average concentrations and number of days per year with at least one 5-minute concentration above benchmark levels, 2) summarized the number of days per year with at least one 5-minute concentration above benchmark levels for each air quality scenario, 3) compared number of days per year with at least one 5-minute concentration above benchmark levels using two percentile forms of the potential alternative 1-hour daily maximum standards (i.e., 98^{th} and 99^{th} percentile), and 4) estimated the probability of having at least one 5-minute concentration above benchmark levels given short-term averaging times (1-hour daily maximum and 24-hour average).

First, staff evaluated the relationship between the short-term peak concentrations and the level of the current annual SO_2 NAAQS in the selected counties. Figure 7-25 illustrates the number of days per year with 5-minute daily maximum SO_2 concentrations above the potential health effect benchmark levels along with the corresponding annual average concentrations. Each data point represents a monitor site-year generated from the modeled 5-minute peaks and air quality adjusted to just meeting the current SO_2 standards. None of the site-years in the selected counties had annual average concentrations above the level of the current NAAQS (30 ppb) by design[46], however there are many more site-years with a greater number of modeled daily 5-minute maximum SO_2 concentrations above the potential health effect benchmark levels than compared with that of the *as is* air quality. There are a decreasing number of exceedances with increasing benchmark concentrations, though there is a greater proportion of monitors with exceedances when considering concentrations adjusted to just meeting the current standard than when using the *as is* air quality (e.g., see Figure 7-19). When considering concentrations adjusted to just meeting the current standard, there is a stronger relationship between the annual average concentrations and the number of benchmark exceedances than observed previously with the *as is* air quality however, the strength of that relationship weakens with increasing benchmark levels.

[46] The current annual SO_2 NAAQS is 30 ppb. Concentrations of up to 30.4 ppb are possible due to a rounding convention. This is why there are several data points just to the right of the dashed line in Figure 7-22.

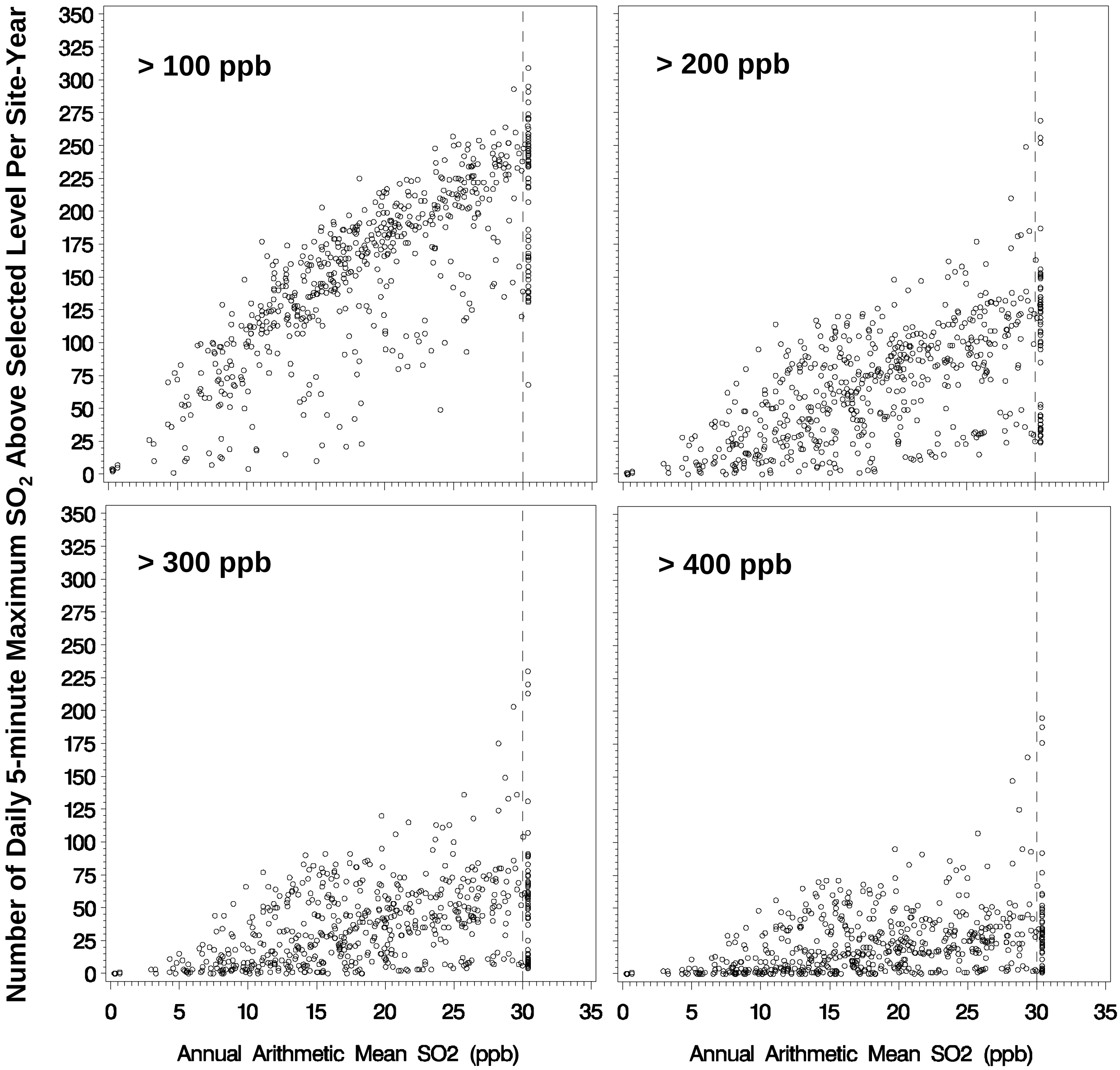

Figure 7-25. The number of days per year with modeled 5-minute maximum SO_2 concentrations above potential health effect benchmark levels per year at 128 ambient monitors in 40 selected counties given the annual average SO_2 concentration, 2001-2006 air quality adjusted to just meet the current NAAQS. The level of the annual average SO_2 NAAQS of 30 ppb is indicated by the dashed line.

Similar relationships are present between the annual average SO_2 concentrations and the number of benchmark exceedances when considering the potential alternative standards. As a reminder, to just meet the current and potential alternative standards staff estimated a unique adjustment factor to simulate the alternative air quality. The direction of the adjustment factor (either upwards or >1; downwards or <1) and magnitude of the adjustment factor used has a direct impact on the estimated number of 5-minute benchmark exceedances. In general, the air quality distributions that just meet the potential alternative standards were enveloped by the *as is* air quality (i.e., a distribution with low concentrations) and the air quality adjusted to just meeting the current standard (i.e., a distribution with generally high concentrations). Therefore, the estimated number of days with exceedances also fell within the range of exceedances generated using the *as is* air quality or the air quality adjusted to just meet the current standard. For example, a comparison of the annual average SO_2 concentrations and number of daily 5-minute maximum exceedances of 200 ppb is presented in Figure 7-26 for six air quality scenarios: four of the 99th percentile 1-hour daily maximum potential alternative standards (i.e., the 100, 150, 200, and 250 ppb); the air quality adjusted to just meet the current standards; and *as is* air quality.

Clearly, in using the air quality adjustment procedure combined with the statistical model to estimate 5-minute maximum SO_2 concentrations, the current standard air quality scenario allows for the greatest estimated number of days per year with potential health effect benchmark exceedances (Figure 7-26). However, at a minimum the annual standard does provide protection against annual average concentrations above the level of the current standard. While there were fewer 5-minute benchmark exceedances using the 1-hour daily maximum forms of a potential alternative standard, two of the levels (1-hour daily maximums of 200 and 250 ppb) did not prevent annual average concentrations from exceeding the current annual standard (Figure 7-26). High annual average concentrations become less of an issue when considering the lower levels of the 1-hour daily maximum potential alternative standards. Even though the 99th percentile 1-hour daily maximum standards of 100 or 150 ppb allow for greater annual average concentrations than when considering *as is* air quality, all but one site-year are below the level of the current annual standard and there are fewer estimated days per year with benchmark exceedances. These results further demonstrate the stronger relationship 5-minute peak concentrations have with 1-hour SO_2 concentrations than with annual average concentrations.

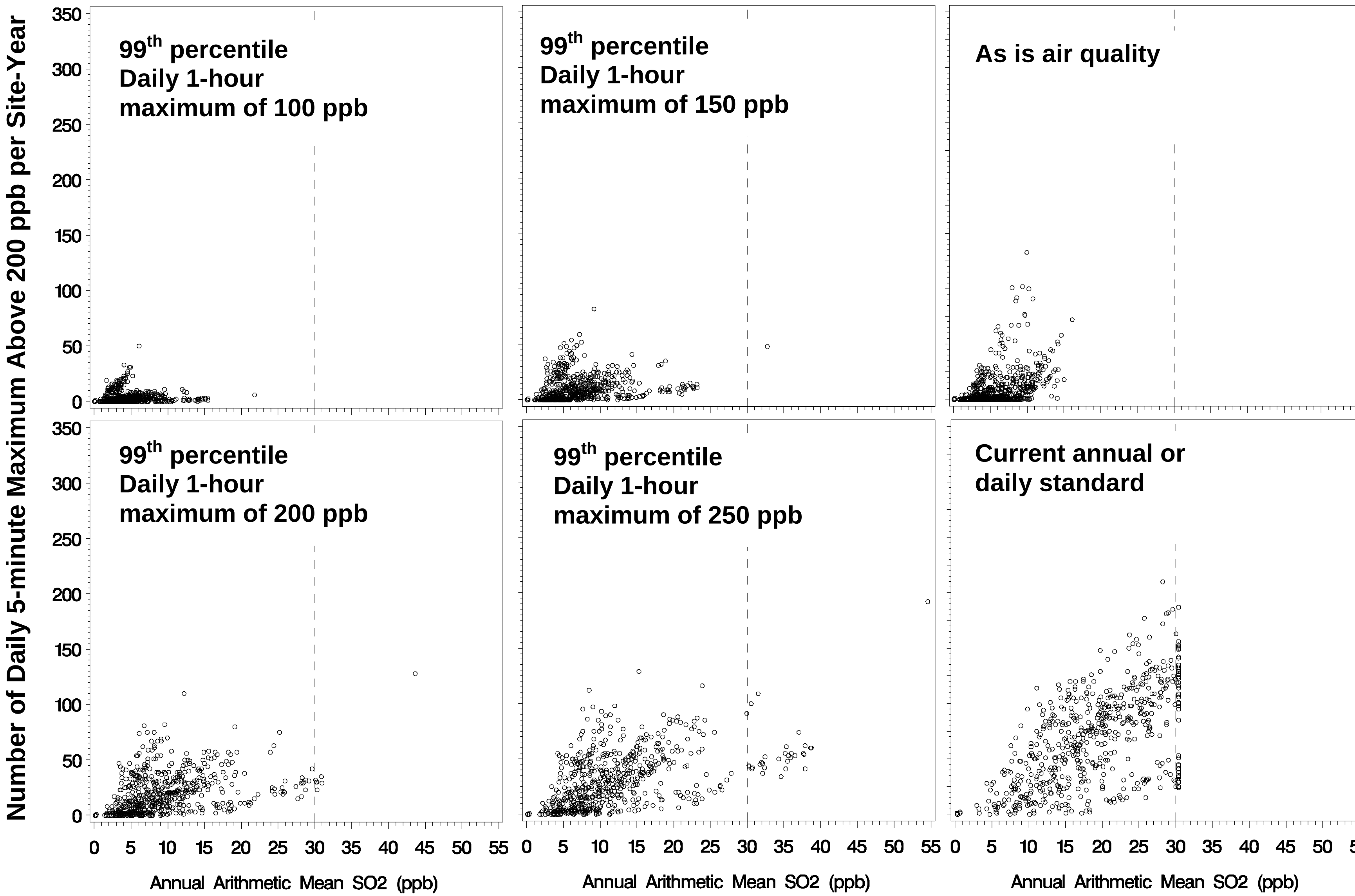

Figure 7-26. The number of modeled daily 5-minute maximum SO_2 concentrations above 200 ppb per year at 128 ambient monitors in 40 selected counties given the annual average SO_2 concentration, 2001-2006 air quality *as is* and that adjusted to just the current and four potential alternative standards (text in graph indicate standard evaluated). The level of the annual average SO_2 NAAQS of 30 ppb is indicated by the dashed line.

Table 7-10. Percent of days having a modeled daily 5-minute maximum SO_2 concentration above the potential health effect benchmark levels given air quality *as is* and air quality adjusted to just meeting the current and each of the potential alternative standards.

Air Quality Scenario[1]	Percent of Days With Daily 5-minute Maximum SO_2 Concentrations Above Benchmark Levels			
	> 100 ppb	> 200 ppb	> 300 ppb	> 400 ppb
as is	9.1	2.4	0.9	0.5
CS	41.0	17.2	9.1	5.3
99-50	0.7	0.0	0.0	0.0
99-100	4.5	0.7	0.2	0.0
98-100	6.9	1.2	0.3	0.1
99-150	10.6	2.2	0.7	0.3
99-200	17.2	4.5	1.6	0.7
99-250	23.6	7.4	2.9	1.3
98-200	22.5	6.9	2.6	1.2

Notes:
[1] *as is* air quality is unadjusted; CS is air quality adjusted to just meet the current standard; x-y are the x^{th} percentile form of a 1-hour daily maximum level of y.

Second, staff summarized the number of days per year with 5-minute maximum SO_2 concentrations above benchmark levels within the 40-county data set for additional comparisons of the air quality scenarios. Table 7-10 provides the percent of all days above each of the benchmark levels considering each of the air quality scenarios. Again, the scenario where air quality just meets the current standard has the greatest percent of days with benchmark exceedances. With each progressive decrease in the 1-hour daily maximum SO_2 concentration levels of the potential alternative standards, there are fewer days with benchmark exceedances. The percent of all days with benchmark exceedances using *as is* air quality was between a potential 1-hour daily maximum alternative standard level of 100 and 150 ppb (99^{th} percentile form), or similar to that of the 98^{th} percentile form at a level of 100 ppb.

Third, staff evaluated two forms of the potential alternative standards: the 99^{th} and 98^{th} percentile forms, each having a 1-hour daily maximum level of either 100 or 200 ppb. For example, Figure 7-27 indicates that nearly all site-years have a greater estimated number of days per year with benchmark exceedances given the 98^{th} percentile form when compared with a 99^{th} percentile form at the same level. This is expected given the number of allowable 1-hour SO_2 concentrations above the 200 ppb level for each of the percentile forms. The two air quality scenarios were compared on a monitor-to-monitor basis and on average, the 98^{th} percentile form allowed for approximately 46, 68, 84, and 86% more benchmark exceedances considering the

100, 200, 300, and 400 ppb benchmark levels, respectively when compared with the 99th percentile form.

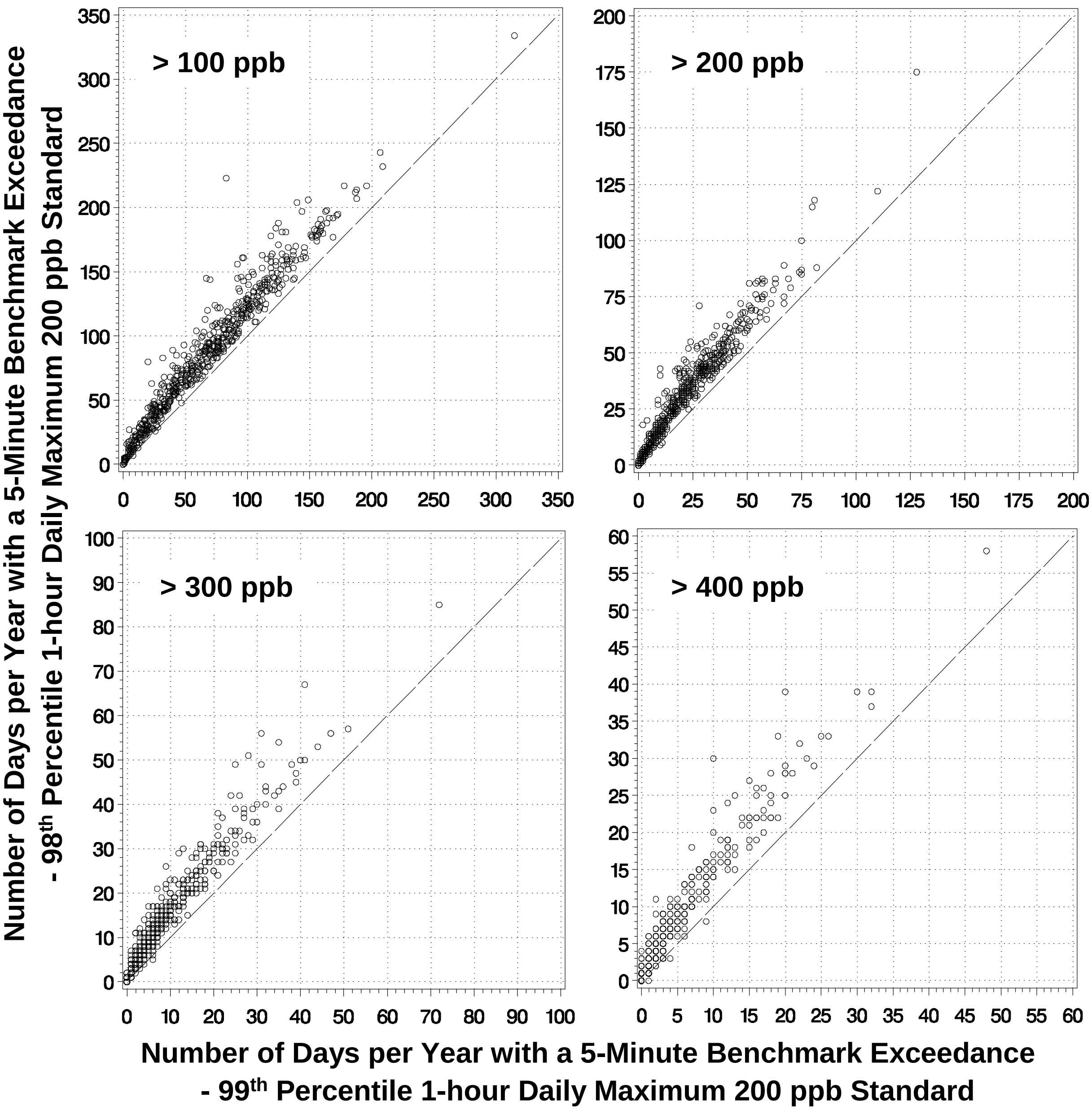

Figure 7-27. The number of days per year with modeled 5-minute maximum SO_2 concentrations above benchmark levels given the 99th and 98th percentile forms, using the 40-county air quality data set adjusted to just meet a 1-hour daily maximum level of 200 ppb.

When a 1-hour daily maximum level of 100 ppb was considered, on average the 98th percentile form of the potential alternative standard allowed for approximately 68, 90, 84, and

74% more benchmark exceedances at each monitor considering the 100, 200, 300, and 400 ppb benchmark levels, respectively when compared with the 99th percentile form. While generally there were greater differences in the percent of exceedances for the two forms when considering the 100 ppb level compared with the 200 ppb level, there were far fewer site-years with benchmark exceedances (Figure 7-28).

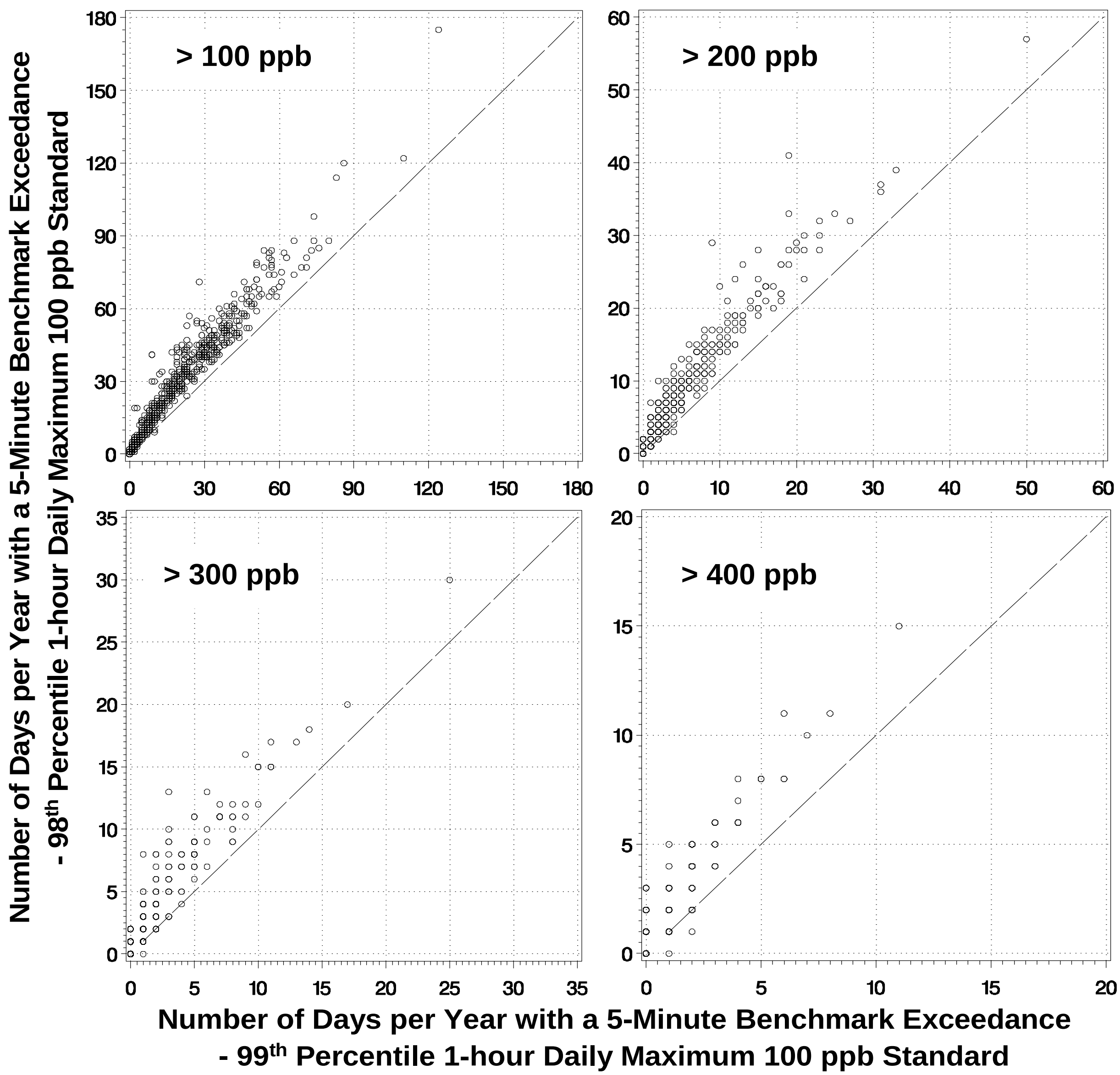

Figure 7-28. The number of days per year with modeled 5-minute maximum SO_2 concentrations above benchmark levels given the 99th and 98th percentile forms, using the 40-county air quality data set adjusted to just meet a 1-hour daily maximum level of 100 ppb.

Fourth, staff estimated the probability of potential health effect benchmark exceedances given the adjusted air quality scenarios and short-term averaging times. Again, patterns in the curves were consistent with what was observed and described previously; monitors within low-population density areas had steeper probability curves compared with those in higher population density areas. Further, there were similarities in the shape and the steepness of the curves when comparing the adjusted air quality probability curves with the curves developed from the corresponding *as is* air quality. Therefore, for the sake of brevity, all of the probability curves for each of the alternative standards are not presented. However, there were some differences in the probability curves worthy of presentation and discussion, using the empirically-based curves for the demonstration.

Figure 7-29 presents the probability of a 5-minute benchmark exceedance using *as is* air quality and air quality adjusted to just meet the current standard, given 1-hour daily maximum SO_2 concentrations. In general, all of the corresponding probability curves for all of the air quality scenarios overlap when considering the 100 and 200 ppb benchmark levels. However, the probability curves associated with exceeding the 300 and 400 ppb benchmark levels were of similar slope, but shifted to the left when considering the *as is* air quality compared with the current standard scenario. This is likely a function of the non-linear form of the statistical model used to estimate the 5-minute maximum SO_2 concentrations, the proportional adjustment procedure to simulate alternative standards, and the form of the air quality characterization metric used.

When adjusting the 1-hour SO_2 concentrations upwards using a proportional factor, a corresponding proportional increase in the number of days per year with benchmark exceedances does not necessarily follow. The statistical model uses multiple distributions of PMRs, not linearly related to 1-hour SO_2 concentrations. Certainly, the total number of days in a year with benchmark exceedances will increase with an upward adjustment of air quality, and does so as observed in Figure 7-26. However, the greatest proportion of monitoring days within any of the air quality scenarios is comprised of days without an exceedance (see Table 7-10). The frequency of exceedances of the higher benchmarks is very low using the *as is* air quality; the few added days with estimated exceedances of 300 or 400 ppb using the simulated air quality is not proportional to the universal increase in hourly concentrations applied to all 1-hour concentrations. Therefore the probability curves tend to be less steep with the upward 1-hour concentration adjustments when considering the higher benchmark levels. Furthermore, days already having an exceedance are only counted once, that is, if there were an exceedance on a given day using the *as is* air quality, it is likely that the same day would also have an exceedance using the adjusted air quality, only it is associated with a greater 1-hour (or 24-hour average) concentration. Again, the 1-hour concentrations are increased without corresponding proportional increase in the number of exceedances when comparing the two air quality scenarios. Conversely, it could also be argued that there may be an increased probability of daily 5-minute exceedances of 300 and 400 ppb when using air quality with a relatively low concentration distribution (such as with the *as is* air quality) compared with a distribution of higher concentrations (such as with the current standard scenario). However, it should be noted that the total number of benchmark level exceedances in a year (and the absence of exceedances at the same high 1-hour daily maximum concentration) under either of these scenarios would be very few, with far fewer numbers of exceedances associated with the relatively low concentration air quality.

This discussion of probability curves can be extended to each of the potential alternative standards. For example, Figure 7-30 illustrates a range in each of the probability curves given each of the alternative air quality scenarios and using monitors sited within high-population density areas. The 100 and 200 ppb benchmark level probability curves exhibit a narrow range across each of the adjusted air quality scenarios. While the estimated 300 and 400 ppb probability curves are wider than the 100 and 200 ppb curves, there is still agreement in the estimated probabilities at many of the 1-hour daily maximum SO_2 values. The range in probability curves tended to be widest at the lowest probabilities/1-hour daily maximum SO_2 concentrations within a given benchmark, likely indicating a greater uncertainty in the relationship between exceedance of the daily 5-minute maximum SO_2 concentrations of 300 and 400 ppb and 1-hour daily maximum SO_2 concentrations less than 130 ppb and 180 ppb, respectively.

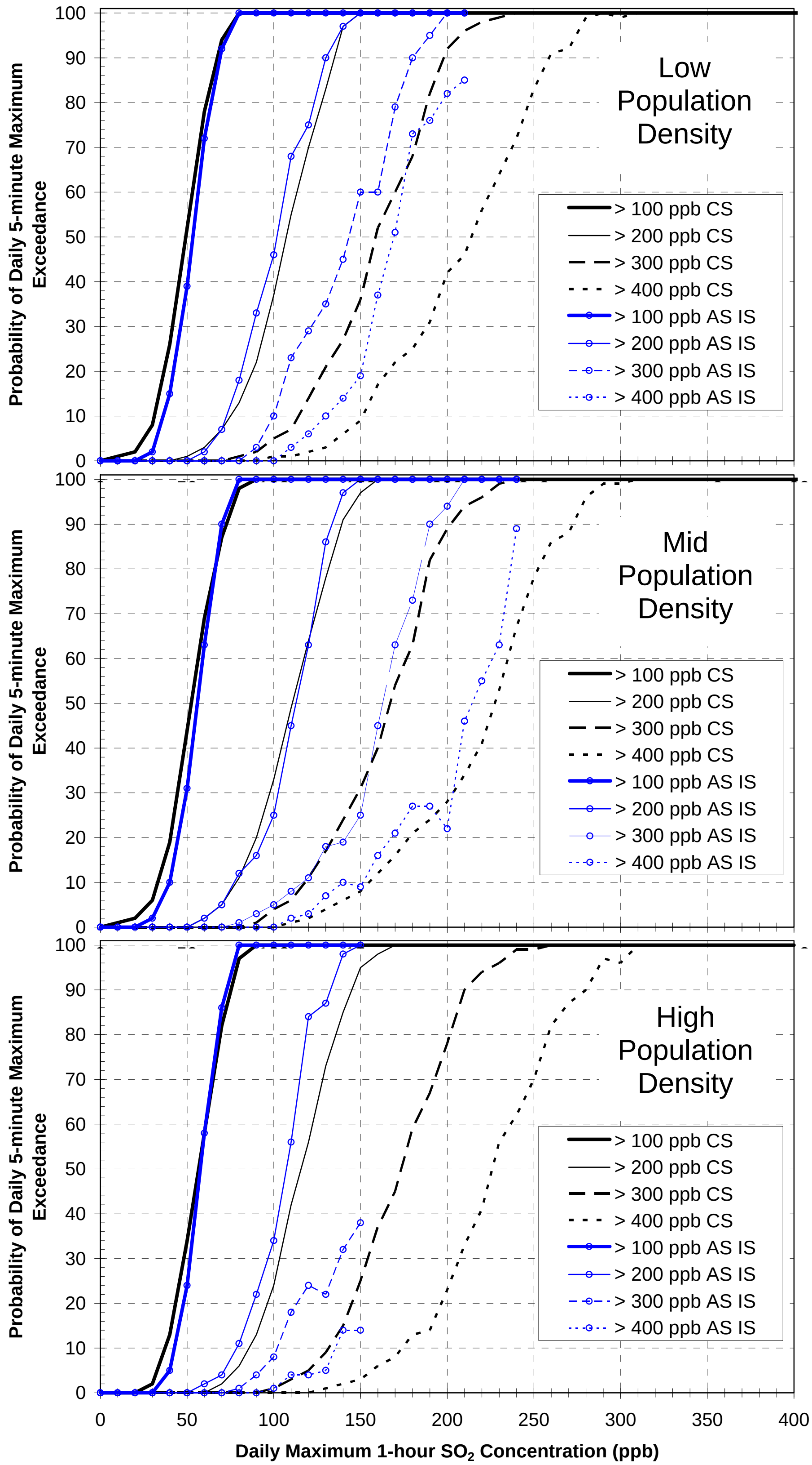

Figure 7-29. Probability of daily 5-minute maximum SO_2 concentrations above potential health effect benchmark levels given 1-hour daily maximum SO_2 concentrations, 2001-2006 air quality *as is* and that adjusted to just meet the current NAAQS. The 5-minute maximum concentrations were modeled from 1-hour measurements collected at 128 ambient monitors from 40 selected counties and then separated by population density within 5 km of monitors.

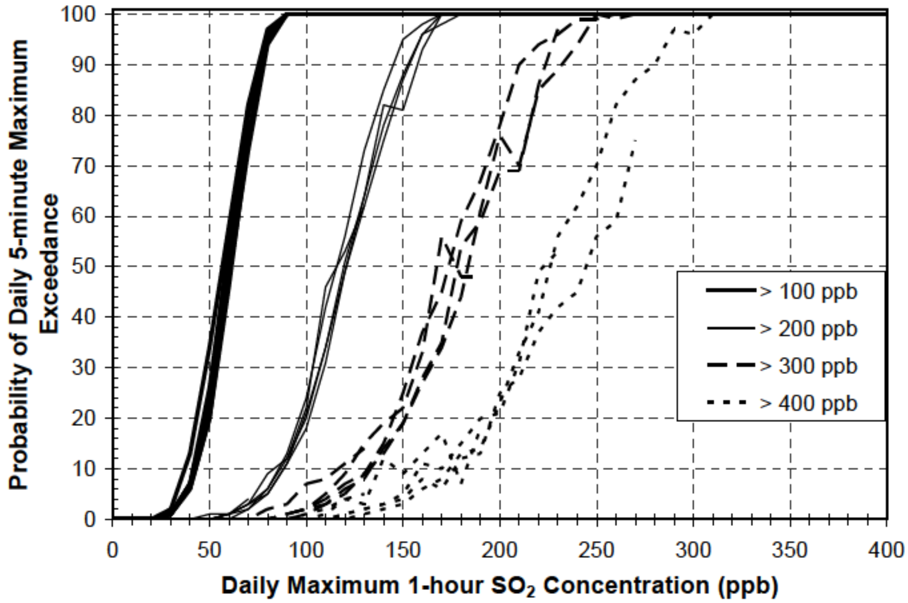

Figure 7-30. Probability of daily 5-minute maximum SO_2 concentrations above potential health effect benchmark levels given 1-hour daily maximum SO_2 concentrations, 2001-2006 air quality adjusted to just meet the current and each of the potential alternative standards (99th percentile form). The 5-minute maximum concentrations were modeled from 1-hour measurements collected at 128 ambient monitors from 40 selected counties, high-population density monitors.

While there are similarities in the probability of daily 5-minute maximum benchmark exceedances for each of the potential alternative standard scenarios given either the 1-hour daily maximum or 24-hour average SO_2 concentrations, there are large differences in the total number of exceedances given a particular county and air quality scenario. Table 7-11 presents the mean number of days in a year where the daily 5-minute maximum SO_2 concentration was above 100 ppb in each of the 40 selected counties and for all air quality scenarios. In considering air quality adjusted to just meeting the current standard and the level of the highest potential alternative standards (200 and 250 ppb 1-hour daily maximum), counties such as Hudson NJ, Tulsa OK, and Wayne WV were estimated to have the greatest number of benchmark exceedances. On average there would be between 100 and 200 days of the year with 5-minute maximum SO_2 concentrations above 100 ppb in these counties. Most of the other locations though had fewer than 100 benchmark exceedances in a year, particularly when considering the two potential alternative 1-hour daily maximum standards. Air quality simulating just meeting the current standard was associated with the greatest number of estimated exceedances at most locations. This consistent pattern was observed with each of the benchmark levels (see below) indicating the limited influence the current standard has on the estimated number of 5-minute benchmark exceedances. Decreases in the potential alternative standard level corresponded with decreases in the number of days per year with benchmark exceedances. Most counties have fewer mean estimated 5-minute benchmark exceedances of 100 ppb using air quality adjusted to just meeting the 99th percentile daily 1-hour maximum concentration of 100 ppb, than that estimated using the *as is* air quality. The were 11 counties that only achieve reduction in the number of benchmark level exceedances from *as is* air quality when considering the 99th percentile daily 1-hour maximum concentration of 50 ppb. This means that to improve current air quality in most locations, a level below 100 ppb would need to be selected when using a 99th percentile 1-hour daily maximum standard form.

In addition, the two percentile forms of the alternative standards (98th and 99th) were evaluated each at two 1-hour daily maximum standard levels (100 and 200 ppb) (Table 7-11). The estimated number of exceedances using a 98th percentile 1-hour daily maximum alternative standard level of 100 ppb fell within those estimated using 99th percentile levels of 100 and 150 ppb. The estimated number of exceedances using a 98th percentile 1-hour daily maximum alternative standard level of 200 ppb was similar to the 99th percentile using a 250 ppb 1-hour concentration level. Both of these patterns were consistent when comparing the different standard forms for each the 5-minute benchmarks (see Tables 7-12 through 7-14).

There were fewer estimated exceedances of 200 ppb given the potential alternative standards than compared with the current standard scenario (Table 7-12). Most counties had fewer than forty days per year with 5-minute SO_2 concentrations above 200 ppb considering the 1-hour daily maximum standards, while the number of exceedances was approximately double that when using air quality adjusted to just meet the current standard. With progressive decreases in the 1-hour daily maximum standard level, the number of days per year with 5-minute maximum SO_2 concentrations also decreases. In 75% of counties, the estimated number of benchmark exceedances using *as is* air quality was above that estimated using 1-hour daily maximum standard level of 100 ppb. The 99th percentile 1-hour daily maximum concentration level of 50 ppb was associated with the fewest days with 5-minute maximum SO_2 concentrations above 200 ppb. On average most locations had zero exceedances of the 200 ppb benchmark level.

Similar results are presented for each the 300 ppb (Table 7-13) and the 400 ppb (Table 7-14) 5-minute benchmark levels, though the difference in the number of exceedances between the current standard and the other air quality scenarios is much greater than was observed for the lower benchmark levels. Most counties had a 5-fold (or greater) number of days with daily 5-minute maximum SO_2 concentrations above 300 or 400 ppb when considering air quality just meeting the current standard compared with air quality adjusted to just meet the 99th percentile 1-hour daily maximum level of 250 ppb. The number of exceedances given *as is* air quality was still within the range of values estimated using the potential standard levels of 100 and 200 ppb; in most counties it was fewer than 10 days per year. Most counties did not have any estimated days per year with 5-minute maximum SO_2 concentrations above 400 ppb given a 99th percentile 1-hour daily maximum of 100 ppb, while 75% of the counties had 1 or fewer exceedances of 300 ppb considering this same potential alternative standard.

Table 7-11. Modeled mean number of days per year with 5-minute maximum concentrations above 100 ppb in 40 selected counties given 2001-2006 air quality *as is* and air quality adjusted to just meet the current and alternative standards.

State	County	*as is*[1]	CS[1]	99th percentile[1]					98th percentile[1]	
				50	100	150	200	250	100	200
AZ	Gila	119	234	9	36	63	89	111	47	107
DE	New Castle	21	123	1	8	19	34	50	12	46
FL	Hillsborough	22	127	3	12	23	37	50	18	53
IL	Madison	24	166	1	11	25	42	60	18	61
IL	Wabash	42	139	6	17	30	43	54	29	64
IN	Floyd	47	211	8	24	43	62	81	34	83
IN	Gibson	58	122	8	23	37	50	63	29	61
IN	Lake	17	186	3	20	41	64	91	31	93
IN	Vigo	27	184	2	12	27	44	63	21	68
IA	Linn	29	103	8	25	42	56	68	32	66
IA	Muscatine	34	123	9	26	41	54	68	32	65
MI	Wayne	29	134	2	18	40	62	80	25	76
MO	Greene	20	92	8	24	37	47	59	30	57
MO	Iron	65	108	9	30	40	48	55	34	54
MO	Jefferson	70	150	6	22	37	50	61	31	61
NH	Merrimack	46	118	7	31	52	68	81	37	76
NJ	Hudson	3	145	1	20	62	111	161	35	150
NJ	Union	2	117	1	16	51	98	141	25	122
NY	Bronx	8	124	2	28	71	115	155	39	137
NY	Chautauqua	38	172	6	18	33	50	70	23	65
NY	Erie	60	163	13	34	52	68	83	39	75
OH	Cuyahoga	16	203	2	23	55	93	122	39	129
OH	Lake	44	164	3	20	41	61	80	27	73
OH	Summit	51	198	3	23	51	81	110	30	96
OK	Tulsa	26	202	4	43	93	133	162	62	154
PA	Allegheny	30	159	1	8	22	41	65	12	58
PA	Beaver	76	194	2	11	30	55	83	18	79
PA	Northampton	14	130	2	25	56	87	114	41	127
PA	Warren	63	110	3	17	33	48	62	25	62
PA	Washington	25	185	2	21	53	88	125	29	110
TN	Blount	62	116	3	19	42	63	83	26	75
TN	Shelby	11	144	3	13	26	39	53	21	57
TN	Sullivan	75	201	2	20	49	74	94	40	100
TX	Jefferson	24	132	3	19	40	58	75	24	68
VA	Fairfax	0	109	1	17	54	98	143	29	129
WV	Brooke	76	220	3	25	62	101	140	40	135
WV	Hancock	78	207	2	21	52	86	118	32	110
WV	Monongalia	39	172	3	15	26	38	50	22	54
WV	Wayne	30	201	4	33	83	138	180	47	166
VI	St Croix	8	67	1	4	11	20	30	10	37

Notes:
[1] These are the air quality scenarios evaluated: *as is* is unadjusted air quality; CS is air quality adjusted to just meet the current standard; the levels of the two percentile forms (99th and 98th) of a 1-hour daily maximum potential alternative standard are given.

Table 7-12. Mean number of modeled days per year with 5-minute maximum concentrations above 200 ppb in 40 selected counties given 2001-2006 air quality *as is* and that adjusted to just meet the current and alternative standards.

				99th percentile[1]					98th percentile[1]	
State	**County**	***as is*[1]**	**CS[1]**	**50**	**100**	**150**	**200**	**250**	**100**	**200**
AZ	Gila	55	171	0	9	22	36	49	15	47
DE	New Castle	4	38	0	1	4	8	13	2	12
FL	Hillsborough	6	50	1	3	7	12	17	5	18
IL	Madison	5	66	0	1	5	11	17	3	18
IL	Wabash	17	75	1	6	11	17	23	11	29
IN	Floyd	17	117	1	7	16	24	33	12	34
IN	Gibson	28	70	1	8	16	22	30	11	29
IN	Lake	2	80	0	3	10	20	31	6	31
IN	Vigo	6	90	0	2	6	12	19	4	21
IA	Linn	10	53	2	8	17	25	34	12	33
IA	Muscatine	14	57	1	9	18	26	34	12	32
MI	Wayne	5	61	0	2	9	18	29	4	25
MO	Greene	6	47	1	8	16	24	31	12	30
MO	Iron	44	77	0	9	21	29	36	13	34
MO	Jefferson	38	99	0	6	14	22	29	11	31
NH	Merrimack	14	68	1	7	18	30	42	10	37
NJ	Hudson	0	31	0	1	7	20	39	3	34
NJ	Union	0	22	0	1	6	15	31	2	24
NY	Bronx	0	32	0	2	11	27	48	3	38
NY	Chautauqua	15	88	1	6	11	18	25	8	24
NY	Erie	29	86	2	13	24	34	43	15	38
OH	Cuyahoga	1	85	0	2	10	23	38	5	38
OH	Lake	11	71	0	3	10	20	30	4	26
OH	Summit	11	96	0	3	12	24	37	4	31
OK	Tulsa	2	112	0	5	19	42	69	9	62
PA	Allegheny	5	52	0	1	3	8	14	1	12
PA	Beaver	17	88	0	2	5	11	20	3	18
PA	Northampton	2	40	0	3	10	25	40	5	41
PA	Warren	25	52	0	3	9	17	25	6	25
PA	Washington	3	66	0	2	10	21	36	4	29
TN	Blount	19	54	0	3	10	20	31	4	26
TN	Shelby	2	35	0	3	7	13	20	5	21
TN	Sullivan	21	121	0	2	9	21	35	6	39
TX	Jefferson	5	71	0	3	10	19	29	5	25
VA	Fairfax	0	21	0	1	6	17	34	2	28
WV	Brooke	16	96	0	3	12	26	43	6	40
WV	Hancock	17	96	0	2	9	21	36	4	32
WV	Monongalia	15	63	0	3	9	15	21	6	22
WV	Wayne	3	71	0	4	16	33	58	6	48
VI	St Croix	2	24	0	1	3	4	7	2	10

Notes:
[1] These are the air quality scenarios evaluated: *as is* is unadjusted air quality; CS is air quality adjusted to just meet the current standard; the levels of the two percentile forms (99^{th} and 98^{th}) of a 1-hour daily maximum potential alternative standard are given.

Table 7-13. Mean number of modeled days per year with 5-minute maximum concentrations above 300 ppb in 40 selected counties given 2001-2006 air quality *as is* and that adjusted to just meet the current and alternative standards.

State	County	*as is*[1]	CS[1]	99th percentile[1]					98th percentile[1]	
				50	100	150	200	250	100	200
AZ	Gila	31	130	0	2	9	18	27	4	25
DE	New Castle	1	17	0	0	1	3	5	1	5
FL	Hillsborough	3	27	0	1	3	6	8	2	9
IL	Madison	1	35	0	0	1	4	7	1	7
IL	Wabash	9	50	0	2	6	9	13	6	17
IN	Floyd	8	75	0	3	8	13	18	5	19
IN	Gibson	16	47	0	3	7	13	18	4	17
IN	Lake	0	42	0	1	3	8	13	2	13
IN	Vigo	2	49	0	1	2	5	8	1	9
IA	Linn	5	35	0	4	8	14	19	6	19
IA	Muscatine	6	39	0	4	9	15	20	6	19
MI	Wayne	1	32	0	0	2	6	12	1	10
MO	Greene	2	32	0	3	7	13	19	5	18
MO	Iron	33	61	0	1	9	17	24	4	23
MO	Jefferson	24	72	0	1	6	11	17	4	18
NH	Merrimack	5	46	0	3	7	14	22	4	19
NJ	Hudson	0	7	0	0	1	4	10	0	9
NJ	Union	0	5	0	0	1	3	8	0	6
NY	Bronx	0	9	0	0	2	7	16	0	11
NY	Chautauqua	9	52	0	2	6	10	13	3	12
NY	Erie	17	59	0	5	13	20	27	6	24
OH	Cuyahoga	0	39	0	0	2	7	13	1	13
OH	Lake	3	41	0	0	2	7	13	1	10
OH	Summit	2	51	0	1	3	8	15	1	12
OK	Tulsa	0	60	0	1	4	12	26	2	22
PA	Allegheny	1	21	0	0	1	2	4	0	4
PA	Beaver	6	42	0	0	2	4	7	1	6
PA	Northampton	1	16	0	1	3	7	15	1	14
PA	Warren	11	31	0	1	3	7	11	1	11
PA	Washington	1	28	0	0	2	7	13	1	10
TN	Blount	7	28	0	0	3	7	13	1	10
TN	Shelby	0	19	0	1	3	6	9	2	10
TN	Sullivan	7	83	0	0	2	6	12	2	15
TX	Jefferson	1	43	0	1	3	7	13	1	10
VA	Fairfax	0	5	0	0	1	4	9	0	7
WV	Brooke	5	45	0	1	4	8	16	2	15
WV	Hancock	4	48	0	0	2	6	12	1	10
WV	Monongalia	7	36	0	1	3	6	11	2	12
WV	Wayne	1	31	0	1	4	10	21	1	16
VI	St Croix	0	11	0	0	1	2	3	1	4

Notes:
[1] These are the air quality scenarios evaluated: *as is* is unadjusted air quality; CS is air quality adjusted to just meet the current standard; the levels of the two percentile forms (99th and 98th) of a 1-hour daily maximum potential alternative standard are given.

Table 7-14. Mean number of modeled days per year with 5-minute maximum concentrations above 400 ppb in 40 selected counties given 2001-2006 air quality *as is* and that adjusted to just meet the current and alternative standards.

				99th percentile[1]					98th percentile[1]	
State	County	*as is*[1]	CS[1]	50	100	150	200	250	100	200
AZ	Gila	18	102	0	0	3	9	15	1	14
DE	New Castle	0	9	0	0	0	1	2	0	2
FL	Hillsborough	2	17	0	1	2	3	5	1	5
IL	Madison	0	21	0	0	0	1	3	0	3
IL	Wabash	6	36	0	1	4	6	8	3	10
IN	Floyd	5	52	0	1	4	8	11	3	12
IN	Gibson	10	34	0	1	4	8	11	2	12
IN	Lake	0	23	0	0	1	3	6	1	6
IN	Vigo	1	30	0	0	1	2	3	1	4
IA	Linn	2	24	0	2	5	9	12	3	12
IA	Muscatine	3	28	0	2	5	9	13	2	12
MI	Wayne	0	18	0	0	1	2	5	0	4
MO	Greene	1	23	0	1	4	8	12	2	11
MO	Iron	25	50	0	0	3	9	15	1	13
MO	Jefferson	16	54	0	0	2	6	10	1	11
NH	Merrimack	2	31	0	1	3	7	12	1	10
NJ	Hudson	0	2	0	0	0	1	3	0	3
NJ	Union	0	1	0	0	0	1	2	0	2
NY	Bronx	0	2	0	0	0	2	5	0	3
NY	Chautauqua	6	34	0	1	3	6	9	2	8
NY	Erie	10	44	0	2	7	13	18	3	15
OH	Cuyahoga	0	19	0	0	1	2	5	0	5
OH	Lake	1	25	0	0	1	3	6	0	4
OH	Summit	1	30	0	0	1	3	6	0	5
OK	Tulsa	0	30	0	0	1	4	10	0	8
PA	Allegheny	0	10	0	0	0	1	2	0	1
PA	Beaver	3	22	0	0	1	2	3	0	3
PA	Northampton	0	7	0	0	1	3	6	1	5
PA	Warren	5	19	0	0	1	3	6	0	6
PA	Washington	0	13	0	0	1	2	5	0	4
TN	Blount	3	15	0	0	1	3	5	0	4
TN	Shelby	0	12	0	0	1	3	5	1	5
TN	Sullivan	3	58	0	0	1	2	5	0	6
TX	Jefferson	1	27	0	0	1	3	6	1	5
VA	Fairfax	0	1	0	0	0	1	3	0	2
WV	Brooke	2	24	0	0	1	3	7	0	7
WV	Hancock	1	25	0	0	0	2	5	0	4
WV	Monongalia	3	25	0	0	1	3	5	1	6
WV	Wayne	0	14	0	0	1	4	8	0	6
VI	St Croix	0	6	0	0	0	1	2	0	2

Notes:
[1] These are the air quality scenarios evaluated: *as is* is unadjusted air quality; CS is air quality adjusted to just meet the current standard; the levels of the two percentile forms (99th and 98th) of a 1-hour daily maximum potential alternative standard are given.

7.4 VARIABILITY ANALYSIS AND UNCERTAINTY CHARACTERIZATION

As discussed in section 6.6, there can be variability and uncertainty in risk and exposure assessments. This section presents a summary of and associated discussions regarding the degree to which variability was incorporated in the air quality analyses and how the uncertainty was characterized for the estimated air quality benchmark exceedances.

7.4.1 Variability Analysis

To the maximum extent possible given the data, time, and resources available for the assessment, staff accounted for variability within the two main components of the air quality characterization: the ambient monitoring concentrations and the statistical model used to estimate 5-minute maximum SO_2 concentrations. The variability accounted for in this analysis is summarized in Table 7-15.

Table 7-15. Summary of how variability was incorporated into the air quality characterization.

Component	Variability	Comment
Ambient SO_2 Monitoring Data	Temporal: 10 to 11 years of 1-hour and 5-minute monitoring data	Broader SO_2 monitoring network and monitors reporting 5-minute maximum concentrations. Subset of 40 counties for detailed analyses comprised two 3-year periods (2001-2003; 2004-2006)
	Spatial: 48 states plus 3 US territories totaling 407 counties.	Broader SO_2 monitoring network. Other analyses considered monitor results separated by population density. Subset of 40 counties for detailed analyses comprised 18 states and 1 US territory.
	9 air quality scenarios	40 county analysis included air quality *as is*, just meeting the current standard and 5 levels (50, 100, 150, 200, 250 ppb) of two percentile forms (98^{th} and 99^{th}); effectively creating a varying decision surface.
5-Minute Peak Statistical Model	19 peak-to-mean (PMR) distributions	PMR distributions used non-parametric form derived from measurement data (complete range of values from 1 to <12). Three monitor concentration variability bins used as a surrogate for variability in local source emissions, along with seven concentration bins. Twenty simulations using random sampling generated a best estimate of exceedances per site-year of data.

7.4.2 Uncertainty Characterization

As discussed in section 6.6, the approach for evaluating uncertainty was adapted from guidelines outlining how to conduct a qualitative uncertainty characterization (WHO, 2008). Staff selected the mainly qualitative approach given the limited data available to inform a probabilistic uncertainty characterization, and time and resource constraints. This qualitative approach used here varies from that of WHO (2008) in that the primary focus is placed on evaluating the impact of the uncertainty; that is, staff qualitatively rate how the source of uncertainty, in the presence of alternative and possibly improved data or information, may affect the estimated number of days with benchmark exceedances. In addition, and consistent with the WHO (2008) guidance, staff discuss the uncertainty in the knowledge-base (e.g., the accuracy of the data used, acknowledgement of data gaps) and decisions made (e.g., selection of particular model forms), though qualitative ratings were assigned only to uncertainty regarding the knowledge-base.

After identifying the key sources of the assessment that may contribute to uncertainty, staff subjectively scaled the magnitude[47] of each identified source of uncertainty and the associated direction of potential influence to the number of benchmark exceedances. We used a three level scale to rate the magnitude: *low* indicated that large changes within the source of uncertainty would have only a small effect on the estimated number of exceedances, *medium* implied that a change within the source of uncertainty may have a proportional effect on the results, and *high* indicated that a small change in the source would have a large effect on results. The direction of influence on number of exceedances was subjectively assigned as *over-estimated*, *under-estimated*, *both* (uncertainty affects assessment endpoint in either direction), or *unknown* (no evidence to judge the uncertainty). Staff also subjectively scaled the knowledge-base uncertainty associated with each identified source using a three level scale: *low* indicated significant confidence in the data used and its applicability to the assessment endpoints, *medium* implied that there were some limitations regarding consistency and completeness of the data used or scientific evidence presented, and *high* indicated the knowledge-base was extremely limited.

Table 7-16 provides a summary of the sources of uncertainty identified in the air quality characterization, the level of uncertainty, and the overall judged bias of each. Further discussion regarding each of these sources of uncertainty and how conclusions were drawn is given in the sections that follow.

[47] This is synonymous with the "level of uncertainty" discussed in WHO (2008), section 5.1.2.2.

Table 7-16. Summary of qualitative uncertainty analysis for the air quality and health risk characterization.

Source	Type	Influence of Uncertainty on Air Quality Benchmark Exceedances		Knowledge-Base Uncertainty	Comments[1]
		Direction	Magnitude		
Air Quality Data	Database Quality	Over	Low	Low	INF: There may be a limited number of poor quality high concentration data within the analytical data sets, potentially influencing the number of benchmark exceedances. KB: Data used in the analyses are of high quality. There is no other source of monitoring data as comprehensive. Data are being used in a manner consistent with one of the defined purposes of ambient monitoring.
Ambient Measurement Technique	Interference	Both	Low – Medium	Medium	INF: Potential interferences can be controlled; the influence may be of greater magnitude when considering upward concentration adjustment procedure. KB: Limited knowledge on concentration dependencies at high concentrations. Limited knowledge of interference controls applied at individual monitors.
Temporal Representation of Monitoring Data	Scale	Unknown	Low – Medium	Medium	INF: Temporal scale is appropriate for analysis performed. Most data used are screened for temporal completeness; however where 5-minute concentrations were reported, data were not screened for completeness. KB: Limited knowledge on direction or magnitude; however 60% of data used would have passed completeness criteria.
	Missing Data	Under	Low	Low	INF: Staff assumed there was an equal probability of missing low and high concentration 5-minute measurements; there could be a few missing high concentration data that would lead to underestimation in benchmark exceedances. No interpolation was performed. KB: All available data are quality assured; most of the data used were temporally complete.

Source	Type	Influence of Uncertainty on Air Quality Benchmark Exceedances		Knowledge-Base Uncertainty	Comments[1]
		Direction	Magnitude		
	Years Evaluated	Over	Low	Low	INF & KB: Little variation in COV and PMRs over years of analysis. Estimates of the probability of exceedances are likely not affected. Estimated number of exceedances could be influenced by historically high concentrations.
Spatial Representation of Monitoring Network	Broader SO_2 Network and 40 County Data Set	Under	Medium	High	INF: It is possible that the current network is not adequately capturing 1-hour SO_2 from a few localized sources. However, given the purpose of the network and purpose of the assessment, staff judges there may be at most a medium level of influence on results with improved spatial representation. KB: Many site-years available from monitors reporting 1-hour concentrations; However, there are no data available to evaluate the spatial representativeness of existing network.
	5-minute Maximum SO_2	Under	Medium	High	INF: Distribution of sources potentially influencing monitors is similar to that of the broader SO_2 network even with limited geographic span. KB: Very few site-years available from monitors reporting 5-minute measurements.
Air Quality Adjustment Procedure	Proportional Approach Used	Both	Low – Medium	Medium	INF: Depends on the degree of proportionality in the air quality distribution and the magnitude of the ambient concentration adjustment. KB: Proportional approach judged adequate in representing the alternative air quality scenarios. However, evaluation only conducted in 7 of 40 counties, was dependent on historic air quality as representative of alternative scenarios, and there was some evidence of deviation from proportionality. Also only one adjustment method was investigated.

Source	Type	Influence of Uncertainty on Air Quality Benchmark Exceedances		Knowledge-Base Uncertainty	Comments[1]
		Direction	Magnitude		
	Spatial Scale	Both	Medium	High	INF: The rate of change in concentrations over time was moderately different at monitors within a county. KB: Analysis is dependent on historic air quality as representative of alternative air quality scenarios. There is lack of knowledge regarding how changes in emissions would affect multiple monitors in a county.
Statistical Model Used for Estimating 5-minute SO_2 Concentrations	Data Screening	Over	Low	Low	INF & KB: Less than 2% of data were removed. Physically realistic PMR bounds were set. Screened data were mostly of low 1-hour concentrations that would never generate a benchmark exceedance.
	Temporal Variation in PMRs	None	Low	Low	INF: Consistency in PMRs across period of analysis. KB: Consistency in PMRs when compared with late 1980s and early 1990s ambient monitoring data.
	Distribution Form of PMRs	None	Low	Low	INF & KB: Non-parametric distributions were determined the most appropriate for the analysis.
	Accuracy	Both	Low – Medium	Medium	INF: Accuracy assessment indicated good agreement, though at upper and lower tails of prediction distribution, the number of exceedances were under- and over-estimated, respectively. KB: Though cross-validation results were reasonable, there may be additional influential variables that may be important in the model construction and possibly not available in extrapolating to the broader data set.
	Reproducibility	None	Low	Low	INF & KB: Limited variation observed in the estimated mean number of benchmark exceedances following random sampling error analysis.
Potential Health Risk Endpoints Used[2]	Ambient SO_2 as an Indicator of SO_2 Exposure	Over	Medium	High	INF: Long-term time averaging comparisons indicate a strong proportional relationship between ambient concentration and personal exposure. KB: The relationship between 5-minute personal exposure and ambient concentration is not known.

Source	Type	Influence of Uncertainty on Air Quality Benchmark Exceedances		Knowledge-Base Uncertainty	Comments[1]
		Direction	Magnitude		
	Consideration of Susceptible Populations	Unknown	Low	Medium	INF & KB: Severe asthmatics are typically not challenged in clinical studies due to expectations of a significant adverse response. Potential health risk could be over- or under-estimated depending on the level of the lowest benchmark selected to represent susceptible individuals. KB: There is no clear quantitative evidence indicating lowest benchmark would either be health protective or at a level a susceptible individual would respond.
	Averaging Time	None	Low	Low	INF & KB: consistently no difference reported in observed responses from either 5- or 10-minute clinical studies.
	Single Counts of Exceedances versus Multiple Exceedances per day	Under	Low	Medium	INF: Potential health risk may be under-estimated because approximately 50% of days with a single exceedance correspond with another (or more) exceedance(s) in that same day. However, in this air quality analysis, time of exposure is not considered, thus limiting the relevance of multiple exceedances. KB: Frequency of multiple exceedances per day using existing measurement data is known for limited number of monitoring sites.

Notes:
[1] INF refers to comments associated with the influence rating; KB refers to comments associated with the knowledge-base rating.
[2] In these cases the influence of the uncertainty to the potential health risk is discussed, not the influence to the estimated number of exceedances.

7.4.2.1 Air Quality Data

The purpose of this section is to discuss staff assumptions and potential uncertainties associated with the data used to construct the various analytical data sets. While the data are being used in a manner consistent with one of the defined purposes of ambient monitoring (i.e., assessing population exposure), both the source of data and its associated quality are discussed. The uncertainty regarding temporal and spatial components of the ambient monitoring data sets is discussed in sections 7.4.2.3 and 7.4.2.4, respectively.

The Air Quality System (AQS) contains ambient SO_2 concentrations collected by EPA, state, local, and tribal air pollution control agencies from hundreds of monitoring stations across the U.S. There are no alternative ambient monitoring data sets available that are as comprehensive as those within AQS. There might be ambient monitoring data available that are not included in the AQS however, staff assumed that given similar collection techniques and quality assurance methods that they would be complementary to AQS monitoring data.

One basic assumption is that the AQS SO_2 air quality data used are quality assured already. Methods exist for ensuring the precision and accuracy of the ambient monitoring data (e.g., EPA, 1983). Reported concentrations contain only valid measures, since values with quality limitations are not entered into the system or are removed following determination of being of lower quality or flagged. There is likely no selection bias in retaining data that are not of reasonable quality if the data are in error; it was assumed that selection of high concentration poor quality data would be just as likely as low concentration data of poor quality. However, the retention of poor quality high concentration data would have greater impact on estimated numbers of exceedances than poor quality low concentration data. Given the numbers of measurements used for the analyses though, it is likely that even if a few poor quality high concentration data are present in the analytical data sets, they would not have a large impact on the results presented here. In addition, a quantitative analysis of available duplicate measures (i.e., originating from co-location of ambient monitors or by duplicate reporting of ambient concentrations, see Appendix A-3) indicated little to no difference in the duplicate values or in the selection of one particular reported (or measured) value over another.

Based on this evaluation, the source and the quality of the ambient monitoring data used likely contribute minimally to uncertainty in the estimated number of benchmark exceedances.

Thus, there is both a low level of uncertainty in the knowledge-base and in the subjectivity of choices made by staff.

7.4.2.2 Ambient Measurement Technique

One potential source of uncertainty within the SO_2 air quality measurements is from interference with other compounds. The ISA notes several sources of positive and negative interference that could increase the uncertainty in the measurement of ambient SO_2 concentrations (ISA, sections 2.3.1 and 2.3.2). Many of the identified sources (e.g., polycyclic aromatic hydrocarbons, stray light, collisional quenching) were described as having limited impact on SO_2 measurement due to the presence of instrument controls that prevent the interference.

The actual impact on any individual monitor though is unknown; the presence of either negative or positive interference, and the degree of interference contributed by one or the other, has not been quantified for any ambient monitor. In addition, it is not known whether there is a concentration dependence on the amount of interference. This may be an important uncertainty in considering the air quality concentrations adjusted to just meet the current and potential alternative standards.

Reported ambient monitoring concentrations could be either over- or under-estimated depending on the type of interference present. Staff judges the magnitude of influence as low to medium, given the potential range of instrument controls present (low magnitude) and possibility for concentration dependence (medium magnitude). The uncertainty in the knowledge-base is judged as medium given the limited quantitative evidence available to assess the potential direction and magnitude of interference at individual monitors, as well as limited evidence regarding the presence of concentration dependence.

7.4.2.3 Temporal Representation of Monitoring Data

Three components of uncertainty were evaluated regarding the temporal representation of the monitoring data. These include uncertainty in the temporal scale (i.e., averaging time of measurements and completeness criteria), how missing data were treated in the analysis, and long term trends in ambient monitoring and concentration variability.

The air quality analysis relied on quality assured 5-minute and 1-hour average SO_2 measurement data (see section 7.4.2.1) and are of the same temporal scale as identified potential health effect benchmarks, where 5-minute measurements were reported. There are frequent missing values within a given valid year that may increase the level of uncertainty in temporal concentration distributions and model estimations (see below); however, given the level of the benchmark concentrations and the low frequency of benchmark exceedances and overall completeness of the monitoring data, it is likely of limited consequence. The magnitude of impact on estimated benchmark exceedances could be significant if some seasons, day-types (e.g., weekday/weekend), or times of the day (e.g., nighttime or daytime) were not equally represented in the data analysis group. For the analyses performed using the broader SO_2 monitoring network and the 40-county data set, a valid year of ambient monitoring was based on 75 percent complete hours/day and days/quarter, and having all four complete quarters/year. The process of assuring temporal completeness prevented potentially influential monitoring data from adversely affecting the air quality characterization using these data sets.

However, there is greater uncertainty in the temporal representation of the combined 5-minute and 1-hour measurement data set because all of the available data were used without considering the standard 75% completeness criteria. Staff elected to use all of the 5-minute SO_2 measurement data rather than further reducing the already limited number of samples and locations represented. The 5-minute measurement data set did however undergo a limited screening that improved the quality of the data set. This included removal of duplicate reporting/measurements, exclusion of concentrations < 0.1 ppb, and screening for technically impossible PMRs (see section 7.4.2.6). These screenings and use of the 5-minute data without the same completeness criteria as the other data analysis groups though would tend to decrease the temporal representation, potentially influencing the observed probability and the estimated number of benchmark exceedances.

Therefore, staff judges the magnitude of influence from this source of uncertainty as low to medium, with a greater magnitude of influence assigned to observations reported for the 5-minute data set and its application in the statistical model. While staff has not performed analyses to determine direction and magnitude of impact in applying the completeness criteria to the 5-minute data set, the uncertainty in the knowledge-base is judged as medium given the overall temporal representation of most of the site-years of data.[48]

Data were not interpolated in the analysis; missing data were not substituted with estimated values and concentrations reported as zero were used as is. For the missing data, it is assumed here that missing values are not systematic, i.e., both high and low concentration data would be absent in equal proportions. There are methods available that can account for time-of-day, day-of-week, and seasonal variation in ambient monitoring concentrations. However, if a method were selected, it would have to not simply interpolate the data but also accurately estimate the probability of peak 1-hour SO_2 concentrations that could occur outside the predictive range of the method. It was judged that if such a method was available or one was developed to substitute data, it would likely add to a similar level of uncertainty as not choosing to substitute the missing values. Again, this can be viewed as having a limited impact on the estimated number of exceedances because using the validity criteria selected for the most temporally representative and complete ambient monitoring data sets possible. In addition, when using the concentrations reported as zero, there is likely limited impact on the estimated number of exceedances and associated probability of exceedances. It is possible that some missing data could have been at a high enough concentration to either exceed a benchmark or result in an estimated benchmark exceedance, implying the direction of influence is towards under-estimating benchmark exceedances. However, given the temporal completeness of much of the data used characterizing air quality, staff judges both the magnitude of influence of missing data and the uncertainty associated with the knowledge-base to be low.

There is uncertainty associated with the selection of monitoring years, particularly if concentrations vary significantly between monitors and across the two averaging times. When using historical monitoring data, staff assumed that the sources present at that time have similar emissions and emission profiles as the current sources. It is clear that the number of SO_2 monitoring sites in the U.S. has changed over time, with a trend of decreasing number of monitors most evident for those reporting the 5-minute maximum SO_2 concentrations (Figure 7-31). Five-minute SO_2 concentrations have been reported in fewer monitors than the 1-hour SO_2 concentrations; generally only a few site-years of data exist for 5-minute SO_2 concentrations

[48] Screening for completeness using the 75% hours/day and days/year criteria would have resulted in only 85 site-years of data. However, this screened data set would include 1,431,470 hours or 60% of the data set used in the current analyses.

(Appendix A, Table A.1-1). This is the reason why, given the limited number of measurements, all of the 5-minute maximum SO_2 data were used in developing the statistical relationships and for the model evaluation without requiring the 75% completeness criteria to be met.

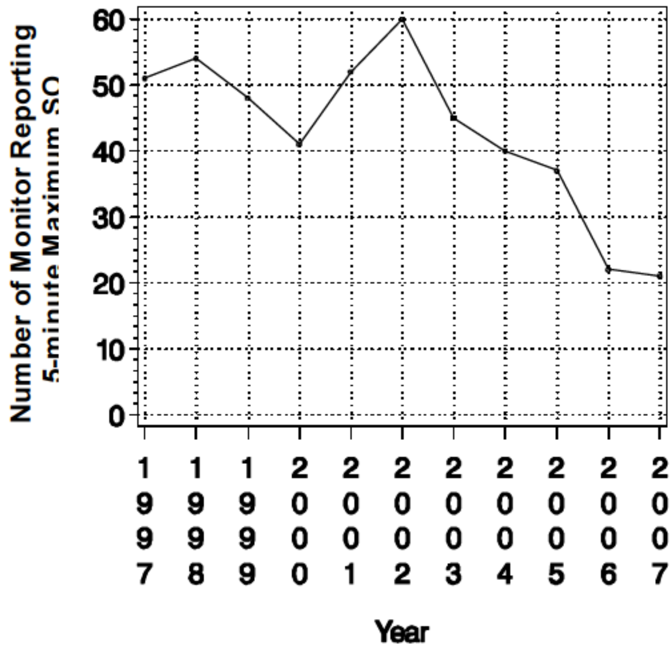

Figure 7-31. Temporal trends in the number of ambient monitors in operation per year for monitors reporting both 5-minute and 1-hour SO_2 concentrations.

However, the variability in monitoring concentrations (both the 1-hour and 5-minute maximum SO_2) does not change significantly across most monitoring years (i.e., years 1997 though 2004) and there is a comparable range between the two averaging times (Figure 7-32). There is some compression in the range of COVs considering some of the more recent years of data, most notable for year 2007. This is possibly due to the reduction in the number of ambient monitors in operation (Figure 7-31) rather than a reduction in the temporal variability in 5-minute or 1-hour concentrations at particular monitors. There may be an over-estimate in the number of benchmark exceedances where there is a broad range of years used in the characterization. However, the estimated probability of exceedances is likely not influenced by year given that the analysis controls for concentration levels and variability changes that may have occurred over time. Furthermore, the selection of a subset of the recent air quality data (2001-2006) used for detailed analyses may reduce the potential impact from changes in national- or location-specific source influences (if one is present). Therefore, due to the limited variation in temporal trends in COV for both 5-minute and 1-hour SO_2 and analysis design (i.e., controlling for concentration level changes, limiting the span of years analyzed) the overall magnitude of influence is expected to be low.

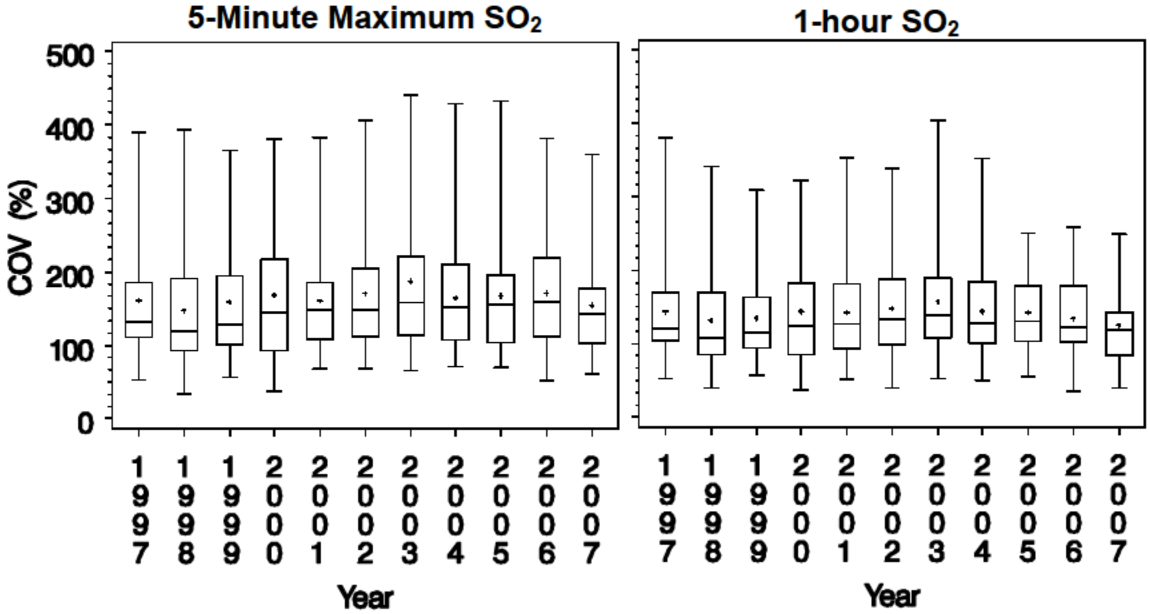

Figure 7-32. Temporal trends in the coefficient of variability (COV) for 5-minute maximum and 1-hour concentrations at the monitors that reported both 5-minute and 1-hour SO_2 concentrations. The number of monitors operating in each year is depicted in Figure 7-31.

7.4.2.4 Spatial Representation of Monitoring Network

The spatial representativeness of the monitoring network can be a source of uncertainty, particularly if the monitoring network is not dense enough to resolve the spatial variability in ambient SO_2 concentrations and if the monitors are not effectively distributed to reflect population exposure. Relative to the physical area, staff acknowledges there are only a few monitors, particularly when considering the set of monitors that reported 5-minute maximum SO_2. The magnitude and direction of influence on the modeled or measured benchmark exceedances will depend on ambient monitoring objectives, monitoring scale, the distribution of SO_2 emission sources, and whether there is large variability in monitoring surface, i.e., areas of differing terrain that are not adequately represented by the current distribution of monitors. These elements will be broadly discussed for each of the data sets used in the air quality characterization and how they could potentially affect the number and probability of benchmark exceedances. The three data sets of interest include monitors from the broader SO_2 network (including monitors within the 40 selected counties) and the monitors reporting 5-minute SO_2 concentrations.

The broader 1-hour monitoring network, by definition, is the most comprehensive data set of the three when considering the number of monitors (n=809) and geographic representation (48 U.S. States, Washington DC, Puerto Rico, and U.S. Virgin Islands). The air quality characterization is improved with the inclusion of modeled 5-minute benchmark exceedances in these areas where 5-minute measurements were not reported. In addition, the use of the broader SO_2 monitoring network in this assessment could assist in identifying and prioritizing locations to begin reporting 5-minute SO_2 measurements. However, the broader geographic span of ambient monitoring does not necessarily confer spatial representativeness. The spatial representativeness of the broader SO_2 monitoring network would remain dependent on the siting of the monitors with respect to important emission sources and potentially exposed populations. Staff assumes that the network design, to a large degree, provides adequate spatial representation of the ambient SO_2 air quality. This may apply to a greater degree to the 40-County data set that used a minimum number of monitors (i.e., >2) to represent a set geographical area (i.e., a county).

Staff acknowledges that in using the broader SO_2 monitoring network and 40-County data set as an indicator of exposure, there could be local areas that are spatially under-represented. Furthermore, portions of the air quality characterization used monitors meeting a 75 percent completeness criterion, without taking into account the monitoring objectives, scale, or land use. Thus, there may be a reduction in spatial representation due to either the inclusion or exclusion of monitors sited near local SO_2 source emissions as a result of the completeness screening. Staff estimates that the magnitude of influence to the number of benchmark exceedances may be at most a medium level in the presence of supplemental spatial monitoring, given the purposes of both the current monitoring network and the air quality characterization. We also judge there would be limited influence on the probability of exceedances with improved spatial representation, given that the probability estimate is driven by ambient concentration level and concentration variability, two variables that have been well characterized by the current ambient monitoring network. In the absence of additional measurements or modeling of the spatial heterogeneity of 1-hour ambient SO_2 concentrations though, staff assigns a high level of uncertainty to the knowledge-base.

The overall SO_2 monitoring network design is also responsible for siting monitors that reported 5-minute concentrations. As a result, staff expects that monitor siting is appropriate and spatially representative for the same reasons discussed above. However, because the monitors reporting 5-minute concentrations are not part of a designed 5-minute SO_2 monitoring network but are entirely voluntary, the direction and magnitude of influence on observed or estimated benchmark exceedances is largely unknown. Note that there were far fewer monitors reporting 5-minute concentrations used in certain analyses (n=98), representing a limited geographic scope in comparison with the broader SO_2 monitoring network. In addition, a greater percentage of monitors reporting 5-minute concentrations had a source-oriented objective (Figure 7-3). However, an analysis of the monitoring attributes indicated similar distributions in the types of sources and the total emissions potentially impacting both sets of data (Figure 7-5). This suggests that the spatial representation of the monitors reporting 5-minute concentrations may be similar to that of the broader SO_2 monitoring network regarding proximity to similar SO_2 sources. In the absence of additional measurements or modeling of the spatial heterogeneity of 5-minute ambient SO_2 concentrations, staff assigns a high level of uncertainty to the knowledge-base.

7.4.2.5 Air Quality Adjustment Procedure

There is uncertainty in the air quality adjustment procedure due to the uncertainty of the true relationship between the adjusted concentrations that are simulating a hypothetical scenario and the *as is* air quality. The adjustment factors used for the current and the potential alternative standards each assumed that all hourly concentrations will change proportionately at each ambient monitoring site. Two elements of this source of uncertainty are discussed, namely uncertainty regarding the proportional approach used and the universal application of the approach to all ambient monitors within each location.

Different sources have different temporal emission profiles, so that equally applied changes to the concentrations at the ambient monitors to simulate hypothetical changes in emissions may not correspond well within all portions of the concentration distribution. When adjusting concentrations upward to just meeting the current standard, the proportional adjustment used an equivalent multiplicative factor derived from the annual mean or daily mean concentration and equally applied that factor to all portions of the concentration distribution, that is, the upper tails were treated the same as the area of central tendency. This may not necessarily reflect changes in an overall emissions profile that may result from, for example, an increase in the number of sources in a location. It is possible that while the mean concentration measured at an ambient monitor may increase with an increase in the source emissions affecting concentrations measured at the monitor, the tails of the hourly concentration distribution might not have the same proportional increase. The increase in concentration at the tails of the distribution could be greater or it could be less than that observed at the mean and is dependent largely on the type of sources influencing the monitor and the source operating conditions. Adjusting the ambient concentrations upwards to simulate the potential alternative standards also carries a similar level of uncertainty although the multiplicative factors were derived from the upper percentiles of the 1-hour daily maximum SO_2 concentrations, rather than the mean, and then applied to the 1-hour SO_2 concentrations equally. If there are deviations from proportionality, the magnitude of influence is likely related to the magnitude of the concentration adjustment factor used. Therefore, there is likely greater uncertainty in the estimated benchmark levels when evaluating the current and the 250 ppb 99^{th} percentile alternative standards (which have the highest adjustment factors), than when considering the 50 ppb and 100 ppb 99^{th} percentile alternative standards (which have the lowest adjustment factors).

In each of these instances of adjusting the concentrations upwards, one could argue that there may be an associated over-estimation in the concentrations at the upper tails of the distributions, possibly leading to over-estimation in the numbers of exceedances of benchmark levels. An analysis was performed using monitors from seven counties evaluated in the air quality characterization to investigate how distributions of hourly SO_2 concentrations have changed over time (Rizzo, 2009). The analysis indicates that a proportional approach is a reasonable model for simulating higher concentrations at most monitoring sites, since historically, SO_2 concentrations have decreased linearly across the entire concentration distribution at each of the monitoring sites and counties evaluated.

At some of monitoring sites analyzed however, there were features not consistent with a completely proportional relationship. This included deviation from linearity primarily at the maximum or minimum percentile concentrations, some indication of curvilinear relationships, and the presence of either a positive or negative regression intercept (Rizzo, 2009). Where multiple monitors were present in a location, there tended to be a mixture of each of these conditions including proportionality (e.g., see Figure 7-33). Not all of the counties analyzed as part of the air quality characterization were included in the evaluation, thus staff assumed that the findings of the Rizzo (2009) analysis were applicable of the 40-County data set. Given the observed range of deviations from proportionality and the level of the concentration adjustment, we judge the magnitude of influence to the estimated benchmark exceedances as between low to medium. The estimated number of benchmark exceedances could be either over- or under-estimated, dependent largely on an individual monitor's air quality distribution and its relationship with proportionality. While staff judged the proportional approach as appropriate, it was based on analyses using historical monitoring data. The uncertainty about future source emission control scenarios is largely unknown. In addition, only one approach was investigated, suggesting that the level of the knowledge-base uncertainty is medium.

Staff applied the proportional adjustment approach universally to all monitors in each county for consistency. The purpose was to preserve the inherent variability in the concentration distribution which has been shown to be relatively consistent with large changes in concentration level. There is however uncertainty associated with emission changes that would affect the concentrations at the monitor having the highest concentration (e.g., the highest annual mean, 98^{th} or 99^{th} percentile 1-hour concentration) that may not necessarily be reflected in the same proportion at other lower concentration sites. This could result in either over- or under-estimations in the number of exceedances at lower concentration sites within a county where the current or alternative standard scenarios were evaluated. For example, Figure 7-33 shows the daily maximum 1-hour SO_2 concentration percentiles for five ambient monitors in Allegheny County PA, where each of the ambient monitors were in operation for years 1998 and 2007. While all five of the monitors generally demonstrate features of proportionality, the differences in regression slope indicate that the rate of change in the concentration distribution was not equal when comparing these monitors for these two monitoring years. These results suggest that even if all monitors within a county demonstrate proportionality, there may be either over- or under-estimations in SO_2 concentrations following the 1-hour concentration adjustment. Staff had limited time and resources to investigate the potential impact of this on the number of benchmark exceedances, though we estimate the magnitude of influence as medium based on the range of observed slopes in the seven counties investigated. The level of uncertainty in the knowledge-base is judged high. This rating is based on the uncertainty regarding how the historical and recent ambient data comparisons relate to the simulated air quality scenario and the lack of knowledge regarding how source emission changes would affect multiple monitors within a county.

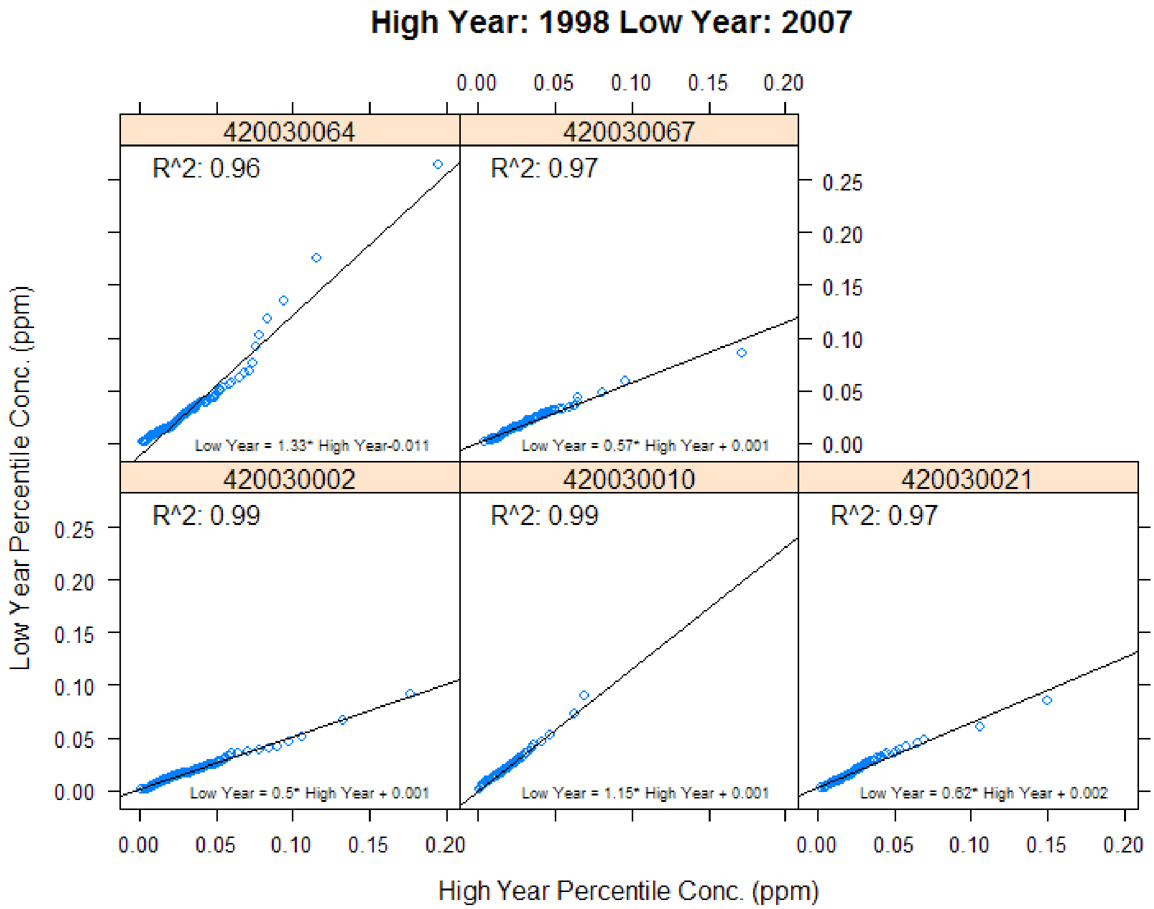

Figure 7-33. Comparison of measured daily maximum SO_2 concentration percentiles in Allegheny County PA for one high concentration year (1998) versus a low concentration years (2007) at five ambient monitors.

7.4.2.6 Statistical Model Used for Estimating 5-minute SO_2 Concentrations

Five components of uncertainty were identified regarding the statistical model and its impact on the estimated number of benchmark exceedances. These include 1) the impact from how the PMR data were screened, 2) the temporal representation of data used in the statistical model development, 3) the form of the distribution used to represent the PMRs, 4) the accuracy of the model in predicting daily 5-minute maximum concentrations, and (5) the reproducibility of the model predictions.

Staff identified data for removal from the final combined 5-minute and 1-hour ambient measurement data set using the PMR as a screening criterion. The calculation of PMRs less than 1 implies the 5-minute peak is less than the 1-hour average, a physical impossibility, and values

>12 are a mathematical impossibility. The 5-minute ambient monitoring data were screened for values outside of these bounds,[49] increasing confidence in the relevance of PMRs used for development of the statistical model. While a total of 40,665 data points were excluded from the data set using the PMR criterion, this comprised less than 2% of the data available to develop the PMR relationship. It was assumed that the criterion used for the data removal would not adversely influence the estimated number of benchmark exceedances in the modeling performed since it was only directed towards identifying unrealistic 5-minute and 1-hour concentration combinations.

Analysis of the data screened by staff revealed that nearly all of the data are for where the calculated PMR was less than one (98% of screened samples) and most of the 1-hour concentrations (approximately 95%) were less than or equal to 5 ppb (Table 7-17). An alternative approach to developing the PMR distributions could have been to include the screened data with an assigned PMR value of one (for where the original PMR was less than one) or twelve (for where the original PMR was greater than twelve) based the 5-minute and 1-hour concentration distributions. If included, these data would have virtually no influence on the estimated number of benchmark exceedances. This is because 1-hour concentrations < 8.3 ppb combined with the PMR distribution principally affected by inclusion of newly assigned ratios (i.e., the < 5 ppb concentration bin) would never generate a benchmark exceedance. Given the limited number of samples removed from further analysis and recognizing there would be less uncertainty when using a data set comprised of PMRs with realistic bounds rather than one using all possible PMR values, staff judges the magnitude of the influence associated with the screening of the 5-minute data as low. In excluding the mostly lower concentration data (as compared to the final data set used) there may be an over-estimation in the percent and probability of exceedances.

[49] It is possible to have a PMR equal to 12. This value is achieved with one 5-minute concentration above zero and the other eleven 5-minute values reporting concentrations of zero. Data used in developing the statistical relationship were screened for values with a PMR equal to 12 however, because it could not be used in the AERMOD/APEX modeling. It is of little consequence because the distributions chosen in estimating the 5-minute concentrations included the 1st through the 99th percentiles, not the minimum and maximum values.

Table 7-17. Summary of descriptive statistics for the data removed using peak-to-mean ratio criterion and the final 1-hour and 5-minute maximum SO_2 data set used to develop PMRs.

	Data removed				Final data set	
	PMR < 1 (n = 39,861)		PMR ≥ 12 (n = 804)		(n = 2,367,686)	
Statistic[1]	5-min max (ppb)	1-hour (ppb)	5-min max (ppb)	1-hour (ppb)	5-min max (ppb)	1-hour (ppb)
mean	1	2	29	2	10	6
p99	6	10	174	10	100	50
p95	3	5	82	4	37	21
p50	1	1.6	15.5	1	3	2
p5	1	1.1	12	0.9	1	1
p1	0.2	0.45	4	0.1	1	0.2

Notes:
[1] mean is the arithmetic average; p99, p95, p50, p5, p1 are the 99th, 95th, 50th, 5th and 1st percentiles of the concentration distribution.

The use of all screened 5-minute maximum SO_2 data (1997 to 2007) in developing the PMR distributions assumes that the source emissions present at that time of measurement are similar to other year source emissions. It could be possible that there is greater uncertainty in the estimated number of exceedances in areas where year-to-year source emissions deviate from a consistent pattern. However, as noted with the concentration variability, the PMRs derived from the 5-minute maximum measurement data do not have a clear trend with monitoring year. Over the 11-year period, the mean of each monitor's annual average PMR is about 1.6 (medians of 1.5; 25th percentiles of 1.4; 75th percentiles of 1.7) (Figure 7-34). This general trend in mean PMRs is consistent with the population-based value used by Stoeckenius et al. (1990) for exposure analyses (mean of 1.6; median of 1.5) and ambient monitor concentration analyses conducted by SAI (1996) (mean 1.7; median 1.5).[50] While there is some indication of greater variability in the PMRs for years 2004-2005 compared with some of the other years used, overall the consistent pattern over time indicates that the use of the older ambient monitoring data in developing the statistical model would have a negligible impact on the predicted concentrations and subsequently the estimated number of benchmark exceedances (i.e., low influence with no apparent direction). Given the consistency of the PMRs derived using recent air quality with that of the earlier analyses, the uncertainty regarding the knowledge-base is judged as low.

[50] Data from Table 2-18 of Stoeckenius (1990) for the Scottish Rites monitoring site and Table 5-2 of SAI (1996).

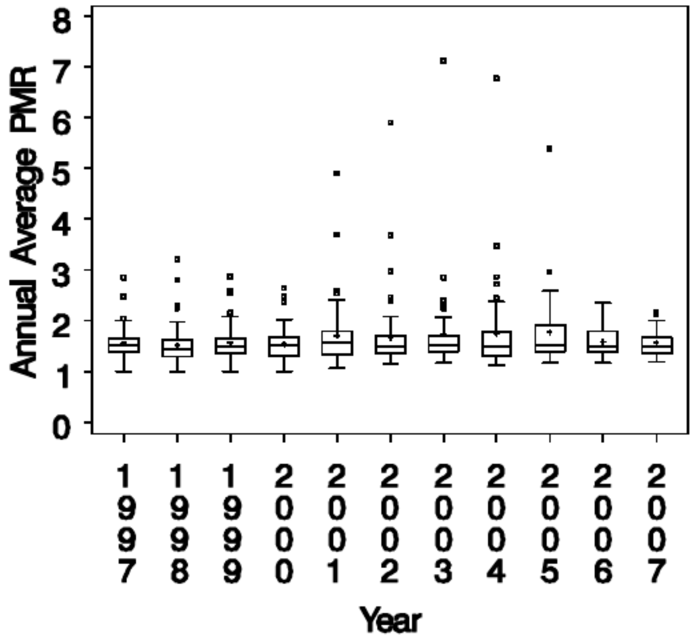

Figure 7-34. Distributions of annual average peak-to-mean ratios (PMRs) derived from the 98 monitors reporting both 5-minute maximum and 1-hour SO_2 concentrations, Years 1997 through 2007.

The PMRs distributions for each COV and concentration bin were represented by a non-parametric form condensed to single percentiles, with each value from the distribution having an equal probability of selection. While there may be other distribution forms that could be alternatively selected, staff judged that use of a fitted distribution would not improve the representation of the true population of PMRs compared with a non-parametric form, and that there would likely be no reduction in the uncertainty of estimated number of exceedances if using a parameterized distribution. While some of the PMR distributions were similar to a lognormal distribution (for example see Figure 7-35), 93 of 95 possible statistical tests performed indicated the distributions were statistically distinct ($p<0.01$) from any of the tested forms (i.e., normal, lognormal, Weibull, gamma, and exponential) (see Figure 7-35 as an example). The PMRs derived from monitors having the greatest COV (all concentration bins) and those derived from the lowest concentration bins (all COV bins) were most common in exhibiting atypical distribution forms. Even when considering practical judgments regarding a potential parametric form (i.e., beyond simply using statistically significant differences as a criterion), most of the observed PMR distributions had large deviations from parametric distributions such as that illustrated by Figure 7-36.

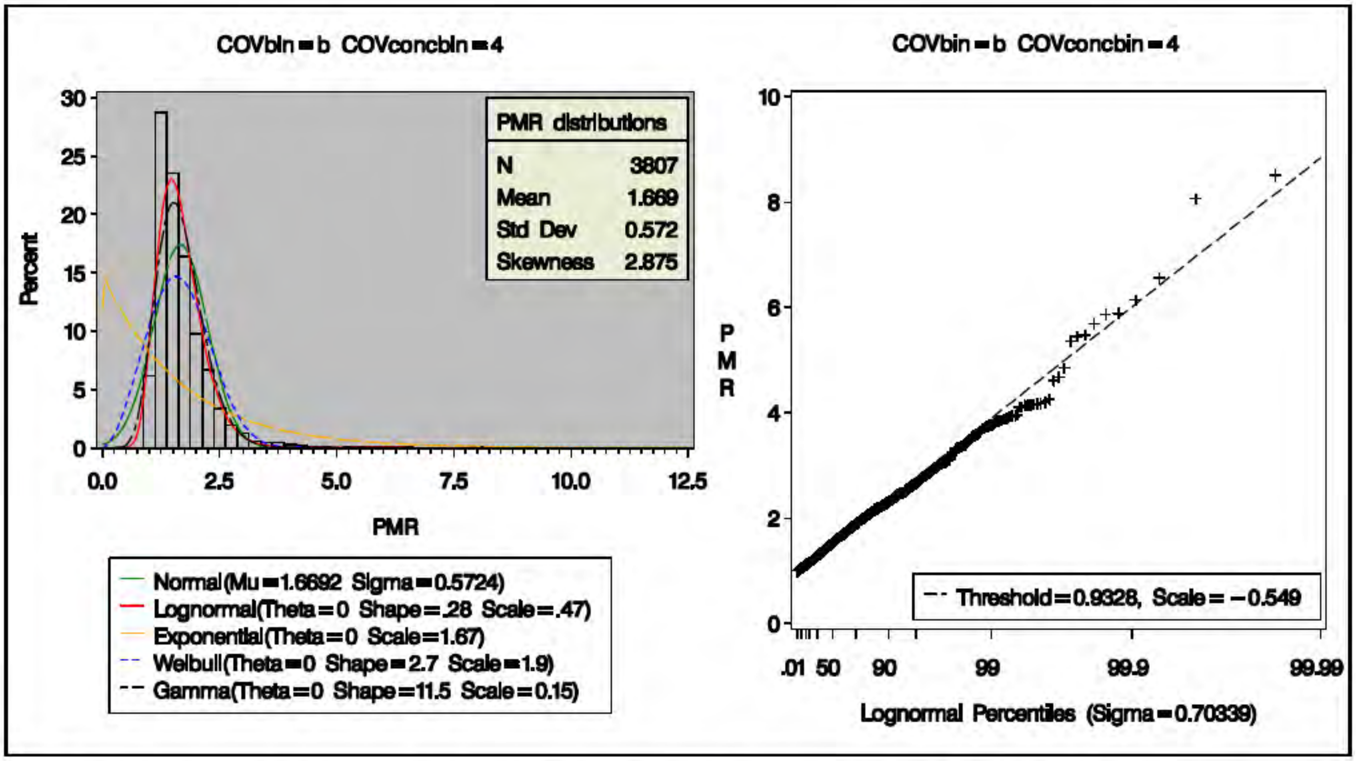

Figure 7-35. Example histogram of peak-to-mean ratios (PMRs) compared with four fitted distributions derived from monitors reporting the 5-minute maximum and 1-hour SO_2 concentrations (left) and the same PMRs compared with expected lognormal percentiles (right). PMRs were derived from monitors with medium level variability (COVbin = b) and 1-hour concentrations between 75 and 150 ppb (COVconcbin = 4).

In addition, while there is uncertainty associated with the use of the empirically-derived data in representing the true population of PMRs, assuming a fitted distribution would not be without its own uncertainties. For example, using a lognormal distribution may underestimate the observed frequency of certain values of PMRs while overestimating others. For PMR distributions that are of similar form with the lognormal distribution, it is likely that the small variation in PMRs selected from a fitted lognormal distribution would have only limited impact on the estimated 5-minute maximum SO_2 concentrations. For distributions exhibiting no similarities to any parametric distribution, experimental justification criteria would need to be developed in selecting the most appropriate form of the distribution, likely requiring multiple test iterations, potentially yielding distributions with greater uncertainty than those of a non-parametric form (e.g., WHO, 2008 page 28). Each of these additional evaluations and iterations would require time and resources not available to staff. Furthermore, the sample sizes for many of the PMR distributions used are well above 1,000 (only 5 of the 19 distributions had fewer than

1,000, with all distributions having greater than 100 samples), providing support that the true distribution may be well-represented by the non-parametric form. Each of these factors mentioned (uncertainty in the form of the distribution, limits on time and resources available, and numbers of samples available) were considered and it was decided by staff that the non-parametric distribution derived from the measurement data would be most appropriate. Therefore, it is judged that the magnitude of influence on the estimated benchmark exceedances is low along with no apparent direction of influence. Since staff employed both statistical and practical comparisons in selection of the distribution form to the maximum extent allowable, the uncertainty regarding the knowledge-base is judged as low.

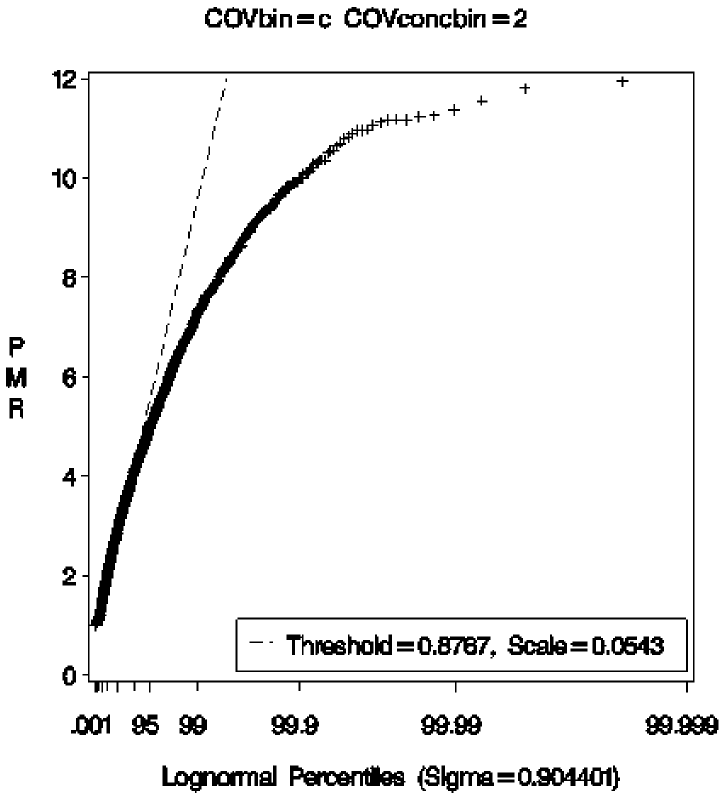

Figure 7-36. Example of a measured peak-to-mean ratio (PMRs) distribution with the percentiles of a fitted lognormal distribution. PMRs were derived from monitors with high COV (COVbin = c) and 1-hour concentrations between 5 and 10 ppb (COVconcbin = 2).

The accuracy in the predicted daily 5-minute maximum SO_2 concentrations above each of the benchmark levels was evaluated using measured concentrations. The results indicated that on average, the statistical model performed well in estimating of these short-term peak concentrations (section 7.2.3.4). There was reasonable agreement in observed versus predicted numbers of benchmark exceedances for most of the monitoring site-years (i.e., about 90% of the data set) and for all of the benchmark levels. Based on this overall assessment of model accuracy, the magnitude of influence the selected model has on contributing uncertainty to the estimated number of exceedances is judged by staff to be low. There was no particular direction of influence; model predictions were equally over- or under-estimated (Figure 7-37, Table 7-6).

The accuracy assessment indicated the estimated number of days with benchmark exceedances could be either over- or under-estimated by as many as 20 to 50 days in a year, primarily at the tails of the prediction distribution. These model prediction errors were limited to several site-years from a few monitors. Figure 7-37 illustrates the model predicted versus the observed number of benchmark exceedances at each of the benchmark levels. While there is generally uniform agreement between the predicted and observed values at the 100 ppb benchmark, there is deviation in the agreement at the greatest and lowest number of days with exceedances for the 200, 300, and 400 ppb benchmark levels. For example, there were a few site-years without any observed benchmark exceedances of 400 ppb, although the statistical model predicted between 2-15 days in a year. This could indicate that a few of the site-years may have moderate over-estimations in the number of days with 5-minute maximum SO_2 concentration exceedances, where the estimated number of exceedances is 15 or less. In addition, site-years with the greatest number of observed exceedances of 400 ppb (about 50 per year) were consistently under-estimated by the model by about 30%. This could imply that when the estimated number of days with 5-minute maximum SO_2 concentrations above 400 ppb is 40 per year, the under-estimate may be as large as 15 days per year.

Neither of these model errors appeared systematically related to an individual source type. Additional monitors sited in the same areas impacted by similar source types had good agreement between the observed and predicted concentrations. For example, at the monitor with the greatest number of measured benchmark exceedances (ID 290930030) and largest under-prediction error, one could argue that variable terrain may be an influential factor. This monitor is about 1.7 km from a primary smelter and located proximal to a ravine running between the source and the monitoring site. The nearby monitor (ID 290930030) sited in elevated terrain (Hogan Mountain) at about 4.6 km from the same source had small prediction errors. These differences in agreement suggest that when considering any individual monitor, there may be factors not accounted for by the statistical model that are important in estimating benchmark exceedances (e.g., terrain). Based on this model accuracy assessment, the magnitude of influence the selected model has on contributing uncertainty to the estimated number of exceedances for individual monitors is likely medium at the lower and upper tails of the prediction distribution. The direction of the influence is likely over-estimation at the lower number of exceedances and under-estimation at the greatest number of exceedances.

Though the cross-validation results are encouraging, there may be additional influential variables not included in the construction of the statistical model that may be important and have the potential to improve the agreement between the observed and predicted values. There is also the possibility of influential variables that are not within the data set used for statistical model development, but exist in the broader 1-hour SO_2 monitoring data set. Staff judged the concentration variability and level as appropriate variables for linking the statistical model with the 1-hour measurement data. In addition, the comparison of ambient monitoring attributes (e.g., objectives, local source emissions) also indicated consistency between the monitors reporting 5-minute maximum concentrations and those reporting only 1-hour average concentrations. However, in the absence of additional 5-minute measurements in areas where there may be unique conditions (e.g., terrain or climatologic influences), staff judges there remains a medium level of uncertainty in the knowledge-base regarding the accuracy in the extrapolation using the statistical model.

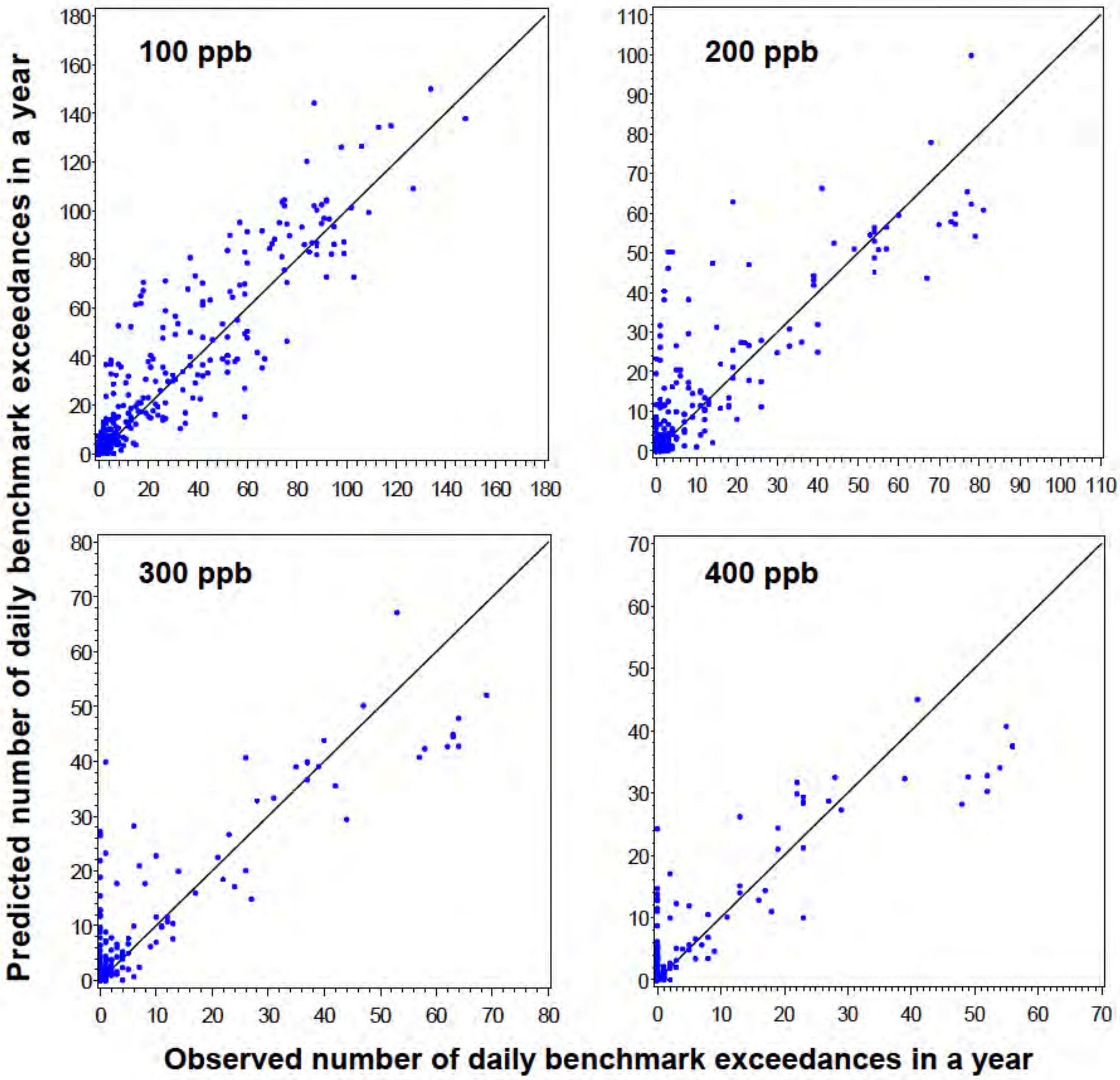

Figure 7-37. Comparison of observed and predicted number of daily benchmark exceedances in a year at the 98 monitors reporting 5-minute maximum SO_2 concentrations.

Staff needed to evaluate the reproducibility of the statistical model because random sampling was employed in generating the PMRs used to estimate 5-minute SO_2 concentrations. The purpose of this analysis was to determine the effect of random sampling error on the estimated number of benchmark exceedances. First, to define terminology used in this analysis: a model *simulation* is where each monitor had all of its years of 1-hour data SO_2 used in estimating 5-minute maximum concentrations and as a result, the number benchmark exceedances was calculated; a model *run* is comprised of twenty such independent simulations (i.e., differing by random number seed) and used to generate a mean number of daily 5-minute maximum SO_2 concentration exceedances for each site-year. This is the same process (i.e., a model run) that was used in generating the air quality characterization.

The reproducibility of the estimated number of benchmark exceedances was evaluated by performing ten independent modeling runs (with twenty simulations per model run) using the 40-county *as is* air quality data set (i.e., having 610 site-years per model simulation). The output from each model run was the mean number of days per site-year an exceedance occurred; therefore, ten mean numbers of exceedances were generated for each of the four benchmarks using the 610 site-years of data. The maximum difference in those ten means was calculated (the minimum mean value subtracted from the maximum mean value) giving the range of the ten means for each benchmark and site-year. For example, in one site-year there were 51, 52, 52, 53, 52, 52, 52, 51, 52, and 52 estimated mean numbers of exceedances of 100 ppb from the 10 model runs. Therefore the range (or maximum difference) is equal to two.

The distributions of the range in mean exceedances by benchmark level are illustrated in Figure 7-38. The range in the mean number of exceedances based on the ten model runs is less than five for all benchmark levels and consistently decreases with increasing benchmark level. On average, maximum difference in the estimated mean numbers of exceedances of 100 ppb was 2 exceedances, while at greater benchmark levels the range was 1 or less. This indicates that the random sampling error has a low impact to the estimated mean number of exceedances per site-year.

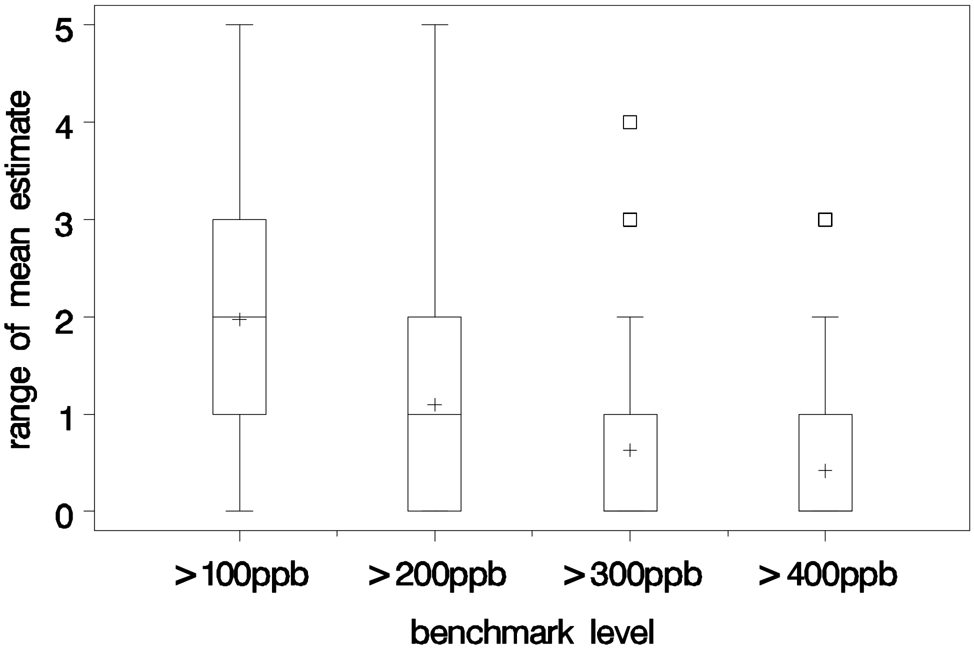

Figure 7-38. Distributions of the maximum difference in the estimated mean number of exceedances per site-year given 10 independent model runs (with 20 simulations per run). Data used are from 40 county *as is* air quality (610 site-years). Box represents the inner quartile range (IQR, or the 25th to 75th percentile), + indicates the mean, whiskers are 1.5 times the IQR.

7.4.2.7 Potential Health Risk Endpoints Used

The choice of potential health effect benchmarks levels and the use of those benchmarks to characterize risks are important uncertainties in the air quality characterization results. Human exposure is characterized by contact of a pollutant with a person, and as such, the air quality characterization assumes that the ambient monitoring concentrations can serve as an indicator of exposure. The ISA reports that personal exposure measurements (PEM) are of limited use since ambient SO_2 concentrations are typically below the detection limit of the personal samplers. There is no method to quantitatively assess the relationship between 5-minute ambient monitoring data and 5-minute personal exposures, particularly since personal exposures are time-averaged over days to weeks, and never by 5-minute averages. Therefore the fraction of actual 5-minute maximum personal exposure concentrations attributed to 5-minute maximum ambient SO_2 is unknown and thus contributes to uncertainty when using ambient air quality data as an indicator of human exposure.

An evaluation in the ISA indicates the relationship between longer-term averaged ambient monitoring concentrations and personal exposures is strong, particularly when ambient concentrations are above the limit of detection. The strength of the relationship between personal and ambient SO_2 concentrations is supported further by the limited presence of indoor sources of SO_2; much of an individuals' personal exposure is of ambient origin. However, SO_2 personal exposure concentrations are reportedly a small fraction of ambient concentrations. This is because local outdoor SO_2 concentrations are typically half that of the ambient monitoring SO_2 concentrations, and indoor concentrations about half that of the local outdoor SO_2 concentrations (ISA). Therefore, while the relationship between personal exposures and ambient SO_2 concentrations is strong, the use of monitoring data as an indicator of SO_2 exposure may lead to an overestimate in the number of peak concentrations those individuals might encounter. While the magnitude of the uncertainty about the true relationship between actual human exposure and any given ambient monitor short-term concentration exceedance is unknown, it is judged by staff to be of a medium magnitude given what is known regarding the relationship between longer-term PEM and ambient SO_2 concentrations.

There is uncertainty regarding how susceptible populations were considered in developing the potential health benchmark levels. The human clinical exposure studies evaluated airways responsiveness in mild to moderate asthmatics. Health effect symptoms and responses were observed in these test subjects exposed to concentrations as low as 200 ppb in the free-breathing chamber studies. As such, a concentration of 200 ppb could well represent a lower range of the benchmark level for mild to moderate asthmatics. However, for ethical reasons, adults with severe asthma and younger asthmatics are not commonly challenged in air pollutant studies. This is because severe asthmatics and/or asthmatic children may be more susceptible than mild asthmatic adults to the effects of SO_2 exposure. Therefore, exposure levels (and hence selected benchmark levels) lower than those used in free-breathing chamber studies may be important in representing populations with greater susceptibility. Staff selected 100 ppb as the lowest benchmark level based on effects observed in mild to moderate asthmatics using facemasks at that level and to consider potential effects in susceptible populations at lower 5-minute concentrations. In the absence of strong quantitative evidence it is difficult to determine if 100 ppb would be health protective for asthmatics (mild, moderate, or severe) or if 100 ppb is a concentration that would elicit an adverse effect. Based on this, staff acknowledges there is medium uncertainty in the knowledge-base regarding representativeness of the lowest benchmark level selected, but judge that the magnitude of influence to the estimated health risk is low given the inclusion of the 100 ppb level.

Staff also acknowledges that there may be uncertainty in the selected potential health effect benchmark averaging time. For example, the used in this assessment were from studies where volunteers were exposed to SO_2 for varying lengths of time. Typically, the SO_2 exposure durations in the controlled human studies were between 5 and 10 minutes. This could be an important uncertainty because the potential health effect benchmark levels were compared to concentration exceedances occurring over 5-minutes. That is, if there were a difference in the response rate for a given concentration level and averaging time, the use of a 5-minute averaging time could either lead to over- or under-estimation in the health risk characterization. The true exposure-response relationship may be dependent on both the combined concentration level and the exposure duration, that is, it is possible that a particular response rate observed at a 10-minute exposure level of concentration *x* may be similar to that of a 5-minute exposure level equal to or greater than concentration *x*. In this hypothetical scenario, if benchmarks were derived from 10 minute exposures and applied in the evaluation of 5-minute ambient concentrations, the risk characterization may well be over-estimated. However, the ISA did not distinguish between health effects observed following either 5- or 10-minute exposures. Therefore the direction of influence to the potential health risk is judged as none, and given a general consistency in the observed responses involving either 5- or 10-minute exposures, staff judges the uncertainty in the knowledge-base as low.

The health effect endpoint used in the air quality characterization was the observed or estimated number days the maximum 5-minute SO_2 concentration exceeded a particular benchmark level. Staff acknowledges that this choice could result in the risk characterization under-estimating the health risk because there can be multiple exceedances of the benchmark levels in a day (Table 7-18). Using the monitors reporting 5-minute SO_2 maximum concentrations, approximately half of the time there was a single benchmark exceedance in a day. For most days having an exceedance (about 80-90%), there were no more than three that occurred in a day. There were several days having many benchmark exceedances within a day (e.g., > 5), particularly when considering the lowest benchmark levels. However in this air quality analysis, none of the elements of exposure are considered (e.g., whether or not time of exposure occurs coincident with elevated activity level), thus limiting the relevance of multiple exceedances within a day. While the risk characterization could be considered under-estimated, the magnitude of influence by this source of uncertainty is judged by staff as low given the defined limits of the air quality characterization. Furthermore, staff acknowledges that multiple benchmark exceedances of 5-minutes can occur within an hour. This issue and its implications for characterizing health risk are more relevant to human exposure than the air quality analysis and are discussed in greater detail in section 8.11.

Table 7-18. The number and percent of days having multiple benchmark exceedances occurring in the same day, using monitors reporting the 5-minute maximum SO_2 concentrations.

Number of Exceedances per Day[1]	5-minute SO_2 Benchmark Level							
	> 100 ppb		> 200 ppb		> 300 ppb		> 400 ppb	
	days[2]	percent[2]	days	percent	days	percent	days	percent
1	3806	43	1390	50	740	50	512	53
2	1923	22	613	22	349	24	248	26
3	1093	12	327	12	183	12	111	12
4	640	7	152	5	87	6	46	5
5	424	5	114	4	48	3	19	2
6	286	3	60	2	25	2	15	2
7	185	2	52	2	22	1	8	1
8	127	1	27	1	8	1	0	0
9	100	1	21	1	4	0	0	0
10	68	1	14	1	5	0	0	0
11	45	1	7	0	2	0	0	0
12	38	0	7	0	0	0	0	0
13	18	0	4	0	1	0	0	0
14	27	0	1	0	0	0	1	0
15	7	0	1	0	1	0	1	0
16	11	0	2	0	0	0	0	0
17	3	0	0	0	0	0	0	0
18	6	0	1	0	1	0	0	0
19	5	0	0	0	0	0	0	0
20	2	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	3	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
Sum	8817		2793		1476		961	

Notes:
[1] The number of 5-minute maximum benchmark exceedances within a day could range from 1 to 24 given the number of hours in a day.
[2] The total number of days having the given number of multiple exceedances within the day.
[3] The percent of days having an exceedance with the given number of multiple exceedances per day.

7.5 KEY OBSERVATIONS

Presented below are key observations resulting from the SO_2 air quality characterization:

- For unadjusted *as is* air quality at ambient monitors measuring 5-minute maximum concentrations, nearly 70% of the 471 site-years analyzed had at least one daily 5-minute maximum concentration above 100 ppb and over 100 site-years (more than 21%) had ≥ 25 days with a daily 5-minute maximum concentration above 100 ppb. Less than half (44%) of the site-years had at least one daily 5-minute maximum concentration above 200 ppb and only 36 site-years had ≥ 25 days with a daily 5-minute maximum concentration above 200 ppb. Approximately 25% and 17% of the 471 site-years analyzed had at least one daily 5-minute maximum concentration above 300 and 400 ppb, respectively, with 23 and 12 site-years having ≥ 25 days with a daily 5-minute maximum concentration above 300 and 400 ppb, respectively (Appendix A, Table A.5-1).

- For any of the air quality scenarios considered, the probability of exceeding the 5-minute maximum benchmark levels was consistently greater at monitors sited in low-population density areas compared with high-population density areas. In addition, an increased probability of any 5-minute benchmark exceedance was consistently related to either increased 24-hour average or 1-hour daily maximum concentrations.
- For unadjusted air quality in the 40 counties selected for detailed analysis, most counties are estimated to have, on average, fewer than 50 days per year where the daily 5-minute maximum ambient SO_2 concentrations are > 100 ppb. Most counties are estimated to have, on average, 25 days per year with daily 5-minute maximum ambient SO_2 concentrations > 200 ppb. Very few counties are estimated to have more than ten days with 5-minute maximum SO_2 concentrations > 300 ppb, while nearly half did not have any days with 5-minute maximum SO_2 concentrations > 400 ppb (Tables 7-11 to 7-14).
- When air quality is adjusted to simulate just meeting the current annual standard in the 40 counties selected for detailed analysis, a hypothetical scenario requiring air quality to be adjusted upward, all locations evaluated are estimated to have multiple days per year where 5-minute maximum ambient SO_2 concentrations are > 100 ppb. Most counties are estimated to have, on average, 100 days or more per year with 5-minute maximum ambient SO_2 concentrations > 100 ppb, while eight of the forty counties are estimated to have 200 days or more per year with 5-minute maximum ambient SO_2 concentrations > 100 ppb. Fewer benchmark exceedances are estimated to occur with higher benchmark levels. For example, only five counties are estimated to have 60 or more days per year with 5-minute maximum ambient SO_2 concentrations that exceed 300 ppb (Table 7-13) and only four counties are estimated to 50 or more days per year with 5-minute maximum ambient SO_2 concentrations that exceed 400 ppb (Table 7-14).
- In all 40 counties, potential alternative standard levels of 100 and 150 ppb are estimated to result in fewer days per year with 5-minute maximum SO_2 concentrations > 300 and > 400 ppb than with the current standards and the potential alternative standard levels of 200 and 250 ppb (Tables 7-13 and 7-14).
- When considering the potential 1-hour daily maximum potential alternative standard levels of 100 and 200 ppb in all 40 counties, corresponding annual average SO_2 concentrations were typically between 3 and 15 ppb, similar to a range of concentrations using unadjusted air quality (Appendix A). When considering the potential alternative standard levels of 200 and 250 ppb, corresponding annual average SO_2 concentrations were typically between 10 and 30 ppb, similar to the range of concentrations observed when using adjusted air quality that just meets the current annual standard.
- Of the fifteen uncertainties qualitatively judged to influence the estimated number of days with air quality benchmark exceedances, three may be associated with over-estimation, three may be associated with under-estimation, while the remaining uncertainties could affect results in both directions (four sources), no direction (four sources), or unknown

direction (one source) (see Table 7-16). The magnitude of influence for four of the six uncertainties associated with either over- or under-estimation was estimated as low (or negligible magnitude of influence). Staff judged the two remaining uncertainties as having a medium magnitude of influence in under-estimating the number of days with benchmark exceedances, both of which were associated with the spatial representation of the monitoring network. Based on this overall characterization regarding the direction and magnitude of influence identified sources of uncertainty, there may be a medium level under-estimate in the number of days with air quality benchmark exceedances.

- For the most part, the knowledge-base uncertainty for sources with unknown or bidirectional influence ranged from low (four sources) to medium (four sources), though uncertainty regarding the spatial scale of the air quality adjustment procedure (direction of influence was both, medium magnitude) was judged as high. The knowledge-base uncertainty was low for four of the six sources associated with either an under- or over-estimation direction of influence. A high degree of uncertainty in the knowledge-base was assigned to the spatial representation of the monitoring network. Based on this overall characterization regarding the knowledge-base, there is a high level of uncertainty associated with the most influential source.
- Staff identified four other sources of uncertainty in the air quality characterization as having influence on the characterization of health risk. The most influential and most uncertain source of the four is associated with the direct use of air quality benchmark exceedances as an indicator of exposure. The number of days with 5-minute exposures above benchmark levels would likely be lower than the number of days where there were ambient SO_2 concentrations above benchmark levels. Thus, the air quality characterization may over-estimate the health risk due to this factor

8. EXPOSURE ANALYSIS

8.1 OVERVIEW

This section documents the methodology and data staff used in the inhalation exposure assessment and associated health risk characterization for SO_2 conducted in support of the current review of the SO_2 primary NAAQS. Two important components of the analysis include the approach for estimating temporally and spatially variable SO_2 concentrations and simulating human contact with these pollutant concentrations. The approach was designed to better reflect exposures that may occur near SO_2 emission sources, not necessarily reflected by the existing ambient monitoring data alone.

Staff used a combined air quality and exposure modeling approach to generate estimates of 5-minute maximum, 24-hour, and annual average SO_2 exposures within Greene County, MO. and three Counties within the St. Louis Metropolitan Statistical Area (MSA) for the year 2002. AERMOD, an EPA recommended dispersion model, was used to estimate 1-hour ambient SO_2 concentrations using emissions estimates from stationary, non-point, and port sources. The Air Pollutants Exposure (APEX) model, an EPA human exposure model, was used to estimate 5-minute population exposures using the census block level hourly SO_2 concentrations estimated by AERMOD and the statistical model described in section 7.2.3. Staff used the person-based exposure profiles to calculate the number of days per year an individual had at least one 5-minute exposure above the potential health effect benchmark levels of 100, 200, 300, and 400 ppb.

Exposure and potential health risk were characterized considering recent air quality conditions (*as is*), for air quality adjusted to just meet the current SO_2 primary standards (0.030 ppm, annual average; 0.14 ppm, 24-hour average), and for just meeting potential alternative standards (see Chapter 5 for selection justification). Specifically, APEX reported the number of times an individual experienced a day with a 5-minute exposure in excess of 100 ppb through 800 ppb.[51] The exposures for each individual were estimated over an entire year therefore, multiple occurrences of exposures above the benchmark levels are also available.

[51] The complete output from APEX includes 5-minute exposure concentrations at 50 ppb increments through 800 ppb which served as an input to the risk assessment performed in Chapter 9. The health effect benchmarks evaluated in the exposure assessment were defined as 100 to 400 ppb by increments of 100 ppb.

The approaches used for assessing exposures in Greene County and St. Louis are described below. Additional model input data and supporting discussion of APEX modeling are provided in Appendix B. Briefly, the discussion in this Chapter includes the following.

- Description of the inhalation exposure model and associated input data used for Green County and St. Louis;
- Evaluation of estimated SO_2 air quality concentrations and exposures; and
- Assessment of the quality and limitations of the input data for supporting the goals of the SO_2 NAAQS exposure and risk characterization.

The overall flow of the exposure modeling process performed for this SO_2 NAAQS review is illustrated in Figure 8-1. Several models were used in addition to APEX and AERMOD including emission factors and meteorological processing models, as well as a number of databases and literature sources to populate the model input parameters. Each of these is described within this Chapter, supplemented with additional details in Appendix B.

8.2 OVERVIEW OF HUMAN EXPOSURE MODELING USING APEX

The EPA has developed the APEX model for estimating human population exposure to criteria and air toxic pollutants. APEX serves as the human inhalation exposure model within the Total Risk Integrated Methodology (TRIM) framework (EPA 2009a; 2009b). APEX was recently used to estimate population exposures in 12 urban areas for the O_3 NAAQS review (EPA, 2007d; 2007e) and in estimating population NO_2 exposures in Atlanta as part of the NO_2 NAAQS review (EPA, 2008d).

APEX is a probabilistic model designed to account for sources of variability that affect people's exposures. APEX simulates the movement of individuals through time and space and estimates their exposure to a given pollutant in indoor, outdoor, and in-vehicle microenvironments. The model stochastically generates a sample of simulated individuals using census-derived probability distributions for demographic characteristics. The population demographics are drawn from the year 2000 Census at the tract, block-group, or block-level, and a national commuting database based on 2000 census data provides home-to-work commuting flows. Any number of simulated individuals can be modeled, and collectively they approximate a random sampling of people residing in a particular study area.

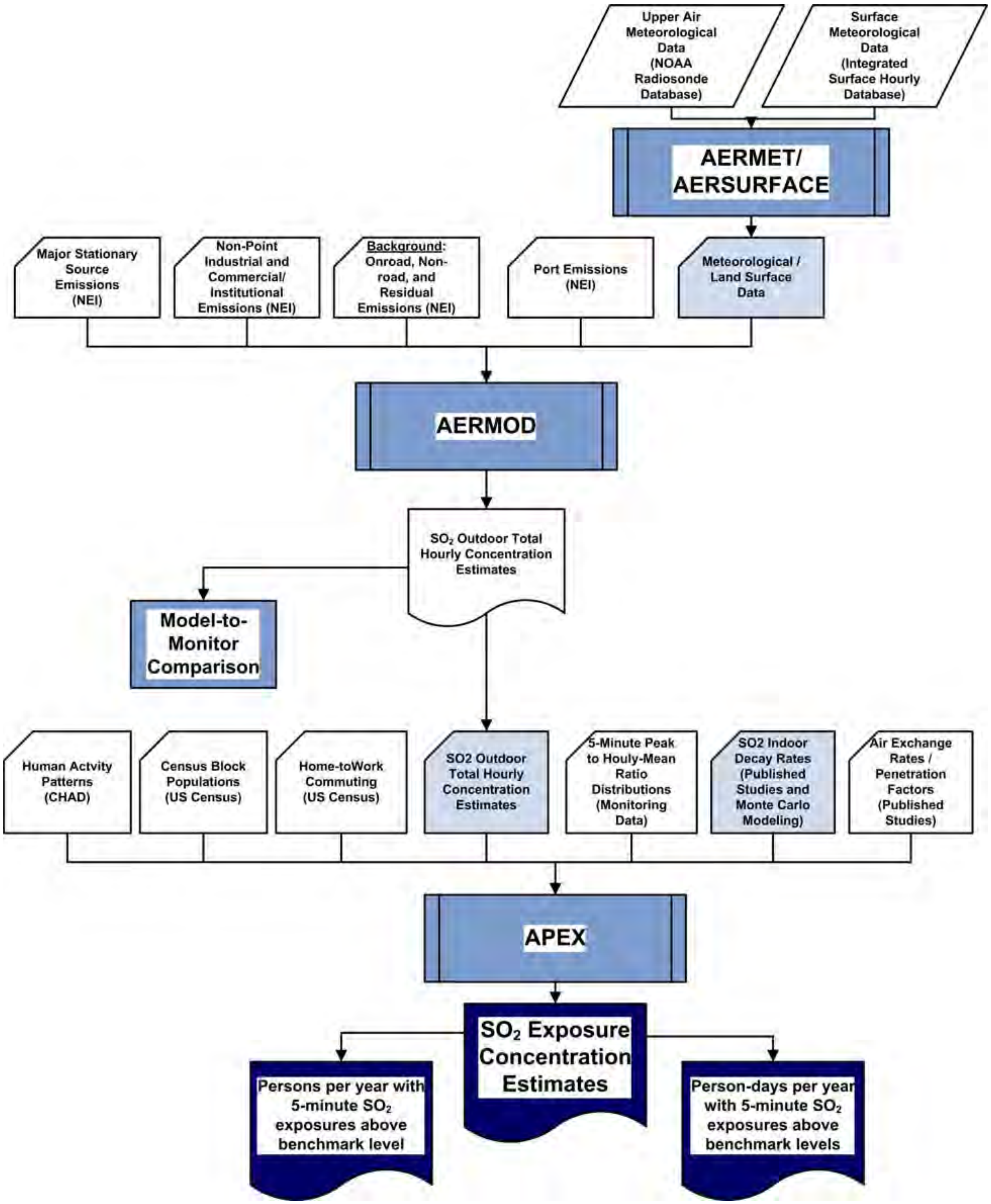

Figure 8-1. General process flow used for SO_2 exposure assessment.

Daily activity patterns for individuals in a study area, an input to APEX, are obtained from detailed diaries that are compiled in the Consolidated Human Activity Database (CHAD) (McCurdy et al., 2000; EPA, 2002). The diaries are used to construct a sequence of activity events for simulated individuals consistent with their demographic characteristics, day type, and season of the year, as defined by ambient temperature regimes (Graham and McCurdy, 2004). The time-location-activity diaries input to APEX contain information regarding an individuals' age, gender, race, employment status, occupation, day-of-week, daily maximum hourly average temperature, the location, start time, duration, and type of each activity performed. Much of this information is used to best match the activity diary with the generated personal profile, using age, gender, employment status, day of week, and temperature as first-order characteristics. The approach is designed to capture the important attributes contributing to an individuals' behavior, and of likely importance in this assessment (i.e., time spent outdoors) (Graham and McCurdy, 2004). Furthermore, these diary selection criteria give credence to the use of the variable data that comprise CHAD (e.g., data collected were from different seasons, different states of origin, etc.).

APEX has a flexible approach for modeling microenvironmental concentrations, where the user can define the microenvironments to be modeled and their characteristics. Typical indoor microenvironments include residences, schools, and offices. Outdoor microenvironments include for example near roadways, at bus stops, and playgrounds. Inside cars, trucks, and mass transit vehicles are microenvironments which are classified separately from indoors and outdoors. APEX probabilistically calculates the concentration in the microenvironment associated with each event in an individual's activity pattern and sums the event-specific exposures within each hour to obtain a continuous series of hourly exposures spanning the time period of interest. The estimated microenvironmental concentrations account for the contribution of ambient (outdoor) pollutant concentration and influential factors such as the penetration rate into indoor microenvironments, air exchange rates, decay/deposition rates, proximity to important outdoor sources, and indoor source emissions. Each of these influential factors are dependent on the microenvironment modeled, available data to define model inputs, and estimation method selected by the model user. And, because the modeled individuals represent a random sample of the population of interest, the distribution of modeled individual exposures can be extrapolated to the larger population within the modeling domain.

The exposure modeling simulations can be summarized by five steps, each of which is detailed in the subsequent sections of this document. Briefly, the five steps are as follows:

1. **Characterize the study area**. APEX selects the census blocks within a study area – and thus identifies the potentially exposed population – based on user-defined criteria and availability of air quality and meteorological data for the area.
2. **Generate simulated individuals**. APEX stochastically generates a sample of hypothetical individuals based on the demographic data for the study area and estimates anthropometric and physiological parameters for the simulated individuals.
3. **Construct a sequence of activity events**. APEX constructs an exposure event sequence spanning the period of the simulation for each of the simulated individuals using time-location-activity pattern data.
4. **Calculate 5-minute and hourly concentrations in microenvironments**. APEX users define microenvironments that people in the study area would visit by assigning location codes in the activity pattern to the user-specified microenvironments. The model calculates all 5-minute concentrations occurring within the hour (one maximum along with eleven other 5-minute values normalized to the hourly mean) in each microenvironment for the period of simulation, based on the user-provided microenvironment descriptions, the hourly air quality data, and peak-to-mean ratios (PMRs; see section 7.2.3). Microenvironmental concentrations are calculated independently for each of the simulated individuals.
5. **Estimate exposures**. APEX estimates a concentration for each exposure event[52] based on the microenvironment occupied during the event. In this assessment, APEX estimated 5-minute exposures. These exposures can also be averaged by clock hour to produce a sequence of hourly average exposures spanning the specified exposure period. The values may be further aggregated to produce daily, monthly, and annual average exposure values.

8.3 CHARACTERIZATION OF STUDY AREAS

8.3.1 Study Area Selection

The selection of areas to include in the exposure analysis takes into consideration the availability of ambient monitoring, the presence of significant and diverse SO_2 emission sources, population demographics, and results of the ambient air quality characterization. Although it could be useful to characterize SO_2 exposures nationwide, because the exposure modeling approach is both time and labor intensive, a regional and source-oriented approach was selected

[52] An exposure event is a continuous period of time during which the factors that affect exposure (microenvironment inhabited, activity performed, ventilation rate, and pollutant concentration) can be considered constant.

to make the analysis tractable and with the goal of focusing on areas most likely to have elevated SO_2 peak concentrations and with sufficient data to conduct the analysis.

A broad study area was first identified based on the results of a preliminary screening of the 5-minute ambient SO_2 monitoring data that were available. The state of Missouri was one of only a few states reporting both 5-minute maximum and continuous 5-minute SO_2 ambient monitoring data (14 total monitors), as well as having over thirty monitors in operation at some time during the period from 1997 to 2007 that measured 1-hour SO_2 concentrations. In addition, the air quality characterization described in Chapter 7 estimated frequent exceedances above the potential health effect benchmark levels at several of the 1-hour ambient monitors within Missouri. In a ranking of estimated SO_2 emissions reported in the National Emissions Inventory (NEI), Missouri ranked 7th out of all U.S. states for the number of stacks with annual emissions greater than 1,000 tons. These stack emissions were associated with a variety source types such as electrical power generating units, chemical manufacturing, cement processing, smelters, and emissions associated with port operations.

In the 1st draft SO_2 REA, several modeling domains were characterized within the selected state of Missouri to assess the feasibility of the modeling methods. These modeling domains were defined as areas within 20 km of a major point source of SO_2 emissions. While modeled air quality and exposure results were generated for several of these domains in the 1st draft REA, changes in the methodology used in this 2nd draft REA precluded additional analysis for most of the domains originally selected. Staff judged the availability of relevant ambient monitoring data within the model domain as essential in evaluating the dispersion model performance, increasing confidence in the predicted air quality and exposure modeling results. For example, when comparing the modeled air quality to ambient monitoring data in Greene County in the 1st draft REA, it was judged by staff that non-point source emissions may contribute to a large proportion of measured ambient concentrations. Addressing non-point source emissions then added a layer to the already complex modeling performed, further limiting the potential number of locations analyzed. Second, to assess the impact of potential alternative standards, baseline conditions (*as is* air quality) need to be known, again requiring ambient monitoring data. Because Greene County had a number of ambient monitors and most of the model input data were already well-defined, it was selected for further modeling in the 2nd draft REA. Additionally, staff decided that modeling a large urban area would be advantageous in combining both large emission sources and large potentially exposed populations. Modeling for St. Louis, Mo. was already underway at the time the 1st draft REA was completed, therefore it was decided that exposure modeling in this domain should be continued and expanded for other sources for the 2nd draft and the final REAs.

8.3.2 Study Area Descriptions

8.3.2.1 Greene County, Mo.

The greater Springfield, Mo., Metropolitan Statistical Area (MSA) consists of five counties in southwestern Missouri including Christian, Dallas, Greene, Polk, and Webster counties. The only city in the region with a population greater than 150,000 is Springfield, in Greene County. Greene County has a total area of approximately 678 mi^2 (1,756 km^2). Due to the complexity of the air quality and exposure modeling performed in this exposure assessment and the focus on receptors within 20 km of stationary sources, the modeling domain was limited to Greene County (see Figure 8-2). The Springfield-Branson Regional Airport (WBAN 13995) served as the source of meteorological data used in the Greene County modeling domain.

8.3.2.2 St. Louis, Mo. Area

The greater St. Louis Metropolitan Statistical Area (MSA) is the 18th largest MSA in the United States and includes the independent City of St. Louis; the Missouri counties of St. Louis, St. Charles, Jefferson, Franklin, Lincoln, Warren, and Washington; as well as the Illinois counties of Madison, St. Clair, Macoupin, Clinton, Monroe, Jersey, Bond, and Calhoun. The total MSA has an area of approximately 8,846 mi^2 (22,911 km^2). Due to the complexity of the air quality and exposure modeling performed in this exposure assessment and the focus on receptors within 20 km of stationary sources, staff limited the modeling domain to three counties directly surrounding the city of St. Louis: St. Louis City, St. Louis County, and St. Charles County (see Figure 8-3). These three counties comprise much of the urban center of the St. Louis MSA, with a combined population of about 1.15 million (2000 Census), which is approximately 45 percent of the Greater St. Louis MSA population.

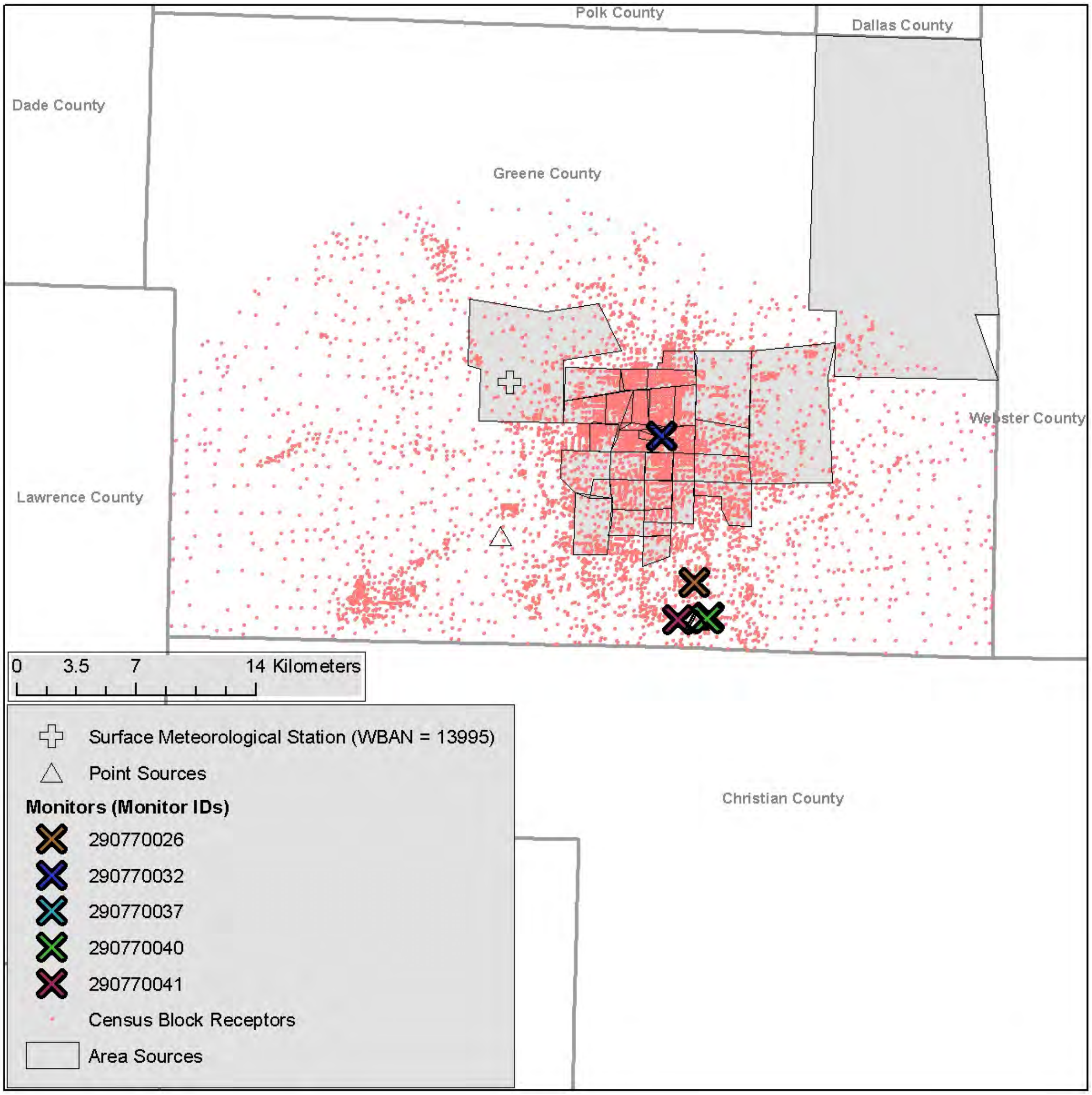

Figure 8-2. Modeling domain for Greene County Mo., along with identified emissions sources, air quality receptors, ambient monitors, and meteorological station.

The St. Louis modeling domain defined in this REA was assembled from three separate modeling domains described in the 1st draft SO_2 REA, aggregated to utilize the most reliable hourly meteorological data available (St. Louis International-Lambert Field; WBAN 13994). It was then reduced to just the three counties of the urban core described above. Figure 8-3 shows the modeling domain for the greater St. Louis, MO area.

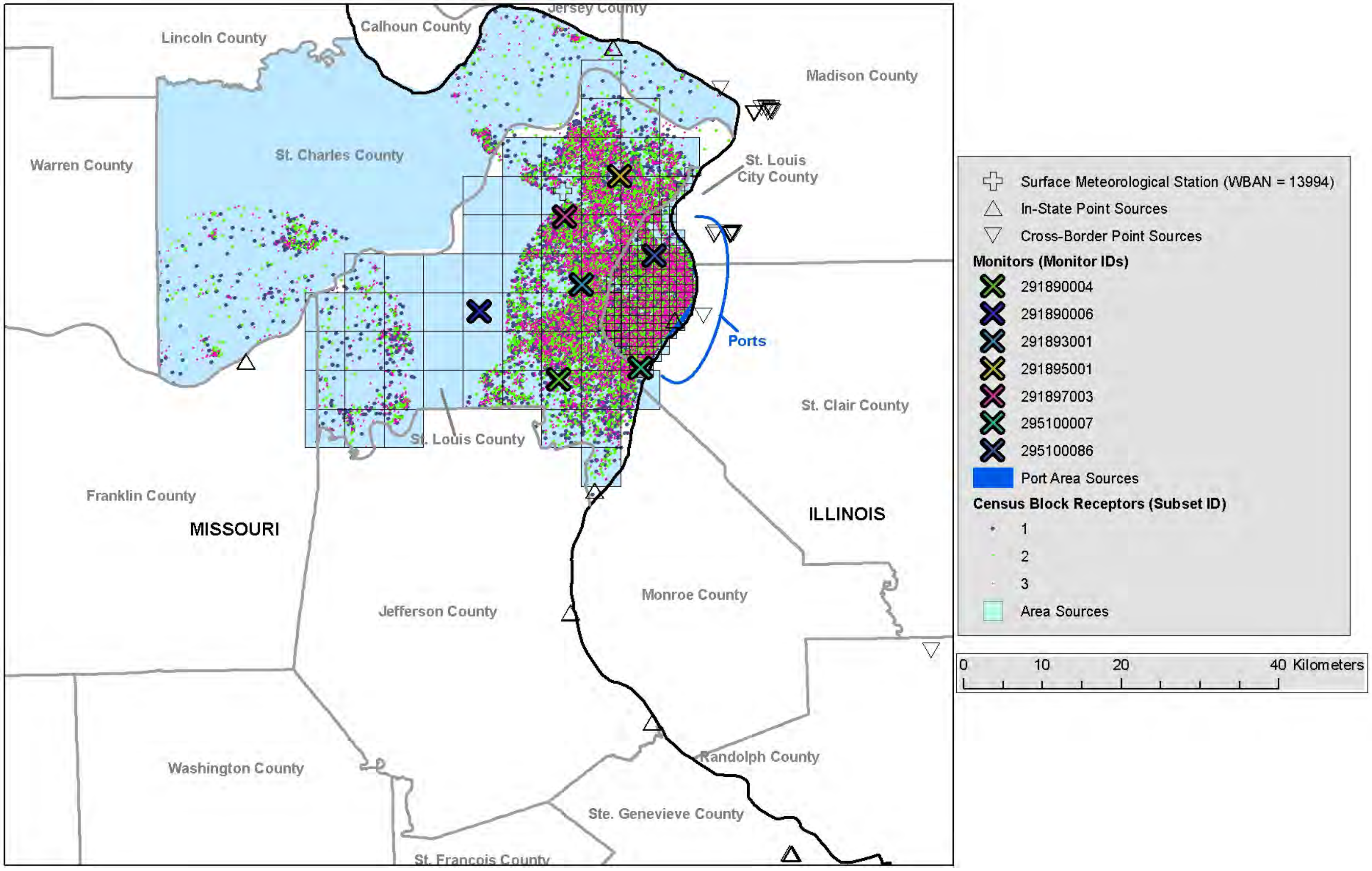

Figure 8-3. Three county modeling domain for St. Louis, Mo., along with identified emissions sources, air quality receptors, ambient monitors, and meteorological station.

8.3.3 Time Period of Analysis

Calendar year 2002 was simulated for both modeling domains to characterize the most recent year of emissions data available for the study locations. Year 2002 temperature and precipitation used in the dispersion modeling was compared with 30-year climate normal period data from 1978 through 2007. For Greene County, 2002 temperatures were similar to the 30-year normal (56.2 °F compared to 56.3 °F) though drier than the 30-year normal (37.8 in. compared to 40.2 in.). For St. Louis, 2002 temperatures were warmer on average than the 30-year normal (57.9 °F compared to 56.8 °F) and received an annual rainfall total that was similar with the 30-year normal (40.9 in. compared to 39.1 in.). See Appendix B, Attachment 1 for further details.

8.3.4 Populations Analyzed

The exposure assessment included the total population residing in each modeled area and population subgroups that were considered more susceptible as identified in the ISA. These population subgroups include:

- Asthmatic children (5-18 years in age)
- All Asthmatics (all ages)

In addition, based on the observed responses in the human clinical trials, all asthmatic exposures were characterized only when the individual was at moderate or greater exertion levels during the exposure events (see sections 8.5.5 and 8.8.2).

8.4 CHARACTERIZATION OF AMBIENT HOURLY AIR QUALITY DATA USING AERMOD

8.4.1 Overview

Air quality data used for input to APEX were generated using AERMOD, a steady-state, Gaussian plume model (EPA, 2004a). For both modeling domains, the following steps were performed.

1. **Collect and analyze general input parameters.** Meteorological data, processing methodologies used to derive input meteorological fields (e.g., temperature, wind speed, precipitation), and information on surface characteristics and land use are needed to help determine pollutant dispersion characteristics, atmospheric stability and mixing heights.

2. **Define sources and estimate emissions.** The emission sources modeled included:
    a. Major stationary emission sources within the domain,
    b. Major stationary emission sources outside the domain (cross-border stacks)
    c. Non-point source area emissions,
    d. Emissions from ports, and
    e. Background sources not otherwise captured.

    However, note that not all source categories were present in both modeling domains.

3. **Define air quality receptor locations**. Two sets of receptors were identified for the dispersion modeling, including ambient monitoring locations (where available) and census block centroids.

4. **Estimate concentrations at receptors**. Full annual time series of hourly concentration were estimated for 2002 by summing concentration contributions from each of the emission sources at each of the defined air quality receptors.

Estimated hourly concentrations output from AERMOD were then used as input to the APEX model to estimate population exposure concentrations. Details regarding both modeling approaches and input data used are provided below. Supplemental information regarding model inputs and methodology is provided in Appendix B.

8.4.2 General Model Inputs

8.4.2.1 Meteorological Inputs

All meteorological data used for the AERMOD dispersion model simulations were processed with the AERMET meteorological preprocessor, version 06341. The National Weather Service (NWS) served as the source of input meteorological data for AERMOD. Tables 8-1 and 8-2 list the surface and upper air NWS stations chosen for the two areas. A potential concern related to the use of NWS meteorological data is the often high incidence of calms and variable wind conditions reported for the Automated Surface Observing Stations (ASOS) in use at most NWS stations. A variable wind observation may include wind speeds up to 6 knots, but the wind direction is reported as missing. The AERMOD model currently cannot simulate dispersion under these conditions. To reduce the number of calms and missing winds in the surface data for each of the four stations, archived one-minute winds for the ASOS stations were used to calculate hourly average wind speed and directions, which were used to supplement the standard archive of winds reported for each station in the Integrated Surface Hourly (ISH) database. Details regarding this procedure are described in Appendix B, Attachment 1.

Table 8-1. Surface stations for the SO_2 study areas.

Area	Station	Identifier	WMO (WBAN)	Latitude[1]	Longitude[1]	Elevation (m)	Time Zone[2]
Greene County	Springfield-Branson Regional AP	SGF	724400 (13995)	37.23528	-93.40028	387	6
St. Louis	Lambert-St. Louis International AP	STL	724340 (13994)	38.7525	-90.37361	161	6

Notes:
[1] Latitude and longitude are the best approximation coordinates of the meteorological towers.
[2] Time zone is the offset from UTC/GMT to LST in hours.

Table 8-2. Upper air stations for the SO_2 study areas.

Area	Station	Identifier	WMO (WBAN)	Latitude	Longitude	Elevation (m)	Time Zone[1]
Greene County	Springfield-Branson Regional AP	SGF	724400 (13995)	37.23	-93.40	394	6
St. Louis	Lincoln-Logan County AP, IL	ILX	724340 (4833)	40.15	-89.33	178	6

Notes:
[1] Time zone is the offset from UTC/GMT to LST in hours.

8.4.2.2 Surface Characteristics and Land Use Analysis

The AERSURFACE tool (US EPA, 2008e) was used to determine surface characteristics (albedo, Bowen ratio, and surface roughness) for input to AERMET. Surface characteristics were calculated for the location of the ASOS meteorological towers, approximated by using aerial photos and the station history from the National Climatic Data Center (NCDC). A draft version of AERSURFACE (08256) that utilizes 2001 National Land Cover Data (NLCD) was used to determine the surface characteristics for this application since the 2001 land cover data will be more representative of the meteorological data period than the 1992 NLCD data supported by the current version of AERSURFACE available on EPA's SCRAM website. All stations considered were located at an airport. Monthly seasonal assignments were defined as shown in Table 8-3 and because the AERSURFACE default seasonal assignments were not used, the surface characteristics were output by month. Note, the winter options can be winter (no snow) or winter (continuous snow on ground).[53] The exposure modeling domains experienced less than 28.5 days per year of at least one inch (25.4 mm) of ground snow depth according to CLIMAP contours,[54] so no month was expected to have continuous snow on ground and hence the designation of winter (no snow) only.

Table 8-3. Seasonal monthly assignments.

Station	Winter (no snow)	Spring	Summer	Autumn
SGF	December, January, February, March	April, May	June, July, August	September, October, November
STL	December, January, February	March, April, May	June, July, August	September, October, November
Seasonal definitions				
Winter (no snow)	Late autumn after frost and harvest, or winter with no snow			
Spring	Transitional spring with partial green coverage or short annuals			
Summer	Midsummer with lush vegetation			
Autumn	Autumn with unharvested cropland			

8.4.3 Stationary Sources Emissions Preparation

8.4.3.1 Emission Sources and Locations

Point Sources

Point sources at major facilities were identified and paired to a representative surface meteorological station. Any stacks listed as in the same location with identical release parameters within a certain resolution (typically to the nearest integer value) were aggregated into a single stack to simplify modeling but retain all emissions. For this analysis, major facilities were defined as those with an SO_2 emission total exceeding 1,000 tpy in 2002. Within such facilities, every stack emitting more than one tpy was included in the modeling inventory. This process resulted in the identification of 11 (combined) stacks in Greene County and 38 (combined) stacks in St. Louis. Additionally, 45 (combined) stacks were identified across the state border that could influence concentrations in St. Louis. These cross-border stacks were modeled the same as the within-state stacks. The locations of all emitting stacks were corrected based on GIS analysis. This was necessary because many stacks in the NEI are assigned the

[53] The designation of winter (continuous snow) would tend to increase wintertime albedo and decrease wintertime Bowen ratio and surface roughness for most land-use types compared to snow-free areas.

[54] NCDC Climate Maps of the United States database (CLIMAPS). See http://cdo.ncdc noaa.gov/cgi-bin/climaps/climaps.pl.

same location, which often corresponds to a location in the facility – such as the front office – rather than the actual stack locations. To correct for this, stack locations were reassigned manually with the Microsoft® Live Maps® Virtual Earth® tool to visually match stacks from the NEI database to their locations within the facilities using stack heights as a guide to stack identification. All release heights and other stack parameters were taken from the values listed in the NEI. Table B.3-1 (in Appendix B) lists all stacks in both domains.

Port-Related Sources

Only the St. Louis modeling domain has relevant port emissions. The Port of St. Louis is one of the nation's largest inland river ports. Activity from this port was modeled as fourteen area sources along the waterfront. All port-related emission sources were considered as non-point area emissions with boundaries based on GIS analysis of aerial photographic images. A release height of 5.0 m with a plume initial vertical standard deviation (σ_{zi}) of 2.33 m was used in all cases to represent emissions from Category 1 and 2 commercial marine vessels. Port emission strength was taken from the NEI for appropriate activity within St. Louis City and allocated uniformly by emission density for all harbor areas. That is, all ports were modeled with the same emission density. The emission profile was taken as the seasonal hourly value from the Emissions Modeling System for Hazardous Pollutants (EMS-HAP) model.

Non-Point Sources

Non-point sources constitute industrial, commercial and institutional facilities as identified in the NEI. Emissions from non-point sources in Greene County are identified for each tract in the County. In Greene County, spatial allocation factors (SAFs) from EPA's EMS-HAP database[55] were used to disaggregate the county-wide emissions from the NEI to census tracts. Tracts with total non-point emission densities greater than 12 tons per year/square mile were digitized and characterized as non-point source area polygons. These tracts accounted for about 87% of the total non-point source emissions in Greene County.

The release heights for non-point area sources are 10.0 m for rural tracts and 20.0 m for urban tracts. Initial vertical dispersion coefficients (σ_{zi}) were 4.67 m for rural tracts and 9.34 m for urban tracts. Because these sources are not well-defined, the release parameters were derived

[55] The SAFs were derived from land use data.

though a series of sensitivity runs to characterize model performance at the ambient monitor locations.

For the St. Louis domain, staff chose a slightly different approach to characterize non-point emissions sources. During model-to-monitor comparisons, it became clear that the spatial allocation of county-wide non-point emissions to tracts, based on SAFs, resulted in an inaccurate spatial pattern of emissions. Therefore, the spatial resolution of non-point sources in this domain was retained at the county level. However, to improve the numerical representation of these emissions in the model, the two counties with the highest non-point source emissions – St. Louis City and St. Louis County – were subdivided into regular grid cells. St. Louis County grid cells were 5 km by 5 km; St. Louis City grid cells were 1 km by 1 km, more closely approximating the smaller and denser census tracts in that region. All county-wide non-point source emissions were spatially allocated uniformly to the grid cells. St. Charles County was modeled as a single area source, with edges approximating the full county boundaries.

The release parameters for the St. Louis domain varied according to the urban and rural designation of individual grid cells. Rural grid cells have a release height of 10 m and initial dispersion length of 4.67 m. Urban grid cells have a release height of 20 m and initial dispersion length of 9.34 m.

Background Sources

For the Greene County modeling domain, background sources were assembled to account for any emissions not otherwise included. These were comprised of any point sources in facilities not meeting the 1,000 tpy selection criteria and any residual non-point sources, as well as on-road and non-road mobile sources. In addition, all emission sources in neighboring Christian County were modeled as a rural, county-wide non-point area source with uniform density. Both background sources were characterized as county-wide polygon rural area sources with release heights of 10.0 m and initial dispersion length of 4.67 m.

For the St. Louis modeling domain, emissions from residual point sources, on-road mobile sources, and non-road mobile sources were combined with the county-wide non-point sources as described above. Thus, no separate background sources were simulated.

8.4.3.2 Urban vs. Rural Designations

This section describes how urban and rural designations were determined for each emission source type. AERMOD has somewhat different treatment for urban and rural sources. For example, when regulatory default settings are employed as they were in this application, no chemical decay is assumed for rural sources, while a 4-hour half-life is assumed for urban sources. Another difference in AERMOD's treatment of urban and rural sources is that for urban sources, additional dispersion is simulated at night to account for increased surface heating within an urban area under stable atmospheric conditions. The magnitude of this effect is weakly proportional to the urban area population.

Point Sources

Urban or rural designations for point sources were made according to EPA guidance based on the land use within 3 km of the source. The 2001 NLCD database was used to make this determination. Table 8-4 lists the land use categories in the 2001 NLCD.

Table 8-4. NLCD2001 land use characterization.

Category	Land Use Type	Category	Land Use Type
11	Open Water	73	Lichens
12	Perennial Ice/Snow	74	Moss
21	Developed, Open Space	81	Pasture/Hay
22	Developed, Low Intensity	82	Cultivated Crops
23	Developed, Medium Intensity	90	Woody Wetlands
24	Developed, High Intensity	91	Palustrine Forested Wetland[1]
31	Barren Land (Rock/Sand/Clay)	92	Palustrine Scrub/Shrub Wetland[1]
32	Unconsolidated Shore[1]	93	Estuarine Forested Wetland[1]
41	Deciduous Forest	94	Estuarine Scrub/Shrub Wetland[1]
42	Evergreen Forest	95	Emergent Herbaceous Wetlands
43	Mixed Forest	96	Palustrine Emergent Wetland (Persistent) [1]
51	Dwarf Scrub	97	Estuarine Emergent Wetland[1]
52	Shrub/Scrub	98	Palustrine Aquatic Bed[1]
71	Grassland/Herbaceous	99	Estuarine Aquatic Bed[1]
72	Sedge/Herbaceous		

Notes:
[1] Coastal NLCD class only.

Each stack where more than half the land use within 3 km fell into categories 21-24 were designated as urban. These categories are consistent with those considered developed by AERSURFACE.[56]

Non-Point Sources

Non-point area sources were defined as rural or urban using a similar methodology as that for the point sources. As noted in the 2008 AERMOD Implementation Guide,[57] in some cases, a population density is more appropriate than a land use characterization. Therefore, non-point area sources were evaluated from both a land use and population density perspective.

In Greene County, area sources were defined as corresponding to the census tract boundaries. Each tract was then considered urban or rural by considering both the population density and land use fraction from NLCD2001. If the population density was greater than 750 persons/km^2 or the developed land use categories 22-24 throughout the tract was greater than 50 percent, the tract was designated as urban. In addition, if a tract was surrounded by urban tracts it was designated as urban, since the emissions from such a tract would likely be subject to urban dispersion conditions.

As explained above, for the St. Louis modeling domain, the counties with the greatest non-point emissions – St. Louis City and St. Louis County – were subdivided into regular grid cells, while St. Charles County was represented as a polygon area source with its political boundaries. The urban or rural designation was then assigned to each based on population density. St. Charles County and all but eleven of the 5 km grid cells in St. Louis County were designated rural; the remaining cells in St. Louis County and all of St. Louis City were designated urban.

Port-Related Sources

Only the St. Louis modeling domain has relevant port emissions. The fourteen port-related non-point area sources described above were designated urban, given their location in the urban core along the waterfront and their associated industrial activities.

[56] *AERSURFACE User's Guide*, U.S. EPA, OAQPS, Research Triangle Park, NC, EPA-454/B-08-001, January 2008.
[57] *AERMOD IMPLEMENTATION GUIDE*, AERMOD Implementation Workgroup, US EPA, OAQPS, Air Quality Assessment Division, Research Triangle Park, NC, Revised January 9, 2008,

Background Sources

Background area sources for Greene County were classified with the same procedures as for non-point area sources. Both Greene and Christian counties were designated rural.

8.4.3.3 Source Terrain Characterization

All corrected locations for the final list of major facility stacks in St. Louis and Greene County domains were processed with a pre-release version of the AERMAP terrain preprocessing tool. This version is functionally equivalent to the current release version of the tool (version 08280). In particular, this updated version allows use of 1 arc-second terrain data from the USGS Seamless Server[58] which allows for more highly resolved values of the source and receptor heights as well as the hill height scales.

Terrain height information for point sources was processed through AERMAP with input data taken from the USGS server. For all area sources (non-point and background source types), the outputs from AERMAP were modified. In these cases, rather than using a single point to represent these large areas, the terrain height for each vertex of the area was estimated with AERMAP. The terrain height for the entire source polygon was then characterized as the average terrain height from all vertices.

8.4.3.4 Emissions Data Sources

Point Sources

Data for the parameterization of major facility point sources in the two modeling domains comes primarily from three sources: the 2002 NEI (EPA, 2007f), Clean Air Markets Division (CAMD) Unit Level Emissions Database (EPA, 2007g), and temporal emission profile information contained in the EMS-HAP (version 3.0) emissions model.[59] The NEI database contains stack locations, emissions release parameters (i.e., height, diameter, exit temperature, exit velocity), and annual SO_2 emissions. The CAMD database has information on hourly SO_2 emission rates for all the electric generating units in the US, where the units are the boilers or equivalent, each of which can have multiple stacks.[60] These two databases generally contain

[58] http://seamless.usgs.gov/index.php
[59] http://www.epa.gov/ttn/chief/emch/projection/emshap30 html
[60] The CAMD database also contains hourly NO_2 emission data for both electric generating units and other types of industrial facilities. In the case of facilities for which CAMD has hourly NO_2 data but not SO_2 data, SO_2 relative

complimentary information, and were first evaluated for matching facility data. However, CAMD lacks SO_2 emissions data for facilities other than electric-generating units. To convert annual total emissions data from the NEI into hourly temporal profiles required for AERMOD, a three tiered prioritization was used, as follows.

1. CAMD hourly concentrations to create relative temporal profiles.
2. EMS-HAP seasonal and diurnal temporal profiles for source categorization codes (SCCs).
3. Flat profiles, that is, a uniform emission rate throughout the day.

Details of these processes were as follows:

Tier 1: CAMD to NEI Emissions Alignment and Scaling

Of the 94 major facility stacks within the model domains identified above (11 in Greene County and 45 cross-border and 38 within-state in the St. Louis domain), 35 (11 in Greene County and 7 cross-border and 17 in-state in the St. Louis domain) were able to be matched directly to sources within the CAMD database. Stack matching was based on the facility name, Office of Regulatory Information Systems (ORIS) identification code (when provided) and facility total SO_2 emissions. For these stacks the relative hourly profiles were derived from the hourly values in the CAMD database, and the annual emissions totals were taken from the NEI. Hourly emissions in the CAMD database were scaled to match the NEI annual total emissions by proportionally scaling each hour. Although the CAMD emissions may be more accurate than the corresponding values in the NEI because they are based on direct emissions monitoring, because CAMD emissions estimates were available for only a subset of sources, the NEI emission totals were used so that the emission estimates would be consistent across all sources.

Tier 2: EMS-HAP to NEI Emissions Profiling

Of the 94 major facility stacks within the two MO domains, 38 stacks (all of which are cross-border stacks in the St. Louis domain) could not be matched to a stack in the in the CAMD database, but had SCC values that corresponded to SCCs that have temporal profiles included in the EMS-HAP emissions model. In these cases, the SCC-specific seasonal and hourly variation (SEASHR) values from the EMS-HAP model were used to characterize the temporal profiles of emissions for each hour of a typical day by season and day type.

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temporal profiles could be approximated by NO_2 temporal profiles. However, there were no such cases for MO facilities.

Tier 3: Other Emissions Profiling

Of the 94 major facility stacks within the two MO model domains, 21 (all from the St. Louis in-state domain) could not be matched to a stack in CAMD database, or to profiles in the EMS-HAP model by SCC code. In these cases, a flat profile of emissions was assumed. That is, emissions were assumed to be constant for all hours of every day, but with an annual total that equals the values from the NEI. A summary of the point source emissions used for the two modeling domains is given in Table 8-5. Appendix B, Table B.3-1 contains all 94 stacks within the modeling domains and the data source used to determine their emissions profiles.

Nearly all of the point sources in both domains were accounted for directly in the dispersion modeling. Table 8-5 shows the point source contribution captured directly within each modeling domain.

Port-Related Sources

Ports were the only non-road sector explicitly simulated in either modeling domain. Only the St. Louis domain had port emissions. All relevant port emissions were directly captured, comprising 51 percent of the total non-road emissions for the domain. Emission profiles for port-related activity were taken from the EMS-HAP model for sectors matching the modeled activity. Table 8-5 shows the port source contribution modeled directly within each modeling domain and compares it to the total non-road emissions.

Non-Point and Background Sources

Non-point polygon area sources were developed to capture non-point commercial/institutional and industrial emissions within the domains, as specified in the NEI. For the St. Louis modeling domain, all non-point emissions were included either in gridded area sources over St. Louis City and St. Louis County or a polygon area source over St. Charles County, as described above. For the Greene County modeling domain, commercial/institutional and industrial non-point area source polygons were created to represent the individual census tracts within the county that captured approximately 87 percent of the relevant emissions countywide from the NEI. Other non-point sources, as well as on-road mobile and non-road mobile sources were included in the background source

Because non-point area source and background area source temporal profiles are unknown, staff derived profiles that provided a best-fit match between the model predictions and monitor data. To determine the most representative average non-point area source emission profile across each modeling domain, we first selected monitors where ambient concentrations were expected to be primarily influenced by area sources. Due to their locations relative to sources, all but one monitor (ID 290770032) in Greene County indicated ambient concentrations were primarily influenced by point source emissions. In St. Louis, all seven ambient monitors (IDs 291890004, 291890006, 291893001, 291895001, 291897003, 295100007, and 295100086) indicated significant influence from area source emissions. Next, simulations were conducted with all sources modeled in detail – except area sources, which were modeled with uniform emission profiles. A weighting function was then determined based on the modeled error for each hour of the day at the one Greene County monitor and as an average of the errors at the seven individual St. Louis area monitors. In both cases, the error function was defined as the ratio of the total observed concentration, minus the total concentration due to all non-point sources, to the concentration predicted by the non-point sources alone. This diurnal error function was then normalized such that its average value is unity. Finally, a corrected non-point emission profile was determined by combining this normalized weighting function with the uniform emission profile.

Figures 8-4 and 8-5 show the diurnal emissions profiles derived for both the St. Louis and Greene County domains compared to other profiles for industrial and commercial/institutional area sources derived from commonly used emissions models, such as SMOKE and EMS-HAP. The shape of the derived temporal profiles imply that the emission sources are active almost exclusively during the daytime from approximately 8 am to 8pm, in contrast to those derived from SMOKE and EMS-HAP, which show less extreme daytime-dominated patterns. Given the large uncertainties about the actual emission sources represented by the industrial and commercial/institutional non-point category and given that such sources are likely to be small facilities, it is reasonable to assume that their cumulative emissions occur almost exclusively during daytime hours. Table 8-5 shows the non-point source contribution modeled directly within each modeling domain and compares it to the total non-point emissions.[61]

[61] Table 8-5 does not have the relevant background contribution for each domain. This is because the total background in each domain includes not only the counties in the modeling domain (three in the St. Louis domain and one in the Greene County domain), but also adjacent counties that could influence concentrations within the modeling domain. In those cases, the total countywide emissions are included in the background. Thus, directly expressing those values would be confusing and are thus omitted.

Table 8-5. Summary of NEI emission estimates and total emissions used for dispersion modeling in Greene County and St. Louis modeling domains.

Modeling Domain	Point Sources			Area Sources			Non-road Sources		
	NEI Emissions (tpy)	Modeled Emissions (tpy)	(%)	NEI Emissions (tpy)	Modeled Emissions (tpy)	(%)	NEI Emissions (tpy)	Modeled Emissions (tpy)	(%)
Greene Co.	9,255	9,047	98%	2,055	1,781	87%	N/A	N/A	N/A
St. Louis	70,016	68,656	98%	15,137	15,137	100 %	3,058	1,559	51%

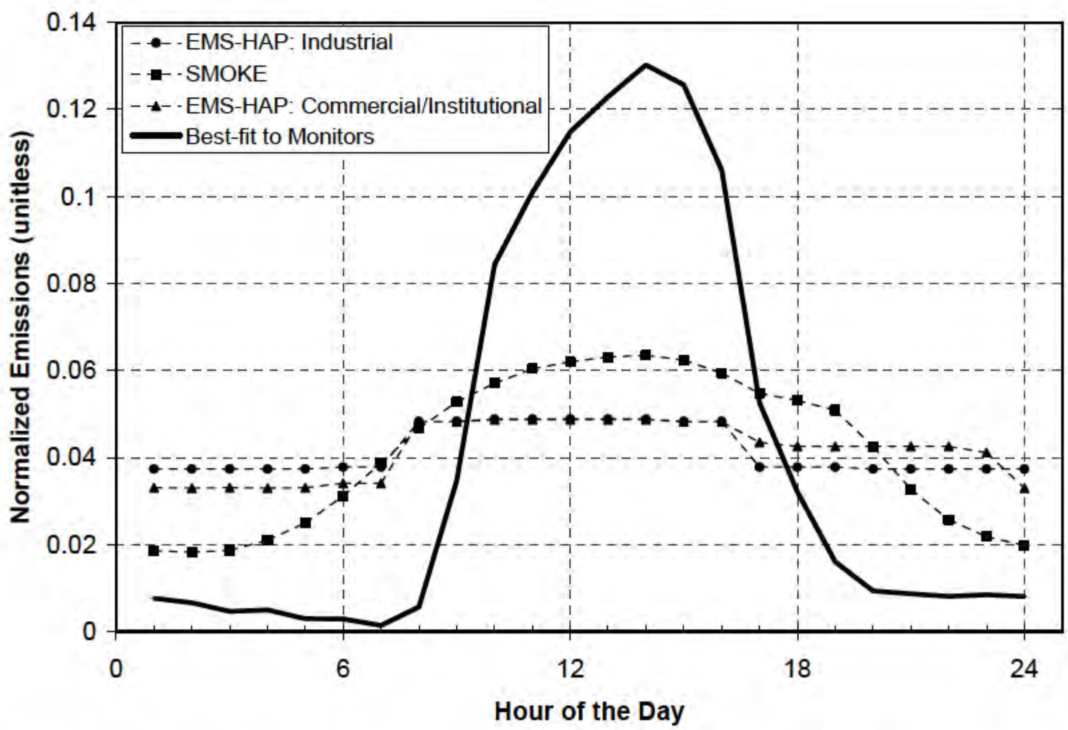

Figure 8-4. Derived best-fit non-point area source diurnal emission profile for the St. Louis domain, compared to other possible profiles.

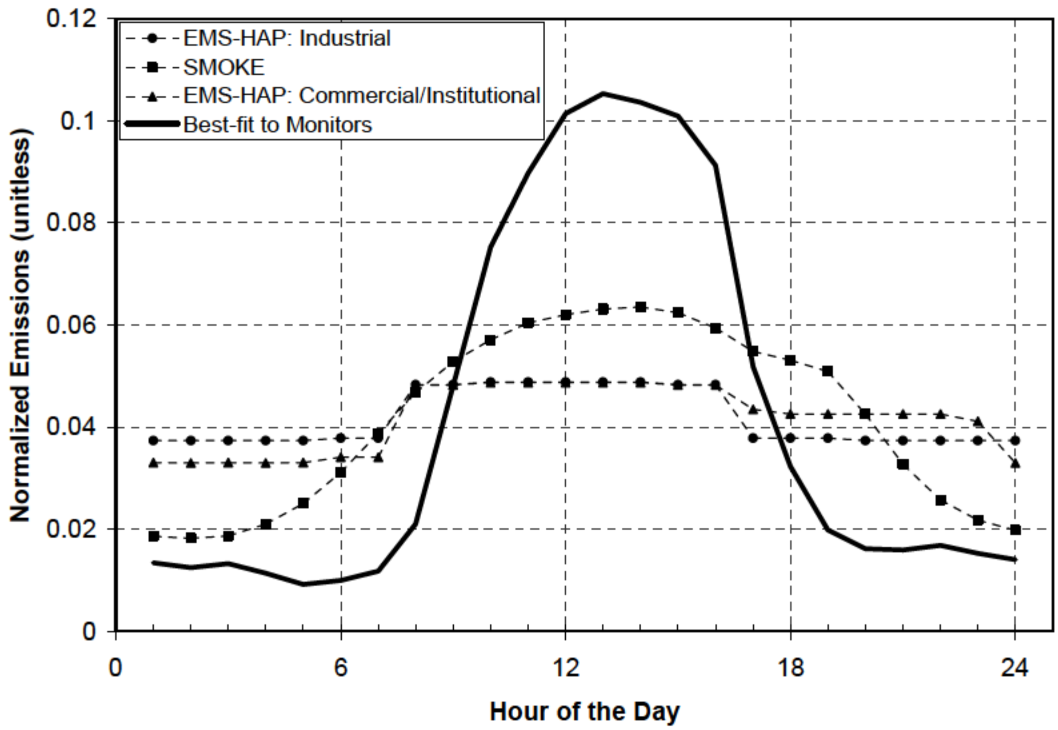

Figure 8-5. Derived best-fit non-point area source diurnal emission profile for the Greene County domain, compared to other possible profiles.

8.4.4 Receptor Locations

Two sets of receptors were chosen to represent the locations of interest within each of the modeling domains. The first set was selected to represent the locations of the residential population of the modeling domain. These receptors were US Census block centroids in the Greene County and St. Louis modeling domains, (Figures 8-2 and 8-3, respectively), that lie within 20 km (12 miles) of any of the major facility stacks.[62] Each of these receptors was modeled at ground level. A total of 17,703 receptors were selected in the St. Louis modeling domain and a total of 5,359 receptors were selected in the Greene County modeling domain.

The second set of receptors included the locations of the available ambient SO_2 monitors. These receptors were used in evaluating the dispersion model performance. In Greene County, there were five ambient monitors with valid ambient monitoring concentrations (Figure 8-2). Within the three St. Louis counties, there were seven monitors (Figure 8-3).

[62] The block centroids used for this analysis are actually population-weighted locations reported in the ESRI database. They were derived from geocoded addresses within the block taken from the Acxiom Corporation InfoBase household database (Skuta and Wombold, 2008; ESRI, 2008). These centroids differ from the "internal points" reported by the US Census, which are often referred to as centroids because they are designed to represent the approximate geographic center of the block.

8.4.5 Modeled Air Quality Evaluation

The hourly SO_2 concentrations estimated from each of the sources within a modeling domain were combined at each receptor. These concentration predictions were then compared with the measured concentrations at ambient SO_2 monitors. Rather than compare concentrations estimated at a single modeled receptor point to the ambient monitor concentrations, a distribution of concentrations was developed for the predicted concentrations for all receptors within a 4 km distance of the monitors. Further, instead of a comparison of central tendency values (mean or median), the full modeled and measurement concentration distributions were used for comparison.

As an initial comparison of modeled versus measured air quality, all modeled receptors within 4 km of each ambient monitor location were used to generate a prediction envelope.[63] This envelope was constructed based on selected percentiles from the modeled concentration distribution at each receptor for comparison to the ambient monitor concentration distribution. The 2.5th and 97.5th percentiles from all monitor distribution percentiles[64] were selected to create the lower and upper bounds of the envelope. The full 1-hour distributions for the ambient measurement data, the modeled monitor receptor,[65] and the prediction envelope were compared using their respective cumulative density functions (CDFs). When illustrating these distributions, the percentiles were plotted on a log-scale as the difference between 100 and the CDF value to allow for visual expansion of the extreme upper percentiles of the distribution. For illustrative purposes, the maximum concentration was defined as 100-99.99 (or 0.01) because the logarithm of zero is undefined.

A second comparison between the modeled and monitored data was performed to evaluate the diurnal variation in SO_2 concentrations. AERMOD receptor concentrations during each hour-of-the-day were averaged (i.e., 365 values for hour 1, 365 values for hour 2, and so on) to generate an annual average SO_2 concentration for each hour at each modeled receptor. Prediction envelopes were constructed similar to that described above from modeled receptors

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[63] 500 m to 4 km is the area of representation of a neighborhood-scale monitor, according to EPA guidance.
[64] As an example, suppose there are 1,000 receptors surrounding a monitor, each receptor containing 8,760 hourly values used to create a concentration distribution. Then say the 73rd percentile concentration prediction is to be estimated for each receptor. The lower bound of the 73rd percentile of the modeled receptors would represented by the 2.5th percentile of all the calculated 73rd percentile concentration predictions, i.e., the 25th highest 73rd percentile concentration prediction across the 1,000 73rd percentile values generated from all of the receptors. Note that at any given percentile along either of the envelope bounds as well as at the central tendency distribution (the receptor 50th percentile), the concentration from a different receptor may be used.
[65] The *modeled monitor* is the modeled air quality at the ambient monitoring location.

located within 4 km of each ambient monitor. The measured ambient monitoring data was also averaged to generate the diurnal profile. Then, annual averaged concentrations for the ambient measurement data, the modeled monitor receptor, and the prediction envelope were plotted by hour-of-the-day for comparison.

Staff also evaluated potential impact of the differences between the predicted and measured 1-hour SO_2 concentrations by comparing the modeled and measured number of 5-minute air quality benchmark exceedances that would result from using each 1-hour concentration distribution. The full year of 1-hour ambient monitored and AERMOD modeled SO_2 concentrations (at the monitor receptor location) were used as input to the 5-minute statistical model and processed as described in section 7.2.5. Measured 5-minute maximum SO_2 concentrations were only available for two of the monitors in Greene County (290770026 and 290770040). These monitoring locations were used to generate the number of days per year with at least one benchmark exceedance. Further, the concentration distributions given by the AERMOD prediction envelopes (i.e., the 2.5th and 97.5th) were used to approximate lower and upper prediction bounds for the number of days per year with 5-minute benchmark exceedances. To do this, first the total numbers of benchmark exceedances in a year[66] were estimated for each monitor using the 1-hour concentration percentiles representing each AERMOD distribution (i.e., the AERMOD monitor receptor, the AERMOD 2.5th, and the AERMOD 97.5th). Then, scaling factors were calculated by dividing each the AERMOD 2.5th and AERMOD 97.5th benchmark exceedance results by that of the exceedances estimated using the AERMOD monitor receptor. These scaling factors were then applied to the full AERMOD monitor receptor predictions that estimated the number of days per year with exceedances to estimate the lower and upper bounds.

8.4.5.1 Greene County Modeled Air Quality Evaluation

For Greene County, there were five monitors used for comparison with the AERMOD 1-hour concentration estimates. For each monitor, staff plotted the model-predicted versus ambient measured concentrations using two methods; the first used a CDF, the second used the

[66] Because the AERMOD p2.5 and p97.5 prediction envelopes are not representing a particular time but are a temporal and spatial mixture of low and high concentrations surrounding each monitor, specific counts of days per year could not be calculated. Staff assumed a proportional relationship existed between the total number of exceedances in a year and the number of days per year with exceedances. Thus, scaling factors can be calculated using the AERMOD monitor receptor data, which had both the percentile form and 8,760 concentrations at specific hours of the day and days of the year.

diurnal profile. In each plot, four concentration distributions were used; the distribution of the modeled 1-hour SO_2 concentrations estimated for the monitor receptor, the upper and lower bounds of the receptor envelope (i.e., generated from all receptors within 4 km of monitor receptor), and the hourly concentration distribution measured at each ambient monitor. The results for Greene County are provided in Figures 8-6 to 8-8. The data used to generate the figures are provided in Appendix B.

When considering the total hourly distribution or CDFs, monitor concentration distributions are generally bounded by the modeled distributions. At some of the upper percentiles of the distributions, the deviations were of varying direction (over- or under-prediction) and magnitude (a few ppb to tens of ppb). For example, monitor ID 290770026 (Figure 8-6) exhibits higher measured concentrations at the upper percentiles of the distribution that extend beyond the AERMOD prediction envelope, however the deviation occurred beyond the 99.5th percentile (maximum observed =114 ppb, AERMOD 97.5th = 101 ppb). At monitor ID 290770032 (Figure 8-6), the measured concentrations fall below the prediction envelope, beginning just beyond the 95th percentile 1-hour concentration.

Even though ambient monitors 290770040 and 290770041 (Figure 8-2) are located approximately 150 m from one another, they exhibited very different measured concentrations at the extreme upper percentiles (Figure 8-7). The greatest difference is in comparing the maximum observed concentrations; 203 ppb versus 33 ppb. The AERMOD predictions followed a similar pattern at the upper percentiles, i.e., the modeled concentrations for the monitor location were greater (50 to 100%) at monitor ID 290770040 when compared with 290770041, but not nearly as great a difference noted at the maximum measured concentrations. The AERMOD prediction envelope was similar for both of these monitors, encompassing the ambient measured concentrations from the 80th through the 99.5th percentiles for both, while completely enveloping all 1-hour concentrations at monitor ID 290770041.

The pattern in the AERMOD modeled concentrations at the monitor location and the ambient measurement concentration distribution for monitor ID 290770037 is nearly identical. The only difference observed is that the measured concentrations are 1-3 ppb greater than the modeled concentrations within the 99th percentile of the distribution. Much of the measured distribution falls within the AERMOD prediction envelope, with deviation occurring just beyond the 99.5th percentile.

The diurnal pattern observed at each of the ambient monitors is represented well by the modeled concentrations; in general concentrations are elevated during the midday hours and lowest during the late-night and early-morning hours. In addition, most of the measured concentrations fall within the AERMOD prediction envelopes at all hours of the day, with a few exceptions. For example, all observed concentrations for monitor ID 290770032 are below that of the upper AERMOD prediction envelope, though at monitor ID 290770026, measured concentrations are above those modeled during the early-morning and late-night hours (Figure 8-6). Much of the deviation during these hours-of-the-day is likely a result of the concentrations at or below the 80^{th} percentile, where measured concentrations were always greater than any of the predicted concentrations at corresponding percentiles of the distribution. While the prediction envelopes encompassed the diurnal pattern observed at monitor IDs 290770040 and 290770041 (Figure 8-7), the results for the modeled concentrations at the monitor locations were not equally representative. The diurnal pattern and magnitude of concentrations was well reproduced at monitor ID 290770041, while modeled concentrations at the monitor location during the midday and evening hours were greater than the measured concentrations at monitor ID 290770040.

Staff evaluated the potential impact the predicted 1-hour concentrations would have on 5-minute air quality benchmark exceedances (Table 8-6). In general, the results for the estimated numbers of days per year with 5-minute concentrations above benchmark levels followed similar patterns to those observed above when considering comparisons of the 1-hour SO_2 concentration distributions. The numbers of benchmark exceedances at monitor ID 290770026 were under-predicted by AERMOD just as was the 1-hour SO_2 concentrations at that monitoring location. However, the number of days with 5-minute concentrations above the benchmark levels for both the measured and modeled ambient concentrations fell within the range of the AERMOD prediction envelopes. There was good agreement in the number of days per year with air quality benchmark exceedances at each of the four other monitors, whether there were none, a few, or several days with expected benchmark exceedances. These results indicate that the magnitude of observed differences in predicted versus measured 1-hour SO_2 concentration does not result in unexpected differences in the number of days per year having 5-minute SO_2 concentrations above the benchmark levels.

Table 8-6. Measured and modeled number of days in year 2002 with at least one 5-minute SO_2 benchmark exceedance at ambient monitors in Greene County.

Monitor ID	5-minute SO_2 Benchmark (ppb)	Number of Days per Year with a 5-minute SO_2 Concentration Above Air Quality Benchmark Level				
		Ambient Monitor[1]		AERMOD[2]		
		Modeled	Measured	p2.5	Monitor	p97.5
290770026	100	57	27	2	19	103
	200	18	0	0	2	9
	300	6	0	0	0	2
	400	2	0	0	0	0
290770032	100	0	-	0	0	0
	200	0	-	0	0	0
	300	0	-	0	0	0
	400	0	-	0	0	0
290770037	100	33	44	1	40	81
	200	14	12	0	13	22
	300	7	1	0	5	6
	400	4	0	0	2	3
290770040	100	7	-	0	25	42
	200	3	-	0	3	5
	300	1	-	0	0	0
	400	0	-	0	0	0
290770041	100	0	-	0	2	17
	200	0	-	0	0	0
	300	0	-	0	0	0
	400	0	-	0	0	0

Notes:
[1] The modeled numbers of 5-minute benchmark exceedances were generated from 1-hour SO_2 ambient monitor measurements input to the 5-minute statistical model. The measured numbers of 5-minute benchmark exceedances were calculated from ambient monitors reporting 5-minute SO_2 concentrations. Both of these values were normalized to a full year (n=365 days) for comparison with the AERMOD predictions.
[2] AERMOD monitor 5-minute benchmark exceedances were generated from 1-hour SO_2 ambient predictions (at monitor receptor location) input to the 5-minute statistical model. AERMOD p2.5 and p97.5 benchmark exceedances were generated from the corresponding hourly prediction envelope distribution and input to the 5-minute statistical model.

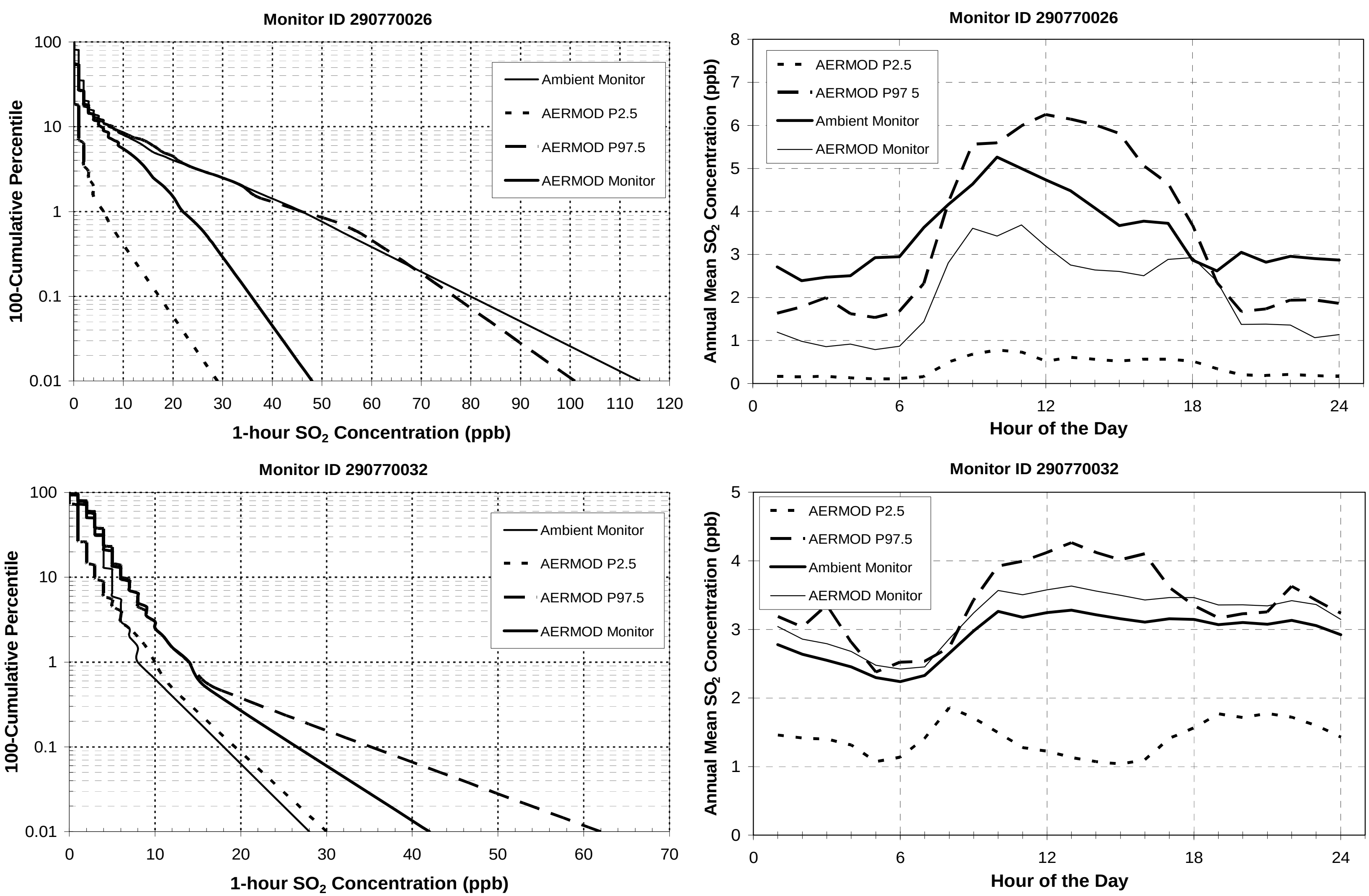


Figure 8-6. Comparison of measured ambient monitor SO_2 concentration distribution and diurnal profile with the modeled monitor receptor and receptors within 4 km of monitors 290770026 and 29077032 in Greene County, Mo. Maximum 1-hour concentration percentile is defined as 0.01 (or 100-99.99) because log(0) is undefined.

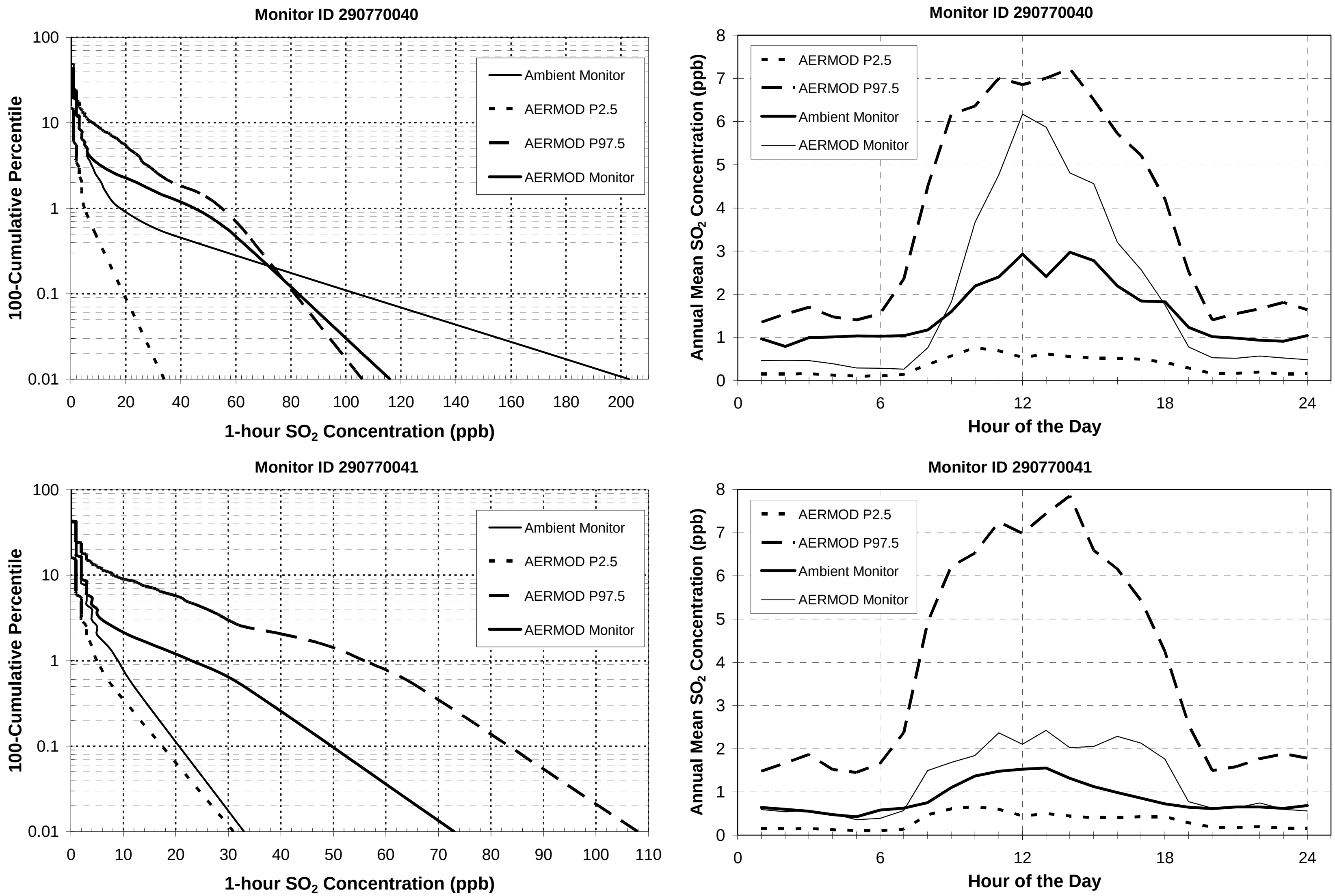


Figure 8-7. Comparison of measured ambient monitor SO_2 concentration distribution and diurnal profile with the modeled monitor receptor and receptors within 4 km of monitors 290770040 and 29077041 in Greene County, Mo. Maximum 1-hour concentration percentile is defined as 0.01 (or 100-99.99) because log(0) is undefined.

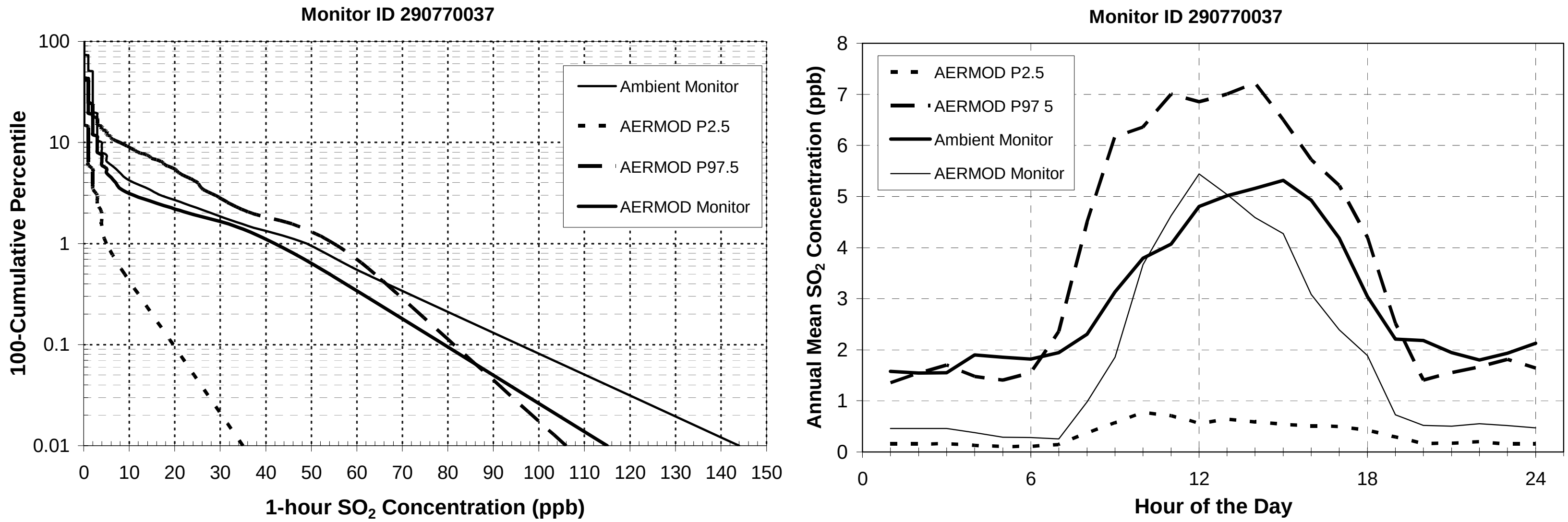


Figure 8-8. Comparison of measured ambient monitor SO_2 concentration distribution and diurnal profile with the modeled monitor receptor and receptors within 4 km of monitor 290770037 in Greene County, Mo. Maximum 1-hour concentration percentile is defined as 0.01 (or 100-99.99) because log(0) is undefined.

8.4.5.2 St. Louis Modeled Air Quality Evaluation

For St. Louis, there were seven monitors used for comparison with the AERMOD concentration estimates. The distribution of the modeled 1-hour SO_2 concentrations estimated for the monitor receptor, the receptor envelope (i.e., all receptors within 4 km of monitor receptor), and the hourly concentration distribution measured at each ambient monitor are provided in Figures 8-9 to 8-12. Data used to generate the figures is provided in Appendix B.

There are distinct differences in the comparison of modeled versus measured concentration distributions at ambient monitoring locations in St. Louis when compared with Greene County. Most noticeable is the width of the prediction envelopes; St. Louis prediction envelopes were not as wide as those generated for Greene County. This indicates that, in comparison with the Greene County modeling domain, there is less spatial variability in the concentrations modeled at receptors surrounding the ambient monitoring locations in St. Louis. This is likely a result of the emission source contributions; four of five ambient monitors in Greene County were primarily influenced by point sources, while most of the concentration contribution for St. Louis monitors was from area source emissions.

The modeled concentrations at the monitor locations and ambient measured concentration distributions showed better overall agreement at the St. Louis monitors, though many of the measured concentrations are outside of the prediction envelopes. For example, at monitor ID 291890006 all measured concentrations up to the 99^{th} percentile fell below the prediction envelope (Figure 8-9) (the maximum was within). Note however that the difference in the measured concentrations was only about 1 ppb when compared with concentrations at any of the envelope percentiles and at most 2 ppb when compared with the modeled concentrations at the monitor receptor. In addition, because most of these under-predictions occur at concentrations well below levels of interest, it is not of great consequence. At the upper percentiles, many of the ambient concentrations fell within the prediction envelopes; 6 of 7 monitors at the maximum percentile were within, 3 of 7 monitors at the 99^{th} percentile were within, and 4 of 7 monitors at the 95^{th} percentile were within the prediction envelopes. Where measured upper percentile concentrations were outside of the prediction envelopes, it was consistently beneath the 2.5^{th} prediction, possibly indicating AERMOD over-prediction at these monitors at certain percentiles of the distribution. When comparing the AERMOD monitor concentrations with the measured ambient concentrations between the 80^{th} and 99^{th} percentile of the distribution, most of the predicted values were greater than the measured concentrations. The magnitude of this over-prediction ranged from about 1 to 2 ppb, although one monitor had a 7 ppb difference at the 99th percentile. Predictions at the maximum concentrations were more balanced; 4 of the 7 monitors had over-predictions, while all predictions (under or over) were approximately within 10 to 35 ppb of the measured concentrations.

The diurnal pattern was reproduced at the St. Louis monitoring locations, with some of the prediction envelopes encompassing much of the measured ambient concentrations (e.g., Figure 8-9, monitor ID 291890004; Figure 8-11 monitor ID 291897003). Again where deviation did occur at a few of the monitors, the contribution of the lower concentrations (i.e., mostly those beneath the 90th percentile) likely played a role in the magnitude of the disagreement. This can be seen at monitor ID 291890006 (Figure 8-10) where most (99%) of the predicted concentrations are consistently above the measure concentrations by 1 to 2 ppb. It is not surprising to see that the difference in comparing the measured versus modeled diurnal profile at every hour-of-the-day is also between 1 to 2 ppb.

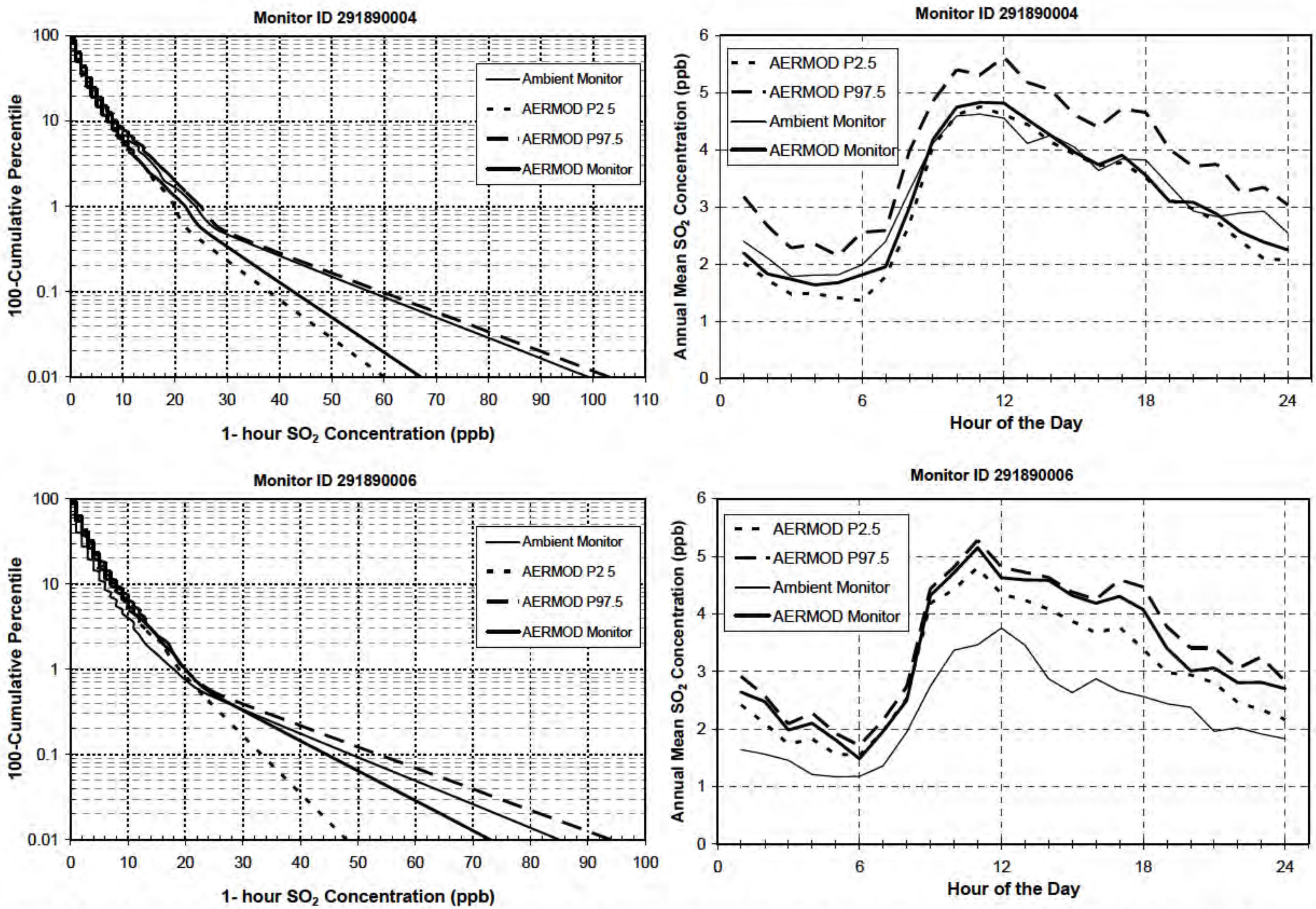


Figure 8-9. Comparison of measured ambient monitor SO_2 concentration distribution and diurnal profile with the modeled monitor receptor and receptors within 4 km of monitors 291890004 and 291890006 in St Louis, Mo. Maximum 1-hour concentration percentile is defined as 0.01 (or 100-99.99) because log(0) is undefined.

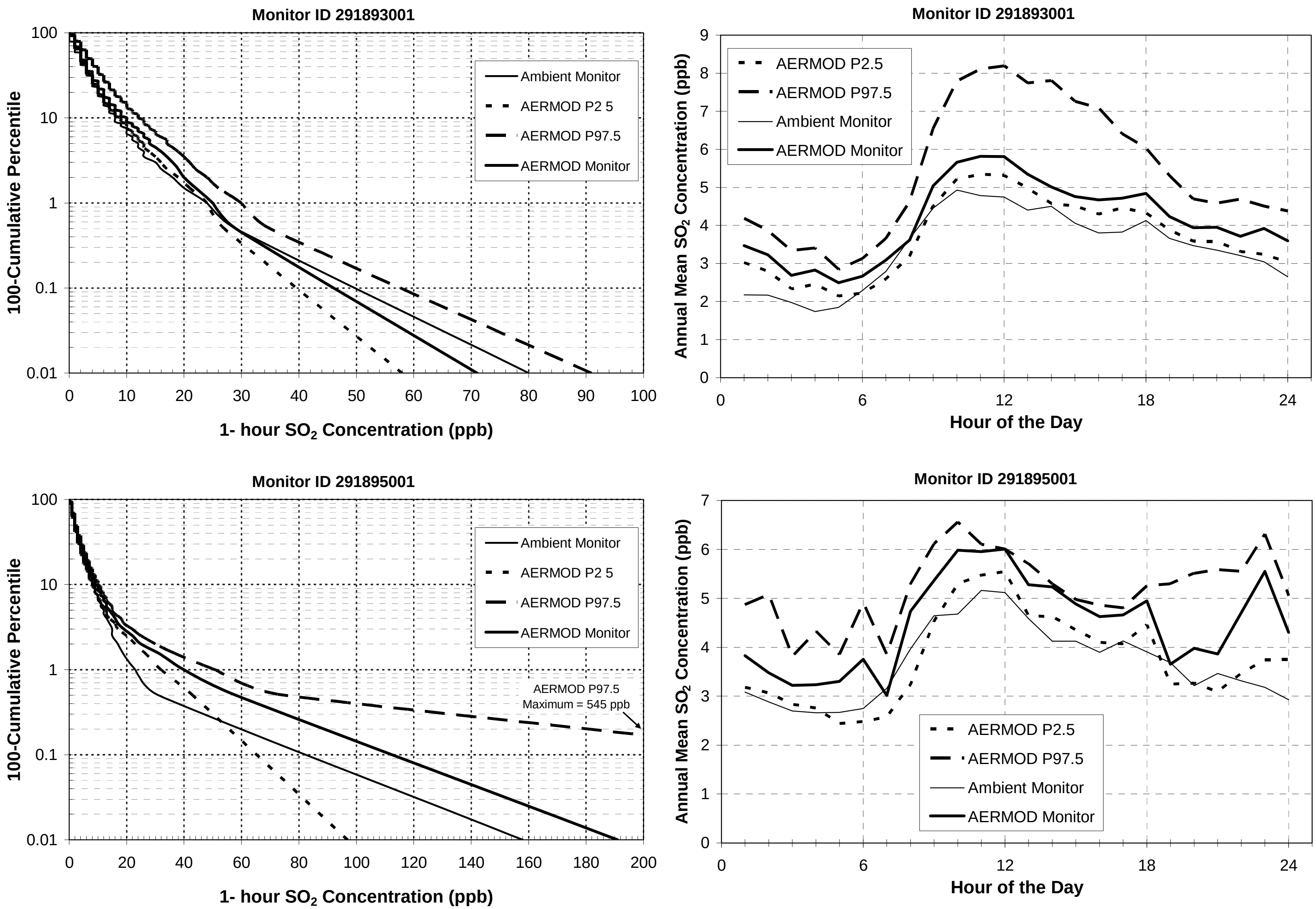


Figure 8-10. Comparison of measured ambient monitor SO_2 concentration distribution and diurnal profile with the modeled monitor receptor and receptors within 4 km of monitors 291893001 and 291895001 in St Louis, Mo. Maximum 1-hour concentration percentile is defined as 0.01 (or 100-99.99) because log(0) is undefined.

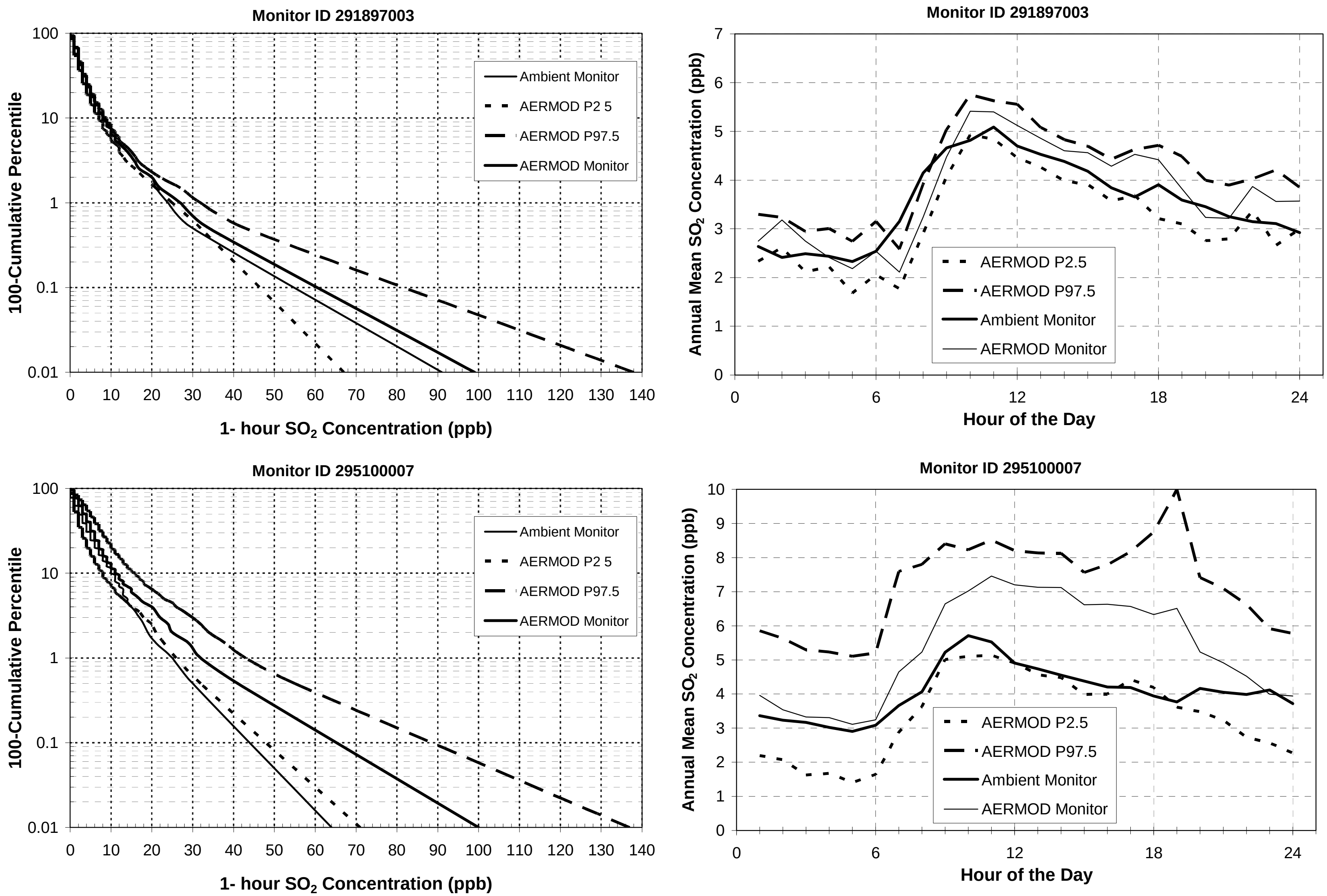
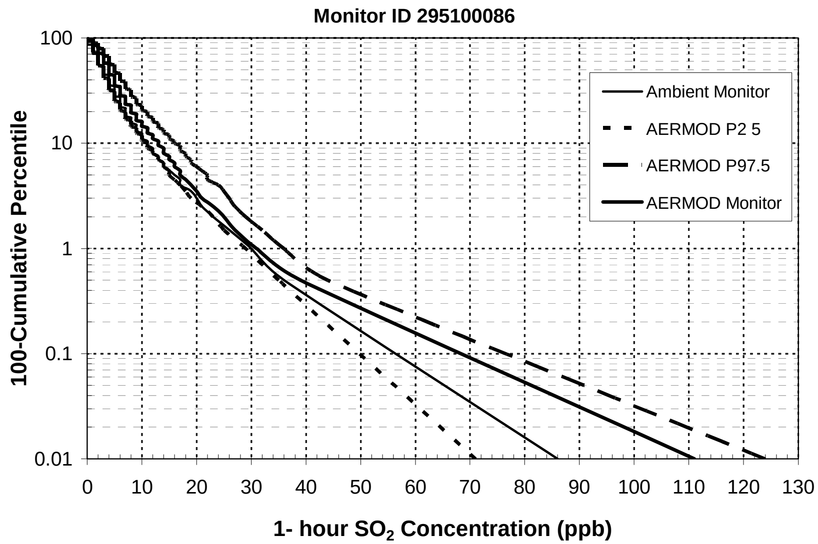


Figure 8-11. Comparison of measured ambient monitor SO_2 concentration distribution and diurnal profile with the modeled monitor receptor and receptors within 4 km of monitors 291897003 and 295100007 in St Louis, Mo. Maximum 1-hour concentration percentile is defined as 0.01 (or 100-99.99) because log(0) is undefined.



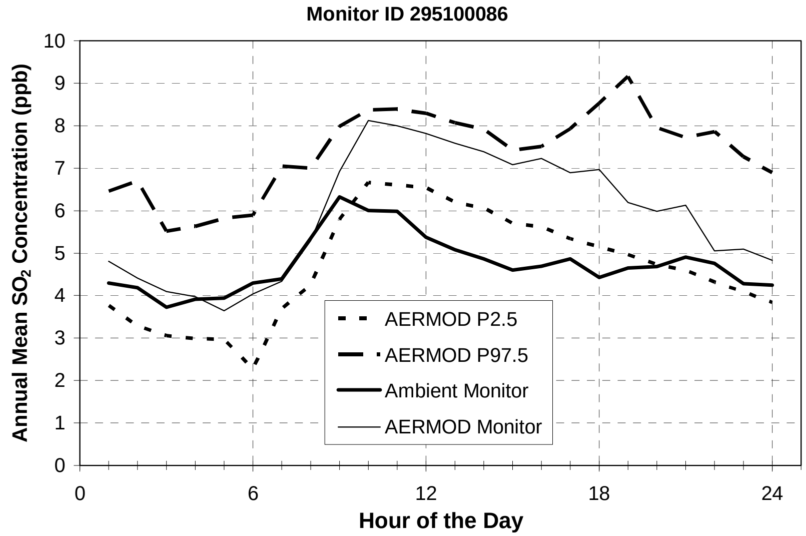


Figure 8-12. Comparison of measured ambient monitor SO_2 concentration distribution and diurnal profile with the modeled monitor receptor and receptors within 4 km of monitor 295100086 in St Louis, Mo. Maximum 1-hour concentration percentile is defined as 0.01 (or 100-99.99) because log(0) is undefined.

8.4.4.3. Using unadjusted AERMOD predicted SO_2 concentrations

The SO_2 concentrations estimated using AERMOD do not have a particular directional influence in over- or under-estimating concentrations, save for small over-estimation primarily observed at the lowest concentrations and some difficulty in reproducing some of the maximum measured concentrations. Most ambient monitoring concentrations fell within the modeled prediction envelopes constructed of modeled receptors surrounding the monitor. In generating the modeled air quality, staff made judgments in appropriately modifying model inputs including an adjustment of the area source temporal emission profile to improve the comparison of the model predictions with the measurement data. Staff went through several iterations of evaluating the model performance in each modeling domain following model input adjustments to obtain the current modeled air quality results. Given the time and resources to perform this assessment, the good agreement in the model-to-monitor comparisons, the degree of confidence in the dispersion modeling system, the spatial representation of the monitors compared with receptors modeled, and the number of comparisons available, staff did not perform any further adjustments to the modeled concentrations to improve the relationship between modeled versus measured concentration at each monitor. Additional details on the staff's reasoning are provided in section 8.11.

8.5 SIMULATED POPULATION

APEX takes population characteristics into account to develop accurate representations of study area demographics. Specifically, age- and gender-specific population counts and employment probability estimates, asthma prevalence rates, and home-to-work commuting locations and probabilities were used to develop representative profiles of hypothetical individuals used in the exposure modeling simulation. In addition, body surface area (BSA) and activity-specific ventilation rates are two important attributes used by APEX to characterize when simulated individuals were at moderate or greater activity levels. Each of these is discussed in the following sections.

8.5.1 Population Counts and Employment Probabilities

Block-level population counts were obtained from the 2000 Census of Population and Housing Summary File 1 (SF-1). Estimates of employment were also developed form census information (US Census Bureau, 2007) and separated into gender and age groups. Children under 16 years of age were assumed to be not employed. Staff also assumed that employment probabilities for a census tract apply uniformly to the constituent census blocks. Further details are provided in Appendix B.2.2.2.

8.5.2 Asthma Prevalence

The population subgroups included in this exposure assessment are asthmatics and asthmatic children. Evaluating exposures of these subgroups with APEX requires the estimation of children's asthma prevalence rates. The proportion of the population of children characterized as being asthmatic was estimated by statistics on asthma prevalence rates recently used in the NAAQS review for O_3 (US EPA, 2007d). See Appendix B, Attachment 2 for details on the derivation. Specifically, an analysis of data provided in the National Health Interview Survey (NHIS) for 2003 (CDC, 2007) generated age and gender specific asthma prevalence rates for children ages 0-17. Staff used these data rather than the aggregate data available at the county level, to retain the variability in asthma prevalence observed with children of different ages. Adult asthma prevalence rates were estimated by gender and for each particular modeling domain based on Missouri regional data (MO DOH, 2002). Table 8-7 provides a summary of the asthma prevalence used in the exposure analysis, stratified by age and gender.

The total population simulated within the two modeling domains was approximately 1.4 million persons, of which there was a total simulated population of about 130,000 asthmatics. The model simulated over 360,000 children ages 5 through 17, of which there were nearly 50,000 asthmatics. The individual populations for each modeling domain and subpopulation of interest are provided in Table 8-8. For comparison, staff weighted the asthma prevalence by population in the three counties reported by the MO Department of Health (2003) for all ages (i.e., St. Charles-8.8%, St. Louis-5.8%, and St. Louis City-16.4%) to generate an asthma prevalence of 8.8%. This asthma prevalence is similar to the 9.2% modeled here using APEX. In Greene County, the reported asthma prevalence was 10.2% (MO Department of Health, 2003), while 9.8% of the simulated population was asthmatic.

Table 8-7. Asthma prevalence rates by age and gender used in Greene County and St. Louis modeling domains.

Modeling Domain (Region)	Age[1]	Asthma Prevalence (%)	
		Females	Males
Greene Co. and St. Louis (Midwest)	0	7.0	3.1
	1	7.1	6.3
	2	7.3	10.8
	3	7.5	15.8
	4	8.1	21.6
	5	9.5	17.8
	6	9.2	12.8
	7	9.0	12.1
	8	8.6	12.8
	9	11.0	14.7
	10	16.2	17.7
	11	19.6	19.0
	12	21.2	19.5
	13	17.0	16.9
	14	14.0	16.8
	15	13.3	18.0
	16	14.0	20.1
	17	16.5	23.7
Greene Co.	>17	10.7	6.1
St. Louis	>17	9.3	5.3

Notes:
[1] Ages 0-17 from the National Health Interview Survey (NHIS) for 2003 (CDC, 2007); ages >17 from (MO DOH, 2002).

Table 8-8. Population modeled in Greene County and St. Louis modeling domains.

Modeling Domain	Population		Asthmatic Population	
	All Ages	Children (5 – 18)	All Ages	Children (5 – 18)
Green Co.	224,145	54,373	21,948	7,285
St. Louis	1,151,094	308,939	105,456	41,714

8.5.3 Commuting Database

Commuting data were originally derived from the 2000 Census, collected as part of the Census Transportation Planning Package (CTPP) (US DOT, 2007). The data used here contain counts of individuals commuting from home-to-work locations at a number of geographic scales. These data were processed to calculate fractions for tract-to-tract flow on a national level (all 50 U.S. states and Washington, D.C.). A software pre-processor was then developed to generate block-level commuting files for APEX using the tract-level commuting data and finely-resolved land use data, assuming the frequency of commuting to a workplace block within a tract is proportional to the amount of commercial and industrial land in the block. Further details are provided in Appendix B.2.2.2.

Note that while travel on roads was accounted for by APEX for other individuals (e.g., unemployed, children, persons who work at home) it was assumed that the vehicle travel (e.g., car, bus, train) occurred within the block the individual resides.

8.5.4 Body Surface Area

Age- and gender-specific BSA is estimated for each simulated individual. Briefly, the BSA calculation is based on logarithmic relationships developed by Burmaster (1998) that use body mass (BM) as an independent variable as follows:

$$BSA = e^{-2\ 2781}\ BM^{0\ 6821} \qquad \text{equation (8-1)}$$

where,

BSA = body surface area (m^2)

BM = body mass (kg)

Each simulated individual's body mass was randomly sampled from age- and gender-specific body mass distributions generated from National Health and Nutrition Examination Survey (NHANES) data for the years 1999-2004.[67] Details in their development and the parameter values are provided in Appendix B, Attachment 3.

8.5.5 Activity-Specific Ventilation Rates

Ventilation is a general term describing the movement of air into and out of the lungs. The rate of ventilation is determined by the type of activity an individual performs which in turn is related to the amount of oxygen required to perform the activity. Minute or total ventilation rate is used to describe the volume of air moved in or out of the lungs per minute.

[67] Demographic (Demo) and Body Measurement (BMX) datasets for each of the NHANES studies were obtained from http://www.cdc.gov/nchs/nhanes/nhanes_questionnaires.htm.

Quantitatively, the volume of air breathed in per minute ($\dot{V}_I$) is slightly greater than the volume expired per minute ($\dot{V}_E$). Clinically, however, this difference is not important, and by convention, the ventilation rate is always measured on an expired sample or $\dot{V}_E$.

The rate of oxygen consumption ($\dot{V}_{O2}$) is related to the rate of energy usage in performing activities as follows:

$$\dot{V}_{O2} = EE \times ECF \qquad \text{equation (8-2)}$$

where,

$\dot{V}_{O2}$ = Oxygen consumption rate (liters O_2/minute)
EE = Energy expenditure (kcal/minute)
ECF = Energy conversion factor (liters O_2/kcal).

The ECF shows little variation and typically, a value between 0.20 and 0.21 is used to represent the conversion from energy units to oxygen consumption units. In this REA, APEX randomly sampled from a uniform distribution defined by these lower and upper bounds to estimate an ECF once for each simulated individual. The activity-specific energy expenditure is highly variable and can be estimated using metabolic equivalents (METs). The METs are ratios of the rate of energy consumption for non-rest activities to the resting rate of energy consumption. Thus energy expenditure can be represented by the following:

$$EE = MET \times RMR \qquad \text{equation (8-3)}$$

where,

EE = Energy expenditure (kcal/minute)
MET = Metabolic equivalent of work (unitless)
RMR = Resting metabolic rate (kcal/minute)

The CHAD database (EPA, 2002) contains distributions of METs for all activities that might be performed by simulated individuals. APEX randomly samples from the various METs distributions to obtain values for every activity performed by each individual. Age- and gender-specific RMR are estimated once for each simulated individual using a linear regression model (see Johnson et al., 2000)[68] as follows:

$$RMR = [b_0 + b_1 (BM) + \varepsilon]F \qquad \text{equation (8-4)}$$

where,

RMR	= Resting metabolic rate (kcal/min)
b_o	= Regression intercept (MJ/day)
b_1	= Regression slope (MJ/day/kg)
BM	= body mass (kg)
ε	= randomly sampled error term, N{0, se}[69] (MJ/day)
F	= Factor for converting MJ/day to kcal/min (0.166)

Finally, Graham and McCurdy (2005) describe an approach to estimate $\dot{V}_E$ using $\dot{V}_{O2}$. In that report, a series of age- and gender-specific multiple linear regression equations were derived from data generated in 32 clinical exercise studies. The algorithm accounts for variability in ventilation rate due to variation in oxygen consumption, the variability within age groups, and both inter- and intra-personal and variability. The basic algorithm follows:

$$\ln(\dot{V}_E / BM) = b_0 + b_1 \ln(\dot{V}_{O2} / BM) + b_2 \ln(1 + age) + b_3\, gender + e_b + e_w \qquad \text{equation (8-5)}$$

where,

ln	= natural logarithm of variable
$\dot{V}_E / BM$	= activity-specific ventilation rate, body mass normalized (liter air/kg)
b_i	= see below
$\dot{V}_{O2} / BM$	= activity-specific oxygen consumption rate, body mass normalized (liter/O_2/kg)
age	= the age of the individual (years)
gender	= gender value (-1 for males and +1 for females)
e_b	= randomly sampled error term for between persons N{0, se), (liter air/kg)
e_w	= randomly sampled error term for within persons N{0, se), (liter air/kg)

[68] The regression equations were adapted by Johnson et al. (2000) using data reported by Schofield (1985). The regression coefficients and error terms used by APEX are provided in Appendix B Attachment 3.
[69] The value used for each individual is sampled from a normal distribution (N) having a mean of zero (0) and variability described by the standard error (se).

As indicated above, the random error (ε) is allocated to two variance components and used to estimate the between-person (inter-individual variability) residuals distribution (e_b) and within-person (intra-individual variability) residuals distribution (e_w). The regression parameters b_0, b_1, b_2, and b_3 are assumed to be constant over time for all simulated persons, e_b is sampled once per person, while whereas e_w is sampled from event to event. Point estimates of the regression coefficients and standard errors of the residuals distributions are given in Table 8-9.

Table 8-9. Ventilation coefficient parameter estimates (b_i) and residuals distributions (e_i) from Graham and McCurdy (2005).

Age group	Regression Coefficients[1]				Random Error[1,2]	
	b_0	b_1	b_2	b_3	e_b	e_w
<20	4.3675	1.0751	-0.2714	0.0479	0.0955	0.1117
20-<34	3.7603	1.2491	0.1416	0.0533	0.1217	0.1296
34-<61	3.2440	1.1464	0.1856	0.0380	0.1260	0.1152
61+	2.5826	1.0840	0.2766	-0.0208	0.1064	0.0676

Notes:
[1] These are the values of the coefficients and residuals distributions described by equation 8-5.
[2] The unique value used for each individual is sampled from a normal distribution (N) having a mean of zero (0) and variability described by the standard error (se).

8.6 CONSTRUCTION OF LONGITUDINAL ACTIVITY SEQUENCES

Exposure models use human activity pattern data to predict and estimate exposure to pollutants. Different human activities, such as spending time outdoors, indoors, or driving, will result in varying pollutant exposure concentrations. To accurately model individuals and their exposure to pollutants, it is critical to understand their daily activities. EPA's CHAD provides data for where people spend time and the activities they perform. Typical time-activity pattern data available for inhalation exposure modeling consist of a sequence of location/activity combinations spanning 24-hours, with 1 to 3 diary-days for any single study individual.

The exposure assessment performed here requires information on activity patterns over a full year. Long-term multi-day activity patterns were estimated from single days by combining the daily records using an algorithm that represents the day-to-day correlation of activities for individuals. The algorithm first uses cluster analysis to divide the daily activity pattern records into groups that are similar, and then select a single daily record from each group. This limited number of daily patterns is then used to construct a long-term sequence for a simulated individual, based on empirically-derived transition probabilities. This approach is intermediate between an assumption of no day-to-day correlation (i.e., re-selection of diaries for each time period) and perfect correlation (i.e., selection of a single daily record to represent all days). Details regarding the algorithm and supporting evaluations are provided in Appendix B, Attachments 4 and 5.

8.7 CALCULATING MICROENVIRONMENTAL CONCENTRATIONS

Probabilistic algorithms are used to estimate the pollutant concentration associated with each exposure event. The estimated pollutant concentrations account for temporal and spatial variability in ambient (outdoor) pollutant concentration and factors affecting indoor microenvironments, such as a penetration, air exchange rate, and pollutant decay or deposition rate. APEX calculates air concentrations in the various microenvironments visited by the simulated person by using the ambient air data estimated for the relevant blocks/receptors, the user-specified algorithm, and input parameters specific to each microenvironment. The method used by APEX to estimate the microenvironmental concentration depends on the microenvironment, the data available for input to the algorithm, and the estimation method selected by the user. The current version of APEX calculates hourly concentrations in all the microenvironments at each hour of the simulation for each of the simulated individuals using one of two methods: a mass balance model or a transfer factors method. Details regarding the algorithms used for estimating specific microenvironments and associated input data derivations are provided in Appendix B.

Briefly, the mass balance method simulates an enclosed microenvironment as a well-mixed volume in which the air concentration is spatially uniform at any specific time. The concentration of an air pollutant in such a microenvironment is estimated using the following processes:

- Inflow of air into the microenvironment
- Outflow of air from the microenvironment
- Removal of a pollutant from the microenvironment due to deposition, filtration, and chemical degradation
- Emissions from sources of a pollutant inside the microenvironment.

A transfer factors approach is simpler than the mass balance model; however, most parameters are derived from distributions rather than single values to account for observed variability. The transfer factors approach does not calculate concentration in a microenvironment from the concentration in the previous hour as is done by the mass balance method and contains only two parameters. A proximity factor is used to account for proximity of the microenvironment to sources or sinks of pollution, or other systematic differences between concentrations just outside the microenvironment and the ambient concentrations (at the measurements site or modeled receptor). The second parameter, a penetration factor, quantifies the amount of outdoor pollutant that penetrates into the microenvironment.

8.7.1 Approach for Estimating 5-Minute Maximum SO_2 Concentrations

Five-minute maximum SO_2 concentrations in each exposure modeling domain were estimated using the empirically-derived PMRs (developed from recent 5-minute SO_2 ambient monitoring data, see section 7.2) and the AERMOD predicted 1-hour SO_2 concentrations. Thus, for every 1-hour SO_2 concentration estimated at every receptor, an associated 5-minute maximum SO_2 concentration was generated (i.e., twenty-four 5-minute maximum SO_2 concentrations per day). These statistically modeled 5-minute maximum SO_2 concentrations were then used to estimate the eleven other 5-minute concentrations that occur within every hour (see below). This spatially complete (at the block level) and consecutive time-series of 5-minute SO_2 concentrations then served as the ambient concentrations input to algorithms within APEX that estimate the microenvironmental concentrations.

The current version of APEX can use ambient concentrations of almost any time step, including an averaging time of 5-minutes. However, if all of the individual block-level receptor files were generated as an input to APEX in this assessment, the size and number of files would become an issue. In this exposure assessment, each of the thousands of receptor files generated by AERMOD would increase by a factor of twelve, creating disk space, pre-processing, and exposure modeling difficulties. In addition, the APEX default exposure output for modeled individuals is the single greatest exposure within a day, thus requiring model changes to obtain output of a different form. Staff believed that to reasonably estimate multiple peak concentrations that might occur within an hour by addressing these issues would further encumber the limited time and resources already available to staff to conduct the assessment.

Staff elected to use a simplified approach to generate all other 5-minute SO_2 concentrations that occur within the hour. The objective of the approach used was not to estimate each of the other eleven 5-minute concentrations with a high degree of certainty; each of these concentrations, by definition, would be lower than the maximum for that hour. While the occurrence of multiple peak concentrations above benchmark levels within an hour is possible, staff assumed that use of the twenty-four 5-minute maximum SO_2 concentrations could provide an accurate estimate of the maximum exposure an individual might experience in a day.[70] Further discussion regarding multiple peak exposures within an hour is given in section 8.11.

The technical approach to estimating SO_2 concentrations real-time within the APEX model rather than modeled externally is as follows. An algorithm was incorporated into the flexible time-step APEX model to estimate the 5-minute maximum SO_2 concentrations using the 1-hour SO_2 concentration, an appropriate PMR (section 7.2), and equation 7-1. The additional eleven 5-minute concentrations within an hour at each receptor were approximated using the following:

$$X = \frac{n\bar{C} - P}{n - 1} \qquad \text{equation (8-6)}$$

where,

X = 5-minute SO_2 concentration in each of non-peak concentration periods in the hour at a receptor (ppb)

$\bar{C}$ = 1-hour SO_2 concentration estimated at a receptor (ppb)

P = estimated 5-minute maximum SO_2 concentration at a receptor (ppb) using equation 7-1.

n = number of time steps within the hour (or 12)

In addition to the level of the 5-minute maximum SO_2 concentration, the actual time of when the contact occurs with a person is also of importance. There is no reason to expect a temporal relationship of the peak concentrations within the hour, thus clock times for peak values were estimated randomly (i.e., any one of the 12 possible time periods within the hour). The PMR assignment also assumes a standard frequency during any hour of the day.

[70] Note that the model still uses all of the statistically-modeled twenty-four 5-minute maximum SO_2 concentrations (one for every hour in the day) in estimating microenvironmental concentrations and personal exposures.

8.7.2 Microenvironments Modeled

In APEX, microenvironments represent the exposure locations for simulated individuals. For exposures to be estimated accurately, it is important to have realistic microenvironments that match closely to the locations where actual people spend time on a daily basis. As discussed above, the two methods available in APEX for calculating pollutant levels within microenvironments are mass balance or a transfer factors approach. Table 8-10 lists the microenvironments used in this study, the calculation method used, and the type of parameters used to calculate the microenvironment concentrations.

Table 8-10. List of microenvironments modeled and calculation methods used.

Microenvironment	Calculation Method	Parameter Types used [1]
Indoors – Residence	Mass balance	AER and DE
Indoors – Bars and restaurants	Mass balance	AER and DE
Indoors – Schools	Mass balance	AER and DE
Indoors – Day-care centers	Mass balance	AER and DE
Indoors – Office	Mass balance	AER and DE
Indoors – Shopping	Mass balance	AER and DE
Indoors – Other	Mass balance	AER and DE
Outdoors – Near road	Factors	PR
Outdoors – Public garage - parking lot	Factors	PR
Outdoors – Other	Factors	None
In-vehicle – Cars and Trucks	Factors	PE and PR
In-vehicle - Mass Transit (bus, subway, train)	Factors	PE and PR
[1] AER=air exchange rate, DE=decay-deposition rate, PR=proximity factor, PE=penetration factor		

8.7.3 Microenvironment Descriptions

8.7.3.1 Microenvironment 1: Indoor-Residence

The Indoor-Residence microenvironment uses several variables that affect SO_2 exposure: whether or not air conditioning is present, the average outdoor temperature, the SO_2 removal rate, and an indoor concentration source.

Air conditioning prevalence rates

Since the selection of an air exchange rate distribution is conditioned on the presence or absence of an air-conditioner, for each modeled area the air conditioning status of the residential microenvironments is simulated randomly using the probability that a residence has an air conditioner. A value of 96% was used to represent the air conditioning prevalence rate in both Greene County and St. Louis, using the data obtained from the St. Louis American Housing Survey of 2004 (AHS, 2005). Air conditioning prevalence is noted as distinct from usage rate, the latter being represented by the air exchange rate distribution and dependent on temperature (see next section).

Air exchange rates

Air exchange rate data for the indoor residential microenvironment were the same used in APEX for the most recent O_3 NAAQS review (EPA, 2007d; see Appendix B, Attachment 6). Briefly, data were reviewed, compiled and evaluated from the extant literature to generate location-specific AER distributions categorized by influential factors, namely temperature and presence of air conditioning. In general, lognormal distributions provided the best fit, and are defined by a geometric mean (GM) and standard deviation (GSD). To avoid unusually extreme simulated AER values, bounds of 0.1 and 10 were selected for minimum and maximum AER, respectively. Table 8-11 summarizes the AER distributions used in modeling indoor residential exposures, separated by A/C prevalence and temperature categories. See Appendix B, Attachment 6 for additional details.

Table 8-11. Geometric means (GM) and standard deviations (GSD) for air exchange rates by A/C type and temperature range.

A/C Type[1]	Temp (ºC)	N	GM	GSD
Central or Room A/C	<=10	179	0.9185	1.8589
	10-20	338	0.5636	1.9396
	20-25	253	0.4676	2.2011
	25-30	219	0.4235	2.0373
	>30	24	0.5667	1.9447
No A/C	<=10	61	0.9258	2.0836
	10-20	87	0.7333	2.3299
	>20	44	1.3782	2.2757

Notes:
[1] All distributions derived from data reported in non-California cities. See Appendix B, Attachment 6 for details in the data used and distribution derivation.

The AER data obtained was limited in the number of samples, particularly when considering these influential factors. When categorizing by temperature, a range of temperatures was used to maintain a reasonable number of samples within each category to allow for some variability within the category, while still allowing for differences across categories. Several distribution forms were investigated (i.e., exponential, log-normal, normal, and Weibull) and in general, lognormal distributions provided the best fit. Fitted lognormal distributions were defined by a geometric mean (GM) and standard deviation (GSD). Because no fitted distribution was available specifically for St. Louis or Greene County, distributions were selected from other locations thought to have similar characteristics, qualitatively considering factors that might influence AERs including the age composition of housing stock, construction methods, and other meteorological variables not explicitly treated in the analysis, such as humidity and wind speed patterns.

SO_2 Removal Rate

Staff estimated distributions of indoor SO_2 deposition rates by applying a Monte Carlo sampling approach to configurations of indoor microenvironments of interest. The relative composition of particular surface materials (e.g., painted wall board, wall paper, wool carpet, synthetic carpet, synthetic floor covering, cloth) within various sized buildings were probabilistically modeled to estimate 1,000 SO_2 deposition rates that in turn were used to parameterize lognormal distributions (Table 8-12). The modeling was fundamentally based on a review of SO_2 deposition conducted by Grontoft and Raychaudhuri (2004) for a variety of building material surfaces under differing conditions of relative humidity. Details on the data used and derivation of removal rates are provided in Appendix B, section 4.

Table 8-12. Final parameter estimates of SO_2 deposition distributions in several indoor microenvironments modeled in APEX.

Microenvironment	Heating or Air Conditioning in Use or Low Ambient Humidity[1]				Air Conditioning Not in Use (Summertime Ambient Morning Relative Humidity of 90%)			
	Geom. Mean (hr^{-1})	Geom. Stand. Dev. (hr^{-1})	Lower Limit (hr^{-1})	Upper Limit (hr^{-1})	Geom. Mean (hr^{-1})	Geom. Stand. Dev. (hr^{-1})	Lower Limit (hr^{-1})	Upper Limit (hr^{-1})
Residence	3.14	1.11	2.20	5.34	13.41	1.11	10.31	26.96
Office	3.99	1.04	3.63	4.37	N/A	N/A	N/A	N/A
School/ Day Care Center	4.02	1.02	3.90	4.21	N/A	N/A	N/A	N/A
Restaurant	2.36	1.28	1.64	4.17	N/A	N/A	N/A	N/A
Other Indoors	2.82	1.21	1.71	4.12	N/A	N/A	N/A	N/A

Notes:
1 Summertime ambient afternoon relative humidity of 50%.
N/A not applicable, assumed by staff to always have A/C in operation.

8.7.3.2 Microenvironments 2-7: All Other Indoor Microenvironments

The remaining six indoor microenvironments, which represent Bars and Restaurants, Schools, Day Care Centers, Office, Shopping, and the broadly defined Other Indoor microenvironments, were all modeled using the same data and functions. An air exchange rate distribution (GM = 1.109, GSD = 3.015, Min = 0.07, Max = 13.8) was based on an indoor air quality study (Persily et al., 2005). This is the same distribution in APEX used for the most recent O_3 NAAQS review (EPA, 2007d) and NO_2 REA (EPA, 2008d). See Appendix B, Attachment 6 for details in the data used and derivation. The SO_2 removal rates in these six indoor microenvironments were estimated as explained in section 8.7.3.1, and described in more detail in Appendix B, section 4. The resulting lognormal distributions for removal rates are presented in Table 8-12. These microenvironments are all assumed to have air-conditioning.

8.7.3.3 Microenvironments 8-10: Outdoor Microenvironments

All outdoor microenvironmental concentrations are well represented by the modeled concentrations. Therefore, both the penetration factor and proximity factor for this microenvironment were set to 1.

8.7.3.4 Microenvironments 11 and 12: In Vehicle- Cars and Trucks, and Mass Transit

There were no available measurement data for SO_2 penetration factors, therefore the penetration factors used were developed from NO_2 data provided in Chan and Chung (2003) and used in the recent NO_2 NAAQS review (EPA, 2008d). NO_2 and SO_2 are expected to have similar penetration rates inside vehicles since both are gases. Although the in-vehicle NO_2 measurements used in the in-vehicle-to-outdoor-ratios might include a small amount of in-vehicle emissions, resulting in some discrepancy between effective penetration factors for NO_2 and SO_2, the additional uncertainty is expected to be small compared to the overall uncertainty implied by the broad uniform distributions.

Inside-vehicle and outdoor NO_2 concentrations were measured for three ventilation conditions: air-recirculation, fresh air intake, and with windows open. Mean in-vehicle-to-outdoor ratio values ranged from about 0.6 to just over 1.0, with higher values associated with increased ventilation (i.e., window open). A uniform distribution U{0.6, 1.0} was selected for the penetration factor for Inside-Cars/Trucks due to the limited data available to describe a more formal distribution and the lack of data available to reasonably assign potentially influential characteristics such as use of vehicle ventilation systems for each location. Mass transit systems, due to the frequent opening and closing of doors, was assigned a uniform distribution U{0.8, 1.0} based on the reported mean values for fresh-air intake (0.796) and open windows (1.032) on urban streets.

8.8 EXPOSURE MEASURES AND HEALTH RISK CHARACTERIZATION

8.8.1 Estimation of Exposure

APEX calculates exposure as a time-series of exposure concentrations that a simulated individual experiences during the simulation period. APEX calculates exposure by identifying concentrations in the microenvironments visited by the person according to the composite diary. In this manner, a time-series of event exposures are found. Then, the time-step exposure concentration at any clock hour during the simulation period is calculated using the following equation:

$$C_i = \frac{\sum_{j=1}^{N} C_{time-step(j)}\, t_{(j)}}{T} \qquad \text{equation (8-7)}$$

where,

C_i	=	Time-step exposure concentration at clock hour *i* of the simulation period (ppm)
N	=	Number of events (i.e., microenvironments visited) in time-step *i* of the simulation period.
$C_{time-step(j)}$	=	Time-step concentration in microenvironment *j* (ppm)
$t_{(j)}$	=	Time spent in microenvironment *j* (minutes)
T	=	Length of time-step (or 5 minutes in this analysis)

From the time-step exposures, APEX calculates time-series of 5-minute, 1-hour, 24-hour, and annual average exposure concentrations that a simulated individual would experience during the simulation period. APEX then statistically summarizes and tabulates the 5-minute time-step (or daily, or annual average) exposures. From this, APEX can calculate two general types of exposure estimates: counts of the estimated number of people whose exposure exceeded a specified SO_2 concentration level 1 or more times in a year and the number of times per year that they are so exposed; the latter metric is in terms of person-occurrences or person-days. The former highlights the number of individuals whose exposure exceeded at least *one or more* times per modeling period the health effect benchmark level of interest. APEX can also report counts of individuals with multiple exposures. This person-occurrences measure estimates the number of times per season that individuals are exposed to the exposure indicator of interest and then accumulates these estimates for the entire population residing in an area.

In this exposure assessment, APEX tabulates and displays the two measures for exposures above levels ranging from 0 to 800 ppb by 50 ppb increments for all exposures. These results are tabulated for the total population and subpopulations (i.e., asthmatics, asthmatic children) of interest.

8.8.2 Estimation of Target Ventilation Rates

Human activities are variable over time, a wide range of activities are possible even within a single hour of the day. The type of activity an individual performs, such as sleeping or jogging, will influence their breathing rate. As discussed above in section 8.5.5, APEX estimates minute-by-minute ventilation rates that account for the expected variability in the activities performed by simulated individuals. The ISA indicates that the adverse lung function responses associated with short-term peak exposures at levels below 1,000 ppb coincide with moderate to heavy exertion levels. Therefore, staff needed to identify a target ventilation rate in the simulated individuals to further characterize the estimated exposures of interest.

The target ventilation for adults (both a mix of males and females) experiencing effects from 5-10 minute SO_2 exposures in many of the controlled human exposure studies was approximately between 40-50 L/min (Table 3-1, ISA).[71] Since there were limited controlled human exposure study data available for asthmatic children, the ventilation targets needed to be normalized. Normalized ventilation rates allow for extrapolation of the adult target ventilation rate and, hence the health effect response associated with that ventilation rate to asthmatic children. One method used to normalize ventilation rate is to generate an equivalent ventilation rate (EVR) based on normalizing the simulated individuals activity-specific ventilation rate (V_E) to their body surface area (BSA). Staff has used EVR in previous O_3 NAAQS reviews to also

[71] Note that study subjects were free-breathing; thus it is expected that there was a mixture of nasal, oral, and oronasal breathing that occurred across the study subjects. Without information regarding the breathing method used by any subject and their corresponding health response, staff assumed that the mixture in breathing method is representative for the simulated population.

identify comparable activity-specific ventilation rates for children and adults (EPA, 2007d; Whitfield et al., 1996). In these reviews, an EVR ranging from 16-30 L/min-m^2 was associated with moderate exertion over a 1-hour exposure event, while an EVR ranging from 13-27 L/min-m^2 was associated with moderate exertion over an 8-hour exposure event.

As was done in the O_3 NAAQS reviews, target ventilation rates were identified in this exposure assessment by normalizing ventilation rates reported in the clinical studies on adults (i.e., 40-50 L/min, also see Table 9-3) to body surface area (BSA) to allow for such an extrapolation from adults to children. Body surface area was not measured in the controlled human exposure studies and the relevant ventilation data were not separated by gender. Staff obtained median estimates of BSA for males (1.94 m^2) and females (1.69 m^2) (EPA, 1997) and calculated a mean value of 1.81 m^2. Based on this data, an EVR = 40/1.81 = 22 L/min-m^2 was used to characterize the minimum target ventilation rate of interest. Individuals at or above an EVR of 22 L/min-m^2 (children or adult) for a 5-minute exposure event were characterized as performing activities at or above a moderate ventilation rate.

8.8.3 Adjustment for Just Meeting the Current and Alternative Standards

We used a different approach to simulate just meeting the current and alternative standards than was used in the Air Quality Characterization (see section 7.2.4). In this case, instead of proportionally adjusting the ambient concentrations, we proportionally adjusted the health effect benchmark levels used in each exposure modeling domain. The benchmark levels were adjusted rather than the air quality to reduce the processing time associated with the modeling of several thousands of receptors in each of the large exposure modeling domains. A proportional adjustment of the selected benchmark level (i.e., division by the adjustment factor) is mathematically equivalent to a proportional adjustment of the air quality concentrations (i.e., multiplication by the adjustment factor).[72] Therefore, the end effect of adjusting exposure model input concentrations upward versus adjusting exposure model benchmark levels downward is identical.

For example, an adjustment factor of 5.10 was determined for year 2002 in Cuyahoga County to simulate ambient concentrations just meeting the current standard. This value was

[72] To evaluate the current and most of the proposed alternative standards, 1-hour ambient concentrations were typically adjusted upwards to just meet the standards. This would correspond to downward adjustments to the benchmark levels.

based on an annual average SO_2 concentration of 5.96 ppb observed at an ambient monitor (ID 390350060) for that year (see Appendix A, section A.3). Therefore in the exposure analysis, the 5-minute potential health effect benchmark levels of 100, 200, 300, and 400 ppb were proportionally adjusted downward to 19.6, 39.2, 58.8, and 78.4 ppb, respectively for year 2002. APEX reported the number of days an individual was exposed above each of the adjusted benchmark levels using the *as is* air quality as the ambient concentration input. To illustrate the relationship between the two procedures (air quality adjustment versus benchmark adjustment), a comparison of the distributions and benchmark exceedances is presented in Figure 8-13. This example used the distribution of hourly SO_2 concentrations measured at one ambient monitor (ID 390350045) within the Cuyahoga County modeling domain for year 2002. Staff used the statistical model (section 7.2.3) to estimate 5-minute maximum SO_2 concentrations from both the adjusted and unadjusted 1-hour SO_2 concentrations. If one were interested in the number of days per year with 5-minute SO_2 benchmark exceedances of 400 ppb under the current standard scenario for example, this would be equivalent to counting the number of days with 5-minute maximum SO_2 concentrations above 78.4 ppb using the *as is* air quality.

For additional clarity, the same ambient air quality data are presented in Figure 8-14, only with expansion of the highest percentiles on the graph to allow for improved visualization of the number of exceedances. When using the air quality adjusted to just meet the current standard, there were 14 days where the maximum 5-minute concentration was greater than 400 ppb.[73] When considering the *as is* air quality without adjustment but with a downward adjustment of the benchmark by the same factor of 5.10, there are the same number of days with exceedances (i.e., 14 exceedances). Due to the relationship between the two procedures, the estimated number of exceedances at each of the other benchmark levels is identical (Table 8-13).

The values for each adjusted benchmark level considering each of the air quality standard scenarios are given in Table 8-14. Staff applied the benchmark adjustment in each of the exposure modeling domains to simulate exposures associated with just meeting the current and alternative standards.

[73] Only 12 points are observed in Figure 8-13 however, three peak concentrations were identical within each of the simulations.

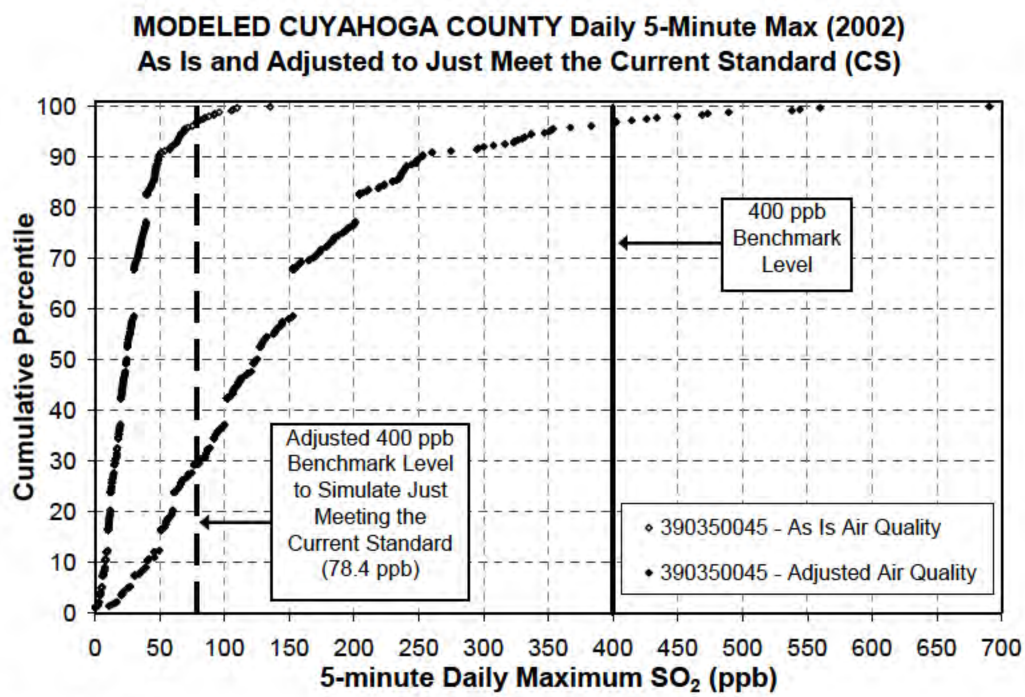


Figure 8-13. Comparison of adjusted ambient monitoring concentrations or adjusted benchmark level (dashed line) to simulate just meeting the current annual average standard at one ambient monitor in Cuyahoga County for year 2002.

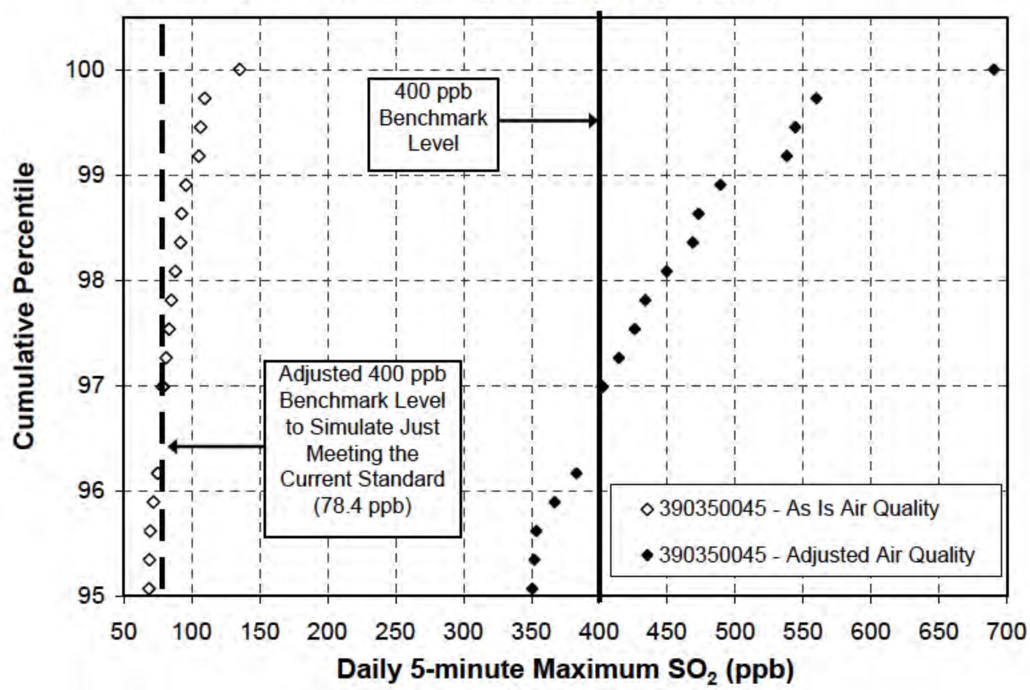


Figure 8-14. Comparison of the upper percentile modeled daily 5-minute maximum SO_2 concentrations using either adjusted 1-hour ambient SO_2 concentrations or an adjusted benchmark level (with *as is* air quality) to simulate just meeting the current annual standard at monitor 390350045 in Cuyahoga County for year 2002. Complete distributions are provided in Figure 8-13.

Table 8-13. Comparison of benchmark levels, adjusted benchmark levels to just meet the current standard, the benchmark level distribution percentiles, and the number of 5-minute SO_2 benchmark exceedances at monitor 390350045 in Cuyahoga County for year 2002.

Benchmark Level (ppb)	Adjusted Benchmark Level[1] (ppb)	Concentration Distribution Percentile[2]	Number of Days with a Benchmark Exceedance[3]
100	19.6	37.3	230
200	39.2	76.7	86
300	58.8	92.0	30
400	78.4	97.0	14

Notes:
[1] The adjustment factor to simulate just meeting the current standard was 5.10.
[2] The percentile of the distribution for each benchmark and adjusted benchmark level was the same.
[3] The number of days with a benchmark exceedance when using either air quality adjusted to just meet the current standard or applying adjusted benchmarks to *as is* air quality was the same.

Table 8-14. Exposure concentrations and adjusted potential health effect benchmark levels used by APEX to simulate just meeting the current and potential alternative standards in the Greene County and St Louis modeling domains.

Modeling Domain	Form[1]	Level[2]	Exposure Concentrations and Adjusted Potential Health Effect Benchmark Levels (ppb)[3]															
			50	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**	**550**	**600**	**650**	**700**	**750**	**800**
Greene County	98	200	20.3	40.5	60.8	81	101.3	121.5	141.8	162	182.3	202.5	222.8	243	263.3	283.5	303.8	324
	99	50	94.3	188.7	283	377.3	471.7	566	660.3	754.7	849	943.3	1037.7	1132	1226.3	1320.7	1415	1509.3
	99	100	47.2	94.3	141.5	188.7	235.8	283	330.2	377.3	424.5	471.7	518.8	566	613.2	660.3	707.5	754.7
	99	150	31.4	62.9	94.3	125.8	157.2	188.7	220.1	251.6	283	314.4	345.9	377.3	408.8	440.2	471.7	503.1
	99	200	23.6	47.2	70.8	94.3	117.9	141.5	165.1	188.7	212.3	235.8	259.4	283	306.6	330.2	353.8	377.3
	99	250	18.9	37.7	56.6	75.5	94.3	113.2	132.1	150.9	169.8	188.7	207.5	226.4	245.3	264.1	283	301.9
	CS		14.4	28.8	43.2	57.6	72	86.4	100.8	115.2	129.6	144	158.3	172.7	187.1	201.5	215.9	230.3
	as is		50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800
St. Louis	98	200	13.3	26.5	39.8	53	66.3	79.5	92.8	106	119.3	132.5	145.8	159	172.3	185.5	198.8	212
	99	50	63.3	126.7	190	253.3	316.7	380	443.3	506.7	570	633.3	696.7	760	823.3	886.7	950	1013.3
	99	100	31.7	63.3	95	126.7	158.3	190	221.7	253.3	285	316.7	348.3	380	411.7	443.3	475	506.7
	99	150	21.1	42.2	63.3	84.4	105.6	126.7	147.8	168.9	190	211.1	232.2	253.3	274.4	295.6	316.7	337.8
	99	200	15.8	31.7	47.5	63.3	79.2	95	110.8	126.7	142.5	158.3	174.2	190	205.8	221.7	237.5	253.3
	99	250	12.7	25.3	38	50.7	63.3	76	88.7	101.3	114	126.7	139.3	152	164.7	177.3	190	202.7
	CS		8	16	24	32	40	48	56	64	72	80	88	96	104	112	120	128
	as is		50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800

Notes:

1 The form of the standard used to adjust the air quality. 98 is the 98th percentile 1-hour daily maximum alternative standard, 99 is the 99th percentile 1-hour daily maximum alternative standard, CS is either the current annual average or 24-hour SO_2 NAAQS (whichever had the lowest factor), *as is* is unadjusted air quality.

2 The level of the potential alternative standards, i.e., the 1-hour daily maximum at the noted percentile of the distribution.

3 Exposure levels were defined in 50 ppb increments from 0 through 800 ppb even though the selected potential health effect benchmark levels were 100 to 400 ppb in 100 ppb increments.

8.9 EXPOSURE MODELING AND HEALTH RISK CHARACTERIZATION RESULTS

Exposure results are presented for simulated asthmatic populations residing in the two modeling domains in Missouri. For each individual, APEX estimates the number of days with a 5-minute SO_2 exposure above the potential health effect benchmark levels year 2002. These short-term exposures were evaluated for all asthmatics and asthmatic children when the exposure corresponded with moderate or greater activity levels (i.e., the simulated individuals EVR during a 5-minute exposure event was >22 L/minute-m^2). The number of persons and days with at least one 5-minute SO_2 exposure at or above any level from 0 through 800 ppb in 50 ppb increments was reported by APEX. Therefore, for each concentration level, an individual at a moderate (or higher) exertion level while exposed would have at most one exceedance of a particular level per day, or 365 per year.

Multiple air quality scenarios were evaluated, including unadjusted air quality (termed *as is*), air quality adjusted to just meet the current NAAQS, and air quality adjusted to just meet several potential alternative 1-hr daily maximum standards. Exposure results are presented in a series of figures that allow for simultaneous comparison of exposures associated with each air quality scenario. Four types of results are provided for each exposure modeling domain: (1) the number of persons in the simulated subpopulation exposed at or above selected levels 1 or more times in a year, (2) the percent of the simulated subpopulation exposed at or above selected levels 1 or more times in a year, (3) the total number of days in a year the simulated subpopulation is exposed (or person days) at or above selected levels, and (4) the percent of time associated with the exposures at or above the selected levels. Tables summarizing all of the exposure results for each modeling domain, air quality scenario, exposure level, and subpopulation are provided in Appendix B.4.

8.9.1 Asthmatic Exposures to 5-minute SO_2 Concentrations in Greene County

When considering the lowest 5-minute benchmark level of 100 ppb, approximately one thousand asthmatics are estimated to be exposed at least once in the year 2002 while at moderate or greater exertion and when considering the current standard air quality scenario (top of Figure 8-15). Each of the potential alternative 1-hr standard air quality scenarios as well as the *as is* air quality scenario result in fewer asthmatics exposed when compared with the current standard scenario, and progressively fewer persons were exposed with decreases in the 1-hour daily maximum concentration levels of the potential alternative standards. The 99th percentile 1-hour daily maximum standard levels of 50 and 100 ppb produced the same number of persons with at least one 5-minute exposure at or above 100 ppb as the *as is* air quality (i.e., 13). With progressive increases in benchmark level, there were corresponding decreases in the number of individuals exposed. None of the asthmatics had a day where 5-minute exposures were above 100 ppb when considering the *as is* air quality scenario. Asthmatic children exhibited similar patterns in the estimated number of exposures at each of the exposure levels, thus comprising a large proportion of the total asthmatics exposed (bottom of Figure 8-15).

The difference between all asthmatics and asthmatic children is best demonstrated by comparing the percent of the subpopulation exposed. Asthmatic children have nearly double the percentage of the subpopulation exposed at any of the benchmark levels considered when compared with that of all asthmatics (Figure 8-16). For example, approximately 1% of asthmatic children experience at least one day with a 5-minute SO_2 exposure at or above 200 ppb in a year in considering the current standard scenario, while approximately 0.6% of all asthmatics experienced a similar exposure. As observed with the numbers of persons exposed, a lower estimated percent of persons was exposed at the higher benchmark levels, though again, the current standard scenario contains the greatest percent of asthmatics exposed when compared with all of the other 1-hour air quality standard scenarios analyzed.

The number of person days or occurrences of exposures is greater than the number of persons exposed, indicating that some of the simulated asthmatics had more than one day with 5-minute exposures above selected benchmark levels (Figure 8-17). For example, when considering all asthmatics and the current standard scenario, there were approximately 22 person days with exposures at or above 300 ppb. This corresponds with the 18 asthmatics estimated to experience at least one day with a 5-minute SO_2 concentration above this level, indicating that a number of persons may have experienced at least 2 benchmark exceedances in the year. For both subpopulations considered, there were no estimated exposures above 300 ppb when considering the 99th percentile 1-hour daily maximum alternative standard level of 200 ppb.

Staff evaluated the microenvironments where the peak exposures frequently occurred. There were very few persons exposed to benchmark levels of 100 ppb or higher considering the *as is* air quality, though 99% or greater experienced their 5-minute maximum SO_2 exposure in an outdoor microenvironment (i.e., outdoors or outdoors near-roads) when considering any of the benchmark levels. For the current standard air quality scenario, approximately 7% of persons were exposed to the 100 ppb benchmark level indoors (i.e., primarily in the persons residence), though with increasing benchmark level (e.g., 300 ppb) the percent of persons with any benchmark exceedances indoors approached zero (i.e., > 99% occurred outdoors). The inside vehicle microenvironment also comprised a small percent of the cases where the exposures above selected levels occurred; at most 2% of benchmark exceedances occurred inside vehicles when considering the lowest benchmark levels.

Two forms of the potential alternative standard were evaluated in Greene County, i.e., the 99th and 98th forms of a 1-hour daily maximum level of 200 ppb. The difference in the exposure results generated for each of these air quality scenarios is provided in Table 8-15. The 99th percentile form of the potential alternative standard results in fewer persons, person-days, and percent of asthmatic persons exposed when compared with estimated exposures using air quality adjusted to just meet a 200 ppb 1-hour daily maximum 98th form. The values listed in the table are small, but from a relative perspective, the percent difference can be large. For example, there is approximately a 40% reduction in the percent of persons exposed when considering the 99th percentile form and the 100 ppb benchmark level. Where there were other higher benchmark levels that were exceeded, the reduction was greater (66% to 100%). For additional relative comparisons for these two standard forms, see the corresponding Figures 8-15 to 8-17.

Table 8-15. Absolute difference in APEX exposure estimates for Greene County using either a 98th or 99th percentile form potential alternative standard at a 1-hour daily maximum level of 200 ppb.

Population	Benchmark Level (ppb)	Absolute Difference in Estimated Exposures using 98th and 99th form[1]		
		Number of Person-days	Number of Persons	Percentage Points[2]
All Asthmatics (21,948)	100	274	157	0.7
	200	27	27	0.1
	300	13	13	0.1
	400	0	0	0
Asthmatic Children (7,285)	100	161	81	0.4
	200	18	18	0
	300	4	4	0
	400	0	0	0

Notes:
[1] Both the 98th and 99th 1-hour daily maximum air quality scenarios were simulated by APEX, using a level of 200 ppb. The value reported is the difference between the 98th and the 99th.
[2] Difference between the percent of persons exposed (98th-200 minus the 99th-200) at each benchmark level.

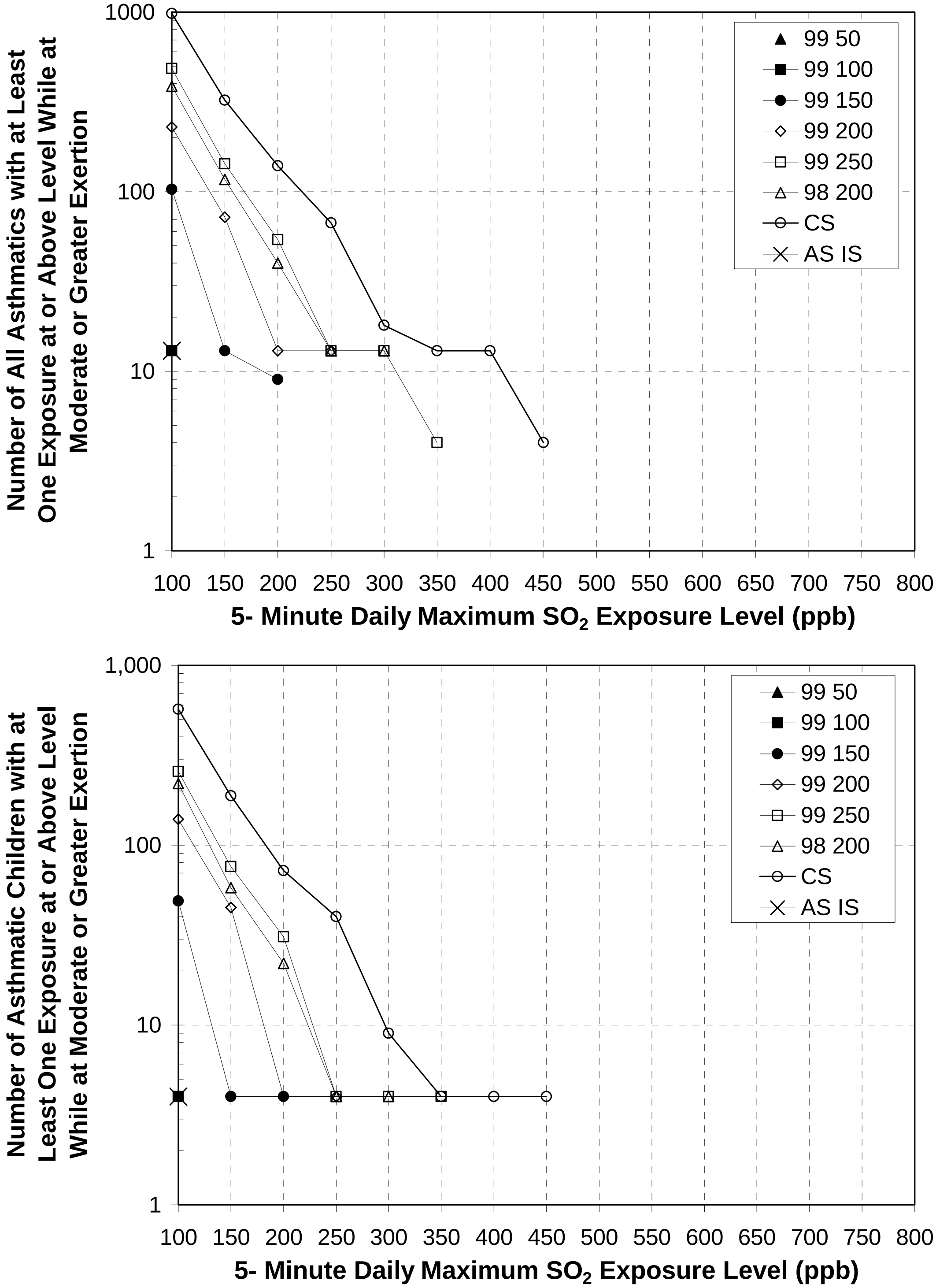
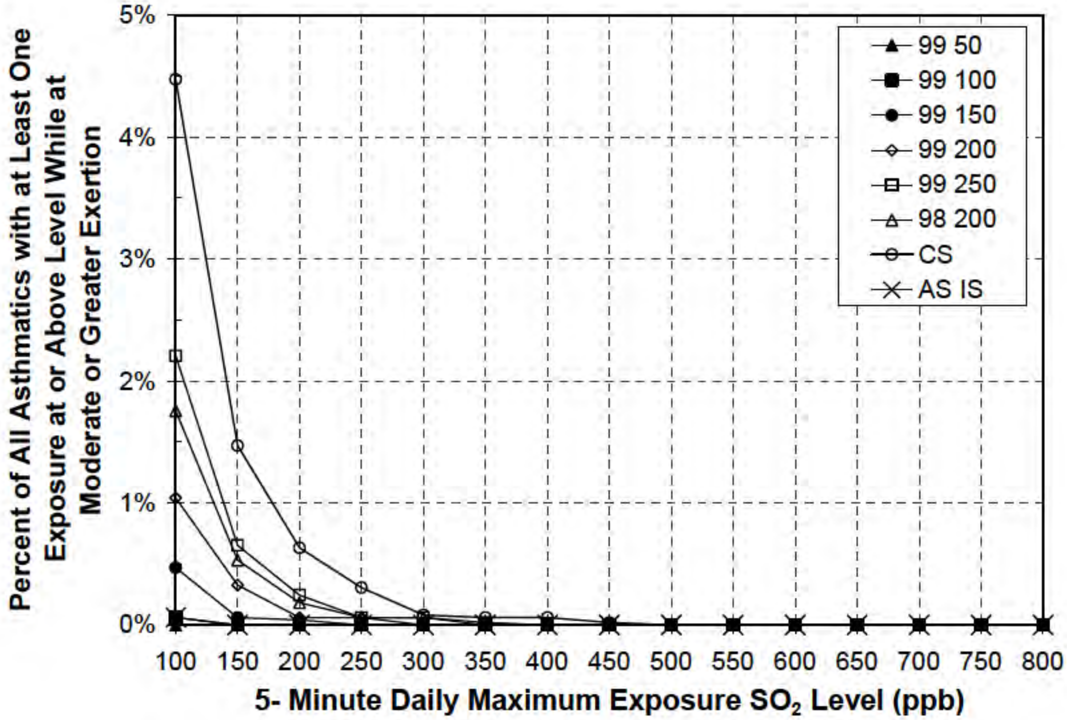


Figure 8-15. Number of all asthmatics (top) and asthmatic children (bottom) experiencing at least one day with a 5-minute SO_2 exposure above selected benchmark levels in Greene County, year 2002 air quality *as is* and adjusted to just meeting the current and potential alternative standards.



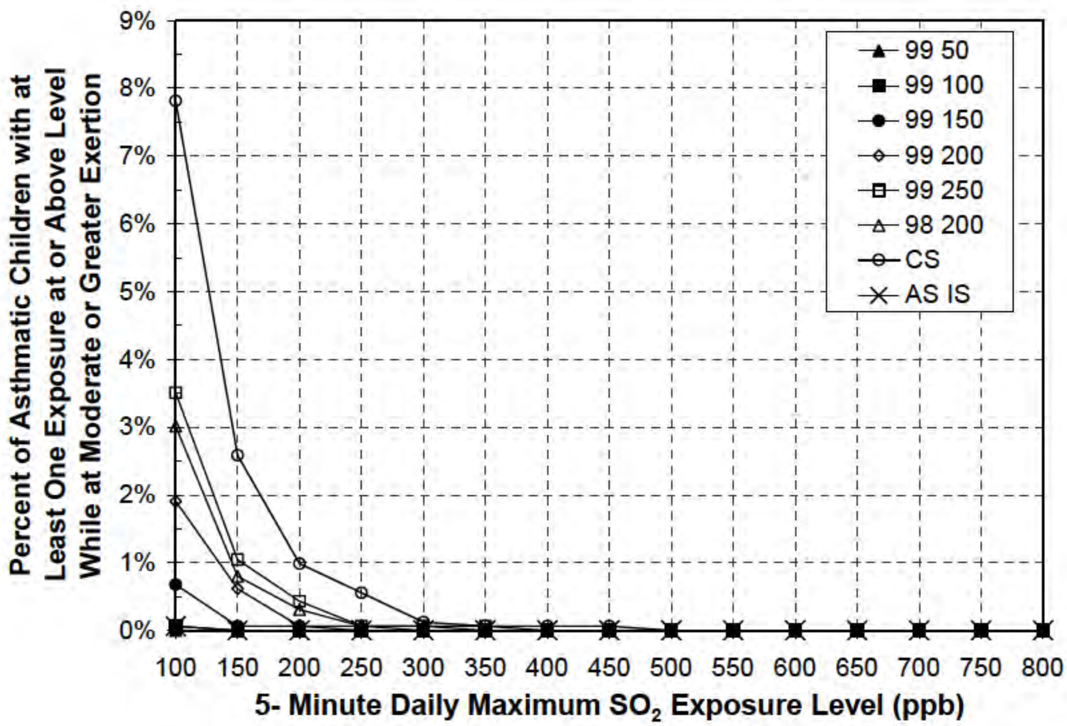
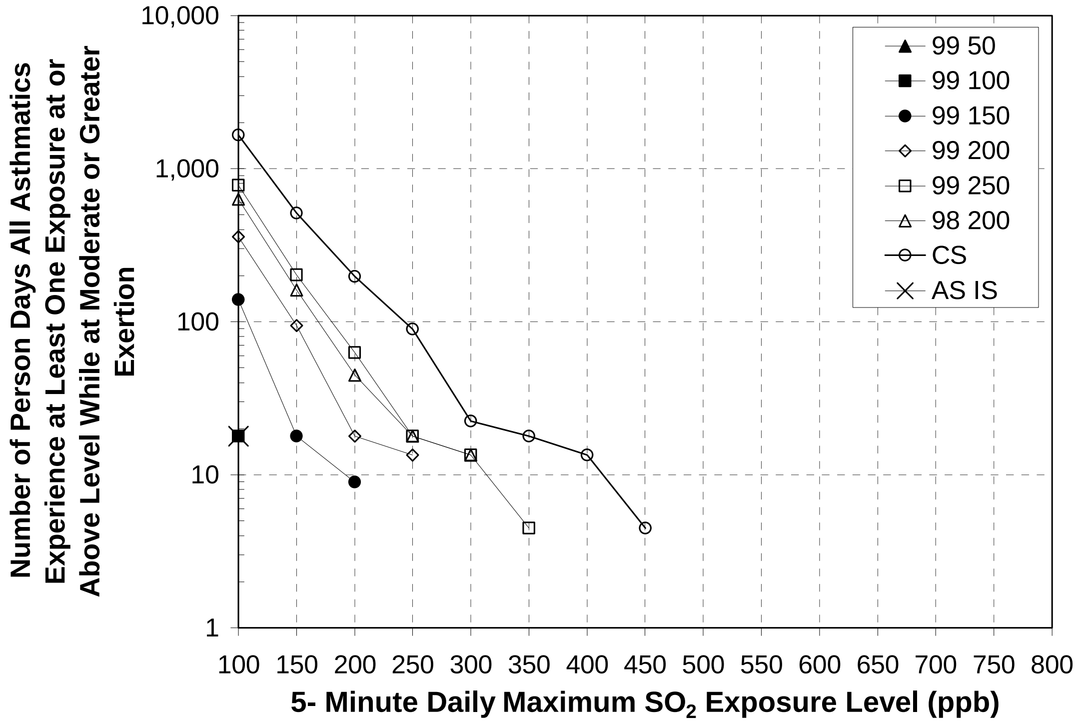


Figure 8-16. Percent of all asthmatics (top) and asthmatic children (bottom) experiencing at least one day with a 5-minute SO_2 exposure above selected benchmark levels in Greene County, year 2002 air quality *as is* and adjusted to just meeting the current and potential alternative standards.



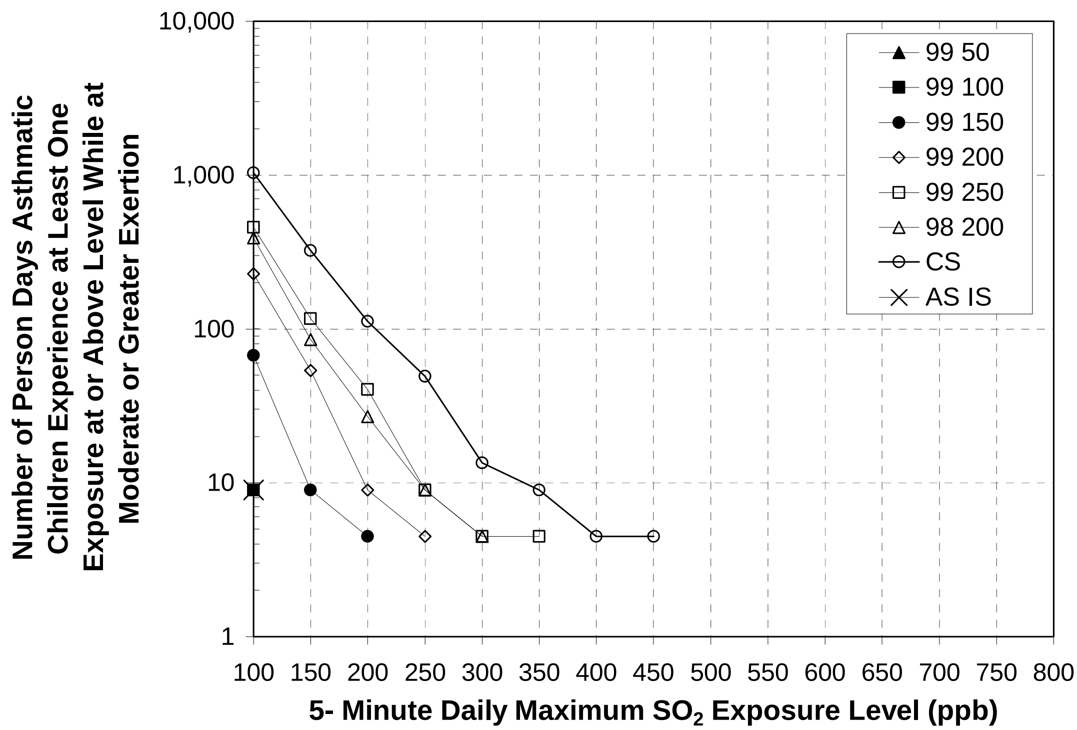


Figure 8-17. Number person days all asthmatics (top) and asthmatic children (bottom) experience a 5-minute SO_2 exposure above selected benchmark levels in Greene County, year 2002 air quality *as is* and adjusted to just meeting the current and potential alternative standards.

8.9.2 Asthmatic Exposures to 5-minute SO_2 in St. Louis

The patterns in the number of persons (either asthmatics or asthmatic children) exposed in St. Louis were different from those observed in Greene County; a greater number of persons were estimated to be exposed in St. Louis at each of the corresponding benchmark levels and air quality scenarios (Figure 8-18). For example, nearly 80,000 asthmatics were estimated to experience at least one day with a 5-minute SO_2 exposure at or above 100 ppb when considering the current standard scenario compared to the one thousand asthmatics estimated in Greene County (section 8.9.1). In addition, there were more persons exposed to the higher benchmark levels in St. Louis compared with Greene County. For example, none of the asthmatics experienced a 5-minute SO_2 concentration exposure above 450 ppb in Greene County considering any of the air quality scenarios. In St. Louis many of the air quality scenarios had persons with exceedances of 450 ppb; the estimated number of persons experiencing at least one day with a 5-minute SO_2 exposure above 450 ppb ranged from a low of 16 (the 99^{th} percentile 1-hour daily maximum standard level of 100 ppb) to over 10,000 (the current standard air quality scenario). We note though, in considering the *as is* air quality scenario, none of the asthmatics in St. Louis had 5-minute SO_2 exposures above a 450 ppb exposure level.

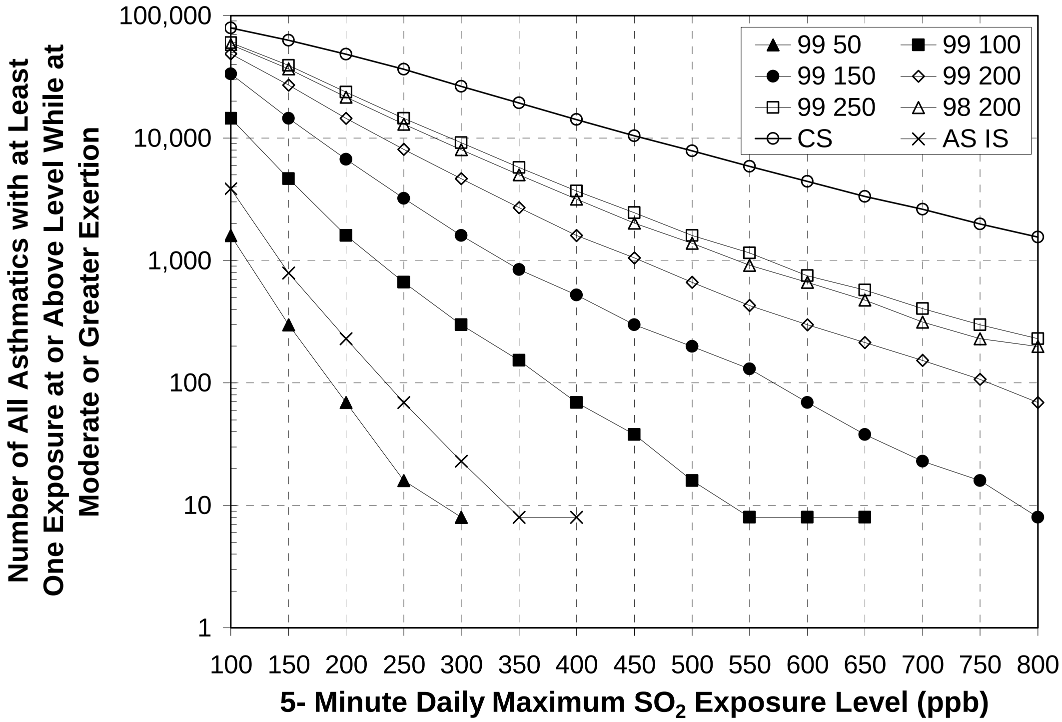
There were also differences in the estimated percent of asthmatics and asthmatic children exposed to concentrations above the benchmark levels in St. Louis when compared with Greene County. For example, over 40% of asthmatic children were estimated to experience at least one day with a 5-minute exposure above 300 ppb in St. Louis considering the current standard air quality scenario, while less than 1% of asthmatic children in Greene County experienced a similar exposure (Figure 8-19). Just as observed with the Greene County estimates though, there were decreases in the percent of persons exposed with decreases in the 1-hour daily maximum level of the potential alternative standards. For example, less than 3% of asthmatic children were estimated to have at least one day with a 5-minute SO_2 exposure above 300 ppb when considering a 99^{th} percentile 1-hour daily maximum standard level of 150 ppb.

The discussion regarding the patterns observed in the number of persons exposed in St. Louis can be extended to the number of person days (i.e., both a greater number and at higher benchmark levels when compared with Greene County). In addition, St. Louis had a greater number of persons with multiple exceedances when compared with Greene County (Figure 8-20). For example, given the 22 person days at or above 300 ppb in Greene County experienced by the 18 asthmatics considering air quality just meeting the current standard, on average this amounts to approximately 1.2 exposures per person per year. In contrast, approximately 26,000 asthmatics had nearly 50,000 person days at the same benchmark level and air quality scenario in St. Louis; on average each person is estimated to experience 1.9 exposures exceeding this benchmark level in a year.

Staff also evaluated the microenvironments where the peak exposures occurred in St. Louis, and again, there were differences when compared with the exposures in Greene County. In St. Louis, there were a greater percentage of benchmark exceedances within indoor and inside vehicle microenvironments, although overall still comprising a small percentage of where the exceedances were occurring. At the 100 ppb benchmark level, approximately 10% of the exposures occur within indoor microenvironments (i.e., principally inside residences) and about 5% occur inside vehicles considering *as is* air quality (Figure 8-21). The percentage increases when considering air quality adjusted to just meeting the current standard, with approximately 30% of benchmark exceedances of 100 ppb occurring indoors and 20% occurring inside vehicles. Just beyond the benchmark level of 400 ppb, nearly all of the exceedances occur outdoors when considering the *as is* air quality, while indoor microenvironments still contribute to around 10% of exceedances, up to a 5-minute exposure level of 800 ppb. For comparison, air quality adjusted to just meet a 99th percentile 1-hour daily maximum standard level of 150 ppb is also shown, and falls within the range of values provided by the *as is* and current standard scenarios.

Two forms of potential alternative standards were also evaluated in St. Louis, using the 99th and 98th percentile forms of a 1-hour daily maximum level of 200 ppb. The difference in the exposure results generated for each of these air quality scenarios is provided in Table 8-16. The 99th percentile form of the potential alternative standard results in fewer persons, person-days, and percent of asthmatic persons exposed when compared with estimated exposures using air quality adjusted to just meet a 200 ppb 1-hour daily maximum 98th percentile form. The impact of the different scenario is greater than that observed in Greene County from a pure numbers perspective given so few persons exposed to concentrations above the benchmark levels in Greene County. From a relative perspective, the percent difference between the two scenarios can also be large. The reduction in the percent of persons exposed when considering the 99th

percentile form ranges from approximately 10% to 50%. For additional relative comparisons between these two standard forms, see the corresponding Figures 8-18 to 8-20.



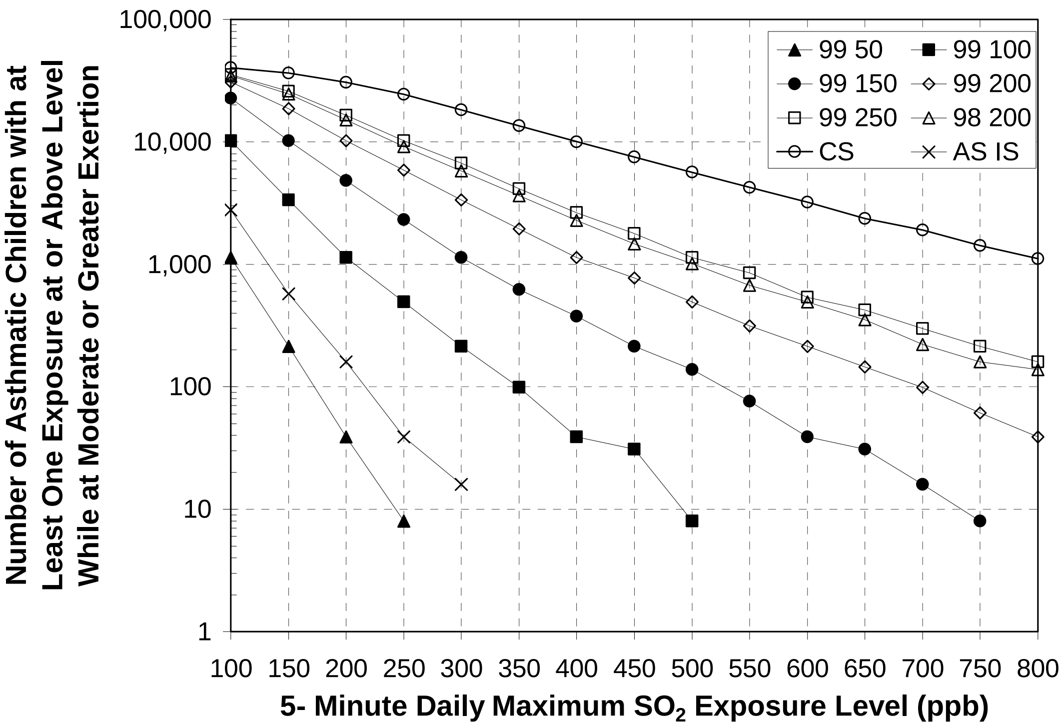


Figure 8-18. Number of all asthmatics (top) and asthmatic children (bottom) experiencing at least one day with a 5-minute SO_2 exposure above selected benchmark levels in St. Louis, year 2002 air quality *as is* and adjusted to just meeting the current and potential alternative standards.

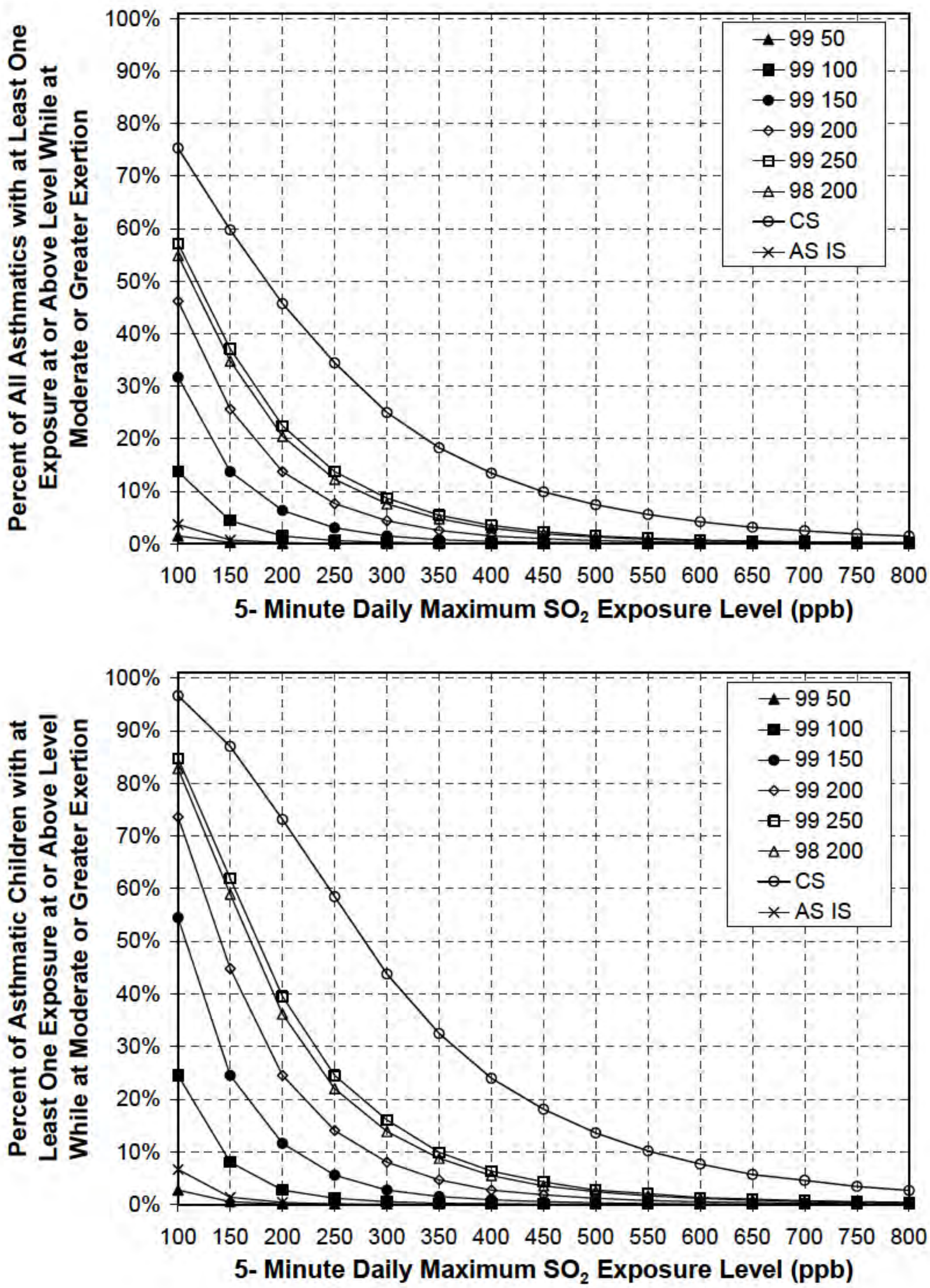
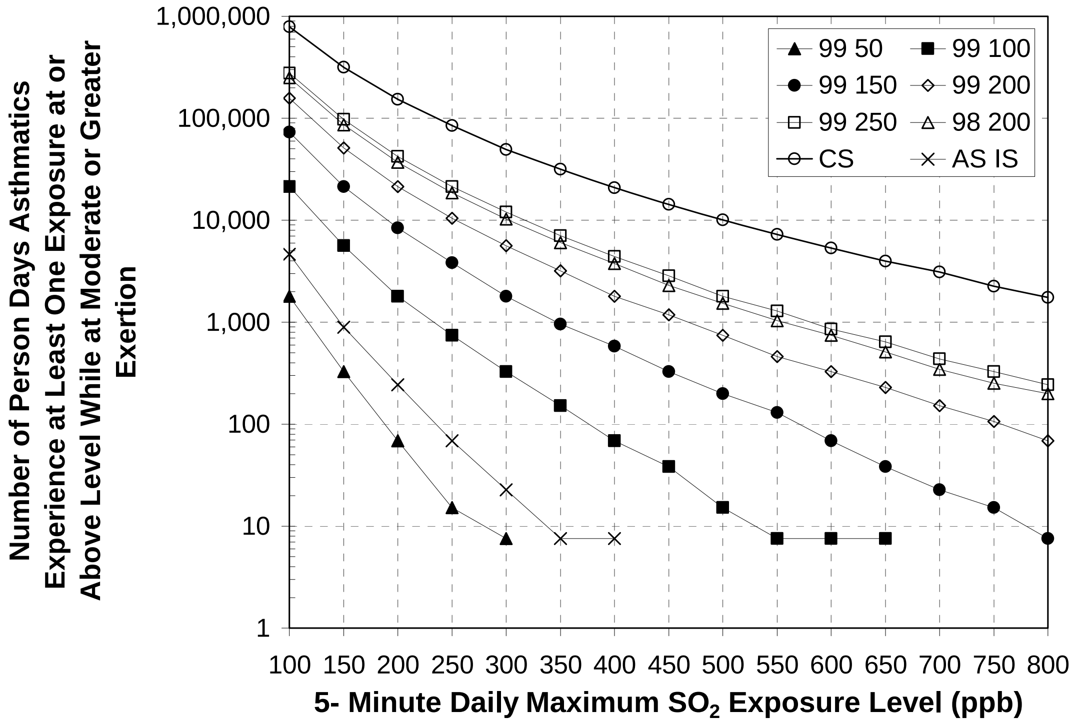


Figure 8-19. Percent of all asthmatics (top) and asthmatic children (bottom) experiencing at least one day with a 5-minute SO_2 exposure above selected benchmark levels in St. Louis, year 2002 air quality *as is* and adjusted to just meeting the current and potential alternative standards.



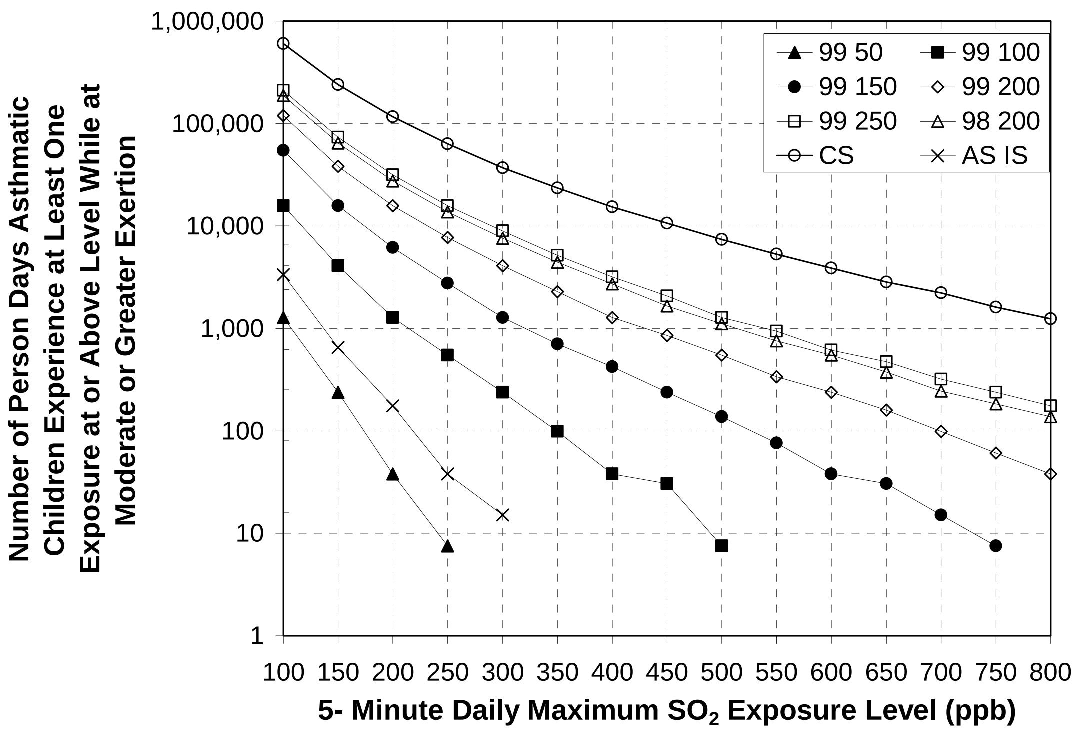


Figure 8-20. Number person days all asthmatics (top) and asthmatic children (bottom) experience a 5-minute SO_2 exposure above selected benchmark levels in St. Louis, year 2002 air quality *as is* and adjusted to just meeting the current and potential alternative standards.

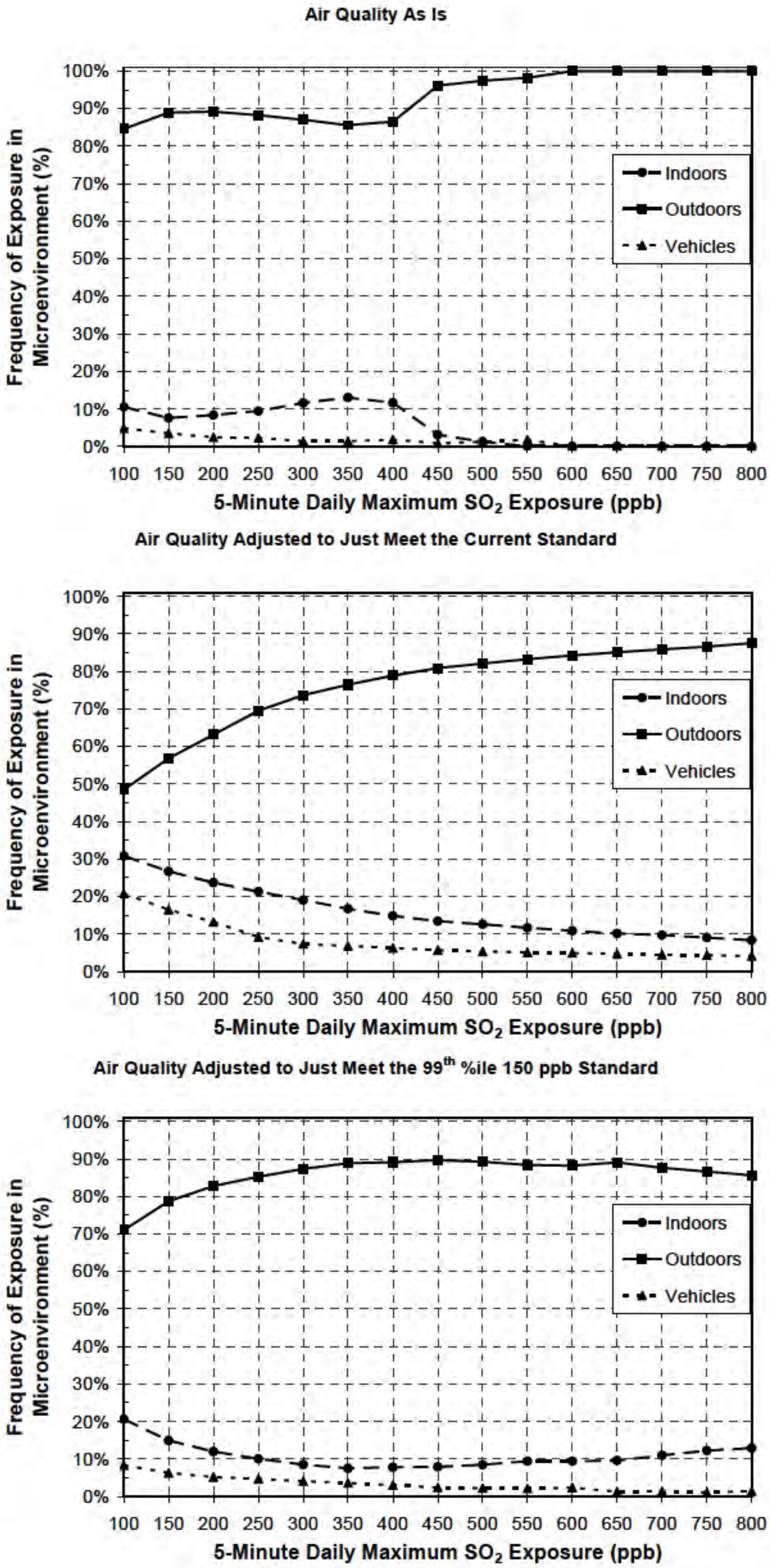


Figure 8-21. The frequency of estimated exposure level exceedances in indoor, outdoor, and vehicle microenvironments given *as is* air quality (top), air quality adjusted to just meeting the current standard (middle) and that adjusted to just meeting a 99th percentile 1-hour daily maximum standard level of 150 ppb (bottom) in St. Louis.

Table 8-16. Absolute difference in APEX exposure estimates for St. Louis using either a 98th or 99th percentile form potential alternative standard at a 1-hour daily maximum level of 200 ppb.

Population	Benchmark Level (ppb)	Absolute Difference in Estimated Exposures using 98th and 99th form[1]		
		Number of Person-days	Number of Persons	Percentage Points[2]
All Asthmatics (105,456)	100	91490	9142	8.7
	200	64531	22194	6.7
	300	31441	16922	3.2
	400	16705	11330	1.5
Asthmatic Children (41,714)	100	69420	3826	9.2
	200	11682	4856	11.6
	300	3496	2425	5.8
	400	1449	1150	2.8

Notes:
[1] Both the 98th and 99th 1-hour daily maximum air quality scenarios were simulated by APEX, using a level of 200 ppb. The value reported is the difference between the 98th and the 99th.
[2] Difference between the percent of persons exposed (98th-200 minus the 99th-200) at each benchmark level.

8.10 REPRESENTATIVENESS OF EXPOSURE RESULTS

8.10.1 Introduction

Due to time and resource constraints the exposure assessment evaluating the current and alternative standards was only applied to the two locations in Missouri. A natural question is how might the estimates from this assessment of exposures in Greene County and St. Louis compare with other areas in the United States that may have elevated short-term SO_2 concentrations. To address this question, additional data were compiled and analyzed to provide context to the exposure modeling results. Because most estimated exceedances were associated with the outdoor microenvironments, this analysis and discussion is centered on time spent outdoors to allow for comparison of the two modeling domains with several other broad regions. In addition, further context is given regarding the SO_2 emissions and air quality in these locations with respect the 39 other counties evaluated in the air quality characterization. The distribution of air conditioning and asthma prevalence rates in the U.S. U.S. and how that distribution compares with those estimated for the two modeling domains is also discussed.

8.10.2 Time spent outdoors

The time spent outdoors by children age 5-17 was calculated from CHAD-Master[74] for five regions of the country. The U.S. states used in the air quality characterization (Chapter 7) were of interest, which already includes Missouri (representing the two exposure modeling domains). Staff analyzed the outdoor time by broad geographic regions because it was thought that the regional climate would have influence on each population. In addition, most of the location descriptors are already broadly defined to protect the identity of persons in CHAD; finer spatial scale such as at a city-level is uncommon. Table 8-17 has the States used to identify CHAD diaries available to populate a data set for each of the five regions. Staff further separated the diaries by time-of-year (school year versus summer)[75] and the day-of-week (weekdays versus weekends), both important factors influencing time spent outdoors (Graham and McCurdy, 2004). Summer days were not separated by day of week; staff assumed that the variation in outdoor time during the summer would not be greatly influenced by this factor for children. The results for time spent outdoors in each region are given in Table 8-18.

Table 8-17. States used to define five regions of the U.S. and characterize CHAD data diaries.

Region	States
Mid-Atlantic (MA)	New York, New Jersey, Delaware, Maryland, District of Columbia, Virginia, West Virginia, Pennsylvania
Midwest (MW)	Ohio, Iowa, Missouri, Illinois, Indiana, Kentucky
Northeast (NE)	Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island
Southeast (SE)	North Carolina, South Carolina, Georgia, Florida, Tennessee, Alabama, Mississippi, Arkansas, Louisiana
Southwest (SW)	Nevada, Utah, Colorado, Arizona, New Mexico, Texas, Oklahoma

Participation rates for the selected time of year and day of week groupings were similar for each of the regions. In general, a smaller percent of children spend time outdoors during the school year (about 45-50%) compared to the summer (about 70-77%). There was no apparent pattern in the day-of week participation rates considering the school year days. However, children did spend more time outdoors on weekend days compared to weekdays at all percentiles of the distribution and within all regions. In addition, children consistently spent more time

[74]Currently available through EPA at mccurdy.tom@epa.gov.
[75]A traditional school year was considered (months of September-May); summer months included June-August.

outdoors during summer days within all regions. There were few differences in outdoor time when comparing each of the regions. Children in Northeastern States had the widest range in the distributions for time spent outdoors. In this region of the U.S., children spent the least amount of time outdoors during the school-year days-of-the-week and the greatest amount of time outdoors on average during the summer. Based on this analysis, it is not expected that the results generated for the two Missouri modeling domains would be largely different from results generated in most areas of the U.S. when considering time spent outdoors, though there may be differences in exposures estimated in Northeastern states.[76] Depending on when the peak exposure events occur in the year, the exposures estimated in these states may be lower or higher.

Table 8-18. Time spent outdoors by geographic region for children ages 5-17 based on CHAD time-location-activity diaries.

Region	Time of Year	Day of Week	Doers[1] (n)	Doers[1] (%)	Time Spent Outdoors (minutes) Mean	SD	Min	Med	P95	Max	GM	GSD
MA	school	weekdays	400	45	113	97	1	90	301	700	73	3.0
		weekends	317	43	158	159	2	120	365	1440	105	2.7
	summer	all	474	71	193	140	5	165	462	1210	146	2.3
MW	school	weekdays	336	42	109	92	2	88	300	550	73	2.7
		weekends	258	41	152	131	1	116	422	870	102	2.7
	summer	all	154	71	193	180	5	143	565	1250	131	2.6
NE	school	weekdays	70	48	106	89	2	75	290	335	66	3.1
		weekends	54	43	148	128	15	115	480	574	105	2.4
	summer	all	23	77	217	148	30	175	465	635	172	2.1
SE	school	weekdays	641	49	120	98	2	95	325	555	84	2.6
		weekends	593	52	157	126	1	123	404	810	112	2.5
	summer	all	244	70	185	147	5	150	480	935	135	2.4
SW	school	weekdays	253	46	119	106	1	90	315	650	80	2.8
		weekends	232	50	162	142	7	120	405	1390	116	2.4
	summer	all	273	76	187	137	2	150	450	840	136	2.5

Notes:
[1] Doers are those engaged in the particular activity, in this case those children that had at least 1 minute of outdoor time recorded in their CHAD time-location-activity diary. The participation rate (%) was estimated by the total number of persons in each subgroup (not included). The *n* indicates the person-days of diaries used to calculate the outdoor time statistics.

[76] Note however that all of the Northeastern data have the fewest number of person days available, in particular the summer days (n=23).

8.10.3 SO_2 Emissions and Ambient Concentrations

St. Louis was not one of the 40 selected counties for the Air Quality Characterization due to its not meeting the selection criteria (see section 7.2.4.2). To provide additional perspective on the exposure results for both the Greene County and St. Louis modeling domains, staff compared the air quality in each of these locations with the other 39 counties, beginning with the estimated number of benchmark exceedances using the available ambient monitoring data.[77] Five-minute maximum SO_2 concentrations were estimated in St. Louis as was done with the other 40 Counties (including Greene County) using the hourly ambient monitoring data (2001-2006). Staff simulated all air quality scenarios (*as is*, current standard, potential alternative standards) and estimated 5-minute maximum SO_2 concentrations using the statistical model. Then, the mean number of days with a 5-minute maximum concentration above a benchmark level in a year for St. Louis were combined with the exceedance results for the 40-counties and ranked in descending order. In addition, two other rank statistics were generated; the average total SO_2 emissions within 20 km of ambient monitors and the average population within 5km of the ambient monitors, both statistics considering the 40 counties and St. Louis area. Each of the two additional variables was also ranked in descending order.

Greene county estimated air quality exceedances rank within the upper quartile (i.e., having some of the highest estimated number of days with 5-minute benchmark exceedances) for many alternative standard scenarios (Table 8-19). Most scenarios have exceedances ranked within upper 50th percentile (including the *as is* scenario), while having the 37th highest ranked emissions. The population ranking was moderate (19th of 41 locations). St. Louis air quality exceedances rank within the 50th-75th percentile for most of the alternative standard scenarios, with a few of the scenarios (e.g., the current standard, and the higher alternative standard) ranked in the upper quartile, while having moderately ranked emissions (26th highest). The number of days with benchmark exceedances for the *as is* scenario in St. Louis was ranked low in comparison with the other 39 counties (approximately the 90th-95th percentile). The mean estimated population surrounding the monitors is ranked in the upper quartile (9th of 41).

[77] The exposure modeling domain was comprised of three counties (St. Charles, St. Louis, and St. Louis City), while the available ambient monitoring data was only available for the latter two counties for years 2001-2006.

Table 8-19. Ranking of selected exposure locations using the modeled number of days with 5-minute benchmark exceedances and the total emissions within 20 km of ambient monitors.

Exposure Modeling Domain	Air Quality Scenario	Benchmark Exceedance Rank (out of 41)[1]			
		100 ppb	200 ppb	300 ppb	400 ppb
Greene County, MO Population – 19th Emissions – 37th	*as is*	31	23	22	21
	Current Standard	40	33	27	23
	99-50	8	4	4	22.5
	99-100	13	6	5	4
	99-150	27	9	7	5
	99-200	32	14	8	8
	99-250	34	22	9	7
	98-200	36	21	9	8
St. Louis, MO Population – 9th Emissions – 26th	*as is*	38	37	39	38.5
	Current Standard	2	3	8	14
	99-50	30	22.5	27	22.5
	99-100	20	30	25	24
	99-150	13	27	30	28.5
	99-200	9	21	29	30
	99-250	8	15	27	28
	98-200	8	16	24	26

Notes:
[1] Benchmark exceedances for the exposure modeling domains were compared with the 40 counties selected for the air quality characterization.

Given these ranked statistics and the results of the exposure assessment (i.e., St. Louis had a much higher percent of asthmatics exposed above benchmark levels than Greene County), the number and percent of persons exposed above benchmark levels are likely more a function of the population density and where the persons reside, rather than just total SO_2 emission levels or the number of air quality benchmark exceedances. In addition, total SO_2 emissions are not necessarily a good indicator of estimated air quality exceedances. Greene County has a high ranking for most of the air quality scenarios but only a moderate ranking for total emissions. Ambient monitors with a high COV (>200%) account for the greatest number of days/year with air quality benchmark exceedances. For example, in Gila County AZ, one of the two monitors in the county had a high COV and was located within 2 km of primary smelter emissions. This county ranked 1st in days/year with exceedances using *as is* air quality, though ranked only 36th for SO_2 emissions (18,000 tpy). Figure 7-10 provided support for the variability bins selected and their relationship with the number of measured air quality benchmark exceedances. Clearly, ambient monitors with the greatest variability in 1-hour SO_2 concentration are the monitors most likely to have 5-minute SO_2 benchmark exceedances.

Greene County was retained in the final exposure assessment based analyses in the 1st draft SO_2 REA. At the time of the analysis, it was noted by staff that the county had a number of ambient monitors available for use in calibrating the dispersion model (two of which were rated as having high COVs), there were some measured benchmark exceedances using *as is* air quality, and there was a moderate population density surrounding the monitors/source emissions. However, based on the air quality characterization and exposure modeling performed here that includes St. Louis, it appears that a less dense population surrounding the potentially important SO_2 emission sources in Greene County primarily contributed to the resultant small percent of asthmatics exposed. This is a common attribute noted at the high COV monitors; most of these monitors are located in areas having low population density. Eighty-nine of the 809 monitors in the broader SO_2 monitoring network were rated as having a high COV; 52 of these monitors (58%) were associated with low population density (<10,000 persons within 5km), 28 moderate population density (31%, 10,000-50,000 persons within 5km), and 9 high population density (10%, >50,000 persons within 5km). It is possible that, in areas having several days/year with air quality benchmark exceedances and a low to moderate population density, the exposure results would be similar to that estimated for Greene County. For example, if an exposure assessment was performed in Gila County AZ (ranked 1st in *as is* air quality benchmark exceedances), it is possible that the percent of persons exposed would be low (ranked 38th in population).

Staff also calculated the total SO_2 emissions from marine vessels, generally referred to as port emissions in this document. Using the data in the 2002 NEI, the total port emissions were calculated for each of the 40 counties used in the air quality characterization and ranked (Table 8-20). The St. Louis modeling domain had the 5th highest total port SO_2 emissions when considering the 40 counties, though these emissions only comprise 2% of the total SO_2 emissions in St. Louis. Thirteen of the 40 counties did not have port emissions, one of which was Greene County. The amount of port emissions in St. Louis was also compared with the top 40 counties in the U.S that had the highest port emissions (Table 8-21). The total SO_2 emissions from ports in St. Louis were ranked 28th, while seven counties had greater port emissions than Jefferson County TX (one of the 40 counties included in the air quality characterization). Note that most of the counties with the greatest port emissions were not evaluated in the air quality characterization because they did not meet the high SO_2 concentration-based selection criterion.

Table 8-20. Total SO_2 emissions and total port SO_2 emissions in the St. Louis and the 40 Counties used in the air quality characterization.

State	County	SO_2 Emissions[1]				
		Total	Ports			
		(tpy)	(tpy)	Rank	% of Total	Rank of %
TX	Jefferson County	33,608	4,489	1	13.4%	3
PA	Allegheny County	56,411	2,666	2	4.7%	9
FL	Hillsborough County	70,231	2,168	3	3.1%	12
NJ	Hudson County	22,300	2,044	4	9.2%	4
MO	St. Louis (3-County Area)	90,135	1,860	5	2.1%	13
DE	New Castle County	53,626	1,693	6	3.2%	11
NJ	Union County	3,840	1,657	7	43.2%	1
TN	Shelby County	31,023	1,243	8	4.0%	10
OH	Cuyahoga County	12,681	631	9	5.0%	8
NY	Bronx County	3,747	295	10	7.9%	7
OH	Lake County	73,316	294	11	0.4%	18
IN	Lake County	40,063	209	12	0.5%	16
WV	Hancock County	2,055	177	13	8.6%	6
MI	Wayne County	74,832	177	14	0.2%	23
WV	Wayne County	1,071	150	15	14.0%	2
MO	Jefferson County	40,481	132	16	0.3%	19
PA	Beaver County	42,685	130	17	0.3%	20
WV	Brooke County	1,355	119	18	8.7%	5
NY	Erie County	50,858	108	19	0.2%	24
OK	Tulsa County	8,181	90	20	1.1%	14
IL	Madison County	27,396	81	21	0.3%	21
IA	Muscatine County	24,890	71	22	0.3%	22
TN	Blount County	5,164	43	23	0.8%	15
PA	Washington County	8,189	41	24	0.5%	17
WV	Monongalia County	92,677	20	25	0.0%	27
IN	Floyd County	48,653	20	26	0.0%	25
NY	Chautauqua County	57,835	9	27	0.0%	28
VA	Fairfax County	3,741	1	28	0.0%	26
IN	Gibson County	127,934	-	29	0.0%	29
IN	Vigo County	66,170	-	29	0.0%	29
PA	Northampton County	58,598	-	29	0.0%	29
MO	Iron County	47,562	-	29	0.0%	29
NH	Merrimack County	31,812	-	29	0.0%	29
TN	Sullivan County	30,999	-	29	0.0%	29
AZ	Gila County	18,594	-	29	0.0%	29
IA	Linn County	17,324	-	29	0.0%	29
OH	Summit County	12,868	-	29	0.0%	29
MO	Greene County	11,819	-	29	0.0%	29
PA	Warren County	5,222	-	29	0.0%	29
VI	St Croix	122	-	29	0.0%	29
IL	Wabash County	55	-	29	0.0%	29

Notes:
[1] SO_2 emissions were calculated from the 2002 NEI. Emissions originating from ports were calculated using SCC for marine vessels: 2280002100, 2280002200, 2280003100, 2280003200, 2282020005.

Table 8-21. The top 40 counties with the greatest total port SO_2 emissions, including SO_2 emissions from ports in the St. Louis modeling domain.

State	County Name	Port Emissions (tpy)	Rank
CA	Los Angeles	13,817	1
LA	St. John the Baptist Parish	10,605	2
CA	Santa Barbara County	8,831	3
TX	Harris County	8,142	4
CA	San Diego County	5,408	5
MD	Baltimore City	4,582	6
LA	Orleans Parish	4,579	7
TX	Jefferson, Co	4,489	8
TX	Nueces County	3,545	9
LA	East Baton Rouge Parish	3,435	10
LA	Iberville Parish	3,179	11
TX	Galveston County	3,123	12
OR	Multnomah County	3,004	13
LA	Calcasieu Parish	2,728	14
PA	Allegheny County	2,666	15
AL	Mobile County	2,582	16
WV	Cabell County	2,575	17
CA	Ventura County	2,406	18
AK	Valdez-Cordova	2,243	19
NH	Cheshire County	2,231	20
FL	Hillsborough County	2,168	21
NY	Kings County	2,112	22
PA	Philadelphia County	2,069	23
NH	Strafford County	2,044	24
NH	Hillsborough County	1,998	25
MN	St. Louis County	1,987	26
VA	Norfolk City	1,980	27
MO	St. Louis 3-County Area	1,860	28
NY	Richmond County	1,818	29
CA	Orange County	1,770	30
MI	Presque Isle County	1,748	31
CA	Contra Costa County	1,716	32
DE	New Castle County	1,693	33
NH	Union County	1,657	34
CA	Orange County	1,615	35
CA	San Francisco County	1,530	36
TX	Brazoria County	1,367	37
WA	Clallam County	1,356	38
NY	Queens County	1,341	39
MI	Alger County	1,284	40
TN	Shelby County	1,243	41

Notes:
[1] SO_2 emissions were calculated from the 2002 NEI. Emissions originating from ports were calculated using SCC for marine vessels: 2280002100, 2280002200, 2280003100, 2280003200, 2282020005.

Table 8-22. SO_2 emission density the two exposure modeling domains and several counties within selected U.S. Cities.

State	City	FIPS[1]	County	Total SO_2 Emissions[2] (tpy)	Land Area[3] (miles^2)	Emission Density (tons/miles^2)
NY	New York	36005 36047 36061 36081 36085	Bronx Kings New York Queens Richmond	38,036	303	125
OH	Cleveland	39035 39085	Cuyahoga Lake	85,997	686	125
MI	Detroit	26163	Wayne	74,832	614	122
PA	Philadelphia	42101	Philadelphia	11,614	135	86
IN	Gary	18089	Lake County	40,063	497	81
MO	St. Louis	29183, 29189, 29510	St. Charles St. Louis St. Louis (city)	90,135	1,130	80
PA	Pittsburgh	42003	Allegheny	56,411	730	77
FL	Tampa	12057	Hillsborough	70,231	1,051	67
NY	Buffalo	36029	Erie County	50,858	1,044	49
IL	Chicago	17031	Cook	35,191	946	37
TX	Beaumont-Port Arthur	48245	Jefferson	33,608	904	37
TX	Houston	48201	Harris	60,924	1,729	35
GA	Atlanta	13067 13089 13121 13135	Cobb DeKalb Fulton Gwinett	48,606	1,570	31
MA	Boston	25017 25019 25021	Middlesex Norfolk Suffolk	23,712	1,282	19
MO	Springfield	29077	Greene County	11,819	675	18
CA	Los Angeles	06037	Los Angeles	17,175	4,061	4

Notes:
[1] Federal Information Processing Standard Code
[2] The emissions totals come from tier 1 data in the 2002 NEI (02nei_v3tier_summary_oct_15_2007.zip).
[3] The county land area statistics come from the Census 2000 STF1. Available at : http://factfinder.census.gov/servlet/

Staff evaluated the emission density within the two exposure modeling domains and for counties within several highly populated U.S. Cities. The emission density was calculated by dividing the total emissions (tpy) by the physical area (mile^2) of the location. These data are presented in Table 8-22. Greene County (or Springfield, Mo.) has one of the lowest emission densities, another attribute of the county that could have led to the few estimated number of persons exposed above benchmark levels. On the other hand, St. Louis has a medium-to-high emission density, likely one of the factors contributing to the much greater estimated numbers of persons exposed above benchmark levels. The emission density in St. Louis is similar in magnitude with counties in Philadelphia PA, Gary IN, and Pittsburgh PA, though much higher than several counties within large U.S cities such as Atlanta, Boston, Chicago, Houston, and Los Angeles. Three cities had a distinctly higher emission density than St. Louis: New York, Cleveland, and Detroit. We note that four counties within these cities with the greatest emission density were evaluated in the air quality characterization: the Bronx, Cuyahoga, Lake, and Wayne.

In considering the air quality benchmark exceedance rankings of other counties combined with their emissions and population density rankings, one could possibly argue for other locations to conduct an exposure analysis that may provide different results for the *as is* air quality scenario.[78] Staff began assessing two additional locations for detailed exposure modeling, i.e., Allegheny and Cuyahoga counties.[79] Unresolved technical issues remained regarding the agreement between dispersion-modeled and ambient measured concentrations, preventing their inclusion in this final REA. The numbers of estimated air quality benchmark exceedances in these two counties were ranked similarly to St. Louis (both counties were within the 50th-75th percentiles). In addition, all of the monitors in Allegheny and Cuyahoga County had at most moderately rated COVs (between 100-200%), suggesting that exposure results estimated in those locations would be similar to that estimated in St. Louis. However, the high emission density for Cuyahoga and Lake Counties (Cleveland) could indicate that a greater number of persons might be exposed above benchmark levels when using the *as is* air quality. While locations such as Los Angeles have greater estimated emissions originating from ports, the SO_2 concentration levels measured at ambient monitoring data in these locations did not approach the levels used for selection in the air quality characterization. In addition, the emission density in Los Angeles County was the lowest of all of the cities selected for that evaluation. Given each of the above rankings and available monitoring data, staff judges St. Louis and Greene County as reasonable choices for the detailed exposure assessment, particularly considering the range of air quality scenarios investigated.

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[78] For example, Hillsborough Fl. has a few bin C monitors, ranks 7th in population, 21st in emissions within 20 km of monitors, 21st in countywide port emissions, and medium emission density.

[79] Allegheny county ranked 10th in population, 31st in SO_2 emissions within 20 km of monitors, and 23rd in countywide port emissions. Cuyahoga county ranked 5th in population, 25th in SO_2 emissions within 20 km of monitors, though not ranked within the top 40 counties using port emissions.

8.10.4 American Housing Survey (AHS) Data

The American Housing Survey (AHS), conducted by the Bureau of the Census for the Department of Housing and Urban Development (HUD), collects data on the nation's housing. Relevant housing characteristic data, including residential prevalence of air conditioning are summarized for 13 locations using the available metropolitan areas surveyed by the AHS (Table 8-23). Because survey years differ for each location and some locations contained more than one survey, the most recent data or data closest to 2002 were selected (the year for the exposure modeling). The A/C prevalence can vary greatly across urban areas, based largely on climate differences. The air conditioning prevalence can influence the air exchange rate in a residence, potentially affecting the infiltration rate of outdoor air concentrations into the indoors residential microenvironment. St. Louis was estimated to have one of the highest air conditioning prevalence rates, though similar rates could be found in Miami, Phoenix, Atlanta, and Washington D.C. A few of the urban areas listed have much lower A/C prevalence rates, including Los Angeles with 57.4% and Boston with 63.1%. For locations having a low A/C prevalence, it is expected that the number of indoor residential exposures to daily maximum NO_2 concentrations above selected benchmarks would be greater compared to those estimated in St. Louis. However, given the limited contribution of the indoor microenvironment to the number of exceedances even considering much lower A/C prevalence rates (section 8.11.2.2.9; also EPA 2008d), modeled increases in the numbers of persons exposed in these other locations would likely be small.

Table 8-23. Residential A/C prevalence for housing units in several metropolitan locations in the U.S. (AHS, 2008).

Location	AHS Survey Year	A/C Prevalence[1] (%)
Atlanta	2004	97.2
Boston	1998	63.1
Chicago	2003	89.6
Cleveland	2004	75.8
Denver	2004	66.9
Detroit	2003	82.4
Los Angeles	2003	57.4
Miami	2002	98.1
New York	2003	83.3
Philadelphia	2003	91.4
Phoenix	2002	94.4
St. Louis[2]	2004	96.7
Washington DC	1998	96.0

Notes:
[1] Represents the percent of total year-round housing units having central or room unit air conditioners (AHS, 2008).
[2] Note, a truncated value of 96% was used as input to APEX. The effect of this to estimated exposures is negligible. See section 8.11.2.2.9.

8.10.5 Asthma Prevalence

Staff compared regional asthma prevalence statistics for children <18 years in age and all persons. For children, the estimated age-adjusted percents of ever having asthma are presented in Table 8-24 using data from Dey et al. (2004). There are similar prevalence rates for asthmatic children in three of the four regions of the U.S. (Midwest, South, and West), suggesting that exposure analyses conducted in these broader regions may result in similar distributions in the percent of asthmatics exposed to the two Missouri modeling domains used in this assessment. The Northeastern U.S. has a higher percentage of asthmatic children. This suggests that there may be a greater percentage of peak exposures to asthmatic children in the Northeast than compared with the percent modeled in St. Louis or Greene County, holding all other influential variables are constant (e.g., time spent outdoors, a similar air quality distribution).

Staff weighted the BRFSS 2002 state-level adult asthma prevalence rates (self-reported) to generate prevalence rates for five U.S regions (Table 8-25).[80] Similar rates (between 7.6-

[80] http://www.cdc.gov/asthma/brfss/02/current/tableC1.htm. Regions were mapped using Table 8-12.

7.9%) were estimated for three of the five regions (Mid-Atlantic, Midwest, and the Southwest), suggesting that exposure analyses conducted in these broader regions may result in similar distributions in the percent of asthmatics exposed to the two Missouri modeling domains used in this assessment. Consistent with that observed for asthmatic children, the Northeastern U.S. has the greatest percent of asthmatic adults. The Southeastern states on average were estimated to have the lowest adult asthma prevalence. This suggests that there may be a greater percentage of peak exposures to asthmatic adults in the Northeast and a lower percentage of peak exposures in the Southeast when compared with the percent modeled in St. Louis or Greene County, holding all other influential variables are constant (e.g., time spent outdoors, a similar air quality distribution).

Table 8-24. Asthma prevalence rates for children in four regions of the U.S.

Region	Asthma Prevalence[1] (%)
Northeast	15.2
Midwest	11.6
South	11.9
West	11.1

Notes:
[1] prevalence is based on the question, "Has a doctor or other health professional ever told you that [child's name] had asthma?'" (Dey et al., 2004)

Table 8-25. Asthma prevalence rates for adults in five regions of the U.S.

Region[1]	Asthma Prevalence[2] (%)
Mid-Atlantic	7.9
Midwest	7.7
Northeast	8.9
Southeast	6.9
Southwest	7.6

Notes:
[1] Table 8-17 was used in mapping the states to regions.
[2] state level data obtained from http://www.cdc.gov/asthma/brfss/02/current/tableC1.htm.

8.11 VARIABILITY ANALYSIS AND UNCERTAINTY CHARACTERIZATION

As discussed in section 6.6, there can be variability and uncertainty in risk and exposure assessments. This section presents a summary and discussion of the degree to which variability was incorporated in the exposure analyses and how the uncertainty was characterized for the estimated number of persons and person days with exposure benchmark exceedances.

8.11.1 Variability Analysis

To the maximum extent possible given the data, time, and resources available for the assessment, staff accounted for variability within the exposure modeling. APEX has been designed to account for variability in nearly all of the input data, including the physiological variables that are important inputs to determining exertion level. As a result, APEX addresses much of the variability in exposure estimates given variability in factors that affect human exposure. The variability accounted for in this analysis is summarized in Table 8-26.

Table 8-26. Summary of how variability was incorporated into the exposure assessment.

Component	Variability Source	Comment
Simulated Individuals	Population data	Individuals are randomly sampled from U.S. census blocks used in model domains, by age and gender.
	Activity patterns	Data diaries are stratified from CHAD based on 30 day-type (summer weekday, non-summer weekday, weekend) and demographic group (males/females, ages 0-4, 5-11, 12-17, 18-64, 65+).
	Block-level commuting	An individuals' commuting location is randomly sampled, using adjusted U.S. census tract data that account for fine-scale land use at the block level.
	Employment	Work status is randomly generated from U.S. census data at the tract-level by age and gender.
Ambient Input	Modeled ambient SO_2 concentrations	Spatial: modeled ambient SO_2 to block-level receptors. Temporal: 1-hour SO_2 for an entire year predicted using AERMOD; 5-minute SO_2 within each hour estimated using APEX.
	Meteorological data	Spatial: Local surface and upper air NWS stations used. Temporal: 1-hour NWS wind data for 2002 (supplemented by1-minute ASOS data).
Physiological Factors Relevant to Ventilation Rate	Resting metabolic rate	Six age-group and two gender-specific regression equations using body mass as an independent variable (Johnson et al., 2000).
	Metabolic equivalents by activity (METS)	Values randomly sampled from distributions developed for specific activities (some age-specific) (EPA, 2002).
	Oxygen uptake per unit of energy expended	Values randomly sampled from a uniform distribution (Johnson et al., 2000).
	Body mass	Values randomly sampled from lognormal distributions by gender and age (Isaacs and Smith, 2005).

Component	Variability Source	Comment
	Body surface area	Gender specific exponential equations using body mass as independent variable (Burmaster, 1998).
	Height	Separate regression equation for children and adults, both gender and age-specific (4-groups); children use age as an independent variable; adults use body weight (Johnson et al., 2000).
Physical Factors Relevant to Microenvironmental Concentrations	Air exchange rates	Residential values randomly selected from lognormal distributions, stratified by 4 temperature groups and presence/absence of air conditioning. Other indoor values randomly sampled from a separate lognormal distribution.
	Air conditioning prevalence rates	Values randomly sampled AHS survey data for St. Louis.
	Removal rates	Values randomly selected for 5 microenvironment-specific distributions, stratified by air conditioning usage.
	Penetration factors	Indoor/outdoor ratios randomly sampled from two uniform distributions for inside-vehicle microenvironments.

8.11.2 Uncertainty Characterization

The methods and the models used in this exposure assessment conform to the most contemporary modeling methodologies available. A similar combined dispersion and exposure modeling approach has been used recently in estimating human exposures for the NO_2 NAAQS REA (EPA, 2008d). This increased level of complexity in the type and number of models used, the overall exposure modeling approaches, and its application in exposure assessments does not necessarily confer decreased levels of uncertainty. Staff believes however, that these types of complex assessments serve as an important step towards raising the degree of confidence in estimating exposures, particularly when the sources of uncertainty are systematically evaluated.

Following the same general approach described in sections 6.6 and 7.8 and adapted from WHO (2008), staff performed a qualitative characterization of the components contributing to uncertainty in the exposure results. First, staff identified the important uncertainties. Then, we qualitatively characterized the magnitude (*low*, *medium*, and *high*) and direction of influence (*over, under, both,* and *unknown*) the source of uncertainty may have on the estimated number of persons and person days above benchmark levels. Finally, staff also qualitatively rated the uncertainty in the knowledge-base regarding each source using *low*, *medium*, and *high* categories. Even though uncertainties in AERMOD concentrations predictions are an APEX input uncertainty, the uncertainties associated with each of the models are addressed separately here for clarity. Table 8-27 summarizes the results of the qualitative uncertainty analysis conducted by staff for the SO_2 exposure assessment.

Table 8-27. Summary of qualitative uncertainty analysis for the exposure assessment.

Source	Type	Influence of Uncertainty on Exposure Benchmark Exceedances		Knowledge-Base Uncertainty	Comments[1]
		Direction	Magnitude		
AERMOD Inputs and Algorithms[2]	Algorithms	Unknown	Low	Low	INF & KB: Multiple historical model evaluations consistently demonstrate unbiased ambient concentrations under variety of conditions. Some potential dispersion scenarios may not be adequately represented and are unknown as to how they apply in this application. However, model-to-monitor comparisons in this application indicate very good agreement.
	Meteorological Data	Unknown	Low – Medium	Low	INF: A limited number of missing hours of wind data remain, potentially leading to under-estimation. Model predictions have low to medium sensitivity to surface roughness characteristics, as long as they are appropriate for the site of the meteorological data inputs. KB: Data are from a well-known and quality-assured source. One minute ASOS wind data used to supplement 1-hour data for improved completeness, reducing the number of calms and missing data.
	Point Source Emissions and Profiles	Both	Low	Low	INF: Temporal emission characteristics are well represented for most modeled point sources. KB: Most temporal data are from a well-known quality-assured source of direct measurements.
	Area Source Emissions and Profiles	Both	Low – Medium	High	INF: Temporal concentration characteristics were well represented when using a generalized area source emission profile, i.e., an aggregate profile covering a variety of emission source types. However, the temporal profile selected can be very influential to 1-hour concentrations where area sources are a significant contributor to emissions. KB: While there were two alternative profiles available, one of which was evaluated, a local generalized temporal emission profile was selected based on yielding the best model-to-monitor agreement. It is largely unknown whether the generalized profile is an appropriate representation of the true temporal profiles that exist for modeled area sources.
APEX Inputs and Algorithms	AERMOD Modeled 1-hour Concentrations	Both	Low – Medium	Medium	INF: Model-to-monitor comparisons indicated very good agreement. Most of the overestimations in concentration occurred at the lowest 1-hour concentrations (Figures 8-8 and 8-9), limiting the magnitude of influence on estimated 5-minute concentrations. The spatial representation of ambient concentrations using modeling is likely an improvement over using concentrations from the limited number of ambient monitors. KB: While model-to-monitor agreement was very good, it is unknown how well all other modeled receptors are represented.

	Accuracy of 5-minute Exposure Estimation	Both	Low – Medium	High	INF: The accuracy of the statistical model used in calculating 5-minute SO_2 ambient concentrations was rated as having at most a medium level of influence (see section 7.4.2.6 and Table 7-16). KB: APEX annual average SO_2 exposures are comparable reported personal exposures of daily to multi-day averaging time. However, there are no 5-minute SO_2 personal exposure data that can be used to evaluate APEX output.
	Population Database	Both	Low	Low	INF & KB: Data are from a reliable, quality assured source. Staff assumed the limited uncertainty in the database would have negligible influence on exposure results.
	Commuting Database and Algorithm	Both	Low	Medium	INF: Most exposures above benchmark levels occur outdoors, not inside vehicles. Also note there is limited modeled spatial heterogeneity in SO_2 concentrations in St. Louis. KB: Data are from a reliable, quality assured source. However land-use data was used as a surrogate for distributing the tract-level commuting data to the block-level.
	Activity Pattern Database	Over	Low – Medium	Medium	INF: Most of the potentially influential factors are within the expected (or assumed) bounds or are controlled for by the exposure modeling approach. Though most components are rated as potentially having a low magnitude of influence in either direction, not accounting for averting behavior by asthmatics could result in a medium level of over-estimation. KB: Data are from a reliable, quality assured source. Available published literature was used for many of the comparisons, though some were limited in direct correspondence and applicability.
	Longitudinal Profile Algorithm	Both	Low – Medium	Medium	INF: The magnitude of potential influence would be mostly directed toward estimates of multiday exposures. KB: Method compared reasonably well with available measurement data and two other methods, however long-term (i.e., monthly, annual) diary profiles do not exist for a population.
	Meteorological Data	Both	Low	Low	INF: Daily maximum temperatures are only used when selecting appropriate diaries to simulate individuals and in selecting air exchange rate distributions. KB: Data are from a well-known and quality-assured source. One minute ASOS wind data used to supplement 1-hour data for improved completeness, reducing the number of calms and missing data.
	Air Exchange Rates	Under	Low – Medium	Medium	INF: Most peak exposures occur outdoors, though indoor exposures may be underestimated when not using all 5-minute concentrations within the hour (section 8.11.2.2.11). KB: Data used are not specific to St. Louis or Greene County Mo.

	A/C Prevalence	Under	Low	Low	INF: Most peak exposures occur outdoors, though indoor exposures may be underestimated when not using all 5-minute concentrations within the hour (section 8.11.2.2.11). However a previous sensitivity analysis (EPA, 2008d) indicates extremely low A/C prevalence has little influence on number and percent of persons exposed. KB: Data used are specific for St. Louis, there is limited variability in the estimate, and compares reasonably with data from a different source.
	Indoor Removal Rate	Unknown	Low	Medium	INF: Most peak exposures occur outdoors, though indoor exposures may be underestimated when not using all 5-minute concentrations within the hour (section 8.11.2.2.11). KB: Data used were obtained from comprehensive review of SO_2 removal rates, however many assumptions were needed in developing the removal rate distributions.
	Occurrence of Multiple Exceedances Within an Hour	Under	Low – Medium	Medium	INF: Analyses indicate that ignoring multiple peaks within the hour under-estimates exposure and hence the number of persons exposed upwards to 35%. KB: While the frequency of multiple exceedances within an hour can be estimated, there are limited continuous 5-minute data available. The representativeness of the available data to modeled receptors is unknown.
	Asthma Prevalence Rate	Both	Low – Medium	Low	INF: The percent of asthmatics for Greene county's simulated population was similar to that of another independent estimate. County specific asthma distributions were not used in St. Louis, there may be an over or under estimate in the number of persons exposed. KB: Data for asthma prevalence are from reliable and quality assured sources.

Notes:
[1] INF refers to comments associated with the influence rating; KB refers to comments associated with the knowledge-base rating.
[2] The magnitude/direction of influence and the uncertainty associated with the knowledge-base for each source identified for AERMOD is characterized for the predicted 1-hour concentrations, not the 5-minute benchmark exceedances.

8.11.2.1 Dispersion Modeling Uncertainties

Air quality data used in the exposure modeling was determined through use of EPA's recommended regulatory air dispersion model, AERMOD (version 07026 (EPA, 2004a)), with meteorological data and emissions data discussed above. Parameterization of meteorology and emissions in the model were made in as accurate a manner as possible to ensure best representation of air quality for exposure modeling. Thus, the resulting air quality values are likely free of systematic errors to the best approximation available through application of modeled data.

The characterization of uncertainty associated with this application of AERMOD is separated into two main sources: 1) model algorithms, and 2) model inputs. While it is convenient to discuss uncertainties in this context, it is also important to recognize that there is some interdependence between the two in the sense that an increase in the complexity of model algorithms may entail an increase in the potential uncertainty associated with model inputs. In the characterization that follows, AERMOD uncertainties are discussed regarding the impact to predicted 1-hour SO_2 concentrations.

8.11.2.1.1 Algorithms

The AERMOD model was promulgated by EPA in 2006 as a "refined" dispersion model for near-field applications (with plume transport distances nominally up to 50 kilometers), based on a demonstration that the model produces largely unbiased estimates of ambient concentrations across a range of source characteristics, as well as a wide range of meteorological conditions and topographic settings (Perry, *et al.*, 2005; EPA, 2003). While a majority of the 17 field study databases used in evaluating the performance of AERMOD are associated with elevated plumes from stationary sources (i.e., typically electrical generating units), a number of evaluations included low-level releases. Moreover, the range of dispersion conditions represented by these evaluation studies provides some confidence that the fundamental dispersion formulations within the model will provide robust performance in other settings.

AERMOD is a steady-state, straight-line plume model, which implies limitations on the model's ability to simulate certain aspects of plume dispersion. For example, AERMOD treats each hour of simulation as independent, with no memory of plume impacts from one hour to the next. As a result, AERMOD may not adequately treat dispersion under conditions of atmospheric stagnation or recirculation when emissions may build up within a region over several hours. This could lead to ambient concentration under-predictions by AERMOD during such periods. On the other hand, AERMOD assumes that each plume may impact the entire domain for each hour, regardless of whether the actual transport time for a particular source-receptor combination exceeds an hour. This could lead to ambient concentration over-predictions by AERMOD. While these assumptions imply some degree of physically unrealistic behavior when considering the impacts of an individual plume simulation, their importance in terms of overall uncertainty will vary depending upon the application. The degree of uncertainty attributable to these basic model assumptions is likely to be more significant for individual plume simulations than for a cumulative analysis based on a large inventory. This question deserves further investigation to better define the limits and capabilities of a modeling system such as AERMOD for large scale exposure assessments such as this. The evidence provided by the model-to-monitor comparisons presented in section 8.4.5 is encouraging as to the viability of the approach in this application when adequate meteorological and other inputs are available. However, each modeling domain and inventory will present its own challenges and will require a separate assessment based on the specifics of the application.

One of the improvements in the AERMOD model formulations relative to the Industrial Source Complex - Short Term (ISCST) model which it replaced is a more refined treatment of enhanced turbulence and other boundary layer processes associated with the nighttime heat island influence in urban areas. The magnitude of the urban influence in AERMOD is scaled based on the urban population specified by the user. Since the sensitivity of AERMOD model concentrations to the user-specified population is roughly proportional to population to the $1/4^{th}$ power, this is not a significant source of uncertainty. The population areas of interest for this application are also well-defined, thus reducing any uncertainty associated with specification of the population or with defining the extent of the modeling domain treated as urban.

Therefore, based on the evidence in historical and recent model evaluations and the improved AERMOD model formulations, staff judges that algorithm uncertainty has a low magnitude of influence on the estimated 1-hour concentrations. The direction of influence is largely unknown, given the limitations in determining how the basic model assumptions apply to a large-scale analysis. While the AERMOD model algorithms are not considered to be a significant source of uncertainty for this assessment, the representativeness of modeled concentrations for any application are strongly dependent on the quality and representativeness of the model inputs. The main categories of model inputs that may contribute to uncertainty are the meteorological input data and emissions estimates. These issues are addressed in the following sections.

8.11.2.1.2 Meteorological Data

Details regarding the representativeness of the meteorological data inputs for AERMOD are addressed separately in section 8.4.2 and in Attachment 1 in Appendix B. The data are from a well-known, reliable source (NWS) and assumed vetted for extraordinary values by the database architects and data users. Calm and missing 1-hour wind data have been supplemented with 1-minute ASOS data averaged to the hour, decreasing the number of each within the input data sets used. A limited number of missing values remained (1.1 – 1.5%), however staff expects these to have a negligible effect on the overall 1-hour concentration profile.

An important issue associated with representativeness is the sensitivity of the AERMOD model to surface roughness, because the roughness at the location of the meteorological tower site used to process the meteorological data for use in AERMOD may be very different from the surface roughness across the full domain of sources. This issue has been shown to be more significant for low-level sources due to the importance of mechanical shear-stress induced turbulence on dispersion for such sources. A previous application of the AERMOD model to support the REA for the NO_2 NAAQS review (EPA, 2008d) provided an opportunity for a direct assessment of this issue by comparing AERMOD modeled concentrations based on processed meteorological data from the Atlanta Hartsfield airport (ATL) with concentrations based on processed meteorological data from a Southeast Aerosol Research and Characterization study (SEARCH) monitoring station located on Jefferson Street (JST) near Georgia Tech. The ATL data were representative of an open exposure, low roughness, site typical for an airport meteorological station. The JST data were representative of a higher roughness exposure more typical of many locations within an urban area. Surface roughness lengths were generally about an order of magnitude higher at the JST site relative to the ATL site. A comparison of AERMOD modeled concentrations for the mobile source NO_x inventory, representing near ground-level emissions, showed relatively good agreement in modeled concentrations based on the two sets of meteorological inputs, at least for the peak of the concentration distribution at four monitor locations across the modeling domain. This suggests that the sensitivity of

AERMOD model results to variations in surface roughness may be less significant than commonly believed, provided that meteorological data inputs are processed with surface characteristics appropriate for the meteorological site.

Therefore, based on the improved completeness of the wind data used and the low sensitivity of peak model predictions to surface roughness characteristics, as long as they are appropriate for the site of the meteorological data inputs, staff judges the potential magnitude of influence from the meteorological data as low to medium. While it is possible that 1-hour concentrations may be under-estimated based on missing wind data, it is largely unknown what the overall direction of influence might be when considering the potential influence of other meteorological parameters such as surface roughness.

8.11.2.1.3 Point Source Emissions and Profiles

As explained in section 8.4.3, point source emission levels were derived from the NEI with source locations independently verified with GIS analysis of aerial photography. Temporal profiles were derived from a variety of databases. Temporal profiles for all the modeled point sources in Greene County and almost half of those in the St. Louis modeling domain were derived from the CAMD database, which provides hourly emission profiles. For the remaining modeled stacks inside the St. Louis domain, a uniform temporal profile was used. For most of point sources located outside of the St. Louis domain but close enough to influence its air quality, the temporal profiles were from the EMS-HAP emission model.

Therefore, given that the emissions data are from well-known quality-assured sources, the emission source locations were independently verified, and that the temporal profiles for most of the emission sources were known, staff judges the magnitude of influence from this potential source of uncertainty as low and assumes there is an equal tendency to over- or under-estimate 1-hour SO_2 concentrations. Further, staff also characterizes the knowledge-base for this source as having a low level of uncertainty.

8.11.2.1.4 Area Source Emissions and Profiles

Details regarding the modeling of non-point and background area sources in AERMOD were addressed in Section 8.4.3. In the case of SO_2, the area source emissions category for AERMOD represents a cumulative approximation of several lesser point sources, such as small commercial/industrial boilers, which are not represented as individual sources within the existing emissions inventories due to their limited emissions. There is a lack of detailed information regarding the location and release characteristics of these small emission sources, thus estimated emissions are typically aggregated at a county level within the emission inventories. Given these limitations in terms the emission inventory, two of the main uncertainties associated with modeling these sources are the temporal and spatial profiles used in simulating their releases. Lacking detailed location information, the emissions are assumed to be uniformly distributed across a specified area, typically at a county or census tract level since the emissions are aggregated at the county level, and spatially allocated using population as one of the surrogates. An additional uncertainty associated with the area source category for SO_2 emissions is the likelihood that the actual emissions may be associated with some plume buoyancy that cannot be explicitly treated using the area source algorithm within the dispersion model. At best, the anticipated aggregate effect of plume buoyancy can be reflected through the release height assigned to the area source.

As discussed in Section 8.4.3, all emissions in the regions of interest were simulated, either through their representative group (point sources, port-related sources, or other non-point area sources) or through cumulative background sources. Staff obtained emission estimates from the 2002 National Emissions Inventory (NEI) however, only annual total emissions at the county level are provided. To better parameterize these emissions for the hourly, census block-level dispersion modeling conducted here, we relied on additional data and an algorithm to optimize model performance based on available model-to-monitor comparisons.

Additional data related to the spatial distribution of non-point emissions was used to spatially allocate county-wide emissions to census tracts in the Greene County domain. Staff used the spatial allocation factors (SAFs), based on land use patterns, from EPA's EMS-HAP database to allocate 87% of the non-point emissions to the subset of specific tracts expected to contain the most emissions. Emissions within each modeled tract were simulated as uniform over the tract, while emissions outside the modeled tracts and other residual emissions were characterized as uniform over an entire county. The performance obtained by using tract-level emission sources in Greene County was verified by model-to-monitor comparisons. In the St. Louis area, model performance evaluations using factors from the EMS-HAP database made it apparent that the spatial allocations were mischaracterized for this area. Thus, in the St. Louis area, spatial bias was avoided by modeling non-point emissions with a uniform density throughout each of the counties of interest instead of allocating emissions to specific census tracts. In both cases, using spatially uniform emissions resolved to the tract or county level improves spatial representation and reduces the overall level of uncertainty.

Unlike point sources, where the temporal profile was based largely on direct observations via the CAMD database, these non-point emission profiles are based on generalized emissions surrogates and may not well represent a specific source or local group of sources. Model performance evaluations of diurnal profiles suggested that temporal factors derived from the EMS-HAP emission model inadequately represented the true, aggregate, temporal release profile.[81] Unlike the spatial allocations, however, uniformly distributing the emissions in time resulted in significantly worse model-to-monitor agreement than using these sample profiles. In order to account for these uncertainties in the temporal profiles of area source emissions, an algorithm was developed to determine the optimal temporal emission release profile in each area. Examination of the diurnal profiles of modeled and monitored concentrations with uniform and with EMS-HAP emission profiles for monitors in locations dominated by area sources showed that, while monitored concentrations increased during the daytime, modeled concentrations actually decreased. An examination of the dispersion characteristics showed that increased dilution during the daytime overcame the small increase in emission strength predicted using the EMS-HAP profile, which lacks local emission information. Thus, it is reasonable to conclude that industrial and commercial/institutional area source emissions in the St. Louis and Greene County areas would have a more pronounced diurnal cycle than is reflected in the EMS-HAP temporal profile.

This method of determining an appropriate, local, non-point source emission profile has the advantage of preserving total emissions reflected in the emission inventory while deducing what the actual temporal emission profile from these local sources should be, based on the observed trends in each region. Essentially, it derives an emission profile that best agrees with observations when coupled with local meteorology and pollutant dispersion. This is justified given the lack of detail regarding emission characteristics of local area sources. This derived profile implies that the emission sources are active almost exclusively during the daytime from approximately 8 am to 8pm. Given that the emission sources represented by the industrial and commercial/institutional non-point category are small, the possibility that their cumulative

[81] Figures 8-4 and 8-5 also show the corresponding temporal profile from the SMOKE emission model, which is very similar to the temporal profile obtained from the EMS-HAP model.

emissions occur almost exclusively during daytime hours is plausible. However, in knowing that there are large variations in the assumed local emission characteristics versus limited and broadly defined emission characteristics for potential area sources, there is high level of uncertainty in the knowledge-base. The selected approach though effectively mitigates the magnitude of influence the uncertainty has on the modeling results by the application of a systematic approach to minimize discrepancies between predicted and observed values. Based on the discussion regarding the use of spatial allocation factors and the adjustments made to the area source temporal profile, staff judges the magnitude of influence to range from low to medium.

8.11.2.2 Exposure Modeling Uncertainties

APEX is a powerful and flexible model that allows for the reasonable estimation of air pollutant exposure to individuals. Since it is based on actual human time-location-activity diaries and accounts for the most important variables known to affect exposure (i.e., where people are located and what they are doing), it has the ability to effectively approximate actual human exposure conditions. In addition, staff selected to the best available input data to temporally and spatially represent the ambient concentrations and exposures given the time and resources allocated for the assessment. However, there are constraints and uncertainties associated with the input data and modeling approaches that may correspond to uncertainties in the modeling results.

In the characterization that follows, exposure modeling uncertainties are discussed regarding their influence to the estimated number of persons and person-days above benchmark exceedances. Staff primarily focused on the uncertainties and assumptions associated with SO_2 specific exposure model inputs, their utilization, and application in this exposure assessment. Note also that some sensitivity analyses for certain components of APEX (see EPA, 2007d; Langstaff, 2007) or input variables (EPA, 2008d) have been performed previously in other NAAQS reviews. Those previous analyses that are relevant to the current SO_2 NAAQS review are also included, though only summarized below.

8.11.2.2.1 AERMOD Modeled 1-hour Concentrations

The AERMOD model-to-monitor comparisons (section 8.4.5) indicated very good agreement. Most over-estimations in 1-hour SO_2 concentrations occurred at the lowest 1-hour concentrations, effectively limiting the potential magnitude of influence on estimated 5-minute air quality and exposure concentrations. At the upper tails of the distribution (> 80^{th} percentile), there was a mixture of over- and under-estimation in 1-hour SO_2 concentrations, most of which were on the order of 1-2 ppb. Staff performed an additional evaluation in Greene County to compare estimated benchmark exceedances resultant from the variable concentration distributions given by the ambient monitoring data and AERMOD predictions (rather than simply comparing the 1-hour concentrations). The results indicated there was not a significant influence to the estimated air quality benchmark exceedances from the limited differences observed in the upper percentiles of the 1-hour concentration distributions.

Further, AERMOD was used in this exposure assessment to improve the spatial representation of ambient concentrations given the limited number of ambient monitors in each modeling domain. The dispersion modeling of SO_2 concentrations to census block receptors is judged by staff as improvement over using monitored concentrations alone as an input to APEX. This may be of greater importance in Greene County where there was greater variability in the modeled concentrations at the receptors surrounding each ambient monitor (see section 8.4.5). In addition, the use of concentrations estimated at the census block centroids is judged by staff a reasonable. This is because the centroids are not expected to be at systematically farther distances from emission source than specific percentages of the population residing within the census block.

Therefore, based on the above discussion, staff judges the potential magnitude of influence from this source of uncertainty as low to medium, recognizing there could be some conditions that would lead to over- or under-estimation of 5-minute SO_2 concentrations. While there are limited differences in the modeled versus measured data, it is unknown how the model-to-monitor agreement represents all other modeled receptors in the absence of additional ambient monitoring data. Based on the discussion above regarding the current and historical AERMOD performance evaluations (section 8.11.2.1.1), staff judges the knowledge-base as having a medium level of uncertainty.

8.11.2.2.2 Accuracy of 5-minute Exposure Estimation

Uncertainties in the accuracy of the statistical model used in calculating 5-minute SO_2 ambient concentrations was rated as having between low and medium levels of influence (section 7.4.2.6 and Table 7-16). Staff assumes, because of the strong relationship between ambient concentrations and personal exposures (in the absence of indoor sources), the same influence rating would apply here with mainly limited opportunities for both over- and under-estimation of 5-minute benchmark exceedances. This strong relationship between ambient concentration and personal exposure though is noted as based solely on longer term averaging times (single day to weeks in duration) and was discussed earlier in section 7.4.2.7.

Staff performed an additional qualitative analysis using the personal exposure measurements reported in the ISA. As a default output from the APEX model, annual average exposures were generated for each simulated individual (i.e., the full population rather than just the identified subpopulation). Exposure results for the entire population (e.g., annual average exposure concentrations) are assumed by staff as representative of exposures the asthmatic population would receive because the asthmatic population should not have its microenvironmental concentrations estimated any differently from those of the total population.[82]

Selected percentiles of the distribution of annual average exposures for the APEX simulated individuals is given in Table 8-28. Annual average AERMOD predicted ambient SO_2 concentrations were calculated for every receptor in the two modeling domains. The selected percentiles of the distribution of annual average concentrations for the AERMOD predicted ambient SO_2 is also given in Table 8-28. As expected, the APEX exposure concentrations are consistently lower than the AERMOD predicted ambient concentrations. The relationship between exposure and ambient, as determined by the ratio of the medians, are approximately 0.18 and 0.23 for St. Louis and Greene Counties, respectively. For general comparison, the range of values developed from personal/ambient concentration linear regression slopes reported by the ISA (ISA, section 2.3.6.2) is generally from 0.07 to 0.13. These measurement values describing the relationship between personal exposure and ambient concentrations may be lower than expected due to presence of personal exposure measurements below the limit of detection. Note, the upper range (i.e., 0.13) was reported from a study containing the greatest percent of samples above the limit of detection (ISA, section 2.3.6.2). We also lack information regarding the value of the regression intercepts in these studies (i.e., if any were non-zero) to approximate ratios that would be more comparable to the modeled values presented here.

For additional comparison, personal exposure measurements conducted in Baltimore, Boston, and Steubenville are presented in Table 8-29 (see ISA Tables 2-14 and 2-15). While

[82] Assumptions regarding activity patterns of asthmatics and non-asthmatics is discussed further in section 8.11.2.5

there are large differences in averaging time, sample size, study year, and city selected, the personal exposure measurement concentrations compare well with selected percentiles of the APEX exposure concentration distribution for the total simulated population in Greene County and St. Louis.

Table 8-28. Distribution of APEX estimated annual average SO_2 exposures for simulated individuals in the Greene County and St. Louis modeling domains.

Annual Average SO_2 (ppb)[1]	Greene County (n=50,000)[2]		St. Louis (n=150,000)[2]	
	APEX - Exposure	AERMOD - Ambient	APEX - Exposure	AERMOD - Ambient
mean	0.4	2.0	1.4	8.2
std	0.2	1.5	0.3	2.4
p0	0.1	0.1	0.4	1.2
p1	0.1	0.2	0.8	2.3
p5	0.2	0.2	1.0	4.5
p10	0.2	0.3	1.1	5.7
p25	0.3	0.6	1.2	6.8
p50	0.4	1.6	1.4	7.9
p75	0.5	3.1	1.6	10.0
p90	0.6	4.2	1.8	11.2
p95	0.6	4.7	2.0	11.6
p99	0.8	5.5	2.4	13.2
p100	1.1	6.0	8.6	45.2

Notes:
[1] mean is the arithmetic mean; std is the arithmetic standard deviation; percentile of the distribution is given by number following “p” (e.g., p25 is the 25th percentile).
[2] number of simulated individuals.

Table 8-29. Personal SO_2 exposure measurement data from the extant literature.

Study[1]	Sarnat (2000)	Sarnat (2001)[2]	Sarnat (2005)	Sarnat (2005)	Brauer (1989)	Sarnat (2006)	Sarnat (2006)
City	Baltimore	Baltimore	Boston	Boston	Boston	Steubenville	Steubenville
Season	Winter	Winter	Summer	Winter	Summer	Summer	Winter
Averaging Time	12 days	1 day	1 day	1 day	1 day	11 Weeks	12 Weeks
n[3]	14	45	28	29	48	10	10
SO_2 Personal Exposures (ppb)[4]							
mean	-	-	0.3 - 0.5	ND - 1.9	-	1.5	0.7
std	-	-	-	-	-	3.3	1.9
p0	ND	-	-	-	-	-	-
p5	-	ND	-	-	-	-	-
p10	-	-	-	-	0.4	-	-
p90	-	-	-	-	1.8	-	-
p95	-	3	-	-	-	-	-
p100	1.2	-	-	-	-	-	-

Notes:
[1] See ISA Tables 2-14 and 2-15 for further details regarding study conditions. Reference is provided here using primary author and year of publication.
[2] The cohort for Sarnat (2001) consisted of 15 seniors, 15 children, and 15 COPD patients. Seniors and COPD patients had similar exposures, with children having somewhat higher exposure.
[3] number persons in study.
[4] mean is the arithmetic mean; std is the arithmetic standard deviation; percentile of the distribution is given by number following "p" (e.g., p10 is the 10th percentile); ND is not detected.

APEX modeled exposures have previously been compared with personal exposure measurements for O_3 (EPA, 2007d). Briefly, APEX O_3 simulation results were compared with weekly personal O_3 concentration measurements for children ages 7-12 (Xue et al., 2005; Geyh et al., 2000). Two separate areas of San Bernardino County were surveyed: urban Upland CA, and the combined small mountain towns of Lake Arrowhead, Crestline, and Running Springs, CA. Available ambient monitoring data for these locations were used as the air quality input to APEX. APEX predicted personal exposures for both locations reasonably well for much of the concentration distribution, but tended to underestimate exposures at the upper percentiles of the distribution. The average difference between the weekly means was less than 1 ppb, with a range of -11 ppb to 8 ppb, though predicted upper bounds for a few weeks with higher exposure concentrations were under-predicted by up to 24 ppb (e.g., Figure 8-22). In addition, modeled exposure concentration variability was less than that observed in the personal exposure measurements. These differences appear to be driven by under-estimation of the spatial variability of the outdoor concentrations (EPA, 2007d).

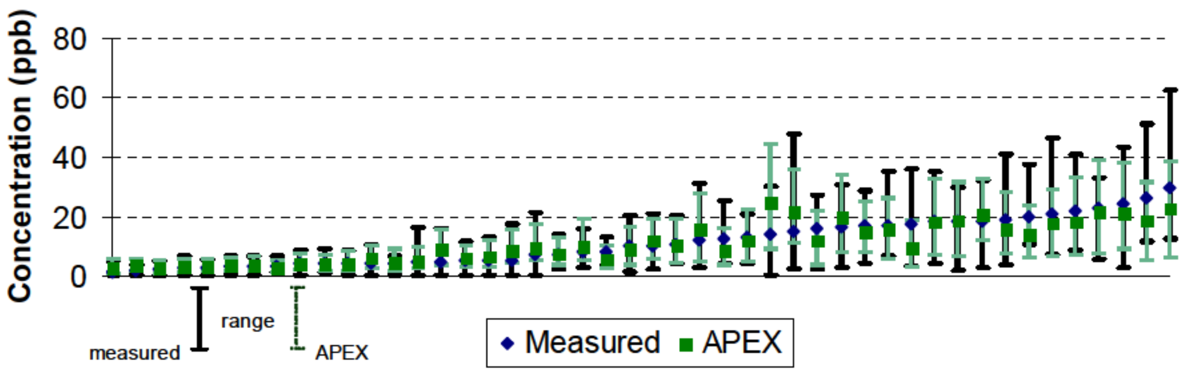

Figure 8-22. Means of weekly average personal O_3 exposures, measured and modeled (APEX), Upland Ca. Figure obtained from EPA (2007d).

In addition, APEX modeled exposures have previously been compared with personal NO_2 exposure measurements in Atlanta (EPA, 2008d). Daily personal NO_2 exposure measurements were obtained from Suh (2008) for 30 participants of a 1999-2000 Atlanta epidemiological study conducted by Wheeler et al. (2006) across two seasons.[83] An exposure distribution was constructed for each individual, simply using the individual's minimum, median, and maximum daily mean exposures (e.g., Figure 8-23, top). Daily mean NO_2 exposures estimated using APEX were also evaluated in a similar manner, by stratifying the results based on the same two seasons. The specific period from 1999-2000 was not modeled by APEX; simulation results for year 2002 were used in the comparison. A distribution of each person's estimated daily exposure was also constructed, using the median daily exposure to represent the central tendency and a 95 % prediction interval to represent the lower and upper bounds of exposure (e.g., Figure 8-23, bottom). The distributions of median daily exposures compared better for the spring season, along with the range of estimated daily mean exposures given by the 95% prediction interval. However, APEX estimated exposures were greater during the fall. Median estimated daily exposures were consistently about 2 ppb higher than the personal exposure measurements across most of the percentiles of the distribution, and the APEX

[83] The minimum number of exposure measurements per subject was three days, the maximum was seven days. Fall was designated for sample collection dates reported in the months of September, October, and November 1999; Spring was designated where sample collection dates were reported in the months of April and May 2000. Only personal NO_2 from ambient sources are discussed here.

upper prediction intervals ranged consistently higher (between 10 and 40 ppb) compared with the maximum personal exposure measurement day (between 10 and 20 ppb).[84]

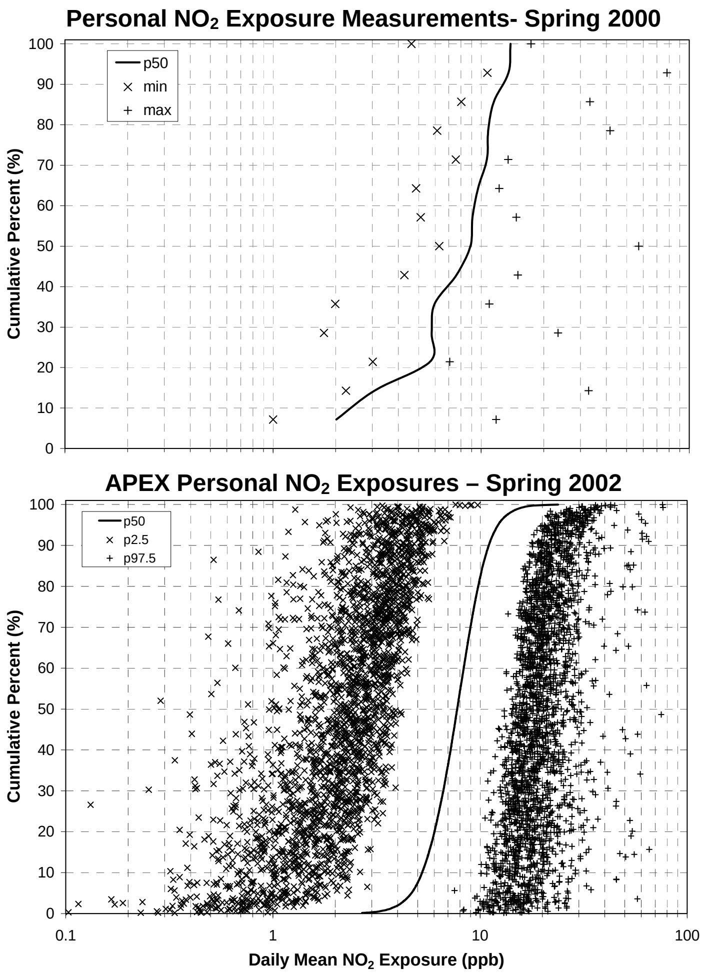

Figure 8-23. Daily average personal NO_2 exposures, measured and modeled (APEX), Atlanta Ga. Figure obtained from EPA (2008d).

It is encouraging that the APEX longer-term exposure estimates are comparable to personal exposure measurements. When also noting that there is a strong relationship between ambient SO_2 concentration and exposure, staff believes that the estimated numbers of days with 5-minute exposures above benchmark levels are also likely reasonable. However, without the

[84] While a direct comparison of APEX estimated maximum daily exposure concentrations with the maximum observed daily personal exposure concentrations is considered qualitative given the large discrepancy in sample sizes and the difference in years compared, it should be noted that considering both seasons, approximately 99.1% of APEX simulated persons had their estimated maximum daily exposure concentrations within the maximum observed daily personal exposure measurement of 78.2 ppb.

availability of 5-minute personal exposure measurements that more closely represent the modeled population, the level of uncertainty in the knowledge-base is judged as high.

8.11.2.2.3 Population Database

The population data are drawn from U.S. Census data from the year 2000. This is a high quality data source for nationwide population data in the U.S., there is none considered as complete and as appropriate for its application in our exposure assessment. As such, uncertainty regarding the knowledge-base is considered low. The data do have some limitations. The Census used random sampling techniques instead of attempting to reach all households in the U.S., as it has in the past. While the sampling techniques are well established and trusted, they may serve as a limited source of uncertainty in exposure results. The Census has a quality section (http://www.census.gov/quality/) that discusses these and other issues with Census data. It is likely the uncertainty in population representation within this data would not affect the APEX exposure results in any particular direction, and given the use of randomly sampled demographics to represent the simulated population, it is expected that the magnitude of influence this source of uncertainty has on the exposure results is low.

8.11.2.2.4 Commuting Database and Algorithm

Commuting pattern data were also derived from the 2000 U.S. Census, again a well-documented, quality-assured source. The data are used in addressing home-to-work travel, certainly within the bounds of the objectives associated with the original data collection. Staff had to make a few simplifying assumptions to allow for practical use of this database to reflect a simulated individual's commute. First, there were a few commuter identifications that necessitated a restriction of their movement from a home-block to a work-block. This is not to suggest that they never travelled on roads, only that their home and work blocks were the same and served as the only source of ambient concentration data for those individuals. Persons restricted to a single block for ambient concentrations include the population not employed outside the home, individuals indicated as commuting within their home-block, and individuals that commute over 120 km a day. This could lead to either over- or under-estimations in exposures if they were in fact to visit a block with either higher or lower SO_2 concentrations. Given that the number of individuals who meet these conditions is likely a small fraction of the total population, staff considers the magnitude of influence as low and associated with either small over- or under-estimation of exposure benchmark exceedances.

Second, although several of the APEX microenvironments account for time spent in travel, the travel is assumed to always occur in basically a composite of the home- and work-blocks. No other provision is made for the possibility of passing through other census blocks during travel. This could also contribute to either over- or under-estimating exposure concentrations, dependent on the number of blocks the simulated individual would actually traverse and the spatial variability of the concentration across different blocks. This could potentially affect a large portion of the population, since we expect that at the block-level, many persons would have a commute transect that included more than two blocks, although the actual number of persons and the number of blocks per commute and the spatial variability across blocks has not been directly quantified. In addition, the commuting route (i.e., which roads individuals are traveling on during the commute) is not accounted for. From a practical perspective though, if staff was to consider multi-block commuting in an exposure modeling exercise, further complexity would need to be added to the modeling while also requiring additional input data that is not readily available (e.g., commuting route data for simulated individuals). These model adjustments would come with a number of additional uncertainties and require additional time and resources not available for the assessment. Therefore, staff elected to not account for multi-block commuting. Note however that the modeled spatial variability within 4 km of ambient monitors in St. Louis was much less than that of the modeled spatial variability Greene County, suggesting that ignoring multi-block commuting transects may be of lesser importance in St. Louis.

Furthermore, the estimation of block-to-block commuter flows relied on the assumption that the frequency of commuting to a workplace block within a tract is proportional to the amount of commercial and industrial land in the block. This assumption could result in over-estimating exposures if 1) the blocks with greater commercial/industrial land density also have greater concentrations when compared with lower density commercial/industrial density blocks, and 2) most persons commute to lower commercial/industrial density blocks. It should also be noted that recent surveys, notably the National Household Transportation Survey (NHTS), have found that most trips taken and most VMT accrued by households are non-work trips, particularly social/recreational and shopping-related travel (Hu and Reuscher, 2004). In addition, geographic differences in infrastructure could lead to differences in commuting method that is not weighted by either the CHAD diaries or the Census commuter dataset. These constitute non-quantified sources of uncertainty that are not addressed by the Census commuter dataset.

Overall, in assessing the influence the commuting database and algorithm have on estimated exposures above benchmark levels, staff judges the magnitude to be low even in Greene County particularly since most benchmark exceedances occur outdoors and not inside vehicles or indoor microenvironments. Even though staff judged the use of land-use is a reasonable surrogate for identifying where people might work, staff believes that, in the absence of block-to-block commuting information to further support this relationship, the uncertainty regarding the knowledge-base is medium.

8.11.2.2.5 Activity Pattern Database

The CHAD time-location activity diaries used are the most comprehensive source of such data and realistically represent where individuals are located and what they are doing. The diaries are sequential records of each persons activities performed and microenvironments visited. There are, however, uncertainties in the exposure results as a result of the CHAD diaries used for simulating individuals. Specific elements of uncertainty include an evaluation of 1) the representativeness of CHAD in reflecting recent human activity patterns, 2) the approach used to allow for geographical representation of influential characteristics, 3) the similarities of asthmatic and non-asthmatic activity patterns, and 4) response of asthmatics to air quality notifications. Discussion regarding the use of individual CHAD diary days in developing longitudinal profiles is presented in section 8.11.2.2.6.

First, a large percentage of the data used to generate the daily diaries were gathered from survey studies conducted between 20 to 30 years ago. While the trends in people's daily activities may not have changed much over the years, it is certainly possible that some differences do exist such as the amount of time spent outdoors, time spent performing activities at a particular level of exertion, and the microenvironments where moderate or greater exertion is likely to occur. It would be extremely difficult to determine real differences in the distribution of these factors that may influence SO_2 exposure. For example, much of the data that is available to test such differences is survey-based. The survey methods used to collect data are not entirely consistent with one another and most of the studies collecting time-location-activity data did not have exposure modeling objectives in their design (Graham and McCurdy, 2004). If one were to test the hypothesis of no observed differences in time spent outdoors using historical and recent data, it is likely significant effects would result from differences in survey methods or overall study design rather than measurable changes in population activities. Staff assumed that if there were a difference between the time spent outdoors (the most important microenvironment for SO_2 exposures) for the simulated population and historical data diaries used to represent them, the difference would be negligible. Therefore, staff judges the magnitude of influence on the number of days with exposures above benchmark levels as low.

Second, CHAD is a collection of data from numerous activity pattern surveys, many having differing data collection objectives. Some of the studies were single city surveys, although a large portion of the data is from National surveys designed to be representative of the U.S. population. In addition, study collection periods occur at different times of the year, possibly resulting in seasonal variation not representative of the modeled locations. Furthermore, the CHAD diaries selected by APEX to represent the Greene County and St. Louis population are not necessarily from individuals residing in these cities, the State of Missouri, or from the Midwest, albeit some of the diaries may be. Each of these factors could contribute to uncertainty in the exposure results if there are location-specific characteristics of the CHAD surveyed population that are distinct from those of the simulated population. However, a few of the limitations associated with the use of diaries from different locations or seasons are corrected by the sampling approaches used in the exposure modeling. For example, diaries used are weighted by population demographics (i.e., U.S. census based age and gender distributions at the modeled census block) and temperature is used as a classification variable to account for expected differences in a location's climate and its effect on human activities.

A sensitivity analysis was recently performed to evaluate the effect that using different CHAD studies has on APEX results for the recent O_3 NAAQS review (see Langstaff (2007) and EPA (2007d)). Briefly, O_3 exposure results were generated using APEX with all of the CHAD diaries and compared with results generated from running APEX using only the CHAD diaries from the National Human Activity Pattern Study (NHAPS), a nationally representative study in CHAD. There was good agreement between the APEX exposure results for the 12 metropolitan areas evaluated (one of which was St. Louis), whether all of CHAD or only the NHAPS component of CHAD is used. The absolute difference in percent of persons above a particular concentration level ranged from -1% to about 4%, indicating that the exposure model results are not being overly influenced by any single study in CHAD. It is likely that similar results would be obtained here for SO_2 exposures. Therefore, staff judges the magnitude of influence from using appropriately sampled CHAD diaries in representing the simulated population as low.

Third, due to limited number of CHAD diaries with health-specific information, all diaries are assumed as appropriate for any simulated individual, provided they concur with age, gender, temperature, and microenvironmental time selection criteria. In addition, data summaries[85] output from the current version of APEX could only be output for the entire simulated population rather than the particular subpopulation. This is a reasonable modeling assumption when considering the calculation of the microenvironmental concentrations, because it is not expected that the asthmatic population would have microenvironmental concentrations different from those of the total population. However, there is uncertainty in the use of all CHAD diaries in simulating any individual without considering the health status of both the surveyed population and the simulated population if in fact health status affects the activity pattern of the simulated individual. In this exposure assessment it was shown that the most important location for contacting the 5-minute peak concentration were outdoor microenvironments. Therefore, if there is a difference in the time spent outdoors (e.g., total time, time-of-day) and activities performed outdoors between asthmatics and healthy individuals, there may be a greater impact to the estimated number of asthmatics exposed (and number of person days) than if there were no difference.

Briefly, the assumption of modeling asthmatics similarly to healthy individuals (i.e., using the same time-location-activity profiles) is supported by the findings of van Gent et al. (2007), at least when considering children 7-10 years in age. These researchers used three different activity-level measurement techniques; an accelerometer recording 1-minute time intervals, a written diary considering 15-minute time blocks, and a categorical scale of activity level. Based on analysis of 5-days of monitoring, van Gent et al. (2007) showed no difference in the activity data collection methods used as well as no difference between asthmatic children and healthy children when comparing their respective activity levels. Contrary to this, an analysis of 2000 BRFSS data by Ford et al. (2003) indicated a statistically significant difference between the percent of current asthmatics (30.9%) and non asthmatics (27.8%) characterized as inactive. In addition, these researchers found significant differences in the percent of asthmatic (26.6%) and

[85] For example, the time spent in microenvironments at or above a potential health effect benchmark level.

non-asthmatic (28.1%) adults achieving recommended levels of physical activity (i.e., either moderate or greater activity levels).

Note though, the issue is not just outdoor time and activity levels, but the intersection of the two that are of importance as well as recognizing the performance capabilities of persons with asthma. A person's overall physical activity level is strongly linked with their time spent outdoors and is considered an important correlate in encouraging increased physical activity among children and adults alike (e.g., Sallis et al., 1998). In addition, introducing regular exercise has been shown to improve physical fitness in asthmatic children, with statistically significant increases in ventilation measures such as maximum minute ventilation rate (VE_{max}) maximum oxygen uptake (VO_{2max}) (e.g., van Vledhoven et al., 2001). Further, in other related research, Santuz et al. (1997) indicated no statistically significant difference between asthmatic and non asthmatic children when comparing maximum exercise performance levels, provided the individuals were conditioned through habitual exercise. Thus it appears that asthmatics are likely to perform activities at elevated levels and do so in outdoor microenvironments.

To support the assumption that there is no difference in CHAD activity patterns used to represent the asthmatic population, staff compared the amount of time spent outdoors at elevated activity levels obtained from three individual asthma studies with estimates of the same metric using the CHAD database. In addition, some of the studies incorporated in CHAD reported whether the individual was asthmatic, non-asthmatic, or not classified. Therefore, staff categorized the data and results as such in this analysis. Table 8-30 summarizes data reported from the three studies and results generated using CHAD data and the known health status.

When considering the three asthma studies, the amount of time spent outdoors at moderate activity level ranges from a low of approximately 2% to a high of about 11% of waking hours. The estimates of outdoor time associated with moderate activity level using CHAD diaries fall within that range (i.e., between 6.5 and 7.5%) with small differences observed between the CHAD asthmatic and CHAD non-asthmatic population. This limited comparison indicates that the CHAD diaries may reasonably approximate the amount of time spent outdoors at moderate activity levels. In addition, comparison of the CHAD asthmatic and non asthmatic population supports the assumption that all CHAD diaries are appropriate in representing asthmatic individuals, regardless of health status. However, the percent of outdoor time associated with strenuous activities using the CHAD database was lower when compared with the three asthma studies. It is difficult to judge whether the time spent outdoors at strenuous activity levels is under-represented by CHAD or it is over-represented by the three asthma studies.

Staff recognizes that there are a number of differences that exist among the three asthmatic studies used along with the CHAD diary data that could contribute to variation in the time spent outdoors at elevated activity levels. This would include: the diary/survey collection methods used, the classification of activities performed and associated activity levels, the number of study subjects, and sample selection methods. The particulars regarding how each of these were addressed across the various studies is wide ranging and could potentially influence the results. However, based on the comparable results observed in time spent outdoors at moderate activity levels, staff judges the magnitude of influence as low with no apparent direction in over- or under-estimation.

Table 8-30. Percent of waking hours spent outdoors at an elevated activity level.

	EPRI (1988)[1]	EPRI (1992)[2]	Shamoo (1994)[3]		CHAD[4]		
Location	Los Angeles	Cincinnati	Los Angeles		All		
Time of Year	April	August	Summer	Winter	Any		
Population	Asthmatic	Asthmatic	Asthmatic	Asthmatic	Asthmatic	Not Asthmatic	Unknown
n	52	136	48	45	1,475	15,848	4,821
Mean age (min-max)	-	26 (1– 78)	33 (18 – 50)		23 (<0 – 99)	27 (<1 – 93)	31 (<1 – 94)
Activity Level	**Percent of Asthmatic Waking Hours Spent Outdoors at Given Activity Level**						
Moderate	7	11	1.9	1.7	7.5	6.5	6.7
Strenuous	2.4	3.3	0.2	0.2	0.04	0.01	0.2

Notes:
[1] Hour diary questionnaire form used for up to three activities per hour. Non-random sample of 26 mild/moderate, 26 moderate/severe asthmatics selected from voluntary clinical studies.
[2] Hour diary questionnaire form used for up to three activities per hour. Random digit dialing and multiplicity sampling used.
[3] Number of minutes performing three self-rated activity levels for three locations per hour. Non-random sample selected from voluntary clinical studies.
[4] Combination of random and non random selection studies, national and city-specific, as well as varying diary protocol (see Graham and McCurdy, 2004). Original CHAD database (n=22,968; EPA, 2002) was screened for persons with no age (n=223) and no sleep (n=601) reported. Median METS values from each activity-specific distribution were assigned to each person's activities. Moderate and vigorous activity levels were selected based on activities having a METS value of 3 to <6 and ≥6, respectively.

Finally, there is also a possibility that information regarding bad air quality may affect the activities performed by the asthmatic population. There has been research regarding *averting behavior*, that is, there is a reduction in time spent outdoors when the individual is informed of the potential for bad air quality days (e.g., Bresnahan, et al. 1997; Mansfield, 2005; KDEH, 2006; Wen et al., 2009). One study reviewed by staff reported no effect on outdoor time (e.g., Yen et. al. 2004). Of the limited studies reviewed by staff, most were focused on the population response to ozone (or smog) air pollution alerts, EPAs Air Quality Index (AQI), or simply self-perceived bad air quality.

In the most recent U.S. study conducted in six states,[86] it was reported that approximately 25-30% of asthmatic adults altered their outdoor activity due to either perceived bad air quality or media alerts, compared with about half as many (12%-16%) non asthmatics altering their outdoor activities (Wen et al., 2009). The media alert response rate was requisite on awareness of the bad air quality media alert for both children (Mansfield et al., 2005) and adults (KDEH, 2006; Wen, 2009). Parents of asthmatic children checked air quality alerts more frequently than parents of non-asthmatic children and, though reported as statistically significant, only about 25% of parents of asthmatic children checked the air quality on a daily basis (Mansfield et. al., 2005). Approximately half of asthmatic and non asthmatic adults were aware of the media alerts (Wen et al., 2009), though among all adults living in the Kansas City MSA,[87] the percent aware is much greater (70%; KDEH, 2006). Of the persons that reported altering their outdoor activities, approximately 60% did so three or fewer times per year.

If there is averting behavior by asthmatics in response to air pollution events, the degree to which an asthmatic's SO_2 exposure would be altered is highly uncertain. Staff acknowledges that there may be fewer asthmatics exposed using APEX if accounting for averting behavior. However, information missing from the published studies that are of importance include 1) the amount outdoor time was reduced, 2) the time-of-day the outdoor time reduction occurred, 3) the distinction between all outdoor activities or moderate or greater activities, 4) influence of asthma severity on aversion rate, 4) the relationship between ozone air quality and the occurrence of short-term SO_2 pollution events modeled here. Given the above averting behavior statistics, there could be at most a 30% over-estimation in the number of persons exposed (i.e., a medium level), though the over-estimation is likely to be less given how the unknown conditions noted above affect averting behavior.

[86] The six states were Colorado, Florida, Indiana, Kansas, Massachusetts, Wisconsin.
[87] Note that Kansas City is in close geographic proximity to both of the Mo. exposure modeling domains.

8.11.2.2.6 Longitudinal Profile Algorithm

Some of the surveys comprising CHAD collected only a single diary-day while others collected several diary days per individual. In this exposure assessment, individuals are simulated for an entire year. APEX creates the annual sequences of daily activities for a simulated individual by sampling human activity data from more than one subject. Therefore, each simulated person essentially becomes a composite of several actual people from within the underlying activity data. Certain aspects of the personal profiles are held constant, though in reality they may change as an individual ages (e.g., body mass). This is likely more important for simulations with long timeframes (e.g., over a year or more), particularly when simulating young children. The method used to link the individual activity diaries together could influence the estimated number of persons exposed, although there would be greater uncertainty in estimating multiple exposures per individual per year rather than single exposures per year. Note however, estimating multiple exposures per individual was not a focus of the exposure assessment.

In a prior analysis, staff evaluated the cluster algorithm used in constructing longitudinal profiles against a sequence of available multiday diaries sets collected as part of the Harvard Southern California Chronic Ozone Exposure Study (Xue et al., 2005; Geyh et al., 2000). Diary data were collected from children between the ages 7 and 12 for six consecutive days/month for an entire year. See Appendix B, Attachment 4 and 5 for details of the comparison. Briefly, the activity pattern records were characterized according to time spent in each of five aggregate microenvironments: indoors-home, indoors-school, indoors-other, outdoors, and in-transit. The predicted value for each stratum was compared to the value for the corresponding stratum in the actual diary data using a mean normalized bias statistic. The evaluation indicated the cluster algorithm can replicate the observed sequential diary data, with some exceptions. The predicted time-in-microenvironment averages matched well with the observed values. For combinations of microenvironment/age/gender/season, the normalized bias ranges from –35% to +41%. Sixty percent of the predicted averages have bias between –9% and +9%, and the mean bias across any microenvironment ranges from -9% to +4%. Although on occasion there were large differences in replicating variance across persons and within-person variance subsets, about two-thirds of the predictions for each case were within 30% of the observed time spent in each microenvironment.

The longitudinal approach used in the exposure assessment was an intermediate between random selection of diaries (a new diary used for every day for each person in the year) and perfect correlation (same diary used for every day for each person in the year). The cluster algorithm used here was also compared with two other algorithms; one that used random sampling and the other employing diversity (*D*) and autocorrelation (*A*) statistics (see EPA, 2007g for details on this latter algorithm). The number of persons with at least one or more exposure to a given O_3 concentration was about 30% less when using the cluster algorithm than when using random sampling, while the number of multiple exposures for those persons exposed was greater using the cluster algorithm (by about 50%). The algorithm employing the *D* and *A* statistics exhibited similar patterns, although were lower in magnitude when compared with random sampling (about 5% fewer persons with one or more exposures, about 15% greater multiple exposures). These exposure results using the cluster algorithm in APEX appeared to be the result of a greater correlation of diaries selected in comparison with the other two algorithms. This outcome conforms to an expectation of correlation between the daily activities of individuals. While the evaluation was performed using 8-hour O_3 as the exposure output, it is expected that similar results would be obtained for 5-minute SO_2 exposures. That is, the characteristics of the diaries that contribute greatly to any pollutant exposure above a given threshold (e.g., time spent outdoors, vehicle driving time, time spent indoors) are likely a strong component in developing each longitudinal profile. Given these results and that the REA is not necessarily focused on health effects resulting from multiday exposures, staff judges the longitudinal approach may have a low to medium magnitude of influence on estimated number of persons exposed. When comparing the modeled profiles with the measurement data, there was a balanced mix of over- and under-estimation of microenvironmental time. Therefore, the direction of influence on the estimated number of persons exposed could be in either direction. Uncertainty in the knowledge-base is rated as medium given the limited longitudinal measurement data available for comparison.

8.11.2.2.7 Meteorological Data

Details regarding the representativeness of the meteorological data inputs for APEX are addressed separately in section 8.4.2 and in Attachment 1 in Appendix B. In addition, uncertainties associated with the data are discussed in section 8.11.2.1.2. Briefly, meteorological data are taken directly from monitoring stations in the assessment areas. Staff assumed that most of the data used are error free and have undergone required quality assurance review. One strength of these data is that it is relatively easy to see significant errors if they appear in the data. Because general climatic conditions are known for the simulated area, it would have been apparent upon review if there were outliers in the dataset, and at this time none were identified. If there were errors remaining in the data, it would be expected to be limited in extent and occur randomly. In addition, to reduce the number of calms and missing winds in the 1-hour MET data, archived one-minute winds for the ASOS stations in each model domain were used to calculate hourly average wind speed and directions. This approach reduces the number of estimated zero concentrations that would be output by AERMOD if not supplemented by the additional wind data, thus preventing a downward bias in the predicted 1-hour SO_2 concentrations. Therefore, staff judges the MET data as having a low level of influence and equally applied to either under- or over-estimation in the number of persons exposed.

There are some limitations in the use of the meteorological data in APEX. APEX only uses the 1-hour daily maximum temperature in selecting an appropriate CHAD diary and indoor microenvironment air exchange rate. Because the model does not represent hour-to-hour variations in meteorological conditions throughout the day, there could be uncertainty in some of the exposure estimates associated with indoor microenvironments (see the next section).

8.11.2.2.8 Air Exchange Rates (AER)

The residential air exchange rate (AER) distributions used to estimate indoor exposures may contribute to uncertainty in the exposure results. Three components of the AER analyzed previously by EPA (2007d) include 1) the extrapolation of air exchange rate distributions between-CMSAs, 2) analysis of within-CMSA uncertainty due to sampling variation, and 3) the uncertainty associated with estimating daily AER distributions from AER measurements with different averaging times. The results of those previous investigations are briefly summarized here. See Appendix B, Attachments 7 and 8 for details in the data used to generate the AER and the sensitivity analyses performed. It should be recognized that in this assessment, the indoor microenvironments have been shown to be largely unimportant in estimating exposure exceedances. Note however, that in ignoring all twelve 5-minute concentrations, the influence of the indoor-residential microenvironment may be under-estimated (section 8.11.2.2.11).

Extrapolation of AER among locations

Air exchange rate (AER) distributions were assigned in the APEX model, as described in the indoors-residential microenvironment. Because location-specific AER data for St. Louis and Greene County were not available and that there were no AER data from cities thought to have similar influential characteristics affecting AER,[88] staff constructed an aggregate distribution of the available AER data from cities outside California to represent the distribution of AERs in St. Louis and Greene County (see Appendix B, Attachment 7).

In the absence of location-specific data for the microenvironments modeled by APEX within each model domain, only limited evaluations were performed. To assess the uncertainty associated with deriving AERs from one city and applying those to another city, between-location uncertainty was evaluated by examining the variation of the geometric means and standard deviations across several cities and originating from several different studies. The evaluation showed a relatively wide variation across different cities in their AER geometric means and standard deviations, stratified by air-conditioning status, and temperature range. For example, Figure 8-24 illustrates the GM and GSD of AERs estimated for several cities in the U.S. where A/C was present and within the temperature range of 20-25 °C. The wide range in GM and GSD pairs implies that the modeling results may be very different if the matching of modeled location to a particular study location was changed. For example, the SO_2 exposure estimates may be sensitive to use of an alternative distribution, say those in New York City, compared with results generated using the aggregate non-California AER distributions. It is possible though that the true distribution could be more similar to the selected distribution from all non-California cities than that of the specific locations given the population of available AER data. It is unclear as to the direction of influence given the limited number of data available for comparison. It is likely that the impact to the number of exceedances is low, given that most of the exceedances occurred outdoors for most of the air quality scenarios evaluated.

[88] Such potential influential factors would include age, composition of housing stock, construction methods used, and other meteorological variables not explicitly treated in the analysis, such as humidity and wind speed patterns.

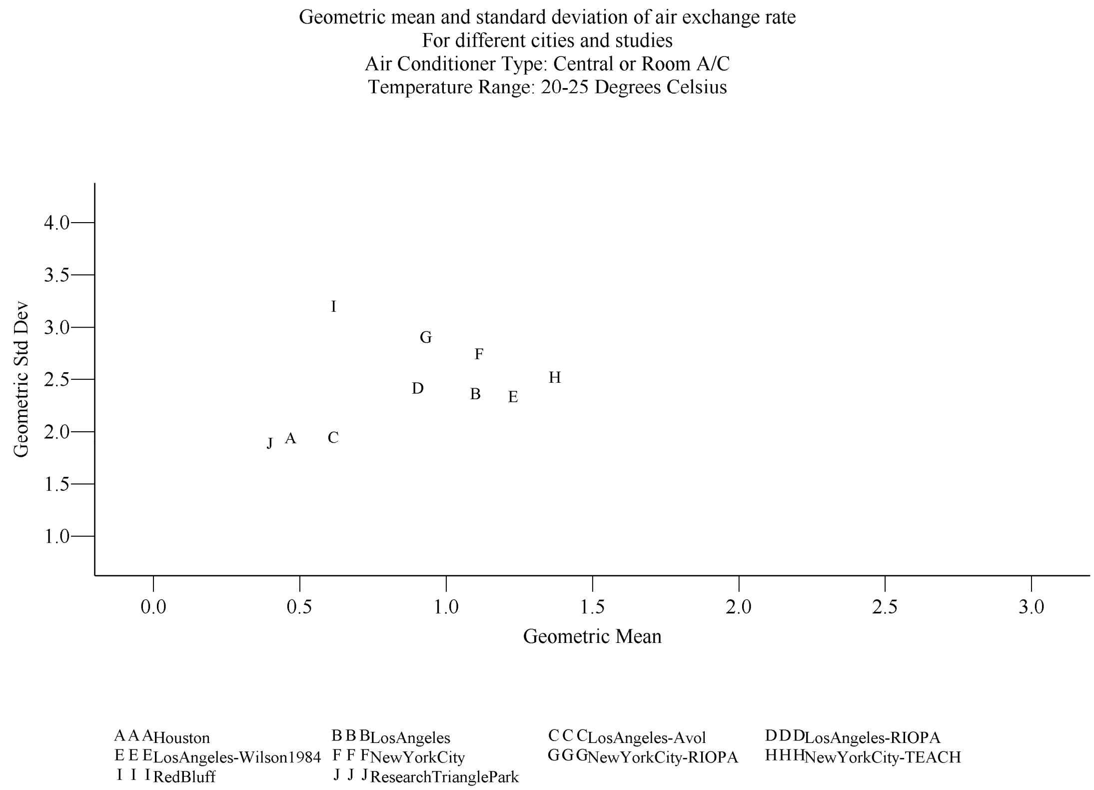

Figure 8-24. Example comparison of estimated geometric mean and geometric standard deviations of AER (h^{-1}) for homes with air conditioning in several cities.

Within location uncertainty

There is also variation in AERs within studies for the same location (e.g., Outside California data), but this is much smaller than the observed variation across different CMSAs. This finding tends to support the approach of combining different studies for a CMSA, where data were available. The within-city uncertainty was assessed by using a bootstrap distribution to estimate the effects of sampling variation on the fitted geometric means and standard deviations for the non-California data used to represent the St. Louis and Greene County AERs. These bootstrap distributions assess the uncertainty due to random sampling variation. They do not address other uncertainties such as the lack of representativeness of the available study data or the variation in the lengths of the AER monitoring periods. Because only the GM and GSD were used, the bootstrap analyses does not account for uncertainties about the true distributional shape, which may not necessarily be lognormal.

One-thousand bootstrap samples were randomly generated for each AER subset (of size N), producing a set of 1,000 pairs of geometric mean (GM) and geometric standard deviation

(GSD). The analysis of the non-California city data used to represent Greene County and St. Louis indicated that the GSD uncertainty for a given AER temperature group tended to have a range within ±0.3 fitted GSD (hr^{-1}), with smaller intervals surrounding the GM (i.e., about ± 0.10 fitted GM (hr^{-1}) (Figure 8-25). Broader ranges were generated from the bootstrap simulation for AER distributions used for Greene County and St. Louis homes without A/C (Figure 8-26), although both still within ±0.5 of the fitted GM and GSD values. Given the limited range in GMs and GSDs, staff judges the magnitude of influence as low and mainly associated with both under- and over estimation of indoor exposure concentrations. See Appendix B, Attachment 7 for further details.

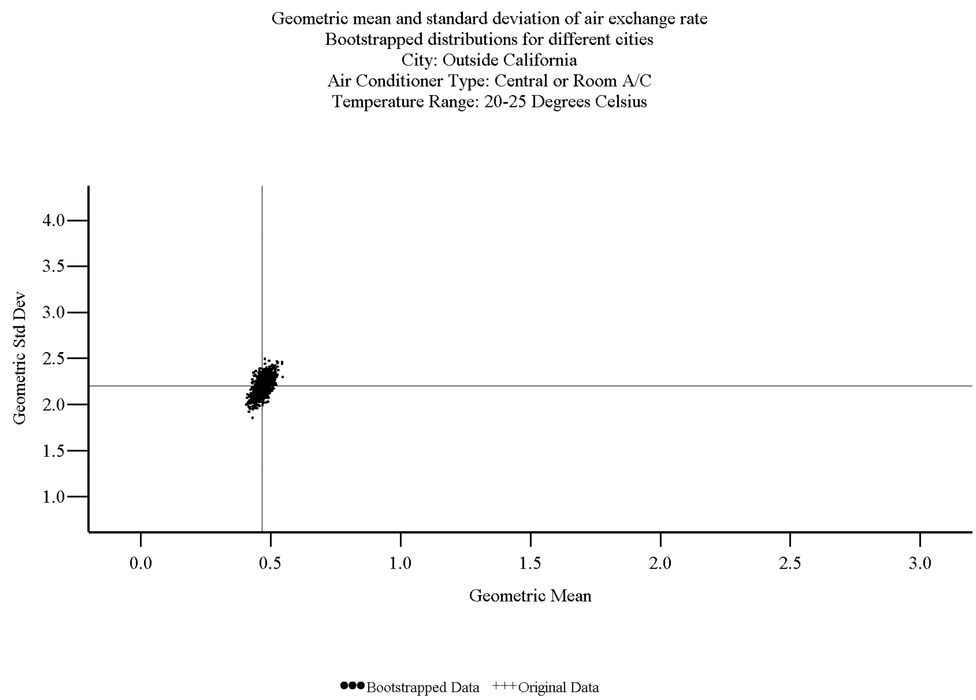

Figure 8-25. Example of boot strap simulation results used in evaluating random sampling variation of AER (h^{-1}) distributions (data from cities outside California). Parameters of the original distribution are given by the intersection of the two inner grid lines

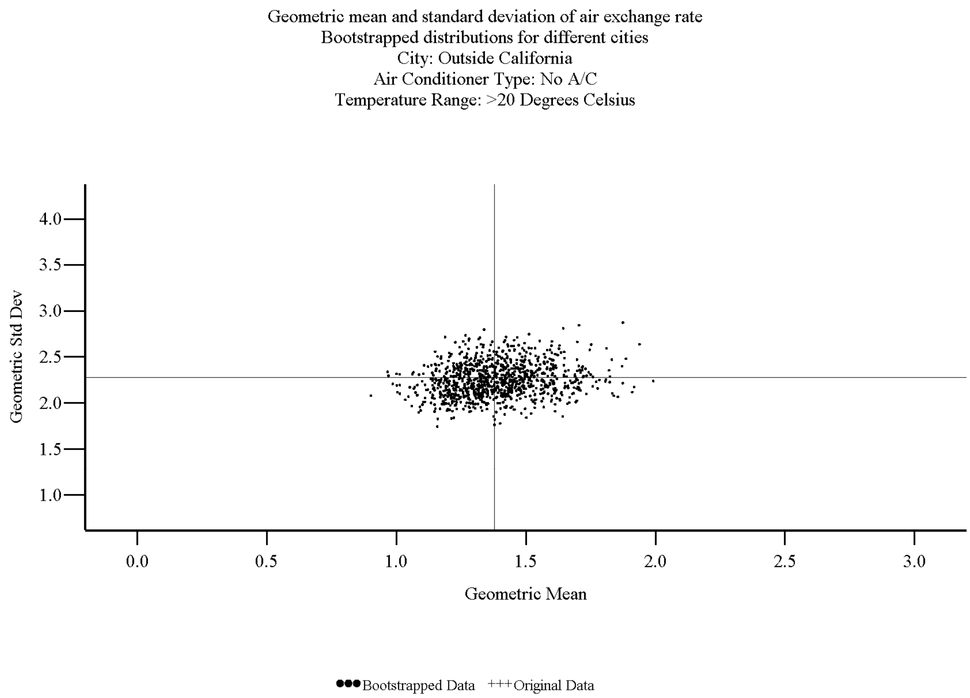

Figure 8-26. Example of boot strap simulation results used in evaluating random sampling variation of AER (h^{-1}) distributions (data from cities outside California). Parameters of the original distribution are given by the intersection of the two inner grid lines

Variation in AER measurement averaging times

Although the averaging periods for the air exchange rates in the study data varied from one day to seven days, the analyses did not take the measurement duration into account and treated the data as if they were a set of statistically independent daily averages. To investigate the uncertainty of this assumption, correlations between consecutive 24-hour air exchange rates measured at the same house were investigated using data from the Research Triangle Park Panel Study (Appendix B, Attachment 8). The results showed extremely strong correlations, providing support for the simplified approach of treating multi-day averaging periods as if they were 24-hour averages. Therefore, staff judges the magnitude of influence as low with unknown direction on the number of persons exposed.

8.11.2.2.9 Air Conditioning Prevalence

Because the selection of an air exchange rate distribution is conditioned on the presence or absence of an air-conditioner, the air conditioning status of the residential microenvironment was simulated randomly using the probability that a residence has an air conditioner, i.e., the residential air conditioner prevalence rate. For this study we used location-specific data for St. Louis (AHS, 2005) and applied that data to Greene County as well. EPA (2007d) details the specification of uncertainty estimates in the form of confidence intervals for the air conditioner prevalence rate, and compares these with prevalence rates and confidence intervals developed from the Residential Energy Consumption Survey (RECS) of 2001 for several aggregate geographic subdivision (e.g., states, multi-state Census divisions and regions) (EIA, 2001).

Briefly, the A/C prevalence rates used for St. Louis were 96%, with reported standard errors of 1.7% (AHS, 2003). Estimated 95% confidence intervals were also small and span approximately 6.5 percentage points (AHS, 2003). The RECS prevalence estimate for Census Divisions was 92% (ranging between 86.4% and 98.4%), while the Census Region prevalence estimate was 83.6% (ranging between 80.0% and 87.2%). This suggests that the A/C prevalence used, while likely being representative of a city in Missouri, may be over-estimated for non-urban locations (such as Greene County).

Furthermore, a sensitivity analysis was performed using a low (55%) and high (97%) A/C prevalence rates as input to APEX in an Atlanta, Ga. exposure assessment used for the recent NO_2 NAAQS review (EPA, 2008d). Upper percentile benchmark exceedances were also of interest in that exposure assessment, only the averaging time was 1-hour instead of 5-minutes used here. Indoor microenvironments were also found in the NO_2 exposure assessment to be unimportant in estimating exposure exceedances. Results from the sensitivity analysis indicated that there was no difference in the percent of the asthmatic population with NO_2 exposure benchmark exceedances with a decreased A/C prevalence. Only a few additional persons (about 100 out of a simulated population of 200,000) experienced exposures above exceedances when using the lower A/C prevalence. Based on the above discussion, staff judges the magnitude of influence to estimated exposures as low, particularly given that indoor exposures to concentrations above the benchmark levels rarely occurs.

8.11.2.2.10 Indoor Removal Rate

There may be uncertainty in the exposure results when considering the estimated parameters, the form (i.e., lognormal) and limits (limited by the bounds of the measurement data) of the distribution used to represent indoor decay. The data used to develop the distribution were obtained from a review of several studies that analyzed SO_2 removal for a variety of building material surfaces (Grontoft and Raychaudhuri, 2004). Potential influential factors such as humidity and air exchange rate were accounted for in developing and applying the removal distributions within the indoor microenvironments. In addition, the distributions were based on a large empirical database and likely well represent expected SO_2 removal within indoor microenvironments.

However, several assumptions were made to characterize the materials used within a simulated indoor microenvironment, some of which were data-based, others in the absence of supporting data, were based solely on professional judgment (see Appendix B.4.1). Staff performed a Monte Carlo simulation using the removal data and 1,000 simulated interior rooms of buildings to generate a distribution of SO_2 removal rates, weighted by the approximated room configurations and proportion of materials present. There are many assumptions staff made that could be modified with newly available data, particularly where inputs were based on professional judgment. It is largely unknown what the direction of influence is in the absence of new or refined input data. While some of the assumptions used may be largely uncertain, the magnitude of the influence is judged by staff as low given the relative contribution of the indoor microenvironments to exposure concentrations above the potential health effect benchmark levels.

8.11.2.2.11 Occurrence of Multiple Exceedances within an Hour

The statistical model described in section 7.2 was used within APEX to estimate a single 5-minute maximum SO_2 concentration for every hour. However, multiple short-term peak concentrations above selected levels are possible within any hour. Analysis of the 5-minute continuous monitoring data indicates that multiple occurrences of 5-minute concentrations above the 100, 200, 300, and 400 ppb within the same hour can be common. Using the continuous monitoring data obtained from years 1997-2007, multiple peak concentrations (i.e., 2 or more) at or above 400 ppb within the same hour occurred with a 61% frequency (Table 8-31). The frequency of multiple exceedances was similar for the lower 5-minute SO_2 concentration levels, where 63, 56, and 53% of the time there were two or more exceedances within the same hour at the 100, 200, and 300 ppb benchmark levels, respectively. These results may suggest that a single peak approach (i.e., 24 peak concentrations per day) for estimating the number of persons and days with 5-minute SO_2 exposures as a surrogate for all possible peak exposure events may lead to an under-estimate in the number of potential exposures.

Table 8-31. Number of multiple exceedances of potential health effect benchmark levels within an hour.

Number of Exceedances of 5-minute SO_2 in 1-hour[1]	Number of Hours with Multiple 5-minute SO_2			
	> 100 ppb	> 200 ppb	> 300 ppb	> 400 ppb
1	1248	267	76	26
2	658	122	31	20
3	411	78	21	7
4	257	35	10	5
5	242	28	6	4
6	153	25	4	1
7	125	14	5	1
8	89	11	2	1
9	64	6	3	1
10	49	6	1	1
11	50	3	0	0
12	73	5	1	0
Total	**3419**	**600**	**160**	**67**

Notes:
[1] The analysis is based on the 16 monitors reporting all 5-minute SO_2 concentrations in an hour (n=3,328,725).

In using the data in Table 8-31 alone, the magnitude of the under-estimation may be somewhat overstated however, particularly when considering the benchmark levels of 200, 300, and 400 ppb. A detailed analysis of the multiple exceedances by each monitor indicated that one of the monitors (ID 420070005) was highly influential in generating the values in Table 8-31, contributing greatly to the multiple peak occurrences at the higher benchmark levels. This Beaver Pa. urban-scale monitor is identified as population-based, within a rural setting, and having agricultural land use (Appendix A). Five out of eight of the sources located within 20 km of this monitor had SO_2 emissions <250 tpy, one smelter emitting about 7,000 tpy was within 2.5 km, and two power generating facilities located approximately 3.4 and 7.5 km from the monitor had SO_2 emissions of 3,000 and 30,000 tpy, respectively. Of the number of hours having multiple exceedances, monitor 420070005 contributed to 61, 73, and 80% of the hours with multiple peaks >200, >300, and >400 ppb, respectively. Following removal of this monitor from the full data set, the occurrence of multiple exceedances of each the 200, 300, and 400 ppb benchmark lowered to approximately 40% of all hours having co-occurring peaks.

This suggests there would be increased uncertainty in the exposure results if the continuous monitoring data were used to design an approach for estimating multiple exceedances within an hour. These continuous monitoring data were available only from 16 ambient monitors, each having a limited number of monitoring years. The analyses above indicated that one of the monitors contributed to most of the hours with multiple peak concentrations. How this one monitor (as well as any other monitor having multiple exceedances) reflects what may occur at the APEX modeled receptors in St. Louis and Greene County (or other different locations) is unknown. There is no simple extrapolation possible using the continuous monitoring data because the time of the peak (and hence multiple peak) concentrations modeled are not known with respect to the simulated individuals' time spent outdoors.

The PMR statistical model is based on both concentration and variability measures, implemented by APEX in estimating a single maximum 5-minute SO_2 concentration for every hour at every receptor. This is based on known concentration and variability relationships described in section 7.2. While APEX can model all twelve 5-minute concentrations, staff chose to normalize the eleven remaining 5-minute SO_2 concentrations within an hour to the 1-hour mean concentration. This decision was based on the already large size of the air quality files used (thousands of receptors across a year) that also required a time consuming post-processing step prior to input in APEX and ultimately, the run time associated with the exposure model simulations. Estimating the 5-minute maximum SO_2 concentrations and the other 11 concentrations within APEX was more efficient than pre-processing all twelve 5-minute SO_2 concentrations.

Having all eleven other 5-minute SO_2 concentrations normalized to the mean could result in under-estimating the number of persons exposed. The exposure simulation could *miss* a persons' exposure that might have occurred if in fact there are multiple peak concentrations within the same hour (a likely event given the continuous monitoring data, roughly between 40-60%). The CHAD time-location-activity diaries used in APEX are fixed, that is, the modeled time spent outdoors is based on the actual time of day and amount of time recorded by the surveyed individual. APEX models exposure on a minute-by-minute basis; if most persons spend time outdoors for a short time (e.g., 5-minutes), then it is possible that persons are not realistically encountering peak concentrations given the normalization of the eleven 5-minute SO_2 concentrations. Therefore, staff analyzed outdoor activities in the CHAD diaries used by APEX to determine the duration of time spent outdoors for each outdoor event.

Figure 8-27 illustrates the distribution of time spent outdoors, given activity outdoor events defined by clock-hour increments (already part of the CHAD design). Thirty-five percent of all outdoor events are for the entire hour; if the event corresponds with the same hour as a simulated peak concentration, there would be no under-estimation in exposure occurring during these events. Therefore, occurrence of multiple peaks within an hour is potentially not an issue for 35% of all exposure events that occur outdoors. However, at each of the other outdoor events, there is a probability of under-estimating the exposure, given by the duration of the event divided by 60 minutes. For example, approximately 15% of outdoor events were 30 minutes. If these outdoor events occurred at the time where there was a second estimated peak concentration in the same hour, there is a 50% chance that the exposure is missed. The probability of missing a potential exposure increases with decreasing duration of the outdoor event and, given the data in Figure 8-27, this could be a frequent occurrence (i.e., about 65% of outdoor events may have some probability of missing an exposure). This analysis does not account for multiple outdoor events that may increase an individual's chance of an exposure above a benchmark level, regardless of the event duration. It also assumes the each of the outdoor events evaluated have an equal probability of occurring at the time of the peak concentration, which may or may not be the case. In addition, the outdoor time distribution is based on all of the CHAD diary days, potentially not the same distribution of diaries that were used in the APEX exposure simulations.

A better method to determine the potential number of missing exposures is to model the exposures using two input data sets: air quality with all continuous 5-minute measurements, and air quality having the measured 5-minute maximum and the eleven other 5-minute concentrations within the hour normalized to the 1-hour mean. Staff constructed a data set using measurements from the continuous-5 ambient monitoring. While there were two monitors reporting continuous 5-minute measurements in Greene County (monitor IDs 290770037 and 290770026), there were only two years with exceedances of the 200 ppb benchmark level, and no exceedances of the 300 or 400 ppb benchmarks. To explore the maximum effect of multiple peak concentrations within an hour, staff used two years of data from monitor ID 420070005, noted above as having the greatest number of air quality benchmark exceedances in a year (years 2002 and 2005 were selected).

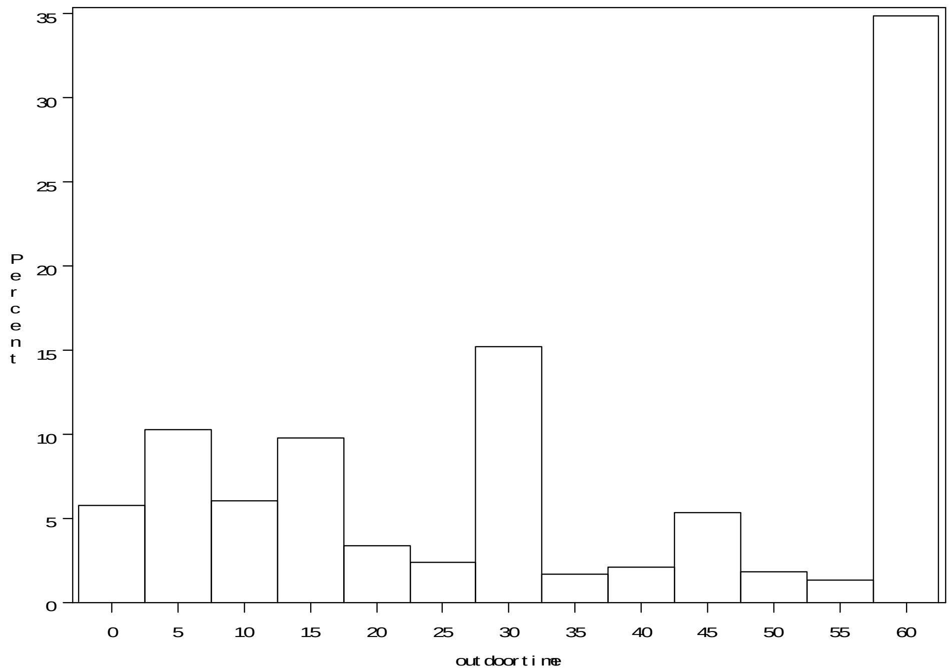

Figure 8-27. Duration of time spent outdoors (in minutes) using all CHAD events

First, staff replaced missing concentrations (approximately 5% of each year) using the time-of-day monthly averaged SO_2 concentration. This data set served as the multiple peak air quality data set to be tested; all measured 5-minute concentrations were used *as is*. Next, staff constructed a similar data set, only this second data set had the maximum measured 5-minute concentration retained and all other eleven 5-minute concentrations within the hour were normalized using the 1-hour mean. This single peak data set reflects what was being modeled by APEX. Each of the data sets were used as the air quality input to an APEX simulation, controlling for all model sampling, the algorithms used, microenvironments modeled, and persons simulated. The only difference in the two runs was the air quality input. Fifty thousand persons were simulated using APEX, 13% of which were asthmatic children. Figure 8-28 illustrates the percent of asthmatic children exposed to selected 5-minute maximum concentrations for each of the two scenarios; a multiple peak scenario and a single maximum peak concentration, using two site-years of continuous monitoring data with the greatest number of benchmark exceedances. As expected, there are more asthmatic children exposed when considering the occurrence of multiple peaks in an hour. The difference in the percent of asthmatic children exposed at each of the benchmark levels is small, about 2-5 percentage points differ between the two simulations. However, considering the percent difference in the numbers of persons exposed at most of the benchmarks levels, the simulations using the single peak air quality method had between 20-35% fewer persons exposed than the multiple peak simulation. Similar results were generated in simulations using the site-year with the 2nd highest number of exceedances only the under-estimation using the single peak method was about 15-30% (Figure 8-29). Based on these analyses, at most the estimated number of persons exposed in St. Louis and Greene County may be under-estimated by 35% when using a single peak method. The actual amount of under-estimation is likely smaller given that these results were generated using site-years of monitoring data having the greatest numbers of exceedances and contributing significantly to the high frequency of multiple peak exceedances.

The location where exposures occur may also be influenced by the presence or absence of multiple peak concentrations. In particular, the modeled indoor 5-minute maximum concentrations may be markedly diluted if the indoor air exchange rate is low and all eleven other 5-minute values within the same hour are normalized to the 1-hour mean concentration. APEX estimates all microenvironmental concentrations using a mass balance method for 5-minute time-steps (equation 8-7) that accounts for estimated microenvironmental concentrations from the previous time-step (EPA, 2009b). While dilution of the indoor air is not an unusual circumstance considering the physical process modeled, it is possible that the number of exposure events from indoor sources is under-estimated when the prior time-step concentration is artificially reduced.

Staff evaluated the microenvironments where peak exposures occurred, by aggregating the time 5-minute exposures occurred into three broad microenvironmental groups: indoors, outdoors, and in-vehicles. A comparison of the APEX simulations using the two air quality input simulations (i.e., multiple peak versus single peak, monitor 420070005 – year 2002) and considering how often peak exposures occur indoors is presented in Figure 8-30. The differences in the percent of indoor exposure exceedances are consistent with the design of the model and the particular input data used. For exposures less than the 400 ppb level, a greater percent of the overall exposures occur indoors using the single peak method than compared with the multiple peak data set. For exposures at or above the 400 ppb level, a smaller percent of the overall exposures occur indoors using the single peak method than compared with the multiple peak data set. In fact, the multiple peak simulation had indoor peak exposures at levels not observed using the single peak method. This is likely a function of the normalized concentrations, that when used in the mass balance equation as the prior time-step microenvironmental concentration, the microenvironmental concentration at time *t* is less than what would be expected.

While this analysis and its findings are encouraging, context is needed to assign relevance to the current exposure analyses in St. Louis and Greene County. As stated earlier, the data set used had the greatest number of benchmark exceedances, designed by staff to observe the effect that multiple peaks within the hour has on estimated exposures. The observed differences in the contribution from the indoor microenvironment may be more appropriately applied in discussions regarding air quality scenarios with high concentrations distributions (e.g., air quality adjusted to just meeting the current standard, Figure 8-21). While the differences in the highest benchmark exceedances are likely of greatest interest when investigating the possibility of missing exposure events, it should be noted that the greatest proportion of all exposure events still occur outdoors (in this simulation, >70% of exposures above 400 ppb occurred outdoors). In addition, the differences observed at the lower benchmarks indicated the role of indoor exposures was fairly similar. At most the difference was four percentage points, with the multiple peak simulation having a consistently lower contribution of exceedances from indoor exposures. Therefore, based on the above discussion, staff judges the magnitude of the potential under-estimation as low to medium.

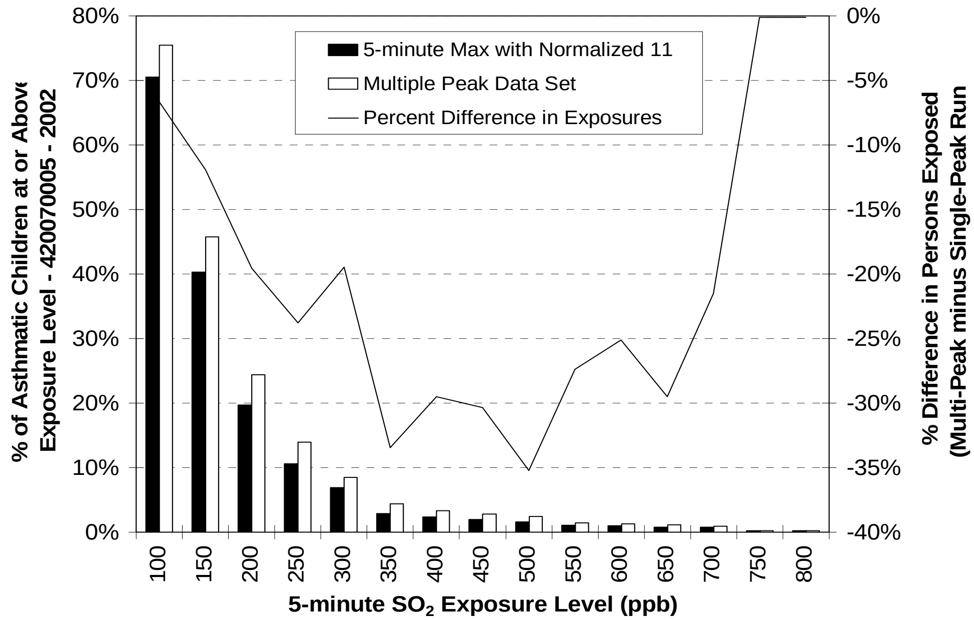

Figure 8-28. Percent of asthmatic children above given exposure level for two APEX simulations: one using multiple peak concentrations in an hour, the other assuming a single peak concentration. Continuous 5-minute monitoring data (ID 42007005, year 2002) were used as the air quality input.

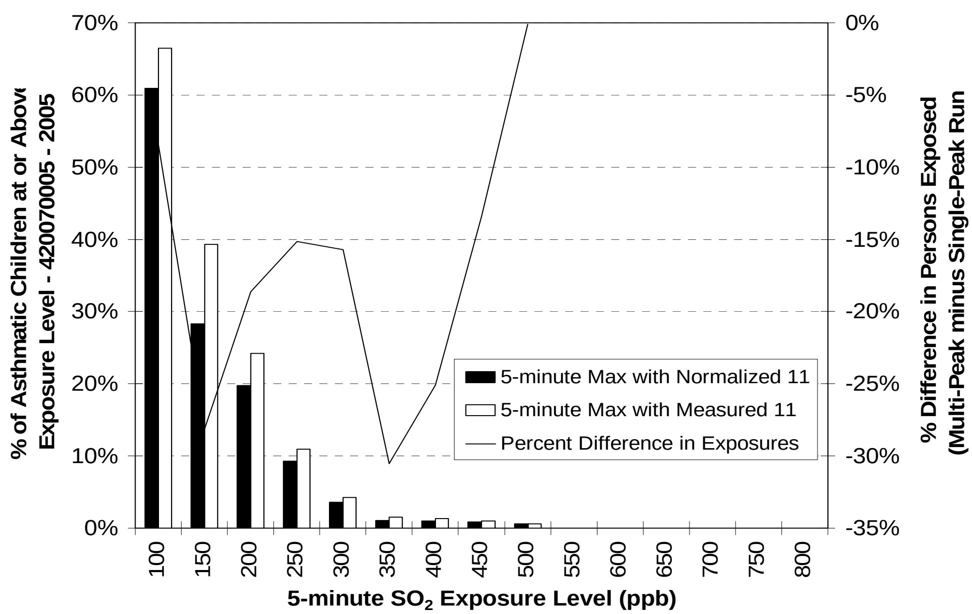

Figure 8-29. Percent of asthmatic children above given exposure level for two APEX simulations: one using multiple peak concentrations in an hour, the other assuming a single peak concentration. Continuous 5-minute monitoring data (ID 42007005, year 2005) were used as the air quality input.

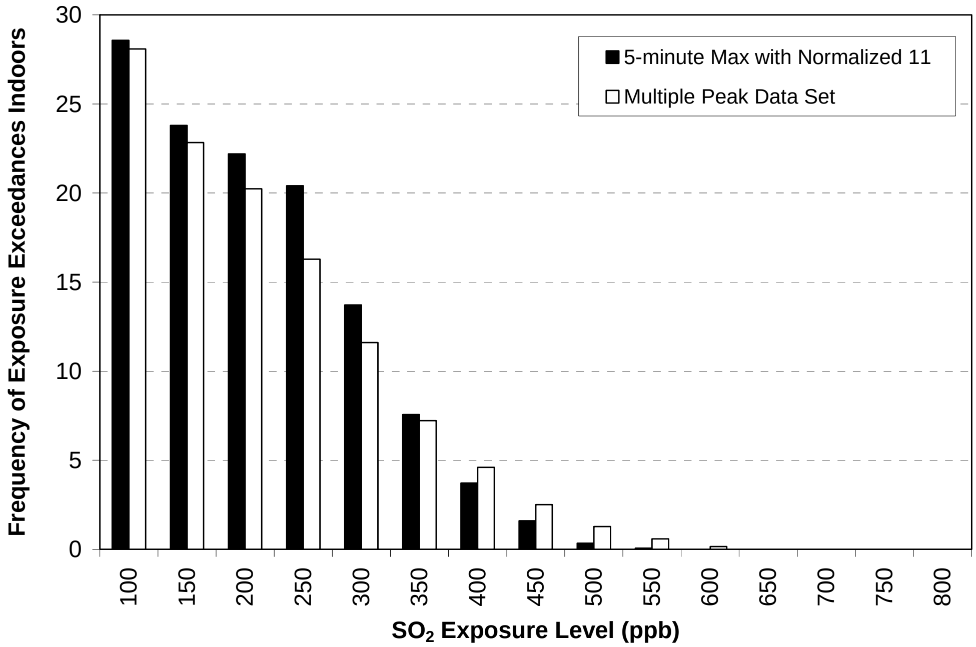

Figure 8-30. Frequency of exposure exceedances indoors for two APEX simulations: one using multiple peak concentrations in an hour, the other assuming a single peak concentration. Continuous 5-minute monitoring data (ID 42007005, year 2002) were used as the air quality input.

8.11.2.2.12 Asthma Prevalence Rate

The best estimate of asthma prevalence used in this analysis was generated using a comprehensive and widely used data set (CDC, 2007). Staff judged that variability in the asthma prevalence based on age was an important attribute to represent in simulating SO_2 exposures, one of the principal reasons for selection of the particular data set. There are however limitations in using the data that may add to uncertainty in the generated exposure results. The percent of asthmatics simulated by APEX using a combined regional (children by age) and local (adults all ages) prevalence was comparable with an independent estimate of the percent of asthmatics within the four counties modeled (9.3% versus 8.8% of the population, respectively). Therefore, the uncertainty in the overall total percent of asthmatics exposed is likely low, particularly in Greene County. In Greene County, 9.8% of the simulated population was asthmatic and compares well with the 10.2% asthma prevalence reported by MO DOH (2003). However, the asthma prevalence across the three-county domain in St. Louis was variable, with St. Louis City County having a high estimated prevalence rate (16.4%) and St Louis County having a much lower prevalence rate (5.8%). This variable distribution was not represented in the exposure modeling simulation; all children and adults in each of the counties used the data summarized in Table 8-7. Therefore in St. Louis City County, the asthma prevalence may have been under-estimated, while in St. Louis County the asthma prevalence may have been over-estimated. This may add to medium level of influence to the total number of asthmatics exposed in St. Louis (not the percent of asthmatics exposed), though the direction of influence is largely unknown because individual county level exposures are not output by the model.

8.12 KEY OBSERVATIONS

Presented below are key observations resulting from the exposure assessment:

- 5-minute exposures to SO_2 were estimated for two areas in Missouri (i.e., Greene County and St. Louis), with both locations having significant SO_2 emission sources. Air quality scenarios investigated by staff included *as is* air quality, air quality adjusted to simulate just meeting the current annual and 24-hour SO_2 standards, and just meeting several alternative 1-hour daily maximum SO_2 standards.
- A number of factors would be expected to contribute to differences in SO_2 exposures across different locations. These include differences such as population density, SO_2 emission density, location and types of SO_2 sources, prevalence of air conditioning, time spent outdoors, and asthma prevalence (section 8.10). As discussed in section 8.10, St. Louis County has a medium-to-high SO_2 emissions density and a medium-to-high population density relative to other urban areas. Relative to the St. Louis study area, Greene County is a more rural county having much lower population density and much lower SO_2 emissions density. Taken together, the estimated exposures for these two locations provide useful insights about urban and rural counties with SO_2 emission sources.
- St. Louis had both a greater number and percent of asthmatic children and adults exposed above the benchmark levels than did Greene County for all air quality scenarios. This is not unexpected given the greater population density and the much greater SO_2 emissions density in St. Louis. Staff believes that the St. Louis exposure estimates provide a useful perspective on the likely overall magnitude and pattern of exposures associated with various SO_2 air quality scenarios in urban areas within the U.S. that have similar population densities, SO_2 emissions densities, and asthma prevalence. Similarly, staff believes that the results for Greene County provide perspective on exposures in more rural areas within the U.S. that have similar emission and population attributes to Greene County.
- Modeled concentrations are reasonable given comparisons to available measurement data
  - AERMOD 1-hour SO_2 concentrations at ambient monitoring receptors and their associated prediction envelops generally replicate and encompass those measured at the ambient monitor. Model-to-monitor agreement was better in St. Louis than in Greene County.

- The degree of under- or over-estimation of 1-hour SO_2 concentrations by AERMOD at ambient monitoring locations in Greene County did not appreciably affect the estimated number of days per year with 5-minute concentrations above benchmark levels.
- APEX-modeled annual mean SO_2 exposures in St. Louis and Green County (arithmetic means, 0.5-1.4 ppb) are comparable to daily and weekly personal exposure measurements in other locations (arithmetic means, 0.3-1.9 ppb).

- Estimated exposures above 5-minute potential health effect benchmark levels at moderate or greater exertion using APEX occurred most frequently outdoors (around 50 to >90%, depending on the air quality scenario and modeling domain).
- Simulating air quality that just meets the current annual standard resulted in the greatest number and percent of asthmatic persons exposed at all benchmark levels. The value depended on both the benchmark level and modeling domain. For example, the percent of asthmatic children exposed at least one day above a benchmark concentration ranged from 0% (400 ppb benchmark) to 8% (100 ppb benchmark) in Greene County, while in St. Louis the corresponding range was 24% to 97 %.
- The exposure results using *as is* air quality were similar to that estimated using air quality adjusted to a 99th percentile 1-hour daily maximum of 50 or 100 ppb in Greene County, though in each of these scenarios, there were only a few persons exposed. In St. Louis, the estimated exposure associated with *as is* air quality was also between that estimated by simulating the 50 and 100 ppb 99th percentile 1-hour daily maximum air quality scenario.
- Staff compared exposure results using the 50 ppb 99th percentile air quality scenario relative to *as is* air quality in St. Louis to estimate the reduction in the number and percent of asthmatic children exposed above each 5-minute health effect benchmark level. No asthmatic children were exposed above the 400 ppb 5-minute benchmark for either the *as is* or 50 ppb 99th percentile alternative standard scenario. There were 121 fewer asthmatic children exposed above the 200 ppb 5-minute benchmark, corresponding to a 76% reduction in exposures, when considering the 50 ppb standard level. Similarly, reductions also were observed at the 100 ppb 5-minute benchmark when considering the 50 ppb standard compared with *as is* air quality: 1,641 (59%) fewer asthmatic children were exposed. (Appendix B.4).
- In both St. Louis and Greene County, there were no reductions in the numbers or percent of persons exposed at any of the 5-minute benchmark levels when comparing exposure results using the 100 ppb 99th percentile air quality standard scenario relative to *as is* air quality.
- Using a 99th versus a 98th percentile form at the same standard level (i.e., 200 ppb) resulted in fewer persons being exposed above benchmark levels when using the 99th percentile. Approximately 1,000 to 5,000 fewer asthmatic children, 1,000 to 90,000 fewer person days, and 2 to 12 fewer percent of persons were exposed above benchmark levels in St. Louis.
- Of the fifteen uncertainties qualitatively judged to influence the estimated number of persons with at least one exposure above the 5-minute SO_2 benchmark levels, one may be associated with over-estimation, three could result in under-estimations, while the

remaining uncertainties could affect exposure results in both (nine sources) or unknown direction (two sources) (see Table 8-27). Nine of these eleven sources with bidirectional influence were rated by staff as being low-medium magnitude of influence. The magnitude of influence for three of the four uncertainties associated with either over- or under-estimation was estimated as being low to medium influence, while the remaining source (i.e., A/C prevalence) was ranked as being low or a negligible magnitude of influence. Two of these four sources of uncertainty (i.e., A/C prevalence and indoor AERs) were parameters used to estimate indoor exposures, which staff believes do not contribute significantly to exposures above benchmark levels. The remaining two sources (i.e., uncertainty in the activity pattern database used and the occurrence of multiple exceedances within an hour) could have an offsetting influence in estimating the number of persons exposed. This is because both of these sources were rated by staff as being low to medium in magnitude, though in opposing direction. Based on this overall characterization related to the direction and magnitude of influence for identified sources of uncertainty, we are unable to characterize the likelihood of the estimates being either over- or under-estimated with respect to the number of persons exposed above benchmark levels.

- The knowledge-base uncertainty for sources with unknown or bidirectional influence ranged from low (five sources) to medium (four sources). Note that most of these sources were rated above as being of low-medium magnitude of influence. A high degree of uncertainty in the knowledge-base was assigned to two sources: the area source emission profile (direction of influence characterized as both, with low-medium rated magnitude) and the accuracy of 5-minute exposures estimated by APEX (direction of influence characterized as both, with low-medium rated magnitude). The knowledge-base uncertainty was medium for three of the four sources identified above that were associated with either under- or over-estimating 5-minute exposures (the remaining source was rated as low). Based on this overall characterization, there is a low-medium level of uncertainty in the knowledge-base for most sources. While two sources were rated as having high knowledge-base uncertainty, they were noted as having similar magnitude of influence on the estimated 1-hour or 5-minute concentrations.

9. HEALTH RISK ASSESSMENT FOR LUNG FUNCTION RESPONSES IN ASTHMATICS ASSOCIATED WITH 5-MINUTE PEAK EXPOSURES

9.1 INTRODUCTION

In the previous review, it was clearly established that subjects with asthma are more sensitive to the respiratory effects of SO_2 exposure than healthy individuals (ISA, section 3.1.3.2). As discussed above in section 4.2, asthmatics exposed to SO_2 concentrations as low as 200-300 ppb for 5-10 minutes during exercise have been shown to experience moderate or greater bronchoconstriction, measured as an increase in sRaw (≥100%) or decrease in FEV_1 (≥15%) after correction for exercise-induced responses in clean air. These studies exposed asthmatic volunteers to SO_2 in the absence of other pollutants that often confound associations in the epidemiological literature. Therefore, these controlled human exposure studies provide direct evidence of a causal relationship between exposure to SO_2 and respiratory health effects. Staff judges the controlled human exposure evidence presented in the ISA with respect to lung function effects in exercising asthmatic subjects as providing an appropriate basis for conducting a quantitative risk assessment for this health endpoint and exposure scenario.

As described in Chapters 5 and 6, staff is utilizing both the epidemiological evidence in the ISA, and an air quality analysis based on U.S. and Canadian ED visit and hospitalization studies for all respiratory causes and asthma to qualitatively inform: (1) the selection of potential 1-hour daily maximum alternative standards to be analyzed in the air quality, exposure, and risk chapters of this document (see Chapter 5), and (2) the adequacy of the current, and potential alternative standards (Chapter 10). However, for the reasons discussed in more detail in section 6.1, staff did not find the overall breadth of the epidemiological evidence to be robust enough to support a quantitative assessment of risk.

A brief description of the approach used to conduct this health risk assessment is presented below. More detailed discussion of the approach can be found in the risk assessment technical support document, prepared by Abt Associates, which is included as Appendix C to this document. The goals of this SO_2 risk assessment are: (1) to develop health risk estimates of the number and percent of the asthmatic population that would experience moderate or greater lung function decrements in response to 5-minute daily maximum peak exposures while engaged in moderate or greater exertion for several air quality scenarios (described below); (2) to develop a better understanding of the influence of various inputs and assumptions on these risk estimates; and (3) to gain insights into the risk levels and patterns of risk reductions associated with meeting several alternative 1-hour daily maximum SO_2 standards. Health risks for lung function effects in exercising asthmatics have been estimated for the following three scenarios: (1) *"as is"* ambient levels of SO_2, (2) air quality adjusted to simulate just meeting the current 24-hour standard, and (3) air quality adjusted to simulate just meeting several alternative 1-hour standards.

As discussed in Chapter 8, the geographic scope of the assessment includes selected locations encompassing a variety of SO_2 emission source types in two areas within the state of Missouri (i.e., Greene County and St. Louis). These areas were identified based on the results of a preliminary screening of the 5-minute ambient SO_2 monitoring data that were available. The state of Missouri was one of only a few states having both 5-minute maximum and continuous 5-minute SO_2 ambient monitoring, as well as having over 30 1-hour SO_2 monitors in operation at some time during the period from 1997 to 2007. In addition, the air quality characterization, described in Chapter 7, estimated frequent exceedances above the potential health effect benchmark levels at several of the 1-hour ambient monitors in Missouri. In a ranking of estimated SO_2 emissions reported in the National Emissions Inventory (NEI), Missouri ranked 7th for the number of stacks with > 1000 tpy SO_x emissions out of all U.S. states. These stack emissions were associated with a variety of source types such as electrical power generating units, chemical manufacturing, cement processing, and smelters. For all these reasons, the current SO_2 lung function risk assessment focuses on Missouri and, within Missouri, on those areas within 20 km of a major point source of SO_2 emissions in Greene County and the St. Louis area.

9.2 DEVELOPMENT OF APPROACH FOR 5-MINUTE LUNG FUNCTION RISK ASSESSMENT

The lung function risk assessment is based on the health effects information evaluated in the ISA and discussed above in Chapter 4. The basic structure of the risk assessment reflects the fact that we have available controlled human exposure study data from several studies involving volunteer asthmatic subjects who were exposed to SO_2 concentrations at specified exposure levels while engaged in moderate or greater exertion for 5- or 10-minute exposures. As discussed in the ISA (section 3.1.3.5), among asthmatics, both the magnitude of SO_2-induced lung function decrements observed in responding individuals and the percent of individuals affected in the group exposed have been shown to increase with increasing 5- to 10-minute SO_2 exposure levels in the range of 200 to 1,000 ppb. Therefore, for the SO_2 lung function risk assessment we have developed probabilistic *exposure-response* relationships based on these data. The analysis was based on the combined data set consisting of all available individual data that describe the relationship between a measure of personal exposure to SO_2 and measures of lung function recorded in these studies. For the purposes of this risk assessment, all of the individual data, including both 5- and 10-minute exposure duration, were combined and treated as representing 5-minute responses. These probabilistic exposure-response relationships were then combined with 5-minute daily maximum peak exposure estimates for mild and moderate asthmatics engaged in moderate or greater exertion associated with the various air quality scenarios mentioned above. A more detailed description of the exposure assessment that was the source of the estimated daily maximum 5-minute peak exposures under moderate or greater exertion is provided above in Chapter 8.

9.2.1 General Approach

The major components of the lung function health risk assessment are illustrated in Figure 9-1. As shown in Figure 9-1, under the lung function risk assessment, exposure estimates for mild and moderate asthmatics for a number of different air quality scenarios (i.e., *"as is"* air quality (representing 2002), just meeting the current 24-hour standard, just meeting alternative standards) are combined with probabilistic exposure-response relationships derived using a combined data base consisting of data from several controlled human exposure studies to develop risk estimates. The air quality and exposure analysis components that are integral to this risk assessment are discussed in greater detail in Chapters 7 and 8 of this document and in the Exposure Assessment TSD (included as Appendix B to this document). Only the air quality and exposure aspects affecting the scope of the lung function risk assessment are briefly discussed in section 9.2.2. A description of the overall approach to estimating the exposure-response relationship is included in section 9.2.3 below.

Two types of risk measures were generated for the lung function risk assessment. The first type included estimates of the number and percentage of all asthmatics (or asthmatic children) experiencing one or more occurrences of a defined lung function response associated with 5-minute exposures to SO_2 while engaged in moderate or greater exertion under a given air quality scenario. The second type of risk measure generated for each defined lung function response is the number of occurrences of the lung function response in asthmatics (or asthmatic children) in a year associated with 5-minute exposures at moderate or greater exertion under a given air quality scenario. Since asthmatic school age children are a subset of all asthmatics, the risk estimates presented for these two groups should not be combined.

To obtain risk estimates associated with SO_2 concentrations under different scenarios, we estimated expected risk given the personal exposures associated with SO_2 concentrations under each scenario – i.e., associated with

- *"as is"* ambient SO_2 concentrations representing 2002 air quality,
- SO_2 air quality levels simulating just meeting the current 24-hour and annual standards, and
- SO_2 air quality levels simulating just meeting specified alternative 1-hour standards.

Note that, in contrast to the headcount risk estimates calculated for the O_3 health risk assessment, the headcount risk estimates calculated for the SO_2 health risk assessment reflect risks associated with all ambient SO_2 concentrations, not just risks in excess of estimated policy-relevant background ambient SO_2 concentrations. This is because policy-relevant background SO_2 concentrations are estimated to be at most 30 parts per trillion and they contribute less than 1% to present day SO_2 ambient concentrations (ISA, section 2.4.6) and thus would have little impact on the risk estimates.

The first measure of risk (i.e., the number or percent of individuals in the designated population to experience at least one lung function response in a year) is calculated as follows:

1) From the exposure modeling described in Chapter 8, we obtain the number of individuals exposed at least once to x ppb SO_2 or higher, for x = 0, 50, 100, … to 800;

2) We then calculate the number of individuals exposed at least once to SO_2 concentrations within each SO_2 exposure bin defined above (item 2 in the illustrative example in Table 9-1 below);

3) We then multiply the number of individuals in each exposure bin (item 2 in Table 9-1 below) by the response probability (item 3 in Table 9-1 below) corresponding to the midpoint of the exposure bin (item 1 in Table 9-1 below); and

4) We sum the results across all of the bins.

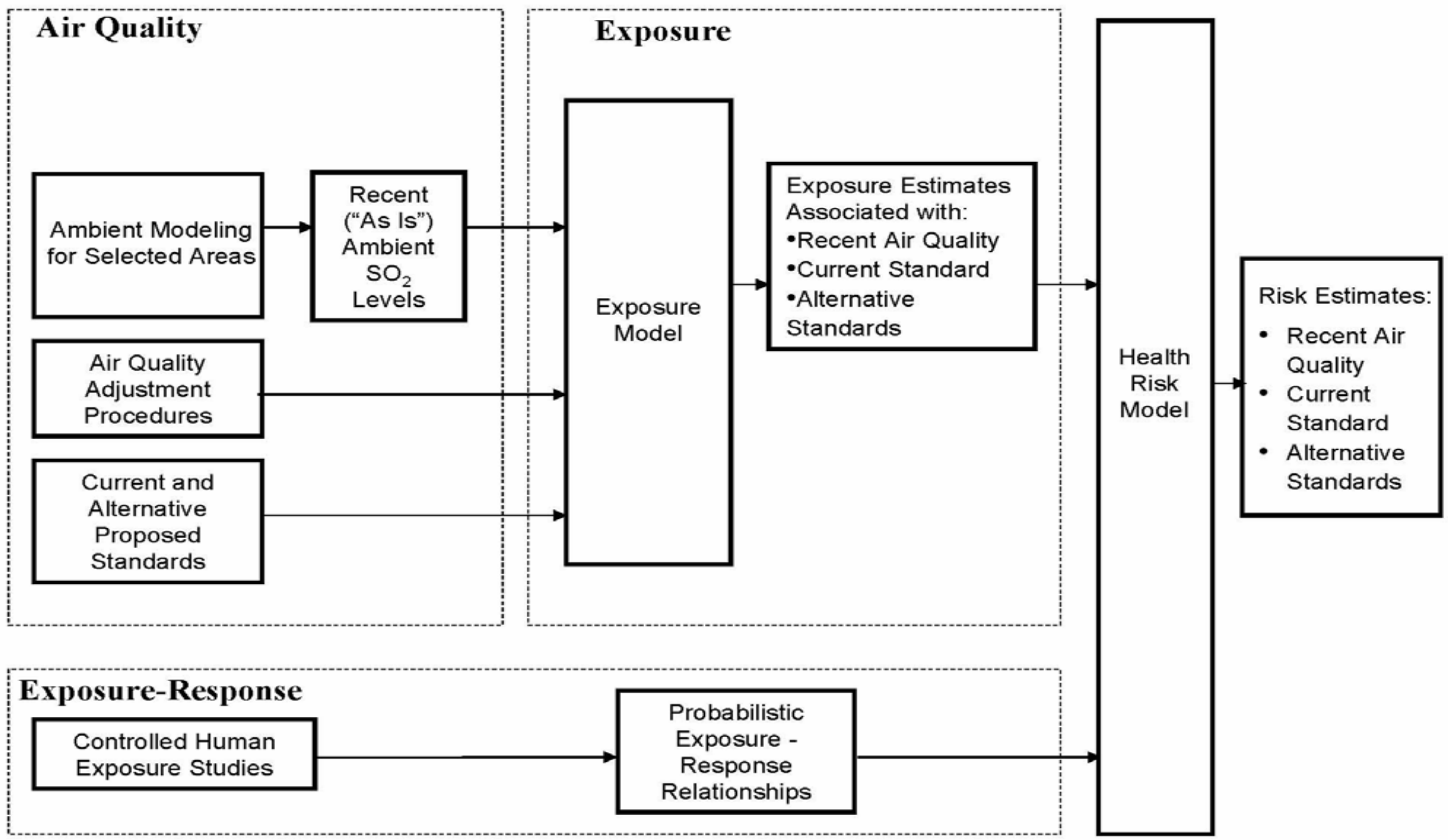

Figure 9-1. Major components of 5-minute peak lung function health risk assessment based on controlled human exposure studies.

Because response probabilities are calculated for each of several percentiles of a probabilistic exposure-response distribution, estimated numbers of individuals with at least one SO_2-related lung function response are similarly percentile-specific. For example, the k^{th} percentile number of individuals, Y_k associated with SO_2 concentrations under a given air quality scenario is:

$$Y_k = \sum_{j=1}^{n} NI_j \; x \; (R_k \mid e_j) \qquad \text{(equation 9-1)}$$

where:

e_j = (the midpoint of) the j^{th} category of personal exposure to SO_2, given "as is" ambient SO_2 concentrations;

NI_j = the number of individuals whose highest exposure is to e_j ppb SO_2, given ambient SO_2 concentrations under the specified air quality scenario;

$RR_k \mid e_j$ = the k^{th} percentile response rate at SO_2 concentration e_j; and

n = the number of intervals (categories) of SO_2 personal exposure concentration.

The k^{th} percentile estimate of the total number responding is then calculated by multiplying the k^{th} percentile risk by the number of people in the relevant population. An example is given in Table 9-1, for the median (i.e., 50^{th} percentile) risk estimate using personal exposures associated with a 99^{th} percentile 100 ppb 1-hour daily maximum SO_2 standard for asthmatics in the St. Louis modeling domain. We note that this calculation assumes that individuals who do not respond at the highest SO_2 concentration to which they are exposed will not respond to any lower SO_2 concentrations to which they are exposed.

The second type of risk measure, the number of occurrences of a defined lung function response in the designated population (i.e., asthmatics or asthmatic children) in a year associated with SO_2 concentrations under a given air quality scenario is calculated as follows:

1) From the exposure modeling described in Chapter 8, we obtain the number of exposure occurrences among the population at and above each benchmark level (i.e., 0 ppb, 50 ppb, 100 ppb, … 800 ppb);

2) We then calculate the number of exposure occurrences within each 50 ppb exposure "bin" (e.g., < 50 ppb, 50-100 ppb, etc.) [89](item 2 in the illustrative example in Table 9-2 below);

[89] The final exposure bin was from 750 to 800 ppb SO_2. In at least one of the alternative standard scenarios, there were a few individuals whose exposure was greater than 800 ppb. For anyone whose exposure exceeded 800 ppb,

Table 9-1. Example calculation of the number of asthmatics in st. louis engaged in moderate or greater exertion estimated to experience at least one lung function response (defined as an increase in sRaw ≥ 100%) associated with exposure to SO_2 concentrations just meeting a 99th percentile, 1-hour 100 ppb standard.

SO_2 Exposure Bin (ppb)			Number of Asthmatics with At Least One Exposure in Bin	Probability of Response at Midpoint SO_2 Level	Estimated Number of Asthmatics Experiencing at Least One Lung Function Response
Lower Bound	Upper Bound	Midpoint (1)	(2)	(3)	=(2) x (3)
0	50	25	53711	0.00406	218
50	100	75	34236	0.02334	799
100	150	125	9835	0.05162	508
150	200	175	3059	0.08563	262
200	250	225	929	0.12300	114
250	300	275	368	0.16220	60
300	350	325	145	0.20210	29
350	400	375	84	0.24190	20
400	450	425	31	0.28060	9
450	500	475	22	0.31830	7
500	550	525	8	0.35430	3
550	600	575	0	0.38850	0
600	650	625	0	0.42090	0
650	700	675	8	0.45150	4
700	750	725	0	0.46600	0
750	800	775	0	0.49380	0
		Total :	102436	Total:	2032

3) We then multiply the number of occurrences in each exposure bin (item 2 in Table 9-2 below) by the response probability (item 3 in Table 9-2 below) corresponding to the midpoint (item 1 in Table 9-2 below) of the exposure bin; and

4) We sum the results across all of the bins.

Similar to the first type of risk measure discussed above, because response probabilities are calculated for each of several percentiles of a probabilistic exposure-response distribution, estimated numbers of occurrences are similarly percentile-specific. The kth percentile number of occurrences, O_k, associated with SO_2 concentrations under a given air quality scenario is:

$$O_k = \sum_{j=1}^{n} N_j \, x \, (R_k \mid e_j) \qquad \text{(equation 9-2)}$$

where:

e_j = (the midpoint of) the jth category of personal exposure to SO_2;

we assumed a final bin from 800 to 850 ppb, and assigned them the midpoint value of that bin,825 ppb. This will result in a slight downward bias in the estimate of risk.

N_j = the number of exposures to e_j ppb SO_2, given ambient SO_2 concentrations under the specified air quality scenario;

$R_k \mid e_j$ = the kth percentile response probability at SO_2 concentration e_j; and

n = the number of intervals (categories) of SO_2 personal exposure concentration.

An example calculation is given in Table 9-2.

Table 9-2. Example calculation of number of occurrences of lung function response (defined as an increase in sRaw ≥ 100%), among asthmatics in St. Louis engaged in moderate or greater exertion associated with exposure to SO_2 concentrations that just meet a 99th percentile 1-hour, 100 ppb standard.

SO_2 Exposure Bin (ppb)			Number of Exposures	Probability of Response at Midpoint SO_2 Level	Expected Number of Occurrences of Lung Function Response
Lower Bound	Upper Bound	Midpoint (1)	(2)	(3)	=(2) x (3)
0	50	25	16519000	0.00406	67067
50	100	75	136621	0.02334	3189
100	150	125	15760	0.05162	814
150	200	175	3826	0.08563	328
200	250	225	1051	0.12300	129
250	300	275	413	0.16220	67
300	350	325	175	0.20210	35
350	400	375	83	0.24190	20
400	450	425	31	0.28060	9
450	500	475	24	0.31830	8
500	550	525	8	0.35430	3
550	600	575	0	0.38850	0
600	650	625	0	0.42090	0
650	700	675	8	0.45150	4
700	750	725	0	0.46600	0
750	800	775	0	0.49380	0
Total Number of Exposures:			16677000	Expected Number of Occurrences:	71672

9.2.2 Exposure Estimates

As noted above, exposure estimates used in the lung function risk assessment were obtained from running the APEX exposure model for the population of individuals with asthma for selected locations encompassing a variety of SO_2 emission source types within two areas in the state of Missouri (i.e., St. Louis and Greene County). Chapter 8 provides additional details about the inputs and methodology used to estimate 5-minute daily maximum peak SO_2 exposures while engaged in moderate or greater exertion for the asthmatic population in these two areas.

These 5-minute exposure estimates for asthmatic children and adult asthmatics have been combined separately with probabilistic exposure-response relationships for lung function response associated with 5-minute SO_2 exposures. Only the highest 5-minute peak exposure (with moderate or greater exertion) on each day has been considered in the lung function risk assessment, since the controlled human exposure studies have shown an acute-phase response that was followed by a short period where the individual was relatively insensitive to additional SO_2 challenges. Staff recognizes that consideration of only the highest 5-minute exposure (with moderate or greater exertion) on each day likely leads to some underestimation of health risks since we are not including the health impact of other 5-minute exposures (with moderate or greater exertion) occurring on the same day.

As described in section 8.8.1, instead of adjusting upward[90] the air quality concentrations to simulate just meeting the current SO_2 standards and potential alternative 1-hr daily maximum standards, to reduce computer processing time, the exposure assessment simulated exposures associated with just meeting various standards by adjusting the health effect benchmark levels by the same factors described for each specific modeling domain and simulated year (see Table 8-11). Since it is a proportional adjustment, the end effect of adjusting concentrations upwards versus adjusting benchmark levels downward within the model is the same. The same follows for where as is concentrations were in excess of an alternative standard level (e.g., 50 ppb for the 99th percentile averaged over three years), only the associated benchmarks are adjusted upwards (i.e., a higher threshold concentration that would simulate lower exposures).

9.2.3 Exposure-Response Functions

Similar to the approach used in the ozone lung function risk assessment (Abt Associates, 2007), we have used a Bayesian Markov Chain Monte Carlo approach to estimate probabilistic exposure-response relationships for lung function decrements associated with 5-minute daily maximum peak exposures while engaged in moderate or greater exertion using the WinBUGS software (Spiegelhalter et al., 1996).[91] The combined data set includes all available individual data from controlled human exposure studies of mild-to-moderate asthmatic individuals exposed for 5- or 10-minutes while engaged in moderate or greater exertion that was summarized in the

[90] To evaluate the current and most of the alternative 1-hr standards analyzed, "as is" ambient concentrations were lower than air quality that would just meet the standards.
[91] See Gleman et al. (1995) or Gilks et al. (1996) for an explanation of these methods.

final ISA. As noted above, for the purposes of this risk assessment, all of the individual response data, including both 5- and 10-minute exposure durations, have been combined and treated as representing 5-minute responses. Table 9-3 summarizes the available controlled human exposure data that have been used to develop the probabilistic exposure-response relationships for the lung function risk assessment.

Table 9-3. Percentage of asthmatic individuals in controlled human exposure studies experiencing SO_2-induced decrements in lung function.

SO_2 Level (ppb)	Exposure Duration	No. of Subjects	Ventilation (L/min)	Lung Funct.	Cumulative Percentage of Responders (Number of Subjects)[1]			Reference	Respiratory Symptoms: Supporting Studies
					sRaw				
					≥ 100% ↑	≥ 200% ↑	≥ 300% ↑		
					FEV_1				
					≥ 15% ↓	≥ 20% ↓	≥ 30% ↓		
200	10 min	40	~40	sRaw	5% (2)	0	0	Linn et al. (1987)[2]	Limited evidence of SO_2-induced increases in respiratory symptoms in some asthmatics: Linn et al. (1983; 1984; 1987; 1988; 1990), Schacter et al. (1984)
	10 min	40	~40	FEV_1	13% (5)	5% (2)	3% (1)	Linn et al. (1987)	
250	5 min	19	~50-60	sRaw	32% (6)	16% (3)	0	Bethel et al. (1985)	
	5 min	9	~80-90	sRaw	22% (2)	0	0		
	10 min	28	~40	sRaw	4% (1)	0	0	Roger et al. (1985)	
300	10 min	20	~50	sRaw	10% (2)	5% (1)	5% (1)	Linn et al. (1988)[3]	
	10 min	21	~50	sRaw	33% (7)	10% (2)	0	Linn et al. (1990)[3]	
	10 min	20	~50	FEV_1	15% (3)	0	0	Linn et al. (1988)	
	10 min	21	~50	FEV_1	24% (5)	14% (3)	10% (2)	Linn et al. (1990)	
400	10 min	40	~40	sRaw	23% (9)	8% (3)	3% (1)	Linn et al. (1987)	Stronger evidence with some statistically significant increases in respiratory symptoms: Balmes et al. (1987)[4], Gong et al. (1995), Linn et al. (1983; 1987), Roger et al. (1985)
	10 min	40	~40	FEV_1	30% (12)	23% (9)	13% (5)	Linn et al. (1987)	
500	5 min	10	~50-60	sRaw	60% (6)	40% (4)	20% (2)	Bethel et al. (1983)	
	10 min	28	~40	sRaw	18% (5)	4% (1)	4% (1)	Roger et al. (1985)	
	10 min	45	~30	sRaw	36% (16)	16% (7)	13% (6)	Magnussen et al. (1990)[4]	
600	10 min	40	~40	sRaw	35% (14)	28% (11)	18% (7)	Linn et al. (1987)	Clear and consistent increases

SO_2 Level (ppb)	Exposure Duration	No. of Subjects	Ventilation (L/min)	Lung Funct.	Cumulative Percentage of Responders (Number of Subjects)[1]			Reference	Respiratory Symptoms: Supporting Studies
					sRaw				
					≥ 100% ↑	≥ 200% ↑	≥ 300% ↑		
					FEV_1				
					≥ 15% ↓	≥ 20% ↓	≥ 30% ↓		
	10 min	20	~50	sRaw	60% (12)	35% (7)	10% (2)	Linn et al. (1988)	in SO_2-induced respiratory symptoms: Linn et al.(1984; 1987; 1988; 1990), Gong et al. (1995), Horstman et al. (1988)
	10 min	21	~50	sRaw	62% (13)	29% (6)	14% (3)	Linn et al. (1990)	
	10 min	40	~40	FEV_1	53% (21)	48% (19)	20% (8)	Linn et al. (1987)	
	10 min	20	~50	FEV_1	55% (11)	55% (11)	5% (1)	Linn et al. (1988)	
	10 min	21	~50	FEV_1	43% (9)	33% (7)	14% (3)	Linn et al. (1990)	
1,000	10 min	28	~40	sRaw	50% (14)	25% (7)	14% (4)	Roger et al. (1985)	
	10 min	10	~40	sRaw	60% (6)	20% (2)	0	Kehrl et al. (1987)	

Notes:

[1]Data presented from all references from which individual data were available. Percentage of individuals who experienced greater than or equal to a 100, 200, or 300% increase in specific airway resistance (sRaw), or a 15, 20, or 30% decrease in FEV_1. Lung function decrements are adjusted for effects of exercise in clean air (calculated as the difference between the percent change relative to baseline with excersise/SO_2 and the percent change relative to baseline with exercise/clean air). Quality control of data was performed by two EPA staff scientists.

[2]Responses of mild and moderate asthmatics reported in Linn et al. (1987) have been combined. Data reported only for the first 10 min period of exercise in the first round of exposures.

[3]Analysis includes data from only mild (1988) and moderate (1990) asthmatics who were not receiving supplemental medication.

[4]One subject was not exposed to 1,000 ppb due to excessive wheezing and chest tightness experienced at 500 ppb. For this subject, the values used for 500 ppb were also used for 1,000 ppb under the assumptions that the response at 1,000 ppb would be equal to or greater than the response at 500 ppb.

[5]Indicates studies in which exposures were conducted using a mouthpiece rather than a chamber.

Source: ISA, Table 3-1 (EPA, 2008c, p.3-10).

The combined data set from Linn et al. (1987, 1988, 1990), Bethel et al. (1983, 1985), Roger et al. (1985), and Kehrl et al. (1987), summarized in Table 9-3, provide data with which to estimate exposure-response relationships between responses defined in terms of sRaw and 5-minute exposures to SO_2 at levels of 200, 250, 300, 400, 500, 600, and 1,000 ppb (the exposure levels included in these studies).[92] Two definitions of response have been used: (1) an increase in sRaw ≥ 100% representing moderate or greater responses and (2) an increase in sRaw ≥ 200% reflecting severe decrements in lung function.

Likewise, the combined data set from Linn et al. (1987, 1988, 1990), summarized in Table 9-3, provide data with which to estimate exposure-response relationships between responses defined in terms of FEV_1 and 5-minute exposures to SO_2 at levels of 200, 300, 400, and 600 ppb (the exposure levels included in these studies). Again, two definitions of response have been used in the health risk assessment: (1) a decrease in FEV_1 ≥ 15% representing moderate or greater responses and (2) a decrease in FEV_1 ≥ 20% representing severe decrements in lung function.

Before estimating exposure-response relationships for 5-minute exposures, we corrected the data from these controlled human exposure studies for the effect of exercise in clean air to remove any systematic bias that might be present in the data attributable to an exercise effect. This correction is reflected in the summary of the response data provided in Table 9-3.[93] Generally, this correction for exercise in clean air is small relative to the total effects measures in the SO_2-exposed cases.

Public comments on the 2nd draft REA stated that there were errors in the data used to create Table 9-3 (UARG, 2009). Johns (2009) describes EPA's evaluation of these data, building upon an initial EPA analysis conducted in the previous NAAQS review (Smith, 1994). The vast majority of the alleged errors were described as rounding errors of the second decimal place introduced by the original study authors. Of the 640

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92 Data from Magnussen et al. (1990) were not used in the estimation of sRaw exposure-response functions because exposures in this study were conducted using a mouthpiece rather than a chamber.

93 Corrections were subject-specific. A correction was made by subtracting the subject's percent change (in FEV_1 or sRaw) under the no-SO_2 protocol from his or her percent change (in FEV_1 or sRaw) under the given SO_2 protocol, and rounding the result to the nearest integer. For example, if a subject's percent change in sRaw under the no-SO_2 protocol was 110.12% and his percent change in sRaw under the 0.6 ppm SO_2 protocol was 185.92%, then his percent change in sRaw *due to SO_2* is 185.92% - 110.12% = 75.8%, which rounds to 76%.

values of sRaw and FEV_1 from Linn et al. (1987), commenters identified 11 discrepancies between the original EPA analysis (Smith, 1994) and what was included in the analysis conducted more recently by EPA (Johns, 2009). EPA has reviewed these comments, and recognizes that some discrepancies were clearly due to transcription errors, while others were due to difficulties reading the last decimal place of the raw data. Commenters also identified 9 cases where the calculated average of individual lung function measurements did not equal the average values presented in Smith (1994). While staff placed more confidence in the average values presented rather than the calculated average of the individual measurements, EPA nonetheless conducted a preliminary re-analysis using the 20 apparent "corrected" values provided by commenters. This resulted in relatively minor and variable changes in SO_2-induced changes in lung function, which did not substantively change the percent responders as presented in Table 9-3. Further, incorporating these 20 changes resulted in an increase in the percent of responders in three table entries, while no decreases in the percent of responders were observed. Although the data presented in Table 9-3 were subjected to quality control procedures (see Johns, 2009), EPA is currently in the process of conducting a full quality assurance review of the data in response to these public comments and expects to present the quantitative results of its evaluation as part of the record for the November proposal. The risk assessment results presented in this document are based on the Johns (2009) summary.

We considered two different functional forms for the exposure-response functions: a 2-parameter logistic model and a probit model. In particular, we used the data in Table 9-3 to estimate the logistic function,

$$y(x;\ \beta,\gamma) = \frac{1}{(1+e^{\beta+\gamma*\ln(x)})} \qquad \text{(equation 9-3)}$$

and the probit function,

$$y(x;\beta,\gamma) = \frac{1}{(2\pi)^{1/2}} \int_{-\infty}^{\beta+\gamma\ln(x)} e^{-t^2/2}dt \qquad \text{(equation 9-4)}$$

for each of the four lung function responses defined above, where *x* denotes the SO_2 concentration (in ppm) to which the individual is exposed, ln(*x*) is the natural logarithm of *x*, *y* denotes the corresponding probability of response (increase in sRaw $\geq$ 100% or $\geq$ 200% or decrease in $FEV_1 \geq 15\%$ or $\geq 20\%$), and β and γ are the two parameters whose values are estimated. [94]

We assumed that the number of responses, s_i, out of N_i subjects exposed to a given SO_2 concentration, x_i, has a binomial distribution with response probability given by equation (9-3) when we assume the logistic model and equation (9-4) when we assume the probit model. The likelihood function is therefore

$$L(\beta,\gamma;data) = \prod_i \binom{N_i}{s_i} y(x_i;\beta,\gamma)^{s_i}\,[1-y(x_i;\,\beta,\gamma)]^{N_i-s_i} \quad . \qquad \text{(equation 9-5)}$$

Some subjects in the controlled human exposure studies participated in more than one study and were exposed to a given SO_2 concentration more than once. However, because there were insufficient data to estimate subject-specific response probabilities, we assumed a single response probability (for a given definition of response) for all individuals and treated the repeated exposures for a single subject as independent exposures in the binomial distribution.

For each model, we derived a Bayesian posterior distribution using this binomial likelihood function in combination with uniform prior distributions for each of the unknown parameters.[95] We used 4,000 iterations as the “burn-in” period followed by 10,000 iterations, a number sufficient to ensure convergence of the resulting posterior distribution. Each iteration corresponds to a set of values for the parameters of the logistic or probit exposure-response function.

For any SO_2 concentration, *x*, we could then derive the n^{th} percentile response value, for any *n*, by evaluating the exposure-response function at *x* using each of the 18,000 sets of parameter values. The resulting median (50^{th} percentile) exposure-

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[94] For ease of exposition, the same two Greek letters are used to indicate two unknown parameters in the logistic and probit models; this does not imply, however, that the values of these two parameters are the same in the two models.

[95] We used the following uniform prior distributions for the 2-parameter logistic model: $\beta \sim U(-10, 0)$; and $\gamma \sim U(-10,0)$; we used the following normal prior distributions for the probit model: $\beta \sim N(0, 1000)$; and $\gamma \sim N(0,1000)$.

response functions based on the 2-parameter logistic and probit models are shown together, along with the data used to estimate these functions, for increases in sRaw $\geq$ 100% and $\geq$ 200% and decreases in FEV_1 $\geq$ 15% and $\geq$ 20% in Figures 9-2, 9-3, 9-4, and 9-5, respectively. The 2.5^{th} percentile, median, and 97.5^{th} percentile curves, along with the response data to which they were fit, are shown separately for each of the eight combinations of (four) response definitions and (two) exposure-response models in Appendix C.

We note that there were only limited data with which to estimate the logistic and probit exposure-response functions, and that the logistic and probit models both appear to fit the data equally well. We also note that since the data being fit has already been corrected to account for the lung function response due to exercise in clean air, then the response must by definition be zero associated with 0 ppm SO_2 exposure. While the CASAC panel in its comments on the 2^{nd} draft REA suggested a possible *a priori* reason to prefer the probit model (based on a hypothesized lognormal distribution of individual thresholds for response), in staff's judgment there is not sufficient evidence to select one model over the other. Therefore, we have chosen to include both the 2-parameter logistic and probit models to develop the risk estimates associated with exposure to SO_2 under the different air quality scenarios considered. While the estimated exposure-response relationships using the two alternative models do not appear to be that different based on visual inspection of Figures 9-2 through 9-5, the differences do translate into substantial differences in the estimated aggregate number of sRaw and FEV_1 responses for St. Louis as discussed later in this chapter.

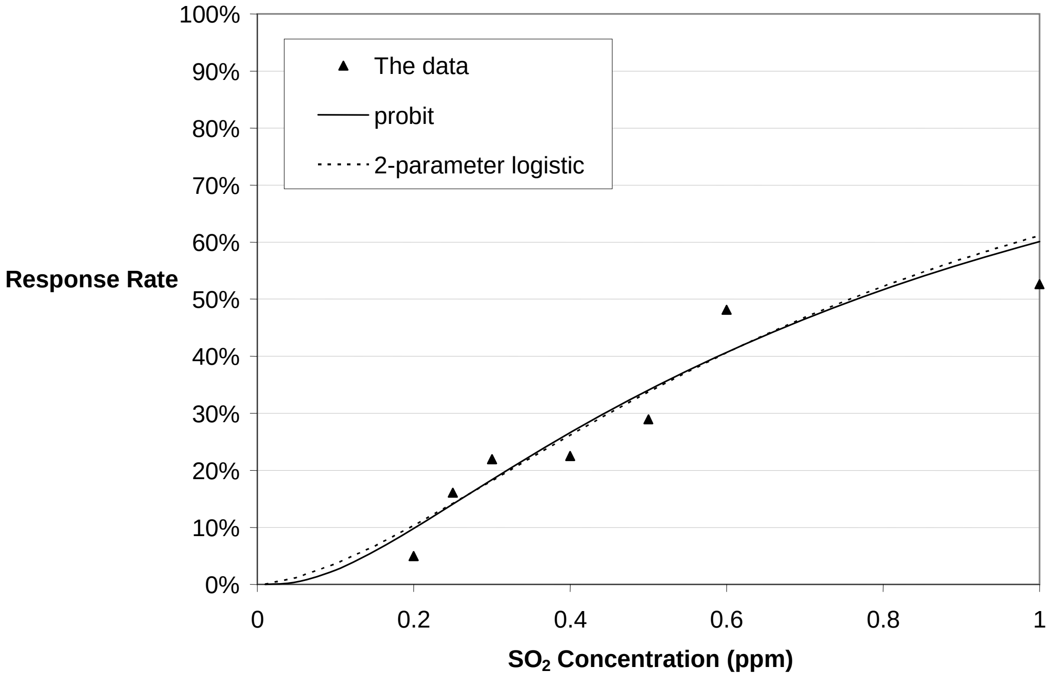


Figure 9-2. Bayesian-estimated median exposure-response functions: increase in sRaw ≥ 100% for 5-Minute exposures of asthmatics under moderate or greater exertion.*

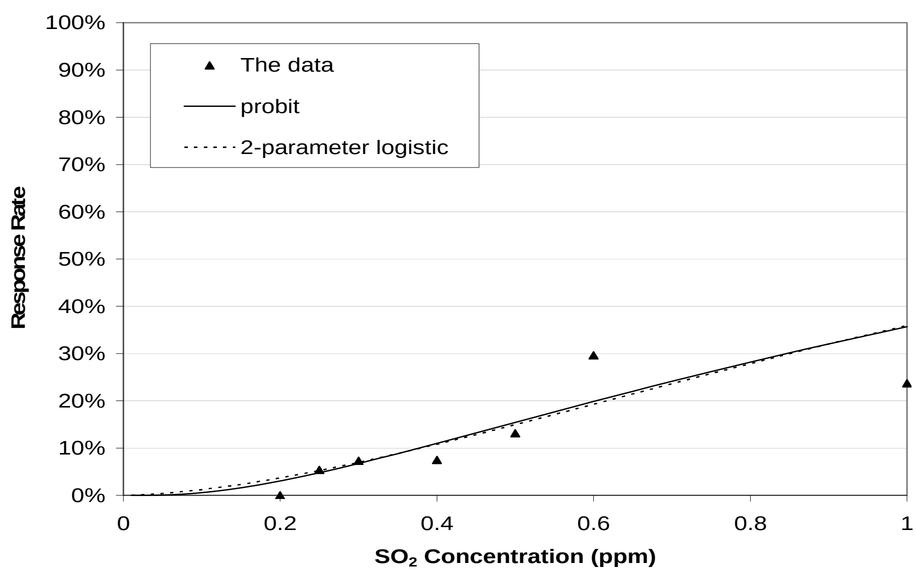


Figure 9-3. Bayesian-estimated median exposure-response functions: increase in sRaw ≥ 200% for 5-minute exposures of asthmatics under moderate or greater exertion.*

*Derived using method described in text based on all of the individual response data from Linn et al. (1987), Linn et al. (1988), Linn et al. (1990), Bethel et al. (1983), Bethel et al. (1985), Roger et al. (1985), and Kehrl et al. (1987).

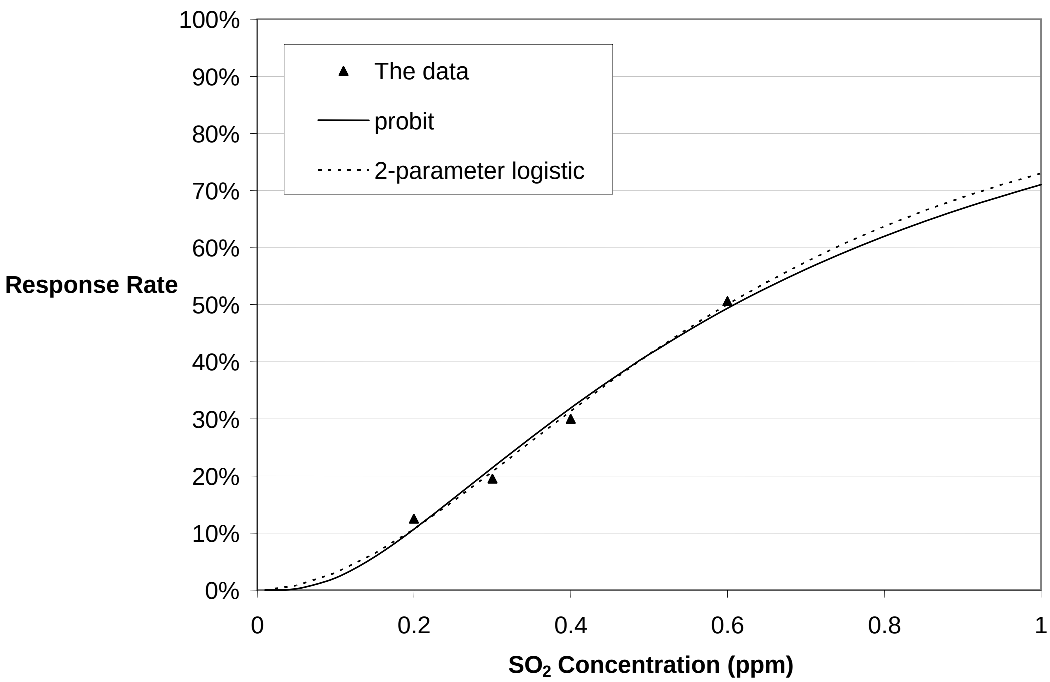


Figure 9-4. Bayesian-estimated median exposure-response functions: decrease in FEV1 ≥ 15% for 5-minute exposures of asthmatics under moderate or greater exertion*.

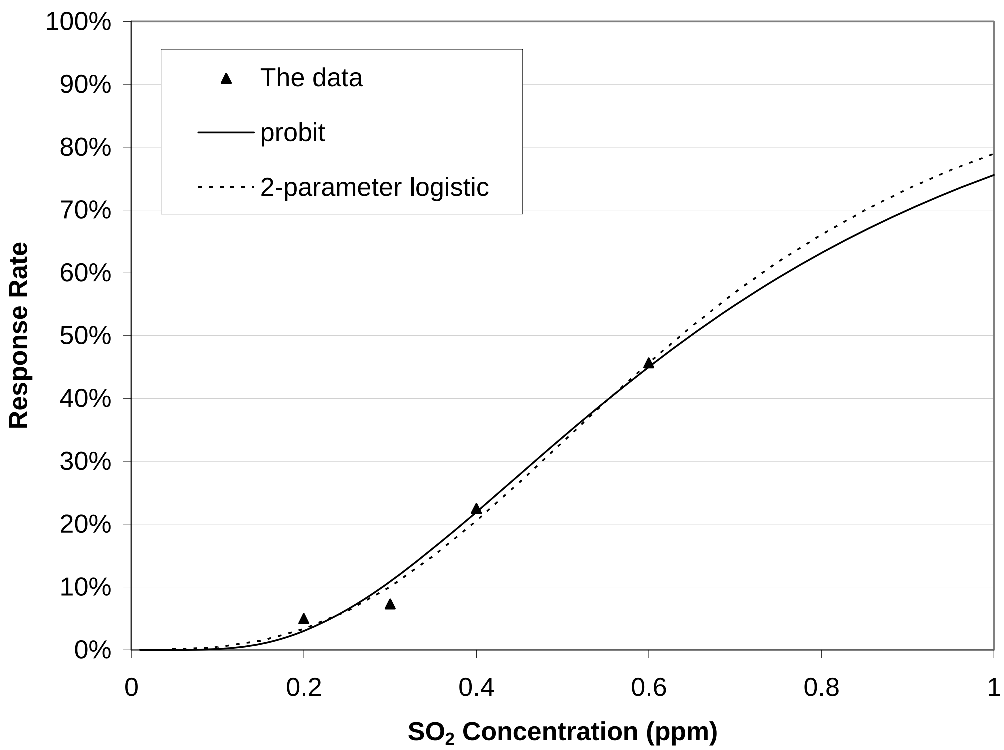


Figure 9-5. Bayesian-estimated median exposure-response functions: decrease in FEV1 ≥ 20% for 5-minute exposures of asthmatics under moderate or greater exertion.*

*Derived using method described in text based on all of the individual response data from Linn et al. (1987), Linn et al. (1988), and Linn et al. (1990).

9.3 LUNG FUNCTION RISK ESTIMATES

In this section, we present and discuss risk estimates associated with several air quality scenarios, including "as is" air quality represented by 2002 monitoring data. In addition, risk estimates are presented for several hypothetical scenarios, equivalent to adjusting air quality upward to simulate just meeting the current annual SO_2 24-hour standard and to adjusting air quality (either up or down) to simulate just meeting potential alternative 98th and 99th percentile daily maximum 1-h standards. As discussed previously in Chapter 5, potential alternative 1-h standards with levels set at 50, 100, 150, 200, and 250 ppb have been included in the risk assessment. Only selected risk estimates are presented in this section and additional risk estimates are presented in Appendix C. Throughout this section and Appendix C the uncertainty surrounding risk estimates resulting from the statistical uncertainty in the SO_2 exposure-response relationships due to sampling error is characterized by ninety-five percent credible intervals around estimates of occurrences, number of asthmatics experiencing one or more lung function response, and percent of total incidence that is SO_2-related.

Risk estimates for selected lung function responses for all asthmatics and asthmatic children associated with 5-minute exposures to ambient SO_2 concentrations while engaged in moderate or greater exertion are presented in Tables 9-4 through 9-9. Tables 9-4 through 9-6 are for all asthmatics and Tables 9-7 through 9-9 are for asthmatic children. Each table includes risk estimates for both Greene County and St. Louis, Missouri. Each table also includes risk estimates based on use of both the 2-parameter logistic and probit exposure-response models. As discussed in section 9.2.3, the risk assessment included two types of lung function responses (i.e., sRaw and FEV_1) and two levels of response for each type of lung function response ($\geq$ 100 and 200% increase for sRaw and $\geq$ 15 and 20% decrease for FEV_1). Risk estimates using sRaw as the measure of lung function response are included in this section because the exposure-response relationships were developed based on a larger set of data from individual subjects, which gives us more confidence in the exposure-response relationship. Additional risk estimates using FEV_1 as the indicator of lung function response are included in Tables 4-3, 4-4, 4-7, and 4-8 in Appendix C and show similar patterns across the current and alternative standards for the two study areas.

Tables 9-4 and 9-5 summarize the estimated number and percent of asthmatics that would experience 1 or more lung function responses in a year, where lung function response was defined as ≥ 100% and ≥ 200% increase in sRaw, in all asthmatics associated with ambient 5-minute SO_2 exposures estimated to occur under "as is" air quality (i.e., air quality based on 2002 monitored and modeled SO_2 air quality data) and under air quality representing just meeting the current SO_2 standards and several alternative 1-hour daily maximum SO_2 standards. Tables 9-7 and 9-8 present the same types of estimates for asthmatic children. The median estimates are presented in each cell of the table with the 95% credible intervals based on statistical uncertainty surrounding the SO_2 coefficient in the exposure-response relationship shown in parentheses below the median estimates.

Tables 9-6 and 9-9 summarize the estimated number of occurrences of two defined levels of lung function response (≥ 100% and ≥ 200% increase in sRaw) in all asthmatics and in asthmatic children, respectively, associated with ambient 5-minute SO_2 exposures estimated to occur under "as is" air quality (i.e., air quality based on 2002 monitored and modeled SO_2 air quality data) and under air quality representing just meeting the current SO_2 standards and several alternative 1-hour daily maximum SO_2 standards.

The current primary SO_2 standards include a 24-hour standard set at 0.14 parts per million (ppm), not to be exceeded more than once per year, and an annual standard set at 0.03 ppm, calculated as the arithmetic mean of hourly averages. In St. Louis, SO_2 concentrations that are predicted to occur if the current standards were just met are substantially higher than "as is" air quality (based on 2002 monitoring and modeling data) and also substantially higher than they would be under any of the alternative 1-hr standards considered in this analysis. Consequently, the levels of response that would be seen if the current standard were just met are well above the levels that would be seen under the "as is" air quality scenario or under any of the alternative 1-hr standards – for asthmatics and for asthmatic children, and for all four definitions of lung function response. We also note that the only standard resulting in decreases in lung function responses relative to the "as is" scenario is the 50 ppb, 99th percentile 1-hr daily maximum standard (corresponding to the 99/50 column in Tables 9-6 through 9-9).

Table 9-4. Number of asthmatics engaged in moderate or greater exertion estimated to experience at least one lung function response associated with exposure to SO_2 concentrations under alternative air quality scenarios in a year.*

Exposure-Response Model	"As is" SO_2 Concentrations**	SO_2 Concentrations that Just Meet the Current Standards***	SO_2 Concentrations that Just Meet Alternative nth Percentile 1-Hr Daily Maximum Standards, with Levels (in ppb) of m (Standard Denoted n/m):					
			99/50	99/100	99/150	99/200	99/250	98/200
Response = Increase in sRaw >= 100%								
Greene County, MO								
2-Parameter Logistic	90 (20 - 390)	210 (80 - 620)	80 (20 - 380)	90 (20 - 390)	100 (20 - 420)	120 (30 - 460)	160 (50 - 520)	140 (40 - 500)
Probit	10 (0 - 180)	110 (40 - 410)	10 (0 - 170)	10 (0 - 180)	20 (0 - 210)	40 (10 - 250)	70 (20 - 310)	60 (20 - 280)
St. Louis, MO								
2-Parameter Logistic	1010 (340 - 3010)	13460 (9740 - 18510)	730 (220 - 2490)	1990 (860 - 4690)	3650 (1900 - 7100)	5520 (3230 - 9490)	7500 (4770 - 11850)	7050 (4410 - 11320)
Probit	500 (140 - 1990)	13050 (9430 - 18100)	290 (70 - 1470)	1340 (520 - 3690)	2930 (1450 - 6200)	4810 (2760 - 8710)	6860 (4310 - 11190)	6400 (3950 - 10640)
Response = Increase in sRaw >= 200%								
Greene County, MO								
2-Parameter Logistic	30 (0 - 210)	70 (20 - 310)	30 (0 - 210)	30 (0 - 210)	30 (0 - 220)	40 (10 - 240)	50 (10 - 270)	50 (10 - 260)
Probit	0 (0 - 80)	30 (10 - 180)	0 (0 - 80)	0 (0 - 90)	10 (0 - 100)	10 (0 - 110)	20 (0 - 140)	10 (0 - 130)
St. Louis, MO								
2-Parameter Logistic	330 (70 - 1520)	5520 (3400 - 8960)	230 (40 - 1290)	670 (210 - 2270)	1280 (510 - 3360)	2010 (940 - 4470)	2830 (1470 - 5590)	2640 (1340 - 5330)
Probit	120 (20 - 880)	5180 (3150 - 8570)	60 (10 - 660)	350 (90 - 1590)	870 (310 - 2680)	1560 (690 - 3820)	2380 (1200 - 5000)	2190 (1070 - 4730)

*Numbers are median (50th percentile) numbers of asthmatics. Numbers in parentheses below the median are 95% cred ble intervals based on statistical uncertainty surrounding the SO_2 coefficient in the logistic and probit exposure-response functions. Numbers are rounded to the nearest ten.

**The "as is" exposure scenario was based on monitoring and modeling using 2002 air quality information.

***The current primary SO_2 standards include a 24-hour standard set at 0.14 parts per million (ppm), not to be exceeded more than once per year, and an annual standard set at 0.03 ppm, calculated as the arithmetic mean of hourly averages.

Table 9-5. Percent of asthmatics engaged in moderate or greater exertion estimated to experience at least one lung function response associated with exposure to SO_2 concentrations under alternative air quality scenarios in a year.*

Exposure-Response Model	"As is" SO_2 Concentrations**	SO_2 Concentrations that Just Meet the Current Standards***	SO_2 Concentrations that Just Meet Alternative nth Percentile 1-Hr Daily Maximum Standards, with Levels (in ppb) of m (Standard Denoted n/m):					
			99/50	99/100	99/150	99/200	99/250	98/200
Response = Increase in sRaw >= 100%								
Greene County, MO								
2-Parameter Logistic	0.4% (0.1% - 1.8%)	1% (0.4% - 2.9%)	0.4% (0.1% - 1.8%)	0.4% (0.1% - 1.8%)	0.5% (0.1% - 2%)	0.6% (0.2% - 2.1%)	0.7% (0.2% - 2.4%)	0.7% (0.2% - 2.3%)
Probit	0.1% (0% - 0.8%)	0.5% (0.2% - 1.9%)	0.1% (0% - 0.8%)	0.1% (0% - 0.8%)	0.1% (0% - 1%)	0.2% (0% - 1.2%)	0.3% (0.1% - 1.4%)	0.3% (0.1% - 1.3%)
St. Louis, MO								
2-Parameter Logistic	1% (0.3% - 2.9%)	13.1% (9.5% - 18.1%)	0.7% (0.2% - 2.4%)	1.9% (0.8% - 4.6%)	3.6% (1.9% - 6.9%)	5.4% (3.2% - 9.3%)	7.3% (4.7% - 11.6%)	6.9% (4.3% - 11.1%)
Probit	0.5% (0.1% - 1.9%)	12.7% (9.2% - 17.7%)	0.3% (0.1% - 1.4%)	1.3% (0.5% - 3.6%)	2.9% (1.4% - 6.1%)	4.7% (2.7% - 8.5%)	6.7% (4.2% - 10.9%)	6.2% (3.9% - 10.4%)
Response = Increase in sRaw >= 200%								
Greene County, MO								
2-Parameter Logistic	0.1% (0% - 1%)	0.3% (0.1% - 1.5%)	0.1% (0% - 1%)	0.1% (0% - 1%)	0.2% (0% - 1%)	0.2% (0% - 1.1%)	0.2% (0% - 1.3%)	0.2% (0% - 1.2%)
Probit	0% (0% - 0.4%)	0.1% (0% - 0.8%)	0% (0% - 0.4%)	0% (0% - 0.4%)	0% (0% - 0.5%)	0% (0% - 0.5%)	0.1% (0% - 0.6%)	0.1% (0% - 0.6%)
St. Louis, MO								
2-Parameter Logistic	0.3% (0.1% - 1.5%)	5.4% (3.3% - 8.7%)	0.2% (0% - 1.3%)	0.7% (0.2% - 2.2%)	1.3% (0.5% - 3.3%)	2% (0.9% - 4.4%)	2.8% (1.4% - 5.5%)	2.6% (1.3% - 5.2%)
Probit	0.1% (0% - 0.9%)	5.1% (3.1% - 8.4%)	0.1% (0% - 0.6%)	0.3% (0.1% - 1.6%)	0.8% (0.3% - 2.6%)	1.5% (0.7% - 3.7%)	2.3% (1.2% - 4.9%)	2.1% (1% - 4.6%)

*Percents are median (50th percentile) percents of asthmatic children. Percents in parentheses below the median are 95% credible intervals based on statistical uncertainty surrounding the SO_2 coefficient in the logistic and probit exposure-response functions. Percents are rounded to the nearest tenth.

**The "as is" exposure scenario was based on monitoring and modeling using 2002 air quality information.

***The current primary SO_2 standards include a 24-hour standard set at 0.14 parts per million (ppm), not to be exceeded more than once per year, and an annual standard set at 0.03 ppm, calculated as the arithmetic mean of hourly averages.

Table 9-6. Number of occurrences (in hundreds) of a lung function response among asthmatics engaged in moderate or greater exertion associated with exposure to SO_2 concentrations under alternative air quality scenarios in a year.*

Exposure-Response Model	"As is" SO_2 Concentrations**	SO_2 Concentrations that Just Meet the Current Standards***	SO_2 Concentrations that Just Meet Alternative nth Percentile 1-Hr Daily Maximum Standards, with Levels (in ppb) of m (Standard Denoted n/m):					
			99/50	99/100	99/150	99/200	99/250	98/200
Response = Increase in sRaw >= 100%								
Greene County, MO								
2-Parameter Logistic	125 (24 - 572)	127 (25 - 577)	125 (24 - 572)	125 (24 - 572)	125 (24 - 573)	126 (24 - 573)	126 (24 - 575)	126 (24 - 574)
Probit	16 (0 - 256)	18 (1 - 261)	16 (0 - 256)	16 (0 - 256)	16 (1 - 257)	16 (1 - 257)	17 (1 - 258)	17 (1 - 258)
St. Louis, MO								
2-Parameter Logistic	657 (128 - 2985)	1672 (663 - 4740)	652 (125 - 2975)	686 (141 - 3041)	762 (176 - 3184)	880 (234 - 3398)	1036 (315 - 3673)	997 (295 - 3604)
Probit	90 (4 - 1346)	933 (393 - 3107)	86 (3 - 1336)	111 (11 - 1402)	170 (33 - 1543)	264 (72 - 1756)	392 (128 - 2031)	360 (114 - 1963)
Response = Increase in sRaw >= 200%								
Greene County, MO								
2-Parameter Logistic	38 (4 - 310)	39 (4 - 312)	38 (4 - 310)	38 (4 - 310)	38 (4 - 310)	38 (4 - 310)	39 (4 - 311)	39 (4 - 311)
Probit	2 (0 - 123)	3 (0 - 124)	2 (0 - 122)	2 (0 - 123)	2 (0 - 123)	2 (0 - 123)	2 (0 - 123)	2 (0 - 123)
St. Louis, MO								
2-Parameter Logistic	201 (21 - 1614)	560 (165 - 2407)	199 (20 - 1609)	211 (24 - 1639)	237 (32 - 1703)	278 (47 - 1799)	332 (68 - 1923)	319 (63 - 1892)
Probit	13 (0 - 643)	258 (86 - 1388)	12 (0 - 639)	18 (1 - 666)	33 (5 - 725)	59 (12 - 814)	95 (24 - 930)	86 (21 - 901)

*Numbers are median (50th percentile) numbers of asthmatics. Numbers in parentheses below the median are 95% cred ble intervals based on statistical uncertainty surrounding the SO_2 coefficient in the logistic and probit exposure-response functions. Numbers are rounded to the nearest whole number.

**The "as is" exposure scenario was based on monitoring and modeling using 2002 air quality information.

***The current primary SO_2 standards include a 24-hour standard set at 0.14 parts per million (ppm), not to be exceeded more than once per year, and an annual standard set at 0.03 ppm, calculated as the arithmetic mean of hourly averages.

Table 9-7. number of asthmatic children engaged in moderate or greater exertion estimated to experience at least one lung function response associated with exposure to SO_2 concentrations under alternative air quality scenarios in a year.*

Exposure-Response Model	"As is" SO_2 Concentrations**	SO_2 Concentrations that Just Meet the Current Standards***	SO_2 Concentrations that Just Meet Alternative nth Percentile 1-Hr Daily Maximum Standards, with Levels (in ppb) of m (Standard Denoted n/m):					
			99/50	99/100	99/150	99/200	99/250	98/200
Response = Increase in sRaw >= 100%								
Greene County, MO								
2-Parameter Logistic	30 (10 - 130)	110 (40 - 270)	30 (10 - 130)	30 (10 - 140)	40 (10 - 150)	50 (20 - 180)	70 (30 - 210)	60 (20 - 200)
Probit	10 (0 - 60)	60 (20 - 200)	0 (0 - 60)	10 (0 - 60)	10 (0 - 80)	20 (10 - 100)	40 (10 - 140)	30 (10 - 130)
St. Louis, MO								
2-Parameter Logistic	590 (220 - 1570)	8020 (6080 - 10370)	400 (130 - 1210)	1220 (560 - 2620)	2240 (1240 - 4010)	3370 (2090 - 5350)	4560 (3060 - 6680)	4290 (2840 - 6390)
Probit	340 (100 - 1150)	7950 (6020 - 10320)	190 (50 - 790)	890 (360 - 2220)	1910 (1000 - 3690)	3080 (1860 - 5110)	4330 (2870 - 6510)	4060 (2640 - 6210)
Response = Increase in sRaw >= 200%								
Greene County, MO								
2-Parameter Logistic	10 (0 - 70)	40 (10 - 130)	10 (0 - 70)	10 (0 - 70)	10 (0 - 80)	20 (0 - 90)	20 (10 - 110)	20 (10 - 100)
Probit	0 (0 - 30)	20 (0 - 90)	0 (0 - 30)	0 (0 - 30)	0 (0 - 40)	10 (0 - 50)	10 (0 - 60)	10 (0 - 60)
St. Louis, MO								
2-Parameter Logistic	190 (50 - 780)	3380 (2190 - 5070)	130 (30 - 610)	410 (140 - 1240)	800 (340 - 1870)	1250 (620 - 2500)	1750 (970 - 3140)	1640 (890 - 3000)
Probit	80 (10 - 500)	3290 (2110 - 5000)	40 (10 - 350)	240 (60 - 950)	580 (220 - 1590)	1030 (480 - 2250)	1560 (830 - 2940)	1440 (740 - 2790)

*Numbers are median (50th percentile) numbers of asthmatic children. Numbers in parentheses below the median are 95% credible intervals based on statistical uncertainty surrounding the SO_2 coefficient in the logistic and probit exposure-response functions. Numbers are rounded to the nearest ten.

**The "as is" exposure scenario was based on monitoring and modeling using 2002 air quality information.

***The current primary SO_2 standards include a 24-hour standard set at 0.14 parts per million (ppm), not to be exceeded more than once per year, and an annual standard set at 0.03 ppm, calculated as the arithmetic mean of hourly averages.

Table 9-8. Percent of asthmatic children engaged in moderate or greater exertion estimated to experience at least one lung function response associated with exposure to SO_2 concentrations under alternative air quality scenarios in a year.*

Exposure-Response Model	"As is" SO_2 Concentrations**	SO_2 Concentrations that Just Meet the Current Standards***	SO_2 Concentrations that Just Meet Alternative nth Percentile 1-Hr Daily Maximum Standards, with Levels (in ppb) of m (Standard Denoted n/m):					
			99/50	99/100	99/150	99/200	99/250	98/200
Response = Increase in sRaw >= 100%								
Greene County, MO								
2-Parameter Logistic	0.4% (0.1% - 1.8%)	1.4% (0.6% - 3.7%)	0.4% (0.1% - 1.8%)	0.4% (0.1% - 1.9%)	0.5% (0.1% - 2.1%)	0.7% (0.2% - 2.4%)	1% (0.3% - 2.9%)	0.9% (0.3% - 2.7%)
Probit	0.1% (0% - 0.9%)	0.9% (0.3% - 2.7%)	0.1% (0% - 0.8%)	0.1% (0% - 0.9%)	0.2% (0% - 1.1%)	0.3% (0.1% - 1.4%)	0.5% (0.2% - 1.9%)	0.4% (0.1% - 1.7%)
St. Louis, MO								
2-Parameter Logistic	1.4% (0.5% - 3.8%)	19.2% (14.6% - 24.9%)	0.9% (0.3% - 2.9%)	2.9% (1.3% - 6.3%)	5.4% (3% - 9.6%)	8.1% (5% - 12.8%)	10.9% (7.3% - 16%)	10.3% (6.8% - 15.3%)
Probit	0.8% (0.2% - 2.8%)	19.1% (14.4% - 24.7%)	0.4% (0.1% - 1.9%)	2.1% (0.9% - 5.3%)	4.6% (2.4% - 8.8%)	7.4% (4.5% - 12.3%)	10.4% (6.9% - 15.6%)	9.7% (6.3% - 14.9%)
Response = Increase in sRaw >= 200%								
Greene County, MO								
2-Parameter Logistic	0.1% (0% - 1%)	0.5% (0.1% - 1.8%)	0.1% (0% - 1%)	0.1% (0% - 1%)	0.2% (0% - 1.1%)	0.2% (0% - 1.3%)	0.3% (0.1% - 1.5%)	0.3% (0.1% - 1.4%)
Probit	0% (0% - 0.4%)	0.2% (0.1% - 1.2%)	0% (0% - 0.4%)	0% (0% - 0.4%)	0% (0% - 0.5%)	0.1% (0% - 0.6%)	0.1% (0% - 0.8%)	0.1% (0% - 0.8%)
St. Louis, MO								
2-Parameter Logistic	0.5% (0.1% - 1.9%)	8.1% (5.3% - 12.2%)	0.3% (0.1% - 1.5%)	1% (0.3% - 3%)	1.9% (0.8% - 4.5%)	3% (1.5% - 6%)	4.2% (2.3% - 7.5%)	3.9% (2.1% - 7.2%)
Probit	0.2% (0% - 1.2%)	7.9% (5% - 12%)	0.1% (0% - 0.8%)	0.6% (0.2% - 2.3%)	1.4% (0.5% - 3.8%)	2.5% (1.2% - 5.4%)	3.7% (2% - 7%)	3.4% (1.8% - 6.7%)

*Percents are median (50th percentile) percents of asthmatic children. Percents in parentheses below the median are 95% credible intervals based on statistical uncertainty surrounding the SO_2 coefficient in the logistic and probit exposure-response functions. Percents are rounded to the nearest tenth.

**The "as is" exposure scenario was based on monitoring and modeling using 2002 air quality information.

***The current primary SO_2 standards include a 24-hour standard set at 0.14 parts per million (ppm), not to be exceeded more than once per year, and an annual standard set at 0.03 ppm, calculated as the arithmetic mean of hourly averages.

Table 9-9. number of occurrences (in hundreds) of a lung function response among asthmatic children engaged in moderate or greater exertion associated with exposure to SO_2 concentrations under alternative air quality scenarios in a year.*

Exposure-Response Model	"As is" SO_2 Concentrations**	SO_2 Concentrations that Just Meet the Current Standards***	SO_2 Concentrations that Just Meet Alternative nth Percentile 1-Hr Daily Maximum Standards, with Levels (in ppb) of m (Standard Denoted n/m):					
			99/50	99/100	99/150	99/200	99/250	98/200
Response = Increase in sRaw >= 100%								
Greene County, MO								
2-Parameter Logistic	71 (13 - 324)	72 (14 - 327)	71 (13 - 324)	71 (14 - 324)	71 (14 - 324)	71 (14 - 325)	71 (14 - 325)	71 (14 - 325)
Probit	9 (0 - 145)	10 (1 - 148)	9 (0 - 145)	9 (0 - 145)	9 (0 - 145)	9 (0 - 146)	10 (0 - 146)	10 (0 - 146)
St. Louis, MO								
2-Parameter Logistic	417 (81 - 1893)	1179 (484 - 3209)	413 (80 - 1885)	439 (91 - 1935)	497 (118 - 2043)	586 (162 - 2206)	704 (222 - 2413)	674 (207 - 2361)
Probit	58 (3 - 855)	692 (296 - 2176)	55 (2 - 847)	74 (8 - 896)	118 (25 - 1004)	189 (53 - 1166)	286 (96 - 1373)	262 (85 - 1321)
Response = Increase in sRaw >= 200%								
Greene County, MO								
2-Parameter Logistic	22 (2 - 175)	22 (2 - 177)	22 (2 - 175)	22 (2 - 175)	22 (2 - 175)	22 (2 - 176)	22 (2 - 176)	22 (2 - 176)
Probit	1 (0 - 69)	2 (0 - 71)	1 (0 - 69)	1 (0 - 69)	1 (0 - 69)	1 (0 - 70)	1 (0 - 70)	1 (0 - 70)
St. Louis, MO								
2-Parameter Logistic	128 (13 - 1023)	397 (122 - 1618)	126 (13 - 1019)	135 (15 - 1042)	155 (22 - 1091)	186 (33 - 1164)	227 (49 - 1257)	217 (45 - 1234)
Probit	8 (0 - 408)	192 (65 - 967)	8 (0 - 405)	12 (1 - 425)	24 (4 - 470)	43 (9 - 538)	70 (18 - 625)	63 (16 - 603)

*Numbers are median (50th percentile) numbers of asthmatics. Numbers in parentheses below the median are 95% cred ble intervals based on statistical uncertainty surrounding the SO_2 coefficient in the logistic and probit exposure-response functions. Numbers are rounded to the nearest whole number.

**The "as is" exposure scenario was based on monitoring and modeling using 2002 air quality information.

***The current primary SO_2 standards include a 24-hour standard set at 0.14 parts per million (ppm), not to be exceeded more than once per year, and an annual standard set at 0.03 ppm, calculated as the arithmetic mean of hourly averages.

As an illustration of the changes in the number of occurrences of sRaw increases ≥ 100% in all asthmatics across the range of standards analyzed in the St. Louis modeling domain, under the current SO_2 standards the median estimate is 117,900. These estimated occurrences decrease for increasingly more stringent alternative 1-hour standards with the 50 ppb, 99th percentile daily maximium 1-hour standard, the most stringent alternative standard analyzed, reducing the median estimated number of occurrences of this lung function response to 41,300. The pattern of reductions observed for all asthmatics is similar to that observed in asthmatic children.

The estimated occurrences of sRaw responses are much lower in Greene County both due to a smaller population as well as fewer exposure occurrences of elevated 5-minute SO_2 concentrations. We also note that the differences in estimated occurrences of lung function responses associated with all of the air quality scenarios analyzed are much smaller for Greene County than in St. Louis. The minimal differences observed in Greene County among the air quality scenarios analyzed is due to the relatively small differences in the distribution of exposures while engaged in moderate or greater exertion among the air quality scenarios analyzed.

Figures 9-7 (a) and (b) show the percent of asthmatics based on use of the logistic and probit exposure-response models, respectively, engaged in moderate or greater exertion in St. Louis, MO estimated to experience at least one lung function response in a year, defined as an increase in sRaw ≥ 100%, attributable to exposure to SO_2 in each exposure "bin" or interval. Figures 9-8(a) and (b) show these same estimates for the percent of asthmatic children. Figure 9-6 displays the legend for Figures 9-7 and 9-8 indicating the exposure bins used in these figures and Table 9-10 provides definitions of the figures' x-axis labels, which represent alternative air quality scenarios. Similar figures are included in Appendix C for lung function responses defined in terms of ≥ 15% and ≥ 20% decrements in FEV_1 for both asthmatics and asthmatic children. Appendix C also includes similar figures for the Greene County study area. As apparent in Figures 9-7 (a) and (b) and in Figures 9-8(a) and (b), the pattern of the contribution of exposures from different concentration intervals on lung function response is very similar for this risk metric using the two alternative exposure-response models. In comparing the risk estimates for all asthmatics (Figure 9-7) with the risk estimates for asthmatic children (Figure 9-8) the total percent responding is higher for asthmatic children. This is due to the greater percentage of 5-minute exposures while engaged in moderate or greater exertion for asthmatic

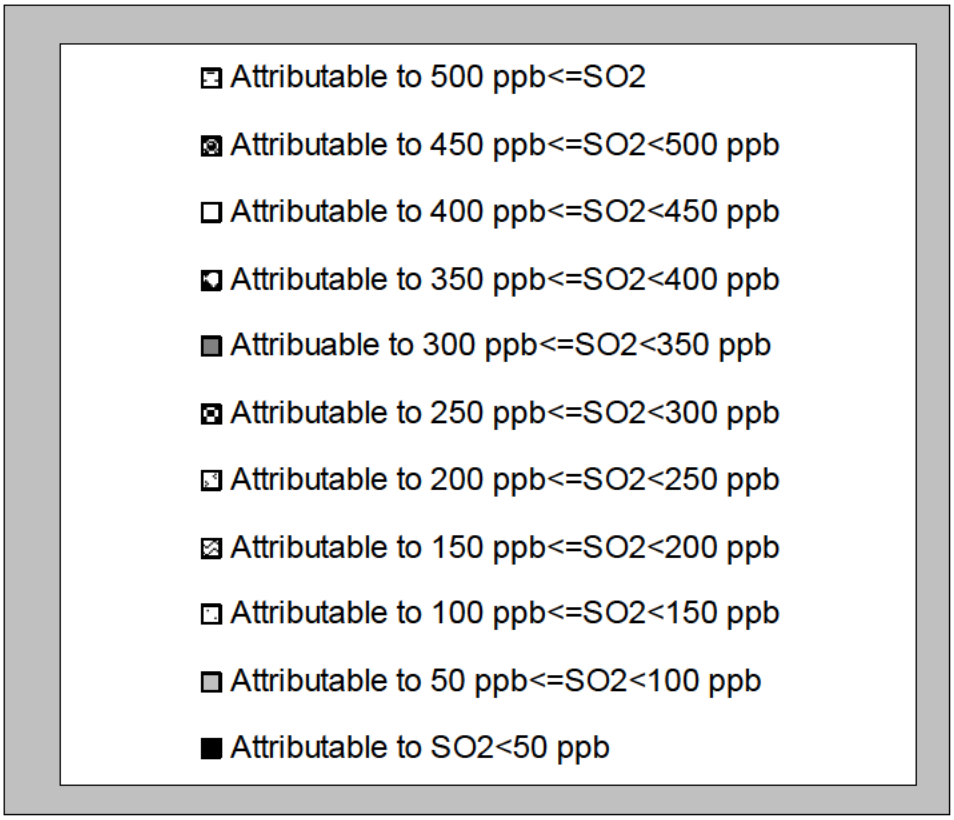
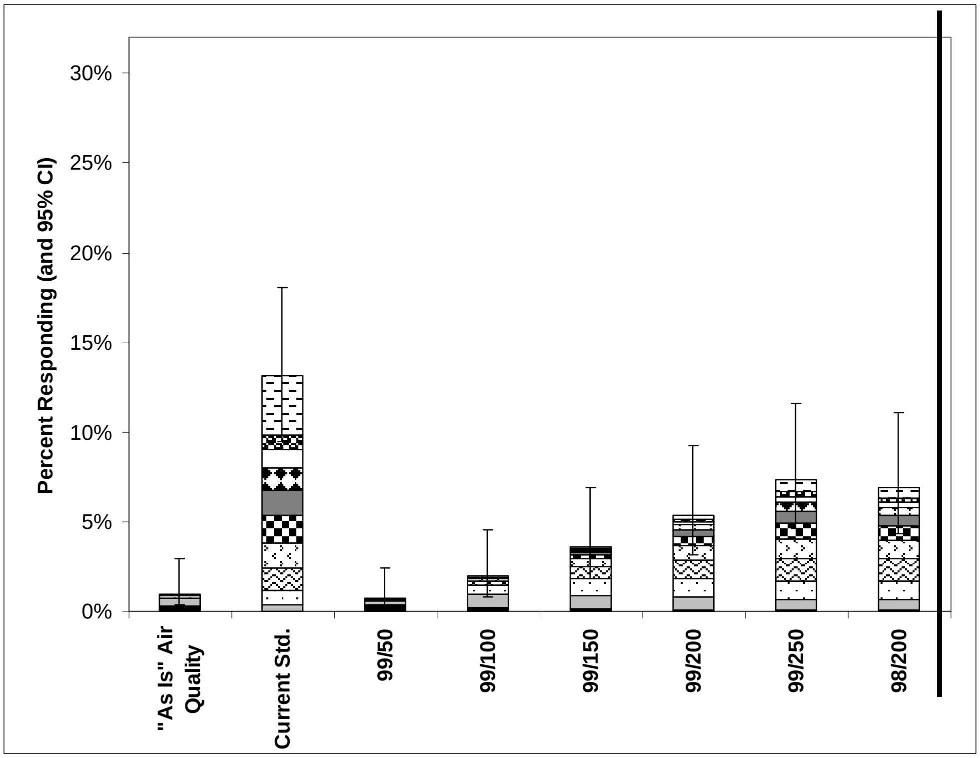


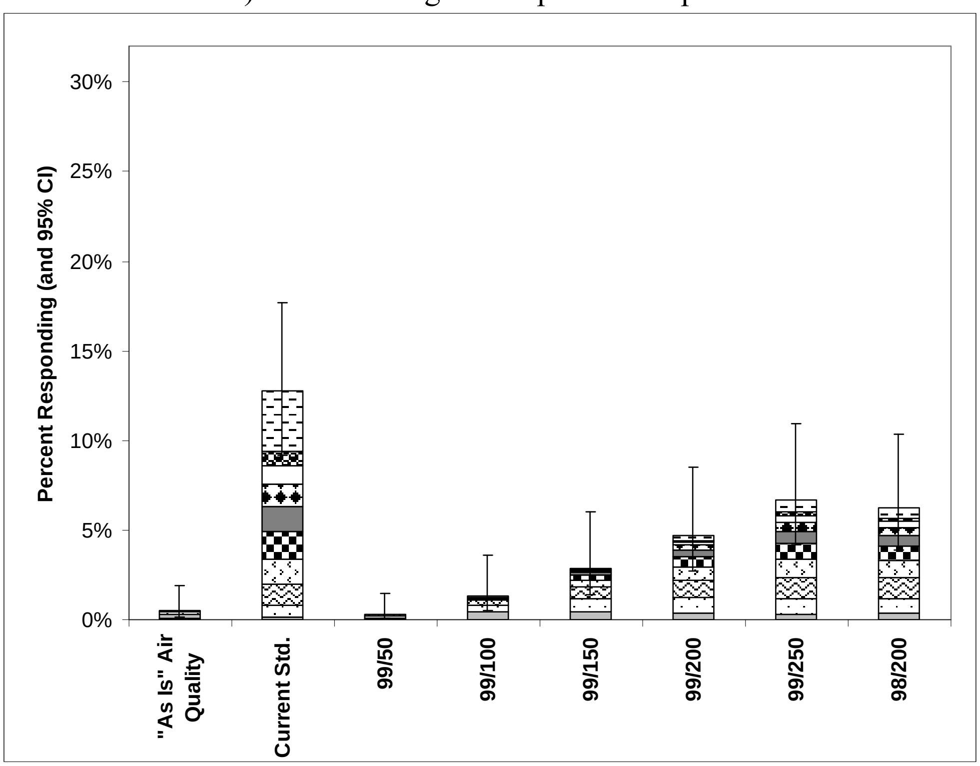
Figure 9-6. Legend for Figures 9-7 and 9-8 showing total and contribution of risk attributable to SO_2 exposure ranges.

Table 9-10. Explanation of labels on the x-axis of Figures 9-7 and 9-8.

Label	**Explanation**
"As Is" Air Quality	Reflects air quality in 2002
Current Standard	Refers to the current suite of standards, which includes a 24-hr standard of 0.14 ppm which is not to be exceeded more than once per year and an annual standard set at 0.03 ppm
99/50	Refers to an alternative standard in which the 99th percentile of the 1-hr daily maximum concentrations must be $\leq$ 50 ppb.
99/100	Refers to an alternative standard in which the 99th percentile of the 1-hr daily maximum concentrations must be $\leq$ 100 ppb.
99/150	Refers to an alternative standard in which the 99th percentile of the 1-hr daily maximum concentrations must be $\leq$ 150 ppb.
99/200	Refers to an alternative standard in which the 99th percentile of the 1-hr daily maximum concentrations must be $\leq$ 200 ppb.
99/250	Refers to an alternative standard in which the 99th percentile of the 1-hr daily maximum concentrations must be $\leq$ 250 ppb.
98/200	Refers to an alternative standard in which the 98th percentile of the 1-hr daily maximum concentrations must be $\leq$ 200 ppb.

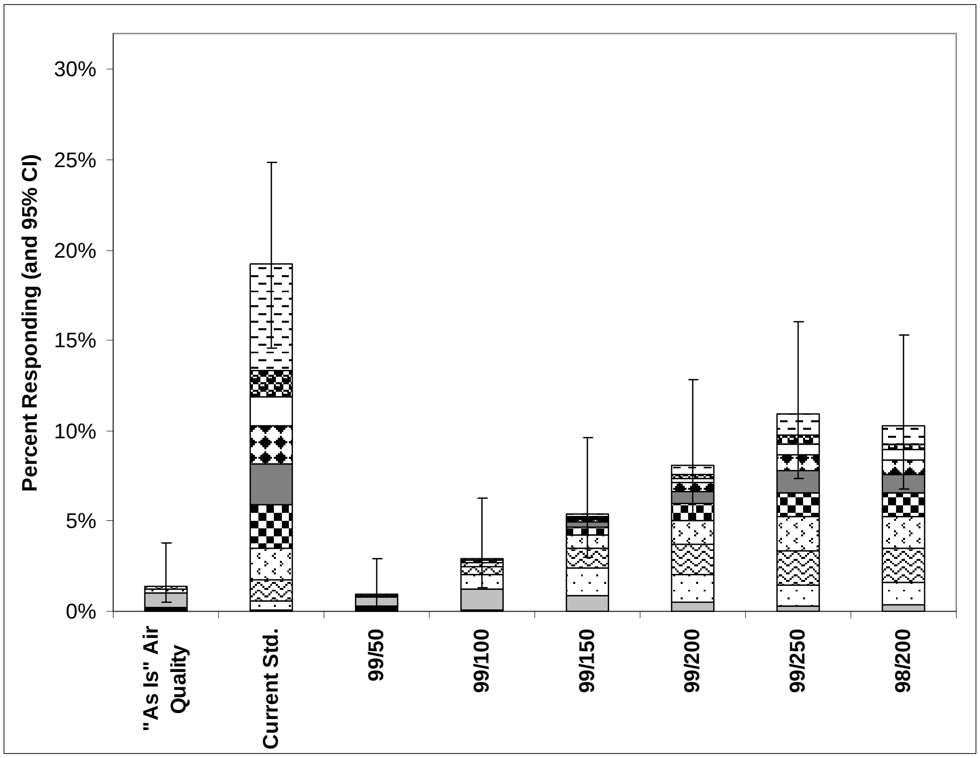


a) Based on Logistic Exposure-Response Model

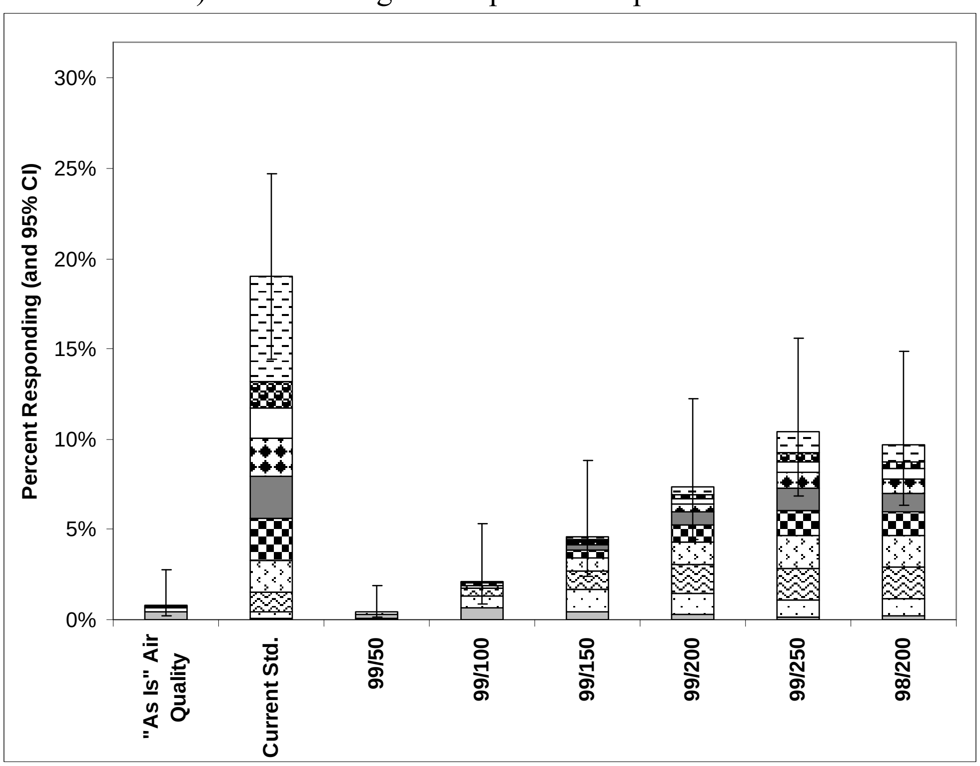


b) Based on Probit Exposure-Response Model

Figure 9-7. Estimated percent of asthmatics experiencing one or more lung function responses (defined as ≥ 100% increase in sRaw) per year associated with short-term (5-minute) exposures to SO_2 concentrations associated with alternative air quality scenarios – total and contribution of 5-minute SO_2 exposure ranges (see Figure 9-6 for legend and Table 9-10 for description of air quality scenarios included on x-axis).



a) Based on Logistic Exposure-Response Model



b) Based on Probit Exposure-Response Model

Figure 9-8. Estimated percent of asthmatic children experiencing one or more lung function responses (defined as ≥ 100% increase in sRaw) per year associated with short-term (5-minute) exposures to SO_2 concentrations associated with alternative air quality scenarios – total and contribution of 5-minute SO_2 exposure ranges (see Figure 9-6 for legend and Table 9-10 for description of air quality scenarios included on x-axis).

children compared to all asthmatics due to the higher frequency of exercise in children compared to adults. Of course the actual number of persons affected is smaller for asthmatic children since they are a subset of all asthmatics.

The numbers of individuals with at least one lung function response attributable to exposures in the lowest exposure concentration bin (i.e., 0 to 50 ppb) are typically quite small. This is because the calculation of numbers of individuals with at least one lung function response uses individuals' highest exposure only. While individuals may be exposed mostly to low SO_2 concentrations, many are exposed at least occasionally to higher levels. Thus, the percentage of individuals in a designated population with at least one lung function response associated with SO_2 concentrations in the lowest bin is likely to be very small, since most individuals are exposed at least once to higher SO_2 levels. For example, the lowest SO_2 exposure bin accounts for only about 0.2 percent of asthmatics estimated to experience at least 1 SO_2-related lung function response. For this very small percent of the population, the lowest exposure bin represents their highest SO_2 exposures under moderate exertion in a year. Figure 9-7 (a) shows a relatively small proportion of asthmatics in St. Louis experiencing at least one response to be experiencing those responses because of exposures in that lowest exposure bin.

While exposures in the lowest bin are not responsible for the greatest portion of the estimated risk for the risk metric expressed as incidence or percent incidence of a defined lung function response 1 or more times per year, exposures in the lowest bin (i.e., 0 to 50 ppb) are responsible for the bulk of the risks expressed as total occurrences of a defined lung function response. As noted in public comments on the 2nd draft SO_2 REA, the assignment of response probability to the midpoint of the exposure bin combined with the lack of more finely divided intervals in this range can lead to significant overestimation of risks based on total occurrences of a defined lung function response. This is because the distribution of population exposures for occurrences is not evenly distributed across the bin, but rather is more heavily weighted toward the lower range of the bin. Thus, combining all exposures estimated to occur in the lowest bin with a response probability assigned to the midpoint of the bin results in a significant overestimate of the risk. Therefore, staff places less weight on the estimated number of occurrences of lung function responses. This overestimation of total occurrences does not impact the risk metric expressed as incidence or percent incidence of a defined lung function response 1 or more times per year because the bulk of the exposures contributing to these risk metrics are not skewed toward the lower range of the reported exposure bins.

9.4 CHARACTERIZING UNCERTAINTY AND VARIABILITY

An important issue associated with any population health risk assessment is the characterization of uncertainty and variability (see section 6.6 for definitions of uncertainty and variability). This section presents a summary and discussion regarding the degree to which variability was incorporated in the health risk assessment for lung function responses and how the uncertainty was characterized for the risk estimates of number and percent of asthmatics and asthmatic children experiencing defined lung function responses associated with 5-minute SO_2 exposures under moderate or greater exertion associated with alternative air quality scenarios.

With respect to variability, the lung function risk assessment incorporates some of the variability in key inputs to the analysis by its use of location-specific inputs for the exposure analysis (e.g., location specific population data, air exchange rates, air quality, and temperature data). The extent to which there may be variability in exposure-response relationships for the populations included in the risk assessment residing in different geographic areas is currently unknown. Temporal variability also is more difficult to address, because the risk assessment focuses on some unspecified time in the future. To minimize the degree to which values of inputs to the analysis may be different from the values of those inputs at that unspecified time, we have used the most current inputs available.

Our approach to characterizing uncertainty includes both qualitative and quantitative elements. From a quantitative perspective, the statistical uncertainty surrounding the estimated SO_2 exposure-response relationships due to sampling error is reflected in the credible intervals that have been provided for the risk estimates in this document. Staff selected a mainly qualitative approach to address other uncertainties in the assessment given the limited data available to inform a probabilistic uncertainty characterization, and time and resource constraints. Following the same general approach described in sections 6.6, 7.4, and 8.11.2 and adapted from WHO (2008), staff performed a qualitative characterization of the components contributing to uncertainty in the lung function risks for all asthmatics and asthmatic children attributable to 5-minute SO_2 exposures under moderate or greater exertion. First, staff identified the important uncertainties. Then, we qualitatively characterized the magnitude (*low*, *medium*, and *high*) and direction of influence (*over, under, both,* and *unknown*) the source of uncertainty may have on the estimated number or percent of persons experiencing a defined lung function response.[96] Finally, staff also qualitatively rated the uncertainty in the knowledge-base regarding each source using *low*, *medium*, and *high* categories. Staff's ratings were based on professional judgment in the context of the knowledge-base for the criteria air pollutants.

Table 9-11 provides a summary of the sources of uncertainty identified in the health risk assessment, the level of uncertainty, and the overall judged bias of each. A brief summary discussion regarding those sources of uncertainty not already examined in Chapters 7 and 8 is included in the comments section of Table 9-11.

The 5-minute daily maximum exposure estimates for asthmatics and asthmatic children while engaged in moderate or greater exertion is an important input to the lung function response risk assessment. A qualitative characterization of uncertainties associated with the exposure model and the inputs to the exposure model are summarized in Table 8-27 and discussed in section 8.11.2.

[96] Definitions of the rating scales can be found in section 6.6.

Table 9-11. Characterization of key uncertainties in the lung function response health risk assessment for St. Louis and Greene County, Missouri.

Source of Uncertainty	Influence of Uncertainty on Lung Function Risk Estimates		Knowledge-Base Uncertainty	Comments[1]
	Direction	Magnitude		
Exposure Model (APEX) Inputs and Algorithms	Unknown	Unknown	Medium to High	See Table 8-27 and section 8.11.2
Spatial representation	Both	Medium	High	See Table 7-16 and discussion in section 7.4.2.4
Air quality adjustment	Both	Low-Medium	Medium	See Table 7-16 and discussion in section 7.4.2.5
Causality	Over	Low-Medium	Low – for levels above 100 ppb Medium – for levels below 100 ppb	INF: While there is very strong support for SO_2 being causally linked to lung function responses within the range of tested exposure levels (i.e., ≥ 200 ppb) and even down to the100 ppb level (where SO_2 was administered by mouthpiece (Sheppard et al. 1981; Koenig et al., 1990)), there is increasing uncertainty about whether SO_2 is causally related to lung-function effects at lower exposure levels below 100 ppb. Since this assessment assumes there is a causal relationship at levels below 100 ppb, the influence of this source of uncertainty would be to over-estimate risk. KB: The SO_2-related lung function responses have been observed in controlled human exposure studies and, thus there is little uncertainty that SO_2 exposures are responsible for the lung function responses observed for SO_2 exposures in the range of levels tested. Given the lack of chamber data at levels below 100 ppb, the KB uncertainty is rated as medium.
Use of 2-parameter logistic and probit models to estimate probabilistic exposure-response relationships	Unknown	Low - for levels at and above 100 ppb Medium – for levels below 100 ppb	Low - for levels above100 ppb Medium – for levels below 100 ppb	KB: It was necessary to estimate responses at SO_2 levels both within the range of exposure levels tested (i.e., 200 to 1,000 ppb) as well as below the lowest exposure levels used in free-breathing controlled human exposure studies (i.e., below 200 ppb). We have developed probabilistic exposure-response relationships using two different functional forms (i.e., probit and 2-parameter logistic). Both functional forms provide reasonable fits to the data in the available range of levels tested. For the risks attributable to exposure levels below 200 ppb, the lowest level tested in free-breathing chamber studies, and particularly below 100 ppb, the lowest level tested in face mask chamber studies, there is greater uncertainty.
Use of 5- and 10-minute lung function response data to estimate 5-	Over	Low	Low	INF: It is reasonable to hypothesize that 10-minute exposures might lead to larger lung function responses, so inclusion of 10-minute response data in the data base used to estimate 5-minute responses would be more likely to result in over-estimating risks. However, there is some evidence that responses generally occur

Source of Uncertainty	Influence of Uncertainty on Lung Function Risk Estimates		Knowledge-Base Uncertainty	Comments[1]
	Direction	Magnitude		
minute lung function risk estimates				in the first few minutes of exposure (see ISA, section 3.1.3.2), suggesting that any overestimation is likely to be very modest in terms of magnitude. KB: The 5-minute lung function risk estimates are based on a combined data set from several controlled human exposure studies, most of which evaluated responses associated with 10-minute exposures. However, since some studies which evaluated responses after 5-minute exposures found responses occurring as early as 5-minutes after exposure, we are using all of the 5- and 10-minute exposure data to represent responses associated with 5-minute exposures. We do not believe that this factor appreciably impacts the risk estimates.
Use of exposure-response data from studies of mild/moderate asthmatics to represent all asthmatics	Under	Medium	Medium	INF & KB: The data set that was used to estimate exposure-response relationships included mild and/or moderate asthmatics. There is uncertainty with regard to how well the population of mild and moderate asthmatics included in the series of SO_2 controlled human exposure studies represent the distribution of mild and moderate asthmatics in the U.S. population. As indicated in the ISA (p. 3-9), the subjects studied represent the responses “among groups of relatively healthy asthmatics and cannot necessarily be extrapolated to the most sensitive asthmatics in the population who are likely more susceptible to the respiratory effects of exposure to SO_2." Thus, the influence of this uncertainty is likely to lead to under-estimating risks and we judge the magnitude of the influence of this uncertainty on the lung function risk estimates to be medium.
Reproducibility of SO_2-induced lung function response	Unknown	Unknown	Low	INF & KB: The risk assessment assumes that the SO_2-induced responses for individuals are reproducible. We note that this assumption has some support in that one study (Linn et al., 1987) exposed the same subjects on two occasions to 0.6 ppm and the authors reported a high degree of correlation ($r > 0.7$ for mild asthmatics and $r > 0.8$ for moderate asthmatics, $p < 0.001$), while observing much lower and nonsignificant correlations ($r = 0.0 – 0.4$) for the lung function response observed in the clean air with exercise exposures.
Use of adult asthmatic lung function response data to estimate exposure-response relationships for asthmatic children	Unknown	Unknown	Low to Medium	INF & KB: Because the vast majority of controlled human exposure studies investigating lung function responses were conducted with adult subjects, the risk assessment relies on data from adult asthmatic subjects to estimate exposure-response relationships that have been applied to all asthmatic individuals, including children. The ISA (section 3.1.3.5) indicates that there is a strong body of evidence that suggests adolescents may experience many of the same respiratory effects at similar SO_2 levels, but recognizes that these studies administered SO_2 via inhalation through a mouthpiece rather than an exposure chamber. This technique bypasses nasal absorption of SO_2 and can result in an increase in lung SO_2 uptake.

Source of Uncertainty	Influence of Uncertainty on Lung Function Risk Estimates		Knowledge-Base Uncertainty	Comments[1]
	Direction	Magnitude		
				Therefore, the uncertainty is greater in the risk estimates for asthmatic children. The direction and magnitude of this uncertainty on the lung function risk estimates is unknown.
Exposure history	Both	Low	Medium	INF & KB: The risk assessment assumes that the SO_2-induced response on any given day is independent of previous SO_2 exposures. For some pollutants (e.g., ozone) prior exposure history can lead to both enhanced and diminished lung function responses depending on the pattern of exposure. Since the assessment is only included the highest daily 5-minute exposure under moderate or greater exertion, and the influence of prior exposures might lead to either enhanced or diminished response based on what we know about other pollutants (i.e., ozone), staff rated the magnitude of the influence of this uncertainty to be low. Given the lack of available information to directly assess this uncertainty for SO_2 exposures in chamber studies staff rated the KB uncertainty to be medium.
Assumed no interaction effect of other co-pollutants on SO_2-related lung function responses	Under	Medium	Medium	INF: Staff judges that it is more likely that exposure to other pollutants might increase the magnitude of lung function response and thus increase the risk estimates. Thus, assuming no interaction is more likely to result in under-estimating risks. KB: Because the controlled human exposure studies used in the risk assessment involved only SO_2 exposures, there is little information to judge whether or not estimates of SO_2-induced health responses are affected by the presence of other pollutants (e.g., $PM_{2.5}$, O_3, NO_2).

Notes:
[1]INF refers to comments associated with the influence rating; KB refers to comments associated with the knowledge-base rating.

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9.5 KEY OBSERVATIONS

Presented below are key observations related to the risk assessment for lung function responses in asthmatics and asthmatic children associated with 5-minute exposures to SO_2 while engaged in moderate or greater exertion:

- Lung function responses estimated to result from 5-minute exposures to SO_2 were estimated for two areas in Missouri (i.e., Greene County and St. Louis) which have significant emission sources of SO_2 for 2002 air quality and for air quality adjusted to simulate just meeting the current suite of annual and 24-hour SO_2 standards and just meeting several alternative 1-hour daily maximum SO_2 standards.
- A number of factors would be expected to contribute to differences in estimated SO_2-related lung function responses across different locations. These include exposure-related differences, such as population density, SO_2 emission density, location and types of SO_2 sources, prevalence of air conditioning, and time spent outdoors, which are discussed in section 8.10, as well as other factors such as differences in population sensitivity to SO_2 and asthma prevalence rates. As discussed in section 8.10, St. Louis County has a medium to high SO_2 emission density and a medium to high population density relative to other medium to high population density urban areas in the U.S. Relative to the St. Louis study area, Greene County is a more rural county with much lower SO_2 emission density and much lower population density. Taken together, the risk estimates for these two locations provide useful insights about urban and rural counties with significant SO_2 emission sources.
- The lung function risk estimates for the St. Louis study area are much higher than for Greene County, which is not unexpected given the greater population density and the much greater SO_2 emission density. Staff believes that the St. Louis risk estimates provide a useful perspective on the likely overall magnitude and pattern of lung function responses associated with various SO_2 air quality scenarios in urban areas within the U.S. that have similar population densities and SO_2 emission densities.
- Risk estimates for Greene County are considerably lower than for the St. Louis study area both with respect to estimated number of asthmatics and the percentage of asthmatics estimated to experience one or more moderate or severe lung function responses. As discussed above, this is not unexpected given the rural nature of Greene County and the fact that it has much lower SO_2 emission density and lower population density than the St. Louis study area.
- Of the alternative regulatory scenarios analyzed, only the 50 ppb/99th percentile daily maximum 1-hr standard is estimated to reduce risks in one of the two modeling study areas (i.e., St. Louis) relative to the "as is" air quality scenario. This reduction is observed for both number and percent of asthmatics and asthmatic children estimated to experience 1 or more lung function responses per year.
- For the St. Louis study area median risk estimates for 1 or more occurrences of moderate lung function responses (i.e., based on sRaw ≥ 100%) per year range from about 11% down to 0.9% of asthmatic children using the 2-parameter logistic exposure-response

model compared to 10.4% down to 0.4% of asthmatic children using the probit exposure-response model for alternative 99th percentile daily maximum 1-hour standards ranging from 250 ppb down to 50 ppb. In general, the risk estimates associated with the use of the probit exposure-response model are lower than those based on the logistic model.

- For the St. Louis study area median risk estimates for 1 or more occurrences of severe lung function responses (i.e., based on sRaw ≥ 200%) per year range from 4.2% down to 0.3% of asthmatic children using the 2-parameter logistic exposure-response model compared to 3.7% down to 0.1% of asthmatic children using the probit exposure-response model for alternative 99th percentile daily maximum 1-hour standars ranging from 250 ppb down to 50 ppb.
- In terms of estimated percentage of asthmatics or asthmatic children experiencing 1 or more lung function responses, risks are greater for asthmatic children, likely because they spend more time at higher exertion levels than adults.
- A broad range of SO_2 exposure concentration intervals, as high as 500 ppb, contributes to the estimated risks of experiencing 1 or more lung function responses per year for some of the standards considered in the assessment. For standards in the range of 100 to 150 ppb SO_2 exposure concentration intervals below 200 ppb contribute most of the estimated risks of experiencing 1 or more lung function response per year.
- Important uncertainties and limitations associated with the risk assessment which were discussed above in section 9.3 and which should be kept in mind as one considers the quantitative risk estimates include:

  - uncertainties related to the exposure estimates which are an important input to the risk assessment which staff rated as medium to high with respect to the knowledge base and which staff rated the overall influence of these uncertainties on the magnitude of the lung function risk estimates as unknown;

  - uncertainties associated with the air quality adjustment procedure that was used to simulate just meeting the current annual and several alternative 1-h daily maximum standards which staff rated as medium with respect to the knowledge base uncertainty and low-medium in terms of the influence of this uncertainty on the magnitude of the lung function risk estimates;

  - statistical uncertainty due to sampling error which is characterized in the assessment through presentation of 95% credible intervals;

  - uncertainty about the shape of the exposure-response relationship for lung function responses at levels well below 200 ppb, the lowest level examined in free-breathing single pollutant controlled human exposure studies which staff rated as low for levels at and above 100 ppb and medium for levels below 100 ppb with respect to knowledge base uncertainty and the influence of this uncertainty on the lung function risk estimates;

  - uncertainty with respect to how well the estimated exposure-response relationships reflect asthmatics with more severe disease than those tested in chamber studies which staff rated as medium with respect to knowledge base uncertainty and the influence of this uncertainty on the magnitude of the lung function risk estimates;

- uncertainty about whether the presence of other pollutants in the ambient air would enhance the SO_2-related responses observed in the controlled human exposure studies which staff rated as medium with respect to knowledge base uncertainty and the influence of this uncertainty on the magnitude of the lung function risk estimates;

- uncertainty about the extent to which the risk estimates presented for the two modeled areas in Missouri are representative of other locations in the U.S. with significant SO_2 point and area sources which staff rated as high with respect to knowledge base uncertainty and medium for the influence of this uncertainty on the magnitude of the lung function risk estimates;

- other uncertainties such as the assumption about causality, use of both 5- and 10-minute data to estimate 5-minute effects, the assumption of reproducible responses, use of adult data to estimate exposure-response for children, and influence of exposure history were generally rated as low to medium with respect to knowledge base uncertainty and low or unknown impact on the magnitude of these uncertainties on the lung function risk estimates.

10. EVIDENCE- AND EXPOSURE/RISK-BASED CONSIDERATIONS RELATED TO THE PRIMARY SO_2 NAAQS

10.1 INTRODUCTION

This chapter considers the scientific evidence in the ISA (EPA, 2008a) and the air quality, exposure and risk characterization results presented in this document as they relate to the adequacy of the current SO_2 primary NAAQS and potential alternative primary SO_2 standards. The available scientific evidence includes epidemiologic, controlled human exposure, and animal toxicological studies. The SO_2 air quality, exposure, and risk analyses described in Chapters 7-9 of this document include characterization of air quality, exposure, and health risks associated with recent SO_2 concentrations and with SO_2 concentrations adjusted to simulate scenarios just meeting the current suite of standards and potential alternative 1-hour standards. In considering the scientific evidence and the exposure- and risk-based information, we have also considered relevant uncertainties. Section 10.2 of this chapter presents our general approach to considering the adequacy of the current standards and the need for potential alternative standards. Sections 10.3 and 10.4 focus on evidence- and exposure-/risk-based considerations related to the adequacy of the current 24-hour and annual standards respectively, while section 10.5 focuses on such considerations related to the need for potential alternative standards (in terms of the indicator, averaging time, form, and level).

These considerations are intended to inform the Agency's policy assessment of a range of options with regard to the SO_2 NAAQS. A final decision will draw upon scientific information and analyses about health effects, population exposure and risks, and policy judgments about the appropriate response to the range of uncertainties that are inherent in the scientific evidence and air quality, exposure, and risk analyses. Our approach to informing these judgments, discussed more fully below, is based on a recognition that the available health effects evidence reflects a continuum consisting of ambient levels at which scientists generally agree that health effects are likely to occur through lower levels at which the likelihood and magnitude of the response become increasingly uncertain. This approach is consistent with the requirements of the NAAQS provisions of the Act and with how EPA and the courts have historically interpreted the Act. These provisions require the Administrator to establish primary standards that, in the Administrator's judgment, are requisite to protect public health with an adequate margin of safety. In so doing, the Administrator seeks to establish standards that are neither more nor less stringent than necessary for this purpose. The Act does not require that primary standards be set at a zero-risk level but rather at a level of protection that avoids unacceptable risks to public health, including the health of at risk populations.

10.2 GENERAL APPROACH

This section describes the general approach that staff is taking to inform decisions regarding the need to retain or revise the current SO_2 NAAQS. The current standards, a 24-hour average of 0.14 ppm (equivalent to 144 ppb), not to be exceeded more than one time per year, and an annual average of 0.03 ppm (equivalent to 30.4 ppb) were retained by the Administrator in the most recent review completed in 1996 (61 FR 25566). The decision to retain the 24-hour standard was largely based on an assessment of epidemiologic studies that supported a likely association between 24-hour average SO_2 exposure and daily mortality, aggravation of bronchitis, and small, reversible declines in children's lung function (EPA 1982, 1994a). Similarly, the decision to retain the annual standard (see section 10.4) was largely based on an assessment of epidemiologic studies finding an association between respiratory symptoms/illnesses and annual average SO_2 concentrations (EPA 1982, 1994a).

The previous review of the SO_2 NAAQS also addressed the question of whether an additional short-term standard (e.g., 5-minute) was necessary to protect against short-term peak SO_2 exposures. Based on the scientific evidence, the Administrator judged that repeated exposures to 5-minute peak levels ≥ 600 ppb could pose a risk of significant health effects for asthmatic individuals at elevated ventilation rates (61 FR 25566). The Administrator also concluded that the likely frequency of such effects should be a consideration in assessing the overall public health risks. Based upon an exposure analysis conducted by EPA (see section 1.1.3), the Administrator concluded that exposure of asthmatics to SO_2 levels that could reliably elicit adverse health effects was likely to be a rare event when viewed in the context of the entire population of asthmatics, and therefore did not pose a broad public health problem for which a NAAQS would be appropriate (61 FR 25566). On May 22, 1996, EPA published its final decision to retain the existing 24-hour and annual standards and not to promulgate a 5-minute standard (61 FR 25566). The decision not to set a 5-minute standard was ultimately challenged by the American Lung Association and remanded back to EPA for further explanation on January 30, 1998 by the D.C. Circuit Court of Appeals (see section 1.1.1). Specifically, the court gave EPA the opportunity to provide additional rationale to support the Agency judgment that 5-

minute peaks of SO_2 do not pose a public health problem when viewed from a national perspective.

To inform the range of options that the Agency will consider in the current review of the primary SO_2 NAAQS, the general approach we have adopted builds upon the approaches used in reviews of other criteria pollutants, including the most recent reviews of the Pb, O_3, PM, and NO_2 NAAQS (EPA, 2007i; EPA, 2007e; EPA, 2005, EPA 2008d). As in these other reviews, we consider the implications of placing more or less weight or emphasis on different aspects of the scientific evidence and the exposure/risk-based information, recognizing that the weight to be given to various elements of the evidence and exposure/risk information is part of the public health policy judgments that the Administrator will make in reaching decisions on the standards.

A series of general questions frames our approach to considering the scientific evidence and exposure/risk-based information. First, our consideration of the scientific evidence and exposure/risk-based information with regard to the adequacy of the current standards is framed by the following questions:

- To what extent does evidence and exposure/risk-based information that has become available since the last review reinforce or call into question evidence for SO_2-associated effects that were identified in the last review?
- To what extent has evidence for different health effects and/or sensitive populations become available since the last review?
- To what extent have uncertainties identified in the last review been reduced and/or have new uncertainties emerged?
- To what extent does evidence and exposure/risk-based information that has become available since the last review reinforce or call into question any of the basic elements of the current standards?

To the extent that the available evidence and exposure/risk-based information suggests it may be appropriate to consider revision of the current standards, we consider that evidence and information with regard to its support for consideration of standards that are either more or less protective than the current standards. This evaluation is framed by the following questions:

- Is there evidence that associations, especially causal or likely causal associations, extend to ambient SO_2 concentrations as low as, or lower than, the concentrations that have previously been associated with health effects? If so, what are the important uncertainties associated with that evidence?

• Are exposures above benchmark levels and/or health risks estimated to occur in areas that meet the current standards? If so, are the estimated exposures and health risks important from a public health perspective? What are the important uncertainties associated with the estimated risks?

To the extent that there is support for consideration of a revised standard, we then consider the specific elements of the standard (indicator for gaseous SO_x, averaging time, form, and level) within the context of the currently available information. In so doing, we address the following questions:

- Does the evidence provide support for considering a different indicator for gaseous SO_x?
- Does the evidence provide support for considering different averaging times?
- What ranges of levels and forms of alternative standards are supported by the evidence, and what are the associated uncertainties and limitations?
- To what extent do specific averaging times, levels, and forms of alternative standards reduce the estimated exposures above benchmark levels and estimated risks attributable to SO_2, and what are the uncertainties associated with the estimated exposure and risk reductions?

The following discussion addresses the questions outlined above and presents staff's conclusions regarding the scientific evidence and the exposure-/risk-based information specifically as they relate to the current and potential alternative standards. This discussion is intended to inform the Agency's consideration of policy options that will be presented during the rulemaking process, together with the scientific support for such options. Sections 10.3 and 10.4 consider the adequacy of the current standards while section 10.5 considers potential alternative standards in terms of indicator, averaging time, form, and level. Each of these sections considers key conclusions as well as the uncertainties associated with the evidence and exposure/risk analyses.

10.3 ADEQUACY OF THE CURRENT 24-HOUR STANDARD

10.3.1 Introduction

In the last review of the SO_2 NAAQS, retention of the 24-hour standard was based largely on epidemiologic studies conducted in London in the 1950's and 1960's. The results of those studies suggested an association between 24-hour average levels of SO_2 and increased daily mortality and aggravation of bronchitis when in the presence of elevated levels of PM (53 FR 14927). Additional epidemiologic evidence suggested that elevated SO_2 levels were associated with the possibility of small, reversible declines in children's lung function (53 FR 14927). However, it was noted that in the locations where these epidemiologic studies were conducted, high SO_2 levels were usually accompanied by high levels of PM, thus making it difficult to disentangle the individual contribution each pollutant had on these health outcomes. It was also noted that rather than 24-hour average SO_2 levels, the health effects observed in these studies may have been related, at least in part, to the occurrence of shorter-term peaks of SO_2 within a 24-hour period (53 FR 14927).

In this review, as described in Chapter 4, the ISA concludes that there is sufficient evidence to infer "a causal relationship between respiratory morbidity and short-term exposure to SO_2" (ISA, section 5.2). The ISA states that the strongest evidence for this judgment is from human exposure studies demonstrating decreased lung function and/or increased respiratory symptoms in exercising asthmatics exposed for 5-10 minutes to ≥ 200 ppb SO_2 (ISA, section 5.2). Supporting this conclusion is a larger body of epidemiologic studies published since the last review observing positive associations between 1-hour daily maximum or 24-hour average SO_2 concentrations and respiratory symptoms, ED visits, and hospital admissions (ISA, section 5.2). Thus, the ISA bases its causal determination between short-term SO_2 exposure and respiratory morbidity on respiratory effects associated with averaging times from 5-minutes to 24-hours.

Here, we will examine the health information first presented in Chapter 4 as it relates to the adequacy of the current 24-hour standard (as well as the annual standard, see section 10.4). Section 10.3.2 will discuss the epidemiologic results. The epidemiologic literature is particularly relevant for evaluating the adequacy of the current 24-hour standard given that the majority of these studies examined possible associations between 24-hour average SO_2 concentrations and respiratory morbidity endpoints (e.g. ED visits or hospitalizations for all respiratory causes). Section 10.3.3 will then discuss the air quality, exposure, and risk based information as it relates to the adequacy of the current 24-hour standard. These analyses are first presented in Chapters 7-9 and describe exposures and their associated health risks given air quality just meeting the current standards. More specifically, these analyses simulate air quality to just meet the current 24-hour or annual standard, whichever is controlling in a given area, and then describe exposure and health risks associated with 5-minute SO_2 benchmark concentrations. As described in section 6.2, these benchmark concentrations are SO_2 exposure levels found in controlled human exposure studies to result in decrements in lung function and/or respiratory symptoms in exercising asthmatics. Finally, considering the evidence presented in section 10.3.2 and the air quality, exposure, and risk information presented in section 10.3.3, staff presents conclusions with regard to the overall adequacy of the current 24-hour standard in section 10.3.4.

10.3.2 Evidence-based considerations

As mentioned above, the ISA found supporting evidence for its conclusion that there is a causal relationship between short-term SO_2 exposures and respiratory morbidity from the reported associations observed in epidemiologic studies of respiratory symptoms and ED visits and hospitalizations. In considering the adequacy of the current 24-hour standard, we note that many epidemiologic studies demonstrating positive associations between ambient SO_2 and respiratory symptoms, ED visits, and hospitalizations were conducted in areas where SO_2 concentrations were less than the level of the current 24-hour (as well as the annual; see section 10.4) NAAQS. With regard to these epidemiologic studies, we note that the ISA characterizes the evidence for respiratory effects as consistent and coherent. The evidence is consistent in that positive associations are reported in studies conducted in numerous locations and with a variety of methodological approaches (ISA, section 5.2). It is coherent in the sense that respiratory symptom results from epidemiologic studies predominantly using 1-hour daily maximum or 24-hour average SO_2 concentrations are generally in agreement with the respiratory symptom results from controlled human exposure studies of 5-10 minutes. These results are also coherent in that the respiratory effects observed in controlled human exposure studies of 5-10 minutes provide a basis for a progression of respiratory morbidity that could lead to the ED visits and hospitalizations observed in epidemiologic studies (ISA, section 5.2).

However, it should be noted that interpretation of the epidemiologic literature is complicated by the fact that SO_2 is but one component of a complex mixture of pollutants present in the ambient air. The matter is further complicated by the fact that SO_2 is a precursor to sulfate, which can be a principal component of PM. Ultimately, this uncertainty calls into question the extent to which effect estimates from epidemiologic studies reflect the independent contribution of SO_2 to the adverse respiratory outcomes assessed in these studies. In order to provide some perspective on this uncertainty, the ISA evaluates epidemiologic studies that employ multi-pollutant models. The ISA concludes that these analyses indicate that although copollutant adjustment has varying degrees of influence on SO_2 effect estimates, the effect of

SO_2 on respiratory health outcomes appears to be generally independent of the effects of gaseous copollutants, including NO_2 and O_3 (ISA, section 5.2). With respect to $PM_{10,}$ evidence of an independent SO_2 effect on respiratory health is less consistent, with some of the positive ED visit and hospitalization results becoming negative (although results were not statistically significantly negative) after inclusion of PM_{10} in regression models (ISA, section 3.1.4.6). In epidemiologic studies of respiratory symptoms, the SO_2 effect estimate often remained relatively unchanged after inclusion of PM_{10} in multipolutant models (although the effect estimate may have lost statistical significance; ISA, section 3.1.4.1). The ISA also finds that SO_2-effect estimates generally remained relatively unchanged in the limited number of studies that included $PM_{2.5}$ and/or $PM_{10-2.5}$ in multipolutant models (ISA, section 3.1.4.6). Taken together, the ISA concludes studies employing multi-pollutant models do suggest that SO_2 has an independent effect on respiratory morbidity outcomes (see Chapter 4; ISA, section 5.2). Thus, the results of experimental and epidemiologic studies form a plausible and coherent data set that supports a relationship between SO_2 exposures and respiratory morbidity endpoints, and calls into question the adequacy of the 24-hour standard to protect public health.

10.3.3 Air Quality, exposure and risk-based considerations

In addition to the evidence-based considerations described above, staff has considered the extent to which exposure- and risk-based information can inform decisions regarding the adequacy of the current 24-hour SO_2 standard, taking into account key uncertainties associated with the estimated exposures and risks. For this review, we have employed three approaches. In the first approach, SO_2 air quality levels were used as a surrogate for exposure. In the second approach, modeled estimates of human exposure were developed for all asthmatics and asthmatic children living in Greene County and St. Louis MO. Notably, this second approach considers time spent in different microenvironments, as well as time spent at elevated ventilation rates. In each of the first two approaches, health risks have been characterized by comparing estimates of air quality or exposure to 5-minute potential health effect benchmarks. These benchmarks are based on controlled human exposure studies involving known 5-10 minute SO_2 exposure levels and corresponding decrements in lung function, and/or increases in respiratory symptoms in asthmatics at elevated ventilation rates (e.g., while exercising; see section 6.2 for further discussion of benchmark levels). In addition to these analyses, staff conducted a quantitative risk assessment for lung function responses associated with 5-minute exposures to characterize SO_2-

related health risks. This assessment combined outputs from the exposure analysis with estimated exposure-response functions derived from the combined individual data from controlled human exposure studies to estimate the number and percent of exposed asthmatics that would experience moderate or greater lung function responses (in terms of FEV_1 and sRaw) at least once per year and to estimate the total number of occurrences of these lung function responses per year (see Chapter 9).

The respiratory effects (i.e., decrements in FEV_1, increases in sRaw, and/or respiratory symptoms) considered in the air quality, exposure, and risk analyses mentioned above are considered by staff to be adverse to the health of asthmatics. As described in section 4.3, staff bases this conclusion on: 1) guidelines published by the ATS; 2) conclusions from the ISA and previous NAAQS reviews; and 3) advice from CASAC. Being mindful of this conclusion, we note the following key points from the ISA:

- Approximately 5-30% of exercising asthmatics are expected to experience moderate or greater lung function decrements (i.e., ≥ 100% increase in sRaw and/or a ≥ 15% decrease in FEV_1) following exposure to 200- 300 ppb SO_2 for 5-10 minutes (ISA, section 3.1).
- Approximately 20-60% of exercising asthmatics are expected to experience moderate or greater lung function decrements (i.e ≥ 100% increase in sRaw and/or a ≥ 15% decrease in FEV_1) following exposure to 400-1000 ppb SO_2 for 5-10 minutes (ISA, Table 5-3).
- At concentrations ≥ 400 ppb, moderate or greater statistically significant decrements in lung function are frequently associated with respiratory symptoms (ISA, section 3.1).
- There is no evidence to indicate that exposure to 200-300 ppb SO_2 for 5- 10 minutes represents a threshold below which no respiratory effects occur.

Given the discussion in section 4.3 and the key points presented above, staff concludes that exposure to 5-10 minute SO_2 concentrations at least as low as 200 ppb can result in adverse respiratory effects in some asthmatics. We note that this conclusion is in agreement with CASAC comments offered on the first draft SO_2 REA. The CASAC letter to the Administrator states: "CASAC believes strongly that the weight of clinical and epidemiology evidence indicates there are detectable clinically relevant health effects in sensitive subpopulations down to a level at least as low as 0.2 ppm SO_2 (Henderson 2008)." This CASAC letter also states: "these sensitive subpopulations represent a substantial segment of the at-risk population (Henderson 2008)." As an additional matter, we note that over 20 million people in the U.S. have asthma (EPA 2008d), and therefore, exposure to SO_2 likely represents a significant public health issue.

Thus, staff finds it is appropriate to consider the air quality, exposure and risk results as they relate to the adequacy of the current 24-hour standard (as well as the current annual (see section 10.4) and potential alternative (see section 10.5) standards). This is because these analyses provide useful information with respect to the current 24-hour standard's ability to limit: 1) 5-10 minute SO_2 concentrations associated with decrements in lung function and/or respiratory symptoms in exercising asthmatics; and 2) the estimated number of exercising asthmatics expected to experience a moderate or greater lung function response.

10.3.3.1 Key Uncertainties

The way in which air quality, exposure, and risk results will inform ultimate decisions regarding the SO_2 standard will depend upon the weight placed on each of the analyses when uncertainties associated with those analyses are taken into consideration. Sources of uncertainty associated with each of the analyses (air quality, exposure, and quantitative risk) are briefly presented below and are described in more detail in Chapters 7-9 of this document. Although we are discussing these uncertainties within the context of the adequacy of the 24-hour standard, they apply equally to consideration of the annual, as well as alternative 1-hour standards.

Air Quality Analysis

A number of key uncertainties should be considered when interpreting air quality results with regard to decisions on the standards. A general description of such uncertainties is highlighted below, and these, as well as other sources of uncertainty are discussed in greater depth in section 7.4 of this document.

- Staff used the broader SO_2 ambient monitoring network, in addition to subsets of data from this network, to characterize air quality in the U.S. There was general agreement in the monitor site attributes and emissions sources potentially influencing ambient monitoring concentrations for each set of data analyzed. However, staff noted that the greatest uncertainty, compared to several other sources of uncertainty, was in the spatial representativeness of both the overall monitoring network and the subsets chosen for detailed analyses.
- Staff developed a statistical model to estimate 5-minute maximum SO_2 concentrations at monitors that reported only 1-hour SO_2 concentrations. Cross-validation of the statistical model for where 5-minute SO_2 measurements existed indicated reasonable model performance. The greatest difference in the predicted versus observed numbers of benchmark exceedances occurred at the lower and upper tails of the distribution, indicating greater uncertainty in the predictions at similarly representative monitors.

- The air quality characterization assumes that the ambient monitoring data and the estimated days per year with benchmark exceedances can serve as an indicator of exposure. Longer-term personal SO_2 exposure (i.e., days to weeks) concentrations are correlated with and are a fraction of ambient SO_2 concentrations. However, uncertainty remains in this relationship when considering short-term (i.e., 5-minute) averaging times because of the lack of comparable measurement data.

St Louis and Greene Counties Exposure Analysis

A number of key uncertainties should be considered when interpreting the St. Louis and Greene County exposure results with regard to decisions on the standards. Such uncertainties are highlighted below, and these, as well as other sources of uncertainty, are also discussed in greater depth in section 8.11 of this document.

- It was necessary for staff to derive an area source emission profile rather than use a default profile to improve the agreement between ambient measurements and predicted 1-hour SO_2 concentrations. The improved model performance reduces uncertainty in the 1-hour SO_2 concentrations predictions, but nonetheless remains as an important uncertainty in the absence of actual local source emission profiles.
- Staff performed the exposure assessment to better reflect both the temporal and spatial representation of ambient concentrations and to estimate the rate of contact of individuals with 5-minute SO_2 concentrations while engaged in moderate or greater exertion. Estimated annual average SO_2 exposures in the two exposure modeling domains are consistent with long-term personal exposures (i.e., days to weeks) measured in other U.S. locations. However, uncertainty remains in the estimated number of persons with 5-minute SO_2 concentrations above benchmark levels because of the lack of comparable measurement data, particularly considering both the short-term averaging time and geographic location.
- While all 5-minute ambient SO_2 concentrations were estimated by the exposure model, each hour was comprised of the maximum 5-minute SO_2 concentration and eleven other 5-minute SO_2 concentrations normalized to the 1-hour mean concentration. Staff assumed that this approach would reasonably estimate the number of individuals exposed to peak concentrations. Sensitivity analyses revealed that both the number of persons exposed and where peak exposures occur can vary when considering an actual 5-minute temporal profile.

St Louis and Greene Counties Quantitative Risk Analysis

A number of key uncertainties should be considered when interpreting the St. Louis and Greene County quantitative risk estimated for lung function responses with regard to decisions on the standards. Such uncertainties are highlighted below, and these, as well as other sources of uncertainty, are also discussed in greater depth in section 9.3 of this document.

- It was necessary to estimate responses at SO_2 levels below the lowest exposure levels used in the free-breathing controlled human exposure studies (i.e., below 200 ppb). We have developed probabilistic exposure-response relationships using two different functional forms (i.e., probit and 2-parameter logistic), but nonetheless there remains greater uncertainty in responses below 200 ppb because of the lack of comparable experimental data.
- The risk assessment assumes that the SO_2-induced responses for individuals are reproducible. We note that this assumption has some support in that one study (Linn et al., 1987) exposed the same subjects on two occasions to 600 ppb and the authors reported a high degree of correlation while observing a much lower correlation for the lung function response observed in the clean air with exercise exposure.
- Because the vast majority of controlled human exposure studies investigating lung function responses were conducted with adult subjects, the risk assessment relies on data from adult asthmatic subjects to estimate exposure-response relationships that have been applied to all asthmatic individuals, including children. The ISA (section 3.1.3.5) indicates that there is a strong body of evidence that suggests adolescents may experience many of the same respiratory effects at similar SO_2 levels, but recognizes that these studies administered SO_2 via inhalation through a mouthpiece (which can result in an increase in lung SO_2 uptake) rather than an exposure chamber. Therefore, the uncertainty is greater in the risk estimates for asthmatic children.
- Because the controlled human exposure studies used in the risk assessment involved only SO_2 exposures, it is assumed that estimates of SO_2-induced health responses are not affected by the presence of other pollutants (e.g., $PM_{2.5}$, O_3, NO_2).

10.3.3.2 Assessment Results

As previously mentioned, the ISA finds the evidence for an association between respiratory morbidity and SO_2 exposure to be "sufficient to infer a causal relationship" (ISA, section 5.2) and that the "definitive evidence" for this conclusion comes from the results of controlled human exposure studies demonstrating decrements in lung function and/or respiratory symptoms in exercising asthmatics (ISA, section 5.2). Accordingly, the exposure and risk analyses presented in this document focused on exposures and risks associated with 5-minute peaks of SO_2 in excess of the potential health effect benchmark values of 100, 200, 300, and 400 ppb SO_2 (see section 6.2). In considering the results presented in these analyses, we particularly note exceedances or exposures with respect to the 200 and 400 ppb 5-minute benchmark levels. We highlight these benchmark levels because (1) 400 ppb represents the lowest concentration in human exposure studies where statistically significant moderate or greater lung function decrements are frequently accompanied by respiratory symptoms; (2) 200 ppb is the lowest level at which effects have been observed (and the lowest level tested) for moderate or greater decrements in lung function in free-breathing human exposure studies. Notably, we also recognize that there is very limited evidence demonstrating small decrements in lung function at 100 ppb from two mouthpiece exposure studies (see section 6.2). However, as previously noted (see section 6.2), the results of these studies are not directly comparable to free-breathing chamber studies, and thus, staff is primarily considering exceedances of the 200 ppb and 400 ppb benchmark levels in its evaluation of the adequacy of the current standards.

Exposures and risks have been estimated for two study areas in Missouri (i.e., Greene County and several counties representing the St. Louis urban area) which have significant emission sources of SO_2. As noted in section 8.10, there were differences in the number of exposures above benchmark values when the results of the Greene County and St. Louis exposure assessments were compared. Moreover, given that the results of the exposure assessment were used as inputs into the quantitative risk assessment, it was not surprising that there were also far fewer asthmatics at elevated ventilation rates estimated to have a moderate or greater lung function response in Greene county when compared to St. Louis. The difference in the St. Louis and Greene County exposure and quantitative risk results are likely indicative of the different types of locations they represent (see section 8.10). Greene County is a rural county with much lower population and emission densities, compared to the St. Louis study area which has population and emissions density similar to other urban areas in the U.S. It therefore follows that there would be greater exposures, and hence greater numbers and percentages of asthmatics at elevated ventilation rates experiencing moderate or greater lung function responses in the St. Louis study area. Thus, when considering the risk and exposure results as they relate to the adequacy of the current standards (as well as the need for considering potential alternative standards), the St. Louis results are more informative in that they suggest that the current standards may not adequately protect public health. Moreover, staff judges that the exposure and risk estimates for the St. Louis study area provide useful insights into exposures and risks for other urban areas in the U.S. with similar population and SO_2 emissions densities.

Air Quality Assessment

The results of our air quality assessment provide additional perspective on the public health impacts of exposure to ambient levels of SO_2. In considering these results, we first note that the benchmark values derived from the controlled human exposure literature are associated with a 5-minute averaging time, but very few state and local agencies in the U.S. report measured 5-minute concentrations since such monitoring is not required. As a result, staff developed a statistical relationship to estimate the highest 5-minute level in an hour, given a reported 1-hour average SO_2 concentration (see section 7.2.3). Thus, many of the outputs of the air quality analysis are presented with respect to statistically estimated 5-minute concentrations in excess of potential health effect benchmark values. Results of these analyses, as they relate to the adequacy of the current standards, are discussed below.

A key output of the air quality analysis is the predicted number of statistically estimated 5-minute daily maximum SO_2 concentrations above benchmark levels given air quality simulated to just meet the level of the current 24-hour or annual SO_2 standards, whichever is controlling for a given county. Under this scenario, in 40 counties selected for detailed analysis, we note that the predicted yearly mean number of statistically estimated 5-minute daily maximum concentrations > 400 ppb ranges from 1-102 days per year[97], with most counties in this analysis experiencing a mean of at least 20 days per year when statistically estimated 5-minute daily SO_2 concentrations exceed 400 ppb (Table 7-14). In addition, the predicted yearly mean number of statistically estimated 5-minute daily maximum concentrations >200 ppb ranges from 21-171 days per year, with about half of the counties in this analysis experiencing ≥ 70 days per year when 5-minute daily maximum SO_2 concentrations exceed 200 ppb (Table 7-12).

Exposure Assessment

When considering the St. Louis exposure results as they relate to the adequacy of the current standard, we focus on the number of asthmatics at elevated ventilation rates estimated to experience at least one benchmark exceedance given air quality that is adjusted upward to simulate just meeting the current 24-hour standard (i.e., the controlling standard in St. Louis). We note that in these analyses, if SO_2 concentrations are such that the St Louis area just meets the current standard, approximately 13% of asthmatics would be estimated to experience at least

[97] Air quality estimates presented in this section represent the mean number of days per year when 5-minute daily maximum SO_2 concentrations exceed a particular benchmark level given 2001-2006 air quality adjusted to just meet the current standards (see Tables 7-11 to 7-14).

one SO_2 exposure concentration greater than or equal to a 400 ppb benchmark level while at elevated ventilation rates (Figure 8-19). Similarly, approximately 46% of asthmatics would be expected to experience at least one SO_2 exposure concentration greater than or equal to a 200 ppb benchmark level while at elevated ventilation rates. When the St. Louis results are restricted to asthmatic children at elevated ventilation rates, approximately 25% and 73% of these children would be estimated to experience at least one SO_2 exposure concentration greater than or equal to the 400 ppb and 200 ppb benchmark levels, respectively (Figure 8-19).

Risk results

When considering the St. Louis risk results as they relate to the adequacy of the current standard, we note the percent of asthmatics at elevated ventilation rates likely to experience at least one lung function response given air quality that is adjusted upward to simulate just meeting the current standards. Under this scenario, 12.7% to 13.1% of exposed asthmatics at elevated ventilation rates are estimated to experience at least one moderate lung function response (defined as an increase in sRaw ≥ 100% (Table 9-5))[98]. Furthermore, 5.1% to 5.4% of exposed asthmatics at elevated ventilation rates are estimated to experience at least one large lung function response (defined as an increase in sRaw ≥ 200% (Table 9-5)). We also note that estimates from this analysis indicate that the percentage of exposed asthmatic children in St. Louis estimated to experience at least one moderate or large lung function response is somewhat greater than the percentage for the asthmatic population as a whole (Table 9-8). In addition, we note that comparable results were observed when moderate or greater lung function responses were defined in terms of FEV_1.

10.3.4 Conclusions regarding the adequacy of the 24-hour standard

As noted above, several lines of scientific evidence are relevant to consider in evaluating the adequacy of the current 24-hour standard to protect the public health. These include causality judgments made in the ISA, as well as the human exposure and epidemiologic evidence supporting those judgments. In particular, we note that numerous epidemiologic studies reporting positive associations between ambient SO_2 and respiratory morbidity endpoints were conducted in locations that met the current 24-hour standard. To the extent that these

[98] The risk results presented represent the median estimate of exposed asthmatics expected to experience moderate or greater lung function decrements. Results are presented for both the probit and 2-parameter logistic functional forms. The full range of estimates can be found in Chapter 9, and in all instances the smaller estimate is a result of using the probit function to estimate the exposure-response relationship.

considerations are emphasized, the adequacy of the current standard to protect the public health would clearly be called into question. This suggests consideration of a revised 24-hour standard and/or that an additional shorter-averaging time standard may be needed to provide additional health protection for sensitive groups, including asthmatics and individuals who spend time outdoors at elevated ventilation rates. Moreover, this also suggests that an alternative SO_2 standard(s) should protect against health effects ranging from lung function responses and increased respiratory symptoms following 5-10 minute peak SO_2 exposures, to increased respiratory symptoms and respiratory-related ED visits and hospital admissions associated with 1-hour daily maximum or 24-hour average SO_2 concentrations.

In examining the exposure- and risk-based information with regard to the adequacy of the current 24-hour SO_2 standard to protect the public health, we note that the results described above (and in more detail in Chapters 7-9) indicate that 5-minute exposures that can reasonably be judged important from a public health perspective are associated with air quality adjusted upward to simulate just meeting the current 24-hour standard. Therefore, exposure- and risk-based considerations reinforce the scientific evidence in supporting the conclusion that consideration should be given to revising the current 24-hour standard and/or setting a new shorter averaging time standard (e.g., 1-hour or less) to provide increased public health protection, especially for sensitive groups (e.g., asthmatics), from SO_2-related adverse health effects.

10.4 ADEQUACY OF THE CURRENT ANNUAL STANDARD

10.4.1 Introduction

In the last review of the SO_2 NAAQS, retention of the annual standard was largely based on an assessment of qualitative evidence gathered from a limited number of epidemiologic studies. The strongest evidence for an association between annual SO_2 concentrations and adverse health effects in the 1982 AQCD was from a study conducted by Lunn et al (1967). The authors found that among children a likely association existed between chronic upper and lower respiratory tract illnesses and annual SO_2 levels of 70 -100 ppb in the presence of 230-301 ug/m^3 black smoke. Three additional studies described in the 1986 Second Addendum also suggested that long-term exposure to SO_2 was associated with adverse respiratory effects. Notably, studies conducted by Chapman et al. (1985) and Dodge et al. (1985) found associations between long-term SO_2 concentrations (with or without high particle concentrations) and cough in children and young adults. However, it was noted that there was considerable uncertainty associated with these studies because they were conducted in locations subject to high, short-term peak SO_2 concentrations (i.e., locations near point sources); therefore it was difficult to discern whether this increase in cough was the result of long-term, low level SO_2 exposure, or repeated short-term peak SO_2 exposures.

It was concluded in the last review that there was no quantitative rationale to support a specific range for an annual standard (EPA, 1994b). However, it was also found that while no single epidemiologic study provided clear quantitative conclusions, there appeared to be some consistency across studies indicating the possibility of respiratory effects associated with long-term exposure to SO_2 just above the level of the existing annual standard (EPA, 1994b). In addition, air quality analyses conducted during the last review indicated that the short-term standards being considered (1-hour and/or 24-hour) could not by themselves prevent long-term concentrations of SO_2 from exceeding the level of the existing annual standard in several large urban areas. Ultimately, both the scientific evidence and the air quality analyses were used by the Administrator to conclude that retaining the existing annual standard was requisite to protect human health.

10.4.2 Evidence-based considerations

The ISA presents numerous studies published since the last review examining possible associations between long-term SO_2 exposure and mortality and morbidity outcomes. This includes discussion of additional epidemiologic studies examining possible associations between long-term SO_2 exposure and respiratory effects in children (in part, the basis for retaining the annual standard in the last review; see section 10.4.1). In addition, the ISA presents results from epidemiologic and animal toxicological studies published since the last review examining possible associations between long-term ambient SO_2 concentrations and adverse respiratory, cardiovascular, and birth outcomes, as well as carcinogenesis. The current ISA also discusses the possible association between long-term SO_2 exposure and mortality.

As an initial consideration with regard to the adequacy of the current annual standard, staff notes that the evidence relating long-term (weeks to years) SO_2 exposure to adverse health effects (respiratory morbidity, carcinogenesis, adverse prenatal and neonatal outcomes, and mortality) is judged to be “inadequate to infer the presence or absence of a causal relationship”

(ISA, Table 5-3). That is, the ISA finds this health evidence to be of insufficient quantity, quality, consistency, or statistical power to make a determination as to whether SO_2 is truly associated with these health endpoints (ISA, Table 1-2). With respect specifically to respiratory morbidity in children, the ISA presents recent epidemiologic evidence of an association with long-term exposure to SO_2 (ISA, section 3.4.2). However, the ISA finds the strength of these epidemiologic studies to be limited because of 1) variability in results across studies with respect to specific respiratory morbidity endpoints, 2) high correlations between long-term average SO_2 and co-pollutant concentrations, particularly PM, and 3) a lack of evaluation of potential confounding (ISA, section 3.4.2.1).

We also note that many epidemiologic studies demonstrating positive associations between 1-hour daily maximum or 24-hour average SO_2 concentrations and respiratory symptoms, ED visits, and hospitalizations were conducted in areas where ambient SO_2 concentrations were well below the current annual NAAQS. This evidence suggests that the current annual standard is not providing adequate protection against health effects associated with shorter-term SO_2 concentrations.

10.4.3 Risk-based considerations

Results of the risk characterization based on the air quality assessment provide additional insight into the adequacy of the current annual standard. Analyses in this document describe the extent to which the current annual standard provides protection against 5-minute peaks of SO_2 in excess of potential health effect benchmark levels. Figure 7-16 counts the number of *measured* 5-minute daily maximum SO_2 concentrations above the 100 -400 ppb benchmark levels for a given annual average SO_2 concentration. None of the monitors in this data set reported annual average SO_2 concentrations above the current NAAQS, but several of the monitors in several of the years frequently reported 5-minute daily maximum concentrations above the potential health effect benchmark levels. Many of these monitors where frequent exceedances were reported had annual average SO_2 concentrations between 5 and 15 ppb, with little to no correlation between the annual average SO_2 concentration and the number of 5-minute daily maximum concentrations above potential health effect benchmark levels. This suggests that the annual standard adds little in the way of protection against 5-minute peaks of SO_2 (see section 7.3.1).

10.4.4 Conclusions regarding the adequacy of the current annual standard

As noted above, the ISA concludes that the evidence relating long-term (weeks to years) SO_2 exposure to adverse health effects (respiratory morbidity, carcinogenesis, adverse prenatal and neonatal outcomes, and mortality) is "inadequate to infer the presence or absence of a causal relationship" (ISA, Table 5-3). The ISA also reports that many epidemiologic studies demonstrating positive associations between short-term (i.e. 1-hour daily maximum, 24-hour average) SO_2 concentrations and respiratory symptoms, as well as ED visits and hospitalizations, were conducted in areas where annual ambient SO_2 concentrations were well below the level of the current annual NAAQS. In addition, analyses conducted in this REA suggest that the current annual standard is not providing protection against 5-10 minute peaks of SO_2. Thus, the scientific evidence and the risk and exposure information suggest that the current annual SO_2 standard: 1) is likely not needed to protect against health risks associated with long term exposure to SO_2; and 2) does not provide adequate protection from the health effects associated with shorter-term (i.e. $\leq$ 24-hours). This suggests that consideration should be given to either revoking the annual standard or retaining it without revision, in conjunction with setting an appropriate short-term standard(s).

10.5 POTENTIAL ALTERNATIVE STANDARDS

10.5.1 Indicator

In the last review, EPA focused on SO_2 as the most appropriate indicator for ambient SO_x. This was in large part because other gaseous sulfur oxides (e.g., SO_3) are likely to be found at concentrations many orders of magnitude lower than SO_2 in the atmosphere, and because most all of the health effects and exposure information was for SO_2. The current ISA has again found this to the case, and although the presence of gaseous SO_x species other than SO_2 has been recognized, no alternative to SO_2 has been advanced as being a more appropriate surrogate for ambient gaseous SO_x. Importantly, controlled human exposure studies and animal toxicology studies provide specific evidence for health effects following exposure to SO_2. Epidemiologic studies also typically report levels of SO_2, as opposed to other gaseous SO_x. Because emissions that lead to the formation of SO_2 generally also lead to the formation of other SO_x oxidation products, measures leading to reductions in population exposures to SO_2 can generally be expected to lead to reductions in population exposures to other gaseous SO_x. Therefore, meeting an SO_2 standard that protects the public health can also be expected to provide some degree of protection against potential health effects that may be independently associated with other gaseous SO_x even though such effects are not discernable from currently available studies indexed by SO_2 alone. Given these key points, staff judges that the available evidence supports the retention of SO_2 as the indicator in the current review. We also note that this would be in agreement with CASAC comments offered on the second draft REA. The consensus CASAC response to Agency charge questions from the second draft REA states: "For indicator, SO_2 is clearly the preferred choice (Samet 2009)."

10.5.2 Averaging Time

EPA established the current 24-hour and annual averaging times for the primary SO_2 NAAQS in 1971. As previously described, (see section 10.3.1) the 24-hour NAAQS was based on epidemiologic studies that observed associations between 24-hour average SO_2 levels and adverse respiratory effects and daily mortality (EPA 1982, 1994b). The annual standard was supported by a few epidemiologic studies that found an association between adverse respiratory effects and annual average SO_2 concentrations (EPA 1982, 1994b). Based on currently available evidence, staff concludes that different averaging time(s) be established for the primary standard(s) as part of the current review. In reaching this conclusion, staff has considered causality judgments from the ISA, results from controlled human exposure and epidemiologic studies, and SO_2 air quality correlations. These considerations are described in more detail below.

10.5.2.1 Evidence-based considerations

As an initial consideration regarding the most appropriate averaging time (e.g., short-term, long-term, or a combination of both) for alternative SO_2 standard(s), we note (as in 10.4.1 above) that the ISA finds evidence relating long-term (weeks to years) SO_2 exposures to adverse health effects to be "inadequate to infer the presence or absence of a causal relationship" (ISA, Table 5-3). In contrast, the ISA judges evidence relating short-term (5-minutes to 24-hours) SO_2 exposure to respiratory morbidity to be "sufficient to infer a causal relationship" and short-term exposure to SO_2 and mortality to be "suggestive of a causal relationship" (ISA, Table 5-3). Taken together, these judgments most directly support standard averaging time(s) that focus protection on SO_2 exposures from 5-minutes to 24-hours.

In considering the level of support available for specific short-term averaging times, we first note the strength of evidence from human exposure and epidemiologic studies. Controlled human exposure studies exposed exercising asthmatics to 5-10 minute peak concentrations of SO_2 and consistently found decrements in lung function and/or respiratory symptoms. Importantly, the ISA describes the controlled human exposure studies as being the "definitive evidence" for its conclusion that there is a causal association between short-term (5-minutes to 24-hours) SO_2 exposure and respiratory morbidity (ISA, section 5.2). Supporting the controlled human exposure evidence is a relatively small body of epidemiologic studies describing positive associations between 1-hour daily maximum SO_2 levels and respiratory symptoms as well as hospital admissions and ED visits for all respiratory causes and asthma (ISA Tables 5.4 and 5.5). In addition to the 1-hour daily maximum epidemiologic evidence, there is a considerably larger body of epidemiologic studies reporting positive associations between 24-hour average SO_2 levels and respiratory symptoms, as well as hospitalizations and ED visits for all respiratory causes and asthma. However, as in the last review, there remains considerable uncertainty as to whether these positive associations are due to 24-hour average SO_2 exposures, or exposure (or multiple exposures) to short-term peaks of SO_2 within a 24-hour period. More specifically, when describing epidemiologic studies observing positive associations between ambient SO_2 and respiratory symptoms, the ISA states "that it is possible that these associations are determined in large part by peak exposures within a 24-hour period" (ISA, section 5.2). The ISA also states that the respiratory effects following 5-10 minute SO_2 exposures in controlled human exposure studies provides a basis for a progression of respiratory morbidity that could result in increased ED visits and hospital admissions (ISA, section 5.2).

The controlled human exposure evidence described above provides support for an averaging time that protects against 5-10 minute peak exposures. Results from the epidemiologic evidence provides support for both 1-hour and 24-hour averaging times. However, it is worth noting again that the effects observed in epidemiologic studies also may be due, at least in part and especially in 24-hour epidemiologic studies, to shorter-term peaks of SO_2. Overall, the evidence mentioned above suggests that a primary concern with regard to averaging time is the level of protection provided against 5-10 minute peak SO_2 exposures. The evidence described above also suggests it would be appropriate to consider the degree of protection averaging times under consideration provide against both 1-hour daily maximum and 24-hour average SO_2 concentrations.

10.5.2.2 Air Quality considerations

The shortest averaging time for the current primary SO_2 standard is 24-hours. We therefore evaluate the potential for a standard based on 24-hour average SO_2 concentrations to limit 5-minute peak SO_2 exposures. Table 10-1 reports the ratio between 99th percentile 5-minute daily maximum and 99th percentile 24-hour average SO_2 concentrations for 42 monitors reporting measured 5-minute data for any year between 2004-2006. Across this set of monitors in 2004, ratios of 99th percentile 5-minute daily maximum to 99th percentile 24-hour average SO_2 concentrations spanned a range of 2.0 to 14.1, with an average ratio of 6.7 (Table 10-1). These results suggest that a standard based on 24-hour average SO_2 concentrations would not likely be an effective or efficient approach for addressing 5-minute peak SO_2 concentrations. That is, using a 24-hour average standard to address 5-minute peaks would likely result in over-controlling in some areas, while under-controlling in others. This analysis also suggests that a 5-minute standard would not likely be an effective or efficient means for controlling 24-hour average SO_2 concentrations.

Table 10-1 also reports the ratios between 99th percentile 5-minute daily maximum and 99th percentile1-hour daily maximum SO_2 levels from this set of monitors. Compared to the ratios discussed above (5-minute daily maximum to 24-hour average), there is far less variability between 5-minute daily maximum and 1-hour daily maximum ratios. More specifically, 39 of the 42 monitors had 99th percentile 5-minute daily maximum to 99th percentile 1-hour daily maximum ratios in the range of 1.2 to 2.5 (Table 10-1). The remaining 3 monitors had ratios of 3.6, 4.2 and 4.6 respectively. Overall, this relatively narrow range of ratios suggests that a standard with a 1-hour averaging time would be more efficient and effective at limiting 5-minute peaks of SO_2 than a standard with a 24-hour averaging time. These results also suggest that a 5-minute standard could be a relatively effective means of controlling 1-hour daily maximum SO_2 concentrations.

Table 10-1 Ratios of 99th percentile 5-minute daily maximums to 99th percentile 24-hour average and 1-hour daily maximum SO_2 concentrations for monitors reporting measured 5-minute data from years 2004-2006[99]

Monitor ID	# of years	5-minute daily max: 24-hour average	5-minute daily max:1-hour daily maximum
110010041	1	3.8	1.4
191770005	1	4.1	1.7
290930030	1	2.9	1.2
290930031	1	3.4	1.6
370670022	1	5.5	1.6
120890005	2	9.4	2.2
190330018	2	8.2	2
190450019	2	11.2	3.6
191390016	2	6.9	1.5
191390017	2	9.8	2.2
191390020	2	6.2	1.8
191630015	2	4.5	1.5
191770006	2	3.1	1.3
291630002	2	7	1.8
380130002	2	8.4	1.9
380150003	2	4.8	1.6
380590002	2	5.6	1.9
380590003	2	8.4	1.9
540990003	2	2	1.4
540990004	2	5.9	2
540990005	2	5.3	2
541071002	2	8.1	1.6
051190007	3	4.7	2.2
051390006	3	12	2.3
080310002	3	5.5	1.7
290770026	3	6.6	1.7
290770037	3	8.1	2.2
290990004	3	14.1	2.5
291370001	3	2.4	1.3
301110084	3	5.8	1.6
380070002	3	6.3	2.1
380130004	3	6.1	1.8
380171004	3	4.3	1.6
380250003	3	5.1	1.6
380530002	3	4	1.4
380530104	3	7.9	4.2
380530111	3	11.6	4.6
380570004	3	7.5	2.3
380650002	3	7.3	1.9
381050103	3	9.7	2.5
381050105	3	6.4	2.4
420070005	3	10.5	2

[99] 99th percentile 5-minute daily maximum, 1-hour daily maximum, and 24-hour average values were identified for each year a given monitor was in operation from 2004-2006. If a monitor was in operation for multiple years over that span, 99th percentile values were identified for each year, averaged, and then the appropriate ratio was determined.

Staff further evaluated the potential of the 1-hour daily maximum standards analyzed in this REA to provide protection against 24-hour average SO_2 exposures. The 99th percentile 24-hour average SO_2 concentrations in cities where key U.S. ED visit and hospitalization studies (for all respiratory causes and asthma) were conducted ranged from 16 ppb to 115 ppb (Thompson and Stewart, 2009). Moreover, effect estimates that remained statistically significant in multipollutant models with PM were found in cities with 99th percentile 24-hour average SO_2 concentrations ranging from approximately 36 ppb to 64 ppb. Table 10-2 uses 2004 air quality data and suggests that a 99th percentile 1-hour daily maximum standard set at a level of 50- 100 ppb would limit 99th percentile 24-hour average SO_2 concentrations observed in epidemiologic studies where statistically significant results were observed in multi-pollutant models with PM. That is, given a 50 ppb 99th percentile 1-hour daily maximum standard, none of the 39 counties analyzed would be expected to have 24-hour average SO_2 concentrations ≥ 36 ppb; and, given a 100 ppb 99th percentile 1-hour daily maximum standard, only 6 of the 39 counties (Linn, Union, Bronx, Fairfax, Hudson, and Wayne) included in this analysis would be estimated to have 99th percentile 24-hour average SO_2 concentrations ≥ 36 ppb. This analysis was also done for the years 2005 and 2006 and similar results were found (Appendix D).

Table 10-2. 99th percentile 24-hour average SO_2 concentrations for 2004 given just meeting the alternative 1-hour daily maximum 99th and 98th percentile standards analyzed in the air quality assessment (note: concentrations in ppb)[100].

State	County	99th percentile					98th percentile	
		50	100	150	200	250	100	200
AZ	Gila	6	12	18	25	31	16	32
DE	New Castle	12	23	35	47	59	28	56
FL	Hillsborough	10	20	30	40	50	28	55
IL	Madison	12	24	36	48	60	28	56
IL	Wabash	7	13	20	27	33	19	38
IN	Floyd	8	15	23	31	39	20	41
IN	Gibson	9	18	27	36	45	20	41
IN	Lake	12	24	36	48	60	31	62
IN	Vigo	10	19	29	39	48	24	48
IA	Linn	21	42	64	85	106	49	98
IA	Muscatine	17	34	51	68	85	38	76
MI	Wayne	17	33	50	66	83	37	74
MO	Greene	12	24	36	48	60	31	62
MO	Jefferson	9	18	27	36	45	25	51
NH	Merrimack	17	33	50	66	83	39	79
NJ	Hudson	19	38	57	76	95	48	96
NJ	Union	18	36	54	72	90	44	89
NY	Bronx	23	47	70	93	117	54	107
NY	Chautauqua	13	27	40	54	67	32	65
NY	Erie	14	27	41	54	68	30	61
OH	Cuyahoga	17	34	51	67	84	40	80
OH	Lake	10	19	29	39	48	23	47
OH	Summit	12	24	36	48	61	27	55
OK	Tulsa	16	32	47	63	79	36	72
PA	Allegheny	12	23	35	47	59	30	60
PA	Beaver	10	20	30	40	51	25	49
PA	Northampton	11	23	34	45	56	36	72
PA	Warren	11	22	33	44	56	28	56
PA	Washington	15	31	46	62	77	36	71
TN	Blount	15	31	46	61	77	35	71
TN	Shelby	17	34	51	68	85	41	81
TN	Sullivan	8	16	24	32	39	23	46
TX	Jefferson	9	17	26	35	44	21	41
VA	Fairfax	23	46	69	92	116	52	103
WV	Brooke	12	24	37	49	61	31	62
WV	Hancock	15	29	44	58	73	35	69
WV	Monongalia	10	20	30	40	50	25	51
WV	Wayne	30	59	89	119	149	67	133
VI	St Croix	14	27	41	54	68	51	101

[100] 99th or 98th percentile 1-hour daily maximum concentrations were determined for each monitor in a given county for the years completed data were available from 2004-2006. These concentrations were averaged, and the monitor with the highest average in a given county was determined. Based on this highest average, all monitors in a given county were adjusted to just meet the potential alternative standards defined above, and for each of the years, the 99th percentile 24-hour average SO_2 concentration was identified. Iron County did not meet completeness criteria for any of these years and is therefore not part of this analysis. Results for the years 2005 and 2006 are presented in Appendix D.

As an additional matter, we note that a 99th percentile 1-hour daily maximum standard at a level of 50-150 ppb could have the effect of maintaining SO_2 concentrations below the level of the current 24-hour and annual standards. That is, under these alternative standard scenarios (using 2004 air quality data), there would be no counties in this analysis with a 2nd highest 24-hour average greater than 144 ppb (Table 10-3). Similarly, under these alternative standard scenarios (using 2004 air quality data), there would be no counties in this analysis with an annual average SO_2 concentration in excess of the current annual standard (30.4 ppb; Table 10-4). These analyses were also done with air quality from the years 2005 and 2006 and similar results were found (Appendix D).

Table 10-3. 2nd highest 24-hour average SO_2 concentrations (i.e., the current 24-hour standard) for 2004 given just meeting the alternative 1-hour daily maximum 99th and 98th percentile standards analyzed in the air quality assessment (note: concentrations in ppb).[101]

		99th percentile					98th percentile	
State	County	50	100	150	200	250	100	200
AZ	Gila	7	14	21	27	34	18	36
DE	New Castle	12	38	57	76	95	45	91
FL	Hillsborough	11	23	34	45	57	31	63
IL	Madison	14	28	42	55	69	32	65
IL	Wabash	10	19	29	39	48	28	55
IN	Floyd	8	17	25	34	42	22	44
IN	Gibson	11	21	32	43	53	24	48
IN	Lake	15	29	44	58	73	38	76
IN	Vigo	10	20	30	40	50	25	50
IA	Linn	28	57	85	113	142	65	130
IA	Muscatine	17	38	57	75	94	43	86
MI	Wayne	19	38	56	75	94	42	84
MO	Greene	17	34	51	67	84	44	87
MO	Jefferson	11	22	33	45	56	31	63
NH	Merrimack	18	37	55	74	92	44	88
NJ	Hudson	21	43	64	86	107	54	109
NJ	Union	19	38	57	77	96	47	95
NY	Bronx	25	51	76	102	127	59	117
NY	Chautauqua	21	42	63	83	104	50	100
NY	Erie	15	31	46	61	77	35	69
OH	Cuyahoga	19	38	58	77	96	47	91
OH	Lake	13	27	40	54	67	32	65
OH	Summit	17	35	52	70	87	39	79
OK	Tulsa	19	38	57	76	95	43	87
PA	Allegheny	13	28	42	56	70	32	71
PA	Beaver	10	21	31	42	52	25	51
PA	Northampton	15	30	45	60	75	48	96
PA	Warren	13	27	40	54	67	34	68
PA	Washington	16	31	50	67	84	36	77
TN	Blount	17	34	50	67	84	39	78
TN	Shelby	19	38	57	76	95	45	90
TN	Sullivan	10	21	31	42	52	30	60
TX	Jefferson	13	25	38	50	63	29	59
VA	Fairfax	26	52	78	104	130	58	117
WV	Brooke	18	36	54	72	90	46	91
WV	Hancock	17	35	52	69	86	41	82
WV	Monongalia	12	24	35	47	59	30	60
WV	Wayne	33	67	100	134	167	75	150
VI	St Croix	17	34	51	68	85	63	126

[101] 99th or 98th percentile 1-hour daily maximum concentrations were determined for each monitor in a given county for the years completed data were available from 2004-2006. These concentrations were averaged, and the monitor with the highest average in a given county was determined. Based on this highest average, all monitors in a given county were adjusted to just meet the potential alternative standards defined above, and for each of the years, the 2nd highest 24-hour maximum concentration was identified. Iron County did not meet completeness criteria for any of these years and is therefore not part of this analysis. Results for years 2005 and 2006 are presented in Appendix D.

Table 10-4. Annual average SO_2 concentrations for 2004 given just meeting the alternative 99th and 98th percentile 1-hour daily maximum standards analyzed in the air quality assessment (note: concentrations in ppb).[102]

State	County	99th percentile					98th percentile	
		50	100	150	200	250	100	200
AZ	Gila	1.7	3.4	5.1	6.8	8.5	4.5	9.0
DE	New Castle	2.0	4.0	6.0	7.9	9.9	4.7	9.5
FL	Hillsborough	1.6	3.2	4.7	6.3	7.9	4.4	8.7
IL	Madison	1.8	3.6	5.4	7.2	9.0	4.2	8.5
IL	Wabash	0.8	1.6	2.3	3.1	3.9	2.2	4.4
IN	Floyd	1.8	3.6	5.3	7.1	8.9	4.7	9.4
IN	Gibson	1.5	2.9	4.4	5.9	7.3	3.3	6.7
IN	Lake	2.0	4.1	6.1	8.2	10.2	5.3	10.7
IN	Vigo	1.5	3.1	4.6	6.1	7.7	3.8	7.6
IA	Linn	1.8	3.5	5.3	7.0	8.8	4.0	8.1
IA	Muscatine	2.5	5.0	7.5	10.0	12.5	5.6	11.2
MI	Wayne	2.5	5.1	7.6	10.2	12.7	5.7	11.3
MO	Greene	2.0	4.1	6.1	8.2	10.2	5.3	10.6
MO	Jefferson	1.5	2.9	4.4	5.8	7.3	4.1	8.3
NH	Merrimack	2.2	4.4	6.5	8.7	10.9	5.2	10.4
NJ	Hudson	6.4	12.8	19.3	25.7	32.1	16.2	32.5
NJ	Union	6.4	12.7	19.1	25.4	31.8	15.7	31.4
NY	Bronx	7.6	15.1	22.7	30.2	37.8	17.4	34.8
NY	Chautauqua	2.6	5.3	7.9	10.5	13.2	6.3	12.7
NY	Erie	3.1	6.1	9.2	12.2	15.3	6.9	13.8
OH	Cuyahoga	3.9	7.7	11.6	15.5	19.3	9.2	18.4
OH	Lake	2.3	4.7	7.0	9.3	11.6	5.6	11.2
OH	Summit	2.6	5.1	7.7	10.2	12.8	5.8	11.5
OK	Tulsa	3.9	7.8	11.7	15.5	19.4	8.9	17.7
PA	Allegheny	2.9	5.8	8.7	11.6	14.5	7.4	14.8
PA	Beaver	2.5	5.1	7.6	10.1	12.7	6.1	12.3
PA	Northampton	4.6	9.1	13.7	18.3	22.8	14.6	29.1
PA	Warren	2.3	4.5	6.7	9.0	11.2	5.7	11.3
PA	Washington	4.3	8.7	13.0	17.4	21.7	10.0	20.0
TN	Blount	3.0	6.1	9.1	12.1	15.2	7.0	14.0
TN	Shelby	3.5	7.0	10.4	13.9	17.4	8.2	16.5
TN	Sullivan	2.1	4.2	6.3	8.4	10.4	6.0	12.0
TX	Jefferson	1.3	2.6	3.9	5.3	6.6	3.1	6.2
VA	Fairfax	7.7	15.5	23.2	30.9	38.6	17.3	34.6
WV	Brooke	4.8	9.6	14.3	19.1	23.9	12.1	24.2
WV	Hancock	4.0	8.0	12.0	16.1	20.1	9.5	19.1
WV	Monongalia	2.2	4.3	6.5	8.7	10.9	5.5	11.1
WV	Wayne	6.1	12.2	18.3	24.4	30.6	13.7	27.4
VI	St Croix	1.2	2.4	3.7	4.9	6.1	4.5	9.1

[102] 99th or 98th percentile 1-hour daily maximum concentrations were determined for each monitor in a given county for the years completed data were available from 2004-2006. These concentrations were averaged, and the monitor with the highest average in a given county was determined. Based on this highest average, all monitors in a given county were adjusted to just meet the potential alternative standards defined above, and for each of the years, the annual concentration was calculated. Iron County did not meet completeness criteria for any of these years and is therefore not part of this analysis. Results for the years 2005 and 2006 are presented in Appendix D

10.5.2.3 Conclusions regarding averaging time

The air quality analyses presented above strongly support that it is likely an alternative 99th percentile (see form discussion in 10.5.3) 1-hour daily maximum standard set at an appropriate level (see level discussion in 10.5.4) can substantially reduce: (1) 5-10 minute peaks of SO_2 shown in human exposure studies to result in respiratory symptoms and/or decrements in lung function in exercising asthmatics, (2) 99th percentile 1-hour daily maximum air quality concentrations in cities observing positive effect estimates in epidemiologic studies of hospital admissions and ED visits for all respiratory causes and asthma, and (3) 99th percentile 24-hour average air quality concentrations found in U.S. cities where ED visit and hospitalization studies (for all respiratory causes and asthma) observed statistically significant associations in multi-pollutant models with PM (i.e., 99th percentile 24-hour average SO_2 concentration ≥ 36 ppb). Thus, staff concludes that a 1-hour daily maximum standard, with an appropriate form and level, can provide adequate protection against the range of health outcomes associated with averaging times from 5-minutes to 24-hours. As an additional matter, we note that this conclusion is in agreement with CASAC comments offered on the second draft SO_2 REA. The CASAC letter to the Administrator states: “CASAC is in agreement with having a short-term standard and finds that the REA supports a one-hour standard as protective of public health (Samet 2009).”

We note that based solely on the controlled human exposure evidence, staff also considered a 5-minute averaging time. However, staff does not favor such an approach. As in past NAAQS reviews, we have considered the stability of the design of pollution control programs in considering the elements of a NAAQS, since more stable programs are more effective, and hence result in enhanced public safety. In this review, staff has concerns about the stability of a 5-minute averaging time standard. Specific concerns relate to the number of monitors needed and the placement of such monitors given the temporal and spatial heterogeneity of 5-minute SO_2 concentrations. Moreover, staff is concerned that compared to longer averaging times (e.g., 1-hour, 24-hour), year-to-year variation in 5-minute SO_2 concentrations is likely to be substantially more temporally and spatially diverse. Consequently, staff judges that a 5-minute averaging time would not provide a stable regulatory target and therefore, is not the preferred approach to provide adequate public health protection. However, as noted above, staff ‘s view is that a 1-hour averaging time, given an appropriate form (see

10.5.3) and level (see 10.5.4), can adequately limit 5-minute SO_2 exposures and provide a more stable regulatory target than setting a 5-minute standard.

10.5.3 Form

When evaluating alternative forms in conjunction with specific levels, staff considers the adequacy of the public health protection provided by the combination of level and form to be the foremost consideration. In addition, we recognize that it is important that the standard have a form that is reasonably stable. As just explained in the context of a five-minute averaging time, a standard set with a high degree of instability could have the effect of reducing public health protection because shifting in and out of attainment could disrupt an area's ongoing implementation plans and associated control programs.

10.5.3.1 Evidence-based considerations

As previously mentioned, staff recognizes that the adequacy of the public health protection provided by a 1-hour daily maximum potential alternative standard will be dependent on the combination of form and level. It is therefore important that the particular form selected for a 1-hour daily maximum potential alternative standard reflect the nature of the health risks posed by increasing SO_2 concentrations. That is, the form of the standard should reflect results from human exposure studies demonstrating that the percentage of asthmatics affected, and the severity of the respiratory response (i.e. decrements in lung function, respiratory symptoms) increases as SO_2 concentrations increase (see section 4.2.2). Taking this into consideration, staff finds that a concentration-based form is more appropriate than an exceedance-based form. This is because a concentration-based form averaged over three years (see below) would give proportionally greater weight to 1-hour daily maximum SO_2 concentrations that are well above the level of the standard, than to 1-hour daily maximum SO_2 concentrations that are just above the level of the standard. In contrast, an expected exceedance form would give the same weight to 1-hour daily maximum SO_2 concentrations that are just above the level of the standard, as to 1-hour daily maximum SO_2 concentrations that are well above the level of the standard. Therefore, a concentration-based form better reflects the continuum of health risks posed by increasing SO_2 concentrations (i.e. the percentage of asthmatics affected and the severity of the response increases with increasing SO_2 concentrations).

10.5.3.2 Risk-based considerations

In considering specific concentration-based forms, we recognize the importance of: 1) minimizing the number of days per year that an area could exceed the level of the standard and still attain the standard; 2) limiting the prevalence of 5-minute peaks of SO_2; and 3) providing a stable regulatory target to prevent areas from frequently shifting in and out of attainment. Given this, we have focused on 98th and 99th percentile forms averaged over 3 years. We first note that in most locations analyzed, the 99th percentile form of a 1-hour daily maximum standard would correspond to the 4th highest daily maximum concentration in a year, while a 98th percentile form would correspond approximately to the 7th to 8th highest daily maximum concentration in a year (Table 10-5; see Thompson, 2009). In addition, results from the air quality analysis suggest that at a given SO_2 standard level, a 99th percentile form is appreciably more effective at limiting 5-minute peak SO_2 concentrations than a 98th percentile form (Figures 7-27 and 7-28[103]). Compared to the same standard with a 99th percentile form, a 98th percentile 1-hour daily maximum standard set at 200 ppb allows for on average, an estimated 68 and 86% more days per year when 5-minute SO_2 concentrations are greater than 200 and 400 ppb respectively (Figure 7-27). Similarly, compared to the same standard with a 99th percentile form, a 98th percentile 1-hour daily maximum standard at 100 ppb allows for on average, an estimated 90 and 74% more days per year when SO_2 concentrations are greater than 200 and 400 ppb respectively[104] (Figure 7-28). We also note that in the 40 counties selected for detailed air quality analysis, the estimated number of benchmark exceedances using a 98th percentile 1-hour daily maximum standard level of 200 ppb was similar to the corresponding 99th percentile standard at 250 ppb (Tables 7-11 through 7-14). Similarly, the estimated number of benchmark exceedances considering a 98th percentile standard at 100 ppb fell within the range of benchmark exceedances estimated for 99th percentile standards at 100 and 150 ppb (Tables 7-11 through 7-14).

[103] In these figures, the two air quality scenarios were compared on a monitor-to-monitor basis (see section 7.3)
[104] Compared to a 200 ppb standard, a standard at 100 ppb results in far fewer site-years experiencing benchmark exceedances (see Figures 7-27 and 7-28).

Table 10-5. SO_2 concentrations (ppb) corresponding to the 2nd-9th daily maximum and 98th/99th percentile forms for alternative 1-hour daily maximum standards (2004-2006).[105]

		SO_2 Daily Maximums								Percentiles	
County	**State**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**	**99th**	**98th**
Gila	AZ	36	33	28	26	25	23	22	21	28	22
New Castle	DE	17	15	15	13	13	12	12	12	15	12
Hillsborough	FL	13	12	12	11	11	10	9	8	12	9
Madison	IL	16	15	14	14	13	13	12	12	14	12
Wabash	IL	21	19	17	17	15	13	13	12	15	13
Floyd	IN	21	19	17	16	14	14	13	12	17	13
Lake	IN	15	12	11	11	10	9	9	8	11	9
Vigo	IN	15	13	13	12	11	11	10	10	13	10
Linn	IA	11	10	10	9	10	9	10	9	10	8
Muscatine	IA	15	15	14	13	13	12	12	12	14	12
Wayne	MI	14	13	13	12	12	12	11	11	13	12
Greene	MO	10	9	8	7	7	6	6	6	8	6
Jefferson	MO	50	43	41	34	31	29	28	27	35	25
Merrimack	NH	16	16	15	14	14	13	13	13	15	13
Hudson	NJ	6	6	6	6	5	5	5	5	6	5
Union	NJ	7	7	6	5	5	5	5	4	6	5
Bronx	NY	8	7	7	7	6	6	6	6	6	6
Chautauqua	NY	11	11	10	10	9	9	8	8	10	8
Erie	NY	17	15	13	12	12	12	11	11	13	11
Cuyahoga	OH	9	9	8	7	7	7	7	7	8	7
Lake	OH	19	19	18	17	16	15	15	14	18	15
Summit	OH	17	16	15	14	14	14	13	13	15	13
Tulsa	OK	11	9	8	8	7	7	7	7	8	7
Allegheny	PA	13	12	11	10	10	9	9	9	11	9
Beaver	PA	30	25	23	22	20	19	19	18	13	11
Northampton	PA	19	17	15	14	12	10	9	9	15	9
Warren	PA	26	24	23	22	19	18	18	18	23	18
Washington	PA	12	11	10	10	9	9	9	9	10	9
Blount	TN	21	20	19	19	18	17	17	16	19	17
Shelby	TN	12	10	9	8	8	8	7	7	9	7
Sullivan	TN	24	22	21	19	16	15	14	14	21	14
Jefferson	TX	15	14	13	12	12	11	11	10	13	11
Fairfax	VA	5	5	4	4	4	4	4	4	4	4
Brooke	WV	21	18	16	14	14	13	12	12	16	12
Hancock	WV	18	17	16	15	15	14	13	13	16	13
Monongalia	WV	23	22	18	17	16	15	14	14	17	14
St Croix	VI	16	13	9	8	5	5	5	4	5	4

As an additional matter, staff compared trends in 98th and 99th percentile design values, as well as design values based on the 4th highest daily maximum from 54 sites located in the 40 counties selected for detailed analysis (see Thompson, 2009). These results suggest that at the

[105] Table 10-5 displays the 2nd through 9th highest, and the 99th and 98th percentiles of the daily maximums for each of the counties. For the alternative daily metrics (the nth maximum and percentiles), the statistics were computed for each year and then averaged over 2004-2006 (see Thompson 2009).

vast majority of sites, there would have been similar changes in 98th and 99th percentile design values over the last ten years (i.e. based evaluating overlapping three year intervals over the last ten years; see Thompson, 2009). These results also demonstrate that design values based on the 4th highest daily maximum are virtually indistinguishable from design values based on the 99th percentile. For illustrative purposes, design value trends for four of these sites are presented in Figure 10-1. As part of this analysis, all of the design values over this ten year period for all 54 sites were aggregated and the standard deviation calculated (see Thompson, 2009). Results demonstrate similar standard deviations – i.e. similar stability -- based on aggregated 98th or aggregated 99th percentile design values over the ten year period (Figure 10-2; see Thompson 2009).

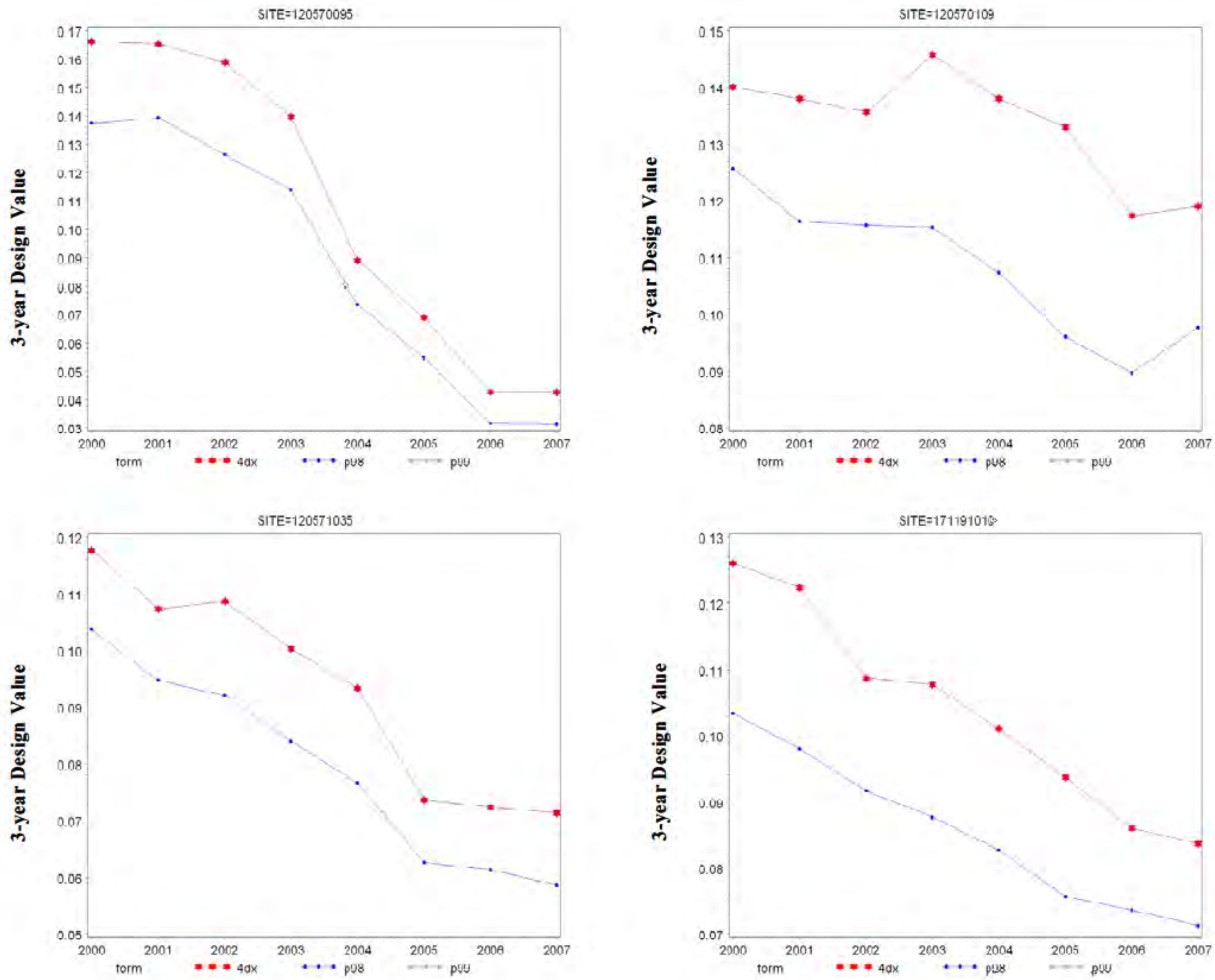

Figure 10-1. Design value trends from 4 of the 54 sites analyzed in Thompson 2009.[106]

106 There were 8 possible 3-year design values from 1997 to 2007 (e.g. 1997-1999, 1998- 2000, etc.). Thus, the design values presented in Figure 10-1 represent the 3-year average of the annual 98th percentile or 99th percentile 1-hour daily maximum, or the 3-year average of 4th highest of the 1-hour daily maximum. (Thompson 2009).

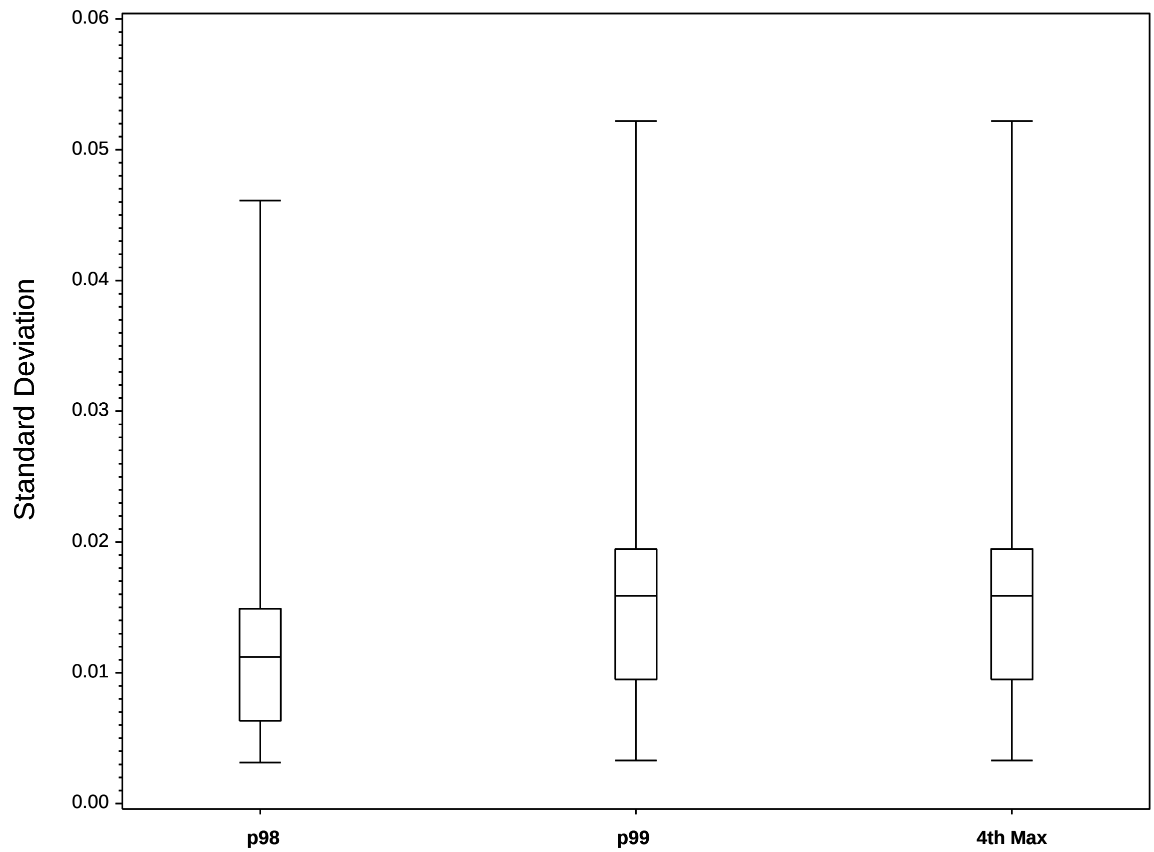

Figure 10-2. Boxplots of the distributions of standard deviations for alternative air quality standard forms.

10.5.3.3 Conclusions regarding form

Staff concludes that a concentration-based form provides the best protection against the health risks posed by increasing SO_2 concentrations (see 10.5.3.1). We also find that at a given standard level, a 99th percentile or 4th highest daily maximum form provides appreciably more public health protection against 5-minute peaks than a 98th percentile or 7th - 8th highest daily maximum form (see 10.5.3.2). In addition, over the last 10 years and for the vast majority of the sites examined, there appears to be little difference in 98th and 99th percentile design value stability (see 10.5.3.2). Thus, staff concludes that consideration be given primarily to a 1-hour daily maximum standard with a 99th percentile or 4th highest daily maximum form.

10.5.4 Level

In sections 10.3.3.3 and 10.4.4 staff concluded that the health evidence presented above in Chapter 4 and the air quality, exposure, and risk information presented in Chapters 7-9 clearly call into question the adequacy of the current SO_2 standards to protect public health with an adequate margin of safety from the respiratory effects of SO_2. In considering potential alternative standards that would provide increased public health protection against these respiratory effects, staff concluded in section 10.5.1 that the most appropriate indicator remains SO_2. In section 10.5.2, staff concluded that an alternative standard with a 1-hour averaging time, set at an appropriate level, can provide adequate protection against the range of respiratory effects observed in both controlled human exposure studies of 5-10 minutes, as well as epidemiologic studies using longer averaging times. In addition, section 10.5.3 concluded that a 99th percentile or 4^{th} highest daily maximum form averaged over three years was most appropriate for potential standards using a 1-hour averaging time. Here, we consider 99^{th} percentile 1-hour daily maximum alternative standard levels that would provide greater public health protection against SO_2-related adverse respiratory effects than that afforded by the current standards. As an initial consideration, we note that Table 10-6 demonstrates that although all counties in the U.S. meet the current 24-hour and annual standards, all of the potential alternative 1-hour daily maximum standard levels (50-250 ppb) analyzed in the air quality, exposure, and risk analyses would be estimated to result in counties in the U.S. with air quality above the level of the given alternative standard. Thus, to varying extents, meeting any of the potential alternative 1-hour daily maximum standards analyzed in this document would represent reductions in ambient SO_2 levels based on air quality from 2004-2006, as well as reductions from SO_2 concentrations that would be allowed under the current standards. All of these potential standards would consequently result in some increased public health protection.

Table 10-6. Percent of counties that may be above the level of alternative standards (based on years 2004-2006)

Alternative Standards and Levels (ppb)	Percent of counties, total and by region not likely to meet a given standard								
	Total Counties (population in millions)	Northeast	Southeast	Industrial Midwest	Upper Midwest	Southwest	Northwest	Southern CA	Outside Regions
Number of counties with monitors	**211 (96.5)**	**52**	**40**	**75**	**19**	**7**	**9**	**6**	**3**
3 year 99th percentile daily 1-hour max:									
250	1 (0.4)	0	0	1	0	14	0	0	33
200	3 (0.8)	0	3	4	0	14	0	0	33
150	10 (2.4)	2	5	20	5	14	0	0	33
100	22 (13.5)	8	13	47	5	14	0	0	33
50	54 (43.5)	38	55	81	37	14	22	0	33
3 year 98th percentile daily 1-hour max:									
200	1 (0.4)	0	0	1	0	14	0	0	33

10.5.4.1 Evidence, Air Quality, Exposure and Risk-based considerations

Chapter 4 discussed the controlled human exposure and epidemiologic evidence with respect to the judgments of causality presented in the ISA. In Chapter 5, our evaluation of the health evidence informed the selection of potential alternative SO_2 standards that would be analyzed in the air quality, exposure, and risk analyses. In Chapter 6, potential health effect benchmark values for use in the air quality and exposure analyses were derived from SO_2 concentrations found in controlled human exposure studies to result in decrements in lung function and/or respiratory symptoms in exercising asthmatics. In this chapter, staff also used the controlled human exposure and the epidemiologic evidence to inform judgments about the adequacy of the current SO_2 standards, and to inform staff conclusions about the indicator, averaging time, and form for potential alternative SO_2 standards.

Staff now considers the health evidence as it relates to evaluating 99th percentile 1-hour daily maximum alternative standard levels.[107] In doing so, we have considered the extent to which a variety of alternative standard levels would limit the magnitude and frequency of 1-hour SO_2 concentrations to provide sufficient protection for at-risk populations against experiencing various respiratory health effects including moderate or greater decrements in lung function, respiratory symptoms, and respiratory-related ED visits and hospitalizations. We note that these health endpoints are logically linked together in that the controlled human exposure evidence demonstrating moderate or greater decrements in lung function and/or respiratory symptoms in exercising asthmatics is recognized by the ISA as supporting the plausibility of associations between ambient SO_2 and the respiratory morbidity endpoints (i.e., respiratory symptoms, emergency department visits, and hospital admissions) reported in epidemiologic studies.

In assessing the extent to which potential alternative standard levels with a 1-hour averaging time and a 99th percentile form limit the array of health outcomes reported in both controlled human exposure and epidemiologic studies, we first note the air quality information provided by authors of key U.S. ED visit and hospitalization epidemiologic studies. This information was presented earlier in Figures 5-1 to 5-4 and is described in detail in Thompson and Stewart (2009). This information characterizes 99th percentile 1-hour daily maximum SO_2 air quality levels in cities and time periods corresponding to key U.S. studies of ED visits and

[107] We note that these considerations are also relevant for consideration of alternative standard levels in conjunction with a 4th highest daily maximum form.

hospitalizations for all respiratory causes and asthma. This information provides the most direct evidence for effects in cities with particular 99th percentile 1-hour SO_2 levels, and hence, is of particular relevance here. This information suggests that the strongest epidemiologic evidence of an association between ambient SO_2 and ED visits and hospitalizations is in cities where 99th percentile 1-hour daily maximum SO_2 concentrations ranged from about 75 to150 ppb. In this range, there are numerous studies that reported positive associations between ambient SO_2 and respiratory related ED visits and hospitalizations (although all results were not statistically significant). In addition, this range of SO_2 levels importantly contains a cluster of epidemiologic studies demonstrating statistically significant results in multi-pollutant models with PM. More specifically, in epidemiologic studies conducted in the Bronx, NY (78 ppb; NYDOH 2006,) and in NYC, NY (82 ppb; Ito et al., 2007), the SO_2 effect estimate remained positive and statistically significant in multi-pollutant models with $PM_{2.5}$ (ISA, Table 5-5). Moreover, in an epidemiologic study conducted in New Haven, CT (150 ppb; Schwartz et al., 1995), the SO_2 effect estimate remained positive and statistically significant in a multi-pollutant model with $PM_{10.}$ Staff notes that while statistical significance in co-pollutant models is an important consideration, it is not necessary for appropriate consideration of and reliance on such epidemiologic evidence.[108] However, the existence of these studies particularly supports consideration of standards levels at and below the range observed in these studies. Given this body of epidemiologic evidence, staff concludes that alternative standard levels at and below 75 ppb should be considered to provide protection against the effects observed in these studies.

With regard to the epidemiologic studies mentioned above, we also note that most of the ED visit and hospitalization effect estimates reported in these studies are with respect to *24-hour average SO_2 concentrations*. Thus, staff investigated whether a 99th percentile 1-hour daily maximum standard at approximately 75 ppb would also limit the *99th percentile 24-hour average SO_2 concentrations* observed in the cluster of studies finding statistically significant results in multipollutant models with PM. Considering these studies, we note that the lowest *99th percentile 24-hour average SO_2 concentration* reported in a study location finding statistically significant associations in a multipollutant model with PM was 36 ppb in Bronx, NY (NYDOH

[108] For example, evidence of a pattern of results from a group of studies that find effect estimates similar in direction and magnitude would warrant consideration of and reliance on such studies even if the studies did not all report statistically significant associations in single- or multi-pollutant models

2006). A standard of approximately 75 ppb was not analyzed in the air quality analysis, but given a 50 ppb 99th percentile 1-hour daily maximum standard, none of the counties analyzed in our analysis would be expected to have *99^th^ percentile 24-hour average* SO_2 *concentrations* ≥ 36 ppb (Table 10-2). However, given a 100 ppb 99th percentile 1-hour daily maximum standard, six of the counties included in the 40-county air quality analysis would be estimated to have *99th percentile 24-hour average* SO_2 *concentrations* ≥ 36 ppb[109]. Thus, although not directly analyzed, a 1-hour standard set at 75 ppb would be expected to limit 24-hour average concentrations from exceeding 36 ppb in most, if not all, these counties. This analysis further indicates that a 99^{th} percentile 1-hour daily maximum standard level should be considered at or below 75 ppb to provide protection against the effects observed in this cluster of epidemiologic studies.

Staff also considered findings from controlled human exposure studies when evaluating potential alternative standard levels. In doing so, we again note that the ISA finds that the most consistent evidence of decrements in lung function and/or respiratory symptoms is from controlled human exposure studies exposing exercising asthmatics to SO_2 concentrations ≥ 400 ppb (ISA, section 3.1.3.5). At SO_2 concentrations ≥ 400 ppb, moderate or greater bronchoconstriction occurs in 20-60% of exercising asthmatics, and compared to exposures at 200- 300 ppb, a larger percentage of subjects experience severe bronchoconstriction. Moreover, at concentrations ≥ 400 ppb, statistically significant moderate or greater bronchoconstriction is frequently accompanied by respiratory symptoms (ISA, Table 5-1). Controlled human exposure evidence has also demonstrated decrements in lung function in exercising asthmatics following 5-10 minute SO_2 exposures starting as low as 200-300 ppb in free-breathing chamber studies. At concentrations ranging from 200 - 300 ppb, the lowest levels tested in free breathing chamber studies, 5-30% percent of exercising asthmatics are likely to experience moderate or greater bronchoconstriction. However, at these lower levels, moderate or greater bronchoconstriction has not been shown to be statistically significant, nor is it frequently accompanied by respiratory symptoms. On the other hand, for understandable ethical reasons, it must also be noted that the subjects participating in these controlled human exposure studies do not necessarily represent the most SO_2 sensitive individuals (e.g. severe asthmatics). Thus, it is reasonable to anticipate that

[109] Given a 99^{th} percentile 1-hour daily maximum standard at 100 ppb, 99^{th} percentile 24-hour average SO_2 concentrations are estimated to be greater than 36 ppb in Linn, Union, Bronx, Hudson, Fairfax, and Wayne counties (Table 10-2)

individuals who are more SO_2 sensitive would have a greater response at 200-300 ppb SO_2, and/or would respond to SO_2 concentrations even lower than 200 ppb. Similarly, there is no evidence to suggest that 200 ppb represents a threshold below which no adverse respiratory effects occur. In fact, very limited evidence from two mouthpiece exposure studies suggests that exposure to 100 ppb SO_2 can result in small decrements in lung function[110]. Moreover, while not directly comparable to free-breathing chamber studies, findings from these mouthpiece studies may be particularly relevant to those asthmatics who breathe oronasally even at rest (EPA, 1994b). Taken together, staff concludes that the level of a 99th percentile 1-hour daily maximum SO_2 standard should be set so as to substantially limit the number of estimated 5-minute peaks ≥ 400 ppb, while also appreciably limiting SO_2 concentrations ≥ 200 ppb.

In evaluating the extent to which alternative standard levels provide substantial protection against 5-minute SO_2 concentrations ≥ 400 ppb, we first note the results of our 40 county air quality analysis. As described above, epidemiologic studies support consideration of levels of a 99th percentile 1-hour daily maximum standard at or below 75 ppb. Thus, it would be instructive to determine if a standard set at approximately 75 ppb would also substantially limit 5-minute SO_2 concentrations > 400 ppb. Results of the air quality analysis indicate that just meeting a 99th percentile 1-hour daily maximum standard at 50 ppb would result in 0 days per year when statistically estimated 5-minute daily maximum SO_2 concentrations are > 400 ppb, whereas a standard at 100 ppb would result in at most 2 days per year when statistically estimated 5-minute daily maximum SO_2 concentrations are > 400 ppb (Table 7-14)[111]. Given the results associated with 99th percentile 1-hour daily maximum standards at 50 and 100 ppb, it is reasonable to conclude that a 99th percentile 1-hour daily maximum standard at 75 ppb would also substantially limit ambient 5-minute SO_2 concentrations ≥ 400 ppb.

In further evaluating the extent to which potential alternative standard levels limit 5-minute SO_2 exposures ≥400 ppb, we consider the results of the St. Louis exposure analysis.[112]

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[110] As first noted in Chapter 6, studies utilizing a mouthpiece exposure system cannot be directly compared to studies involving freely breathing subjects, as nasal absorption of SO_2 is bypassed during oral breathing, thus allowing a greater fraction of inhaled SO_2 to reach the tracheobronchial airways. As a result, individuals exposed to SO_2 through a mouthpiece are likely to experience greater respiratory effects from a given SO_2 exposure. Nonetheless, these studies do provide very limited evidence for SO_2- induced respiratory effects at 100 ppb.

[111] Air quality estimates presented in this section represent the mean number of days per year when 5-minute daily maximum SO_2 concentrations exceed a particular benchmark level given 2001-2006 air quality adjusted to just meet alternative 99th percentile 1-hour daily maximum standards at 50, 100, or 150 ppb (see Tables 7-11 to 7-14).

[112] As described in section 10.3.3.2, staff is primarily considering the St. Louis exposure and risk results when evaluating the adequacy of the current and potential alternative 99th percentile 1-hour daily maximum SO_2 standards.

Results indicate air quality just meeting a 99th percentile 1-hour daily maximum standard at 50 or 100 ppb would result in an estimated < 1% of asthmatics at elevated ventilation rates experiencing at least one 5-minute daily maximum SO_2 exposure ≥ 400 ppb (Figure 8-19). Similarly, this analysis also indicates that air quality just meeting a 50 or 100 ppb standard would result in an estimated < 1% of asthmatic children at elevated ventilation rates experiencing at least one 5-minute daily maximum SO_2 exposure ≥ 400 ppb. These results necessarily suggest that a standard at approximately 75 ppb would also substantially limit exposures of all asthmatics and asthmatic children to SO_2 concentrations ≥ 400 ppb.

We next evaluated the extent to which 99th percentile 1-hour daily maximum standard levels provide appreciable protection against 5-minute SO_2 concentrations ≥ 200 ppb. Results of the 40 county air quality analysis indicate that a standard level of 50 ppb would result in at most 2 days per year when statistically estimated 5-minute daily maximum SO_2 concentrations would be > 200 ppb, whereas a standard level of 100 ppb would result in at most 13 days per year when statistically estimated 5-minute daily maximum SO_2 concentrations would be > 200 ppb (Table 7-12). Thus, a standard set at 75 ppb would result in somewhere between 2 and 13 days per year when statistically estimated 5-minute daily maximum SO_2 concentrations would be > 200 ppb.

Results from the St. Louis exposure analysis estimate that air quality just meeting a 50 ppb, or 100 ppb 1-hour daily maximum standard would result in a corresponding < 1% or 1.5% of asthmatics at elevated ventilation rates experiencing at least one 5-minute daily maximum SO_2 exposure ≥ 200 ppb (Figure 8-19). Moreover, just meeting a 50 ppb, or 100 ppb 99th percentile 1-hour daily maximum standard would be estimated to result in a corresponding <1% or 2.7% of asthmatic children at elevated ventilation rates experiencing at least one 5-minute daily maximum SO_2 exposure ≥ 200 ppb (Figure 8-19). Thus, a standard set at 75 ppb would be estimated to result in somewhere between <1 and 1.5% of asthmatics, or <1 and 2.7% of asthmatic children, at elevated ventilation rates experiencing at least one 5-minute daily maximum SO_2 exposure ≥ 200 ppb.

As an additional consideration, we note the results of the St. Louis risk assessment indicate that a 99th percentile 1-hour daily maximum standard at 75 ppb would likely provide appreciable protection against moderate or greater lung function responses. More specifically, given a 99th percentile 1-hour daily maximum standard at 50 ppb, the median percentage of asthmatics at elevated ventilation rates estimated to experience at least one ≥ 100% increase in sRaw ranges from 0.3% to 0.7% (and 0.4% to 0.9% for asthmatic children)[113]. In addition, given air quality just meeting a 100 ppb standard, the estimated median percentage of asthmatics at elevated ventilation rates experiencing at least one ≥ 100% increase in sRaw ranges from 1.3 to 1.9% (and 2.1 to 2.9% for asthmatic children) (Table 9-5). Thus, we can expect that a standard at 75 ppb would limit risk estimates to somewhere between the risks associated with the 50 and 100 ppb, 99th percentile 1-hour daily maximum standards.

Being mindful that the most severe effects associated with SO_2 exposure are those observed in epidemiologic studies (i.e. respiratory-related ED visits and hospitalizations), staff concludes that consideration also should be given to a standard level of 50 ppb. A 99th percentile 1-hour daily maximum standard at 50 ppb would provide an increased margin safety against the air quality levels observed in the cluster of epidemiologic studies observing statistically significant positive associations between SO_2 and respiratory-related ED visits and hospitalizations in studies with multipollutant models with PM (i.e. 99th percentile 1-hour daily maximum SO_2 concentrations ≥ 78 ppb). Moreover, as demonstrated in Table10-2, a 99th percentile 1-hour daily maximum standard set at 50 ppb would also be expected to limit *99th percentile 24-hour average SO_2 concentrations* significantly. That is, given a 1-hour daily maximum standard set at 50 ppb, Table 10-2 demonstrates that most counties included in the 40-county air quality analysis would have *99th percentile 24-hour average SO_2 concentrations* below 15 ppb, ranging from 6-30 ppb.

Recognizing that there are important uncertainties associated with the controlled human exposure evidence, we note that a 99th percentile 1-hour daily maximum standard set at 50 ppb could also be considered if emphasis is placed on the: 1) uncertainty that the participants in controlled human exposure studies do not represent the most SO_2 sensitive individuals; and/or 2) very limited evidence suggesting decrements in lung function down to 100 ppb when SO_2 is administered via mouthpiece (see section 6.2). Under this scenario, we note that a standard set at 50 ppb would provide increased protection against 5-minute SO_2 concentrations ≥ 100 ppb. Results from the 40 county air quality analysis indicate that a 99th percentile 1-hour daily maximum standard set at 50 ppb would be estimated to result in at most 13 days per year when statistically estimated 5-minute daily maximum SO_2 concentrations are > 100 ppb (Table 7-11).

[113] As first noted in section 10.3.3.2, results are presented for both the probit and 2-parameter logistic functional forms. The full range of estimates can be found in Chapter 9, and in all instances the smaller estimate is a result of using the probit function to estimate the exposure-response relationship.

In addition, the St. Louis exposure analysis estimates that a 50 ppb 99th percentile 1-hour daily maximum standard would likely result in 1.5% of asthmatics, and 2.7% of asthmatic children at elevated ventilation rates experiencing at least one SO_2 concentration ≥ 100 ppb per year (Figure 8-19).

In considering alternative standard levels > 100 ppb, we first note that as mentioned in section 10.3.3, staff concluded that exposure to 5-10 minute SO_2 concentrations at least as low as 200 ppb can result in adverse respiratory effects in some asthmatics. Thus, in order to limit 5-10 minute SO_2 concentrations from exceeding 200 ppb, the level of a 99th percentile 1-hour daily maximum standard would have to be < 200 ppb. We note that this conclusion is in accord with consensus CASAC comments following their review of the second draft REA. The CASAC letter to the Administrator states: "the draft REA appropriately implies that levels greater than 150 ppb are not adequately supported."

This letter also stated that "an upper limit of 150 ppb posited in Chapter 10 could be justified under some interpretations of weight of evidence, uncertainties, and policy choices regarding margin of safety" (Samet 2009). A 99th percentile 1-hour daily maximum SO_2 standard set in this range would have to place considerable weight on the uncertainties in the epidemiologic health evidence presented in the ISA. That is, the emphasis on the uncertainties would have to lead to a judgment that effects reported in epidemiologic studies are due in large part to co-occurring pollutants, rather than to SO_2. Under this scenario, results of the 40 county air quality analysis indicate that just meeting a 99th percentile 1-hour daily maximum standard set at a level of 150 ppb would result in at most 7 days per year when statistically estimated 5-minute daily maximum SO_2 concentrations would be > 400 ppb (Table 7-14). In addition, the St. Louis exposure analysis indicates that a 99th percentile 1-hour daily maximum standard at 150 ppb would be estimated to result in ≤ 1% of asthmatics, or asthmatic children at elevated ventilation rates experiencing at least one SO_2 exposure ≥ 400 ppb (Figure 8-19). Taken together, it can reasonable be concluded that a 99th percentile 1-hour daily maximum standard up to 150 ppb could similarly limit SO_2 exposures ≥ 400 ppb when compared to standards in the range of 50-100 ppb[114].

[114] Given a 50 or 100 ppb standard, the 40 county air quality analysis estimated at most 0 to 2 days per year when statistically estimated 5-minute daily maximum SO_2 concentrations would be ≥ 400 ppb. In addition, the St. Louis exposure analysis indicated that ≤ 1% of asthmatics, or asthmatic children at elevated ventilation rates would be expected to experience at least one SO_2 exposure ≥ 400 ppb.

However, it is important to note that a 99th percentile 1-hour daily maximum standard up to 150 ppb would provide considerably less protection against 5-minute SO_2 concentrations ≥ 200 ppb than standards in the range of 50 -100 ppb. Results of the 40 county air quality analysis indicate that a 99th percentile 1-hour daily maximum standard at 150 ppb would result in at most 24 days per year when statistically estimated 5-minute daily maximum SO_2 concentrations would be > 200 ppb. Moreover, the St. Louis exposure analysis indicates that a 150 ppb standard would be estimated to result in 6.4% of all asthmatics, and 11.6% of asthmatic children experiencing an SO_2 exposure ≥ 200 ppb (Figure 8-19). Finally, we consider the results of the St. Louis risk assessment. This assessment indicates that given a 150 ppb standard, the estimated median percentage of exposed asthmatics at elevated ventilation rates estimated to experience at least one ≥ 100% increase in sRaw per year ranges from 2.9% to 3.6% (and 4.6% to 5.4% for asthmatic children). Several aspects of these assessment results raise questions as to the sufficiency of the protection that would be provided by a standard set at this level, when compared to similar standards at or below 75 ppb.

10.5.4.1 Conclusions regarding level

Staff concludes that the health evidence and the air quality, exposure, and risk information presented above most strongly support consideration of 99th percentile 1-hour daily maximum standards in the range of 50- 75 ppb. However, if significant weight is placed on the uncertainties in the epidemiologic and controlled human exposure evidence, levels up to 150 ppb could be considered, recognizing the questions that would be raised by levels at the higher end of this range. Staff recognizes that selecting an appropriate level that will protect public health with an adequate margin of safety will be based on the relative weight given to different types of information from the air quality, exposure, and risk assessment, as well as to the evidence, and the uncertainties associated with the evidence and assessments.

10.5.4.2 Implications for the Current SO_2 Standards

Finally, staff recognizes that the particular level selected for a new 1-hour daily maximum standard will have implications for reaching decisions on whether to retain or revoke the current 24-hour and annual standards. That is, with respect to SO_2-induced respiratory morbidity, the lower the level selected for a 99th percentile 1-hour daily maximum standard, the less additional public health protection the current standards would be expected to provide. As an initial consideration, we note that all 99th percentile 1-hour daily maximum SO_2 standard levels being considered (i.e. 50 – 150 ppb) are expected to prevent ambient SO_2 concentrations in the 40 counties analyzed in the air quality analysis from exceeding the levels of the current 24-hour and annual standards (Tables 10-3 and 10-4). Moreover, Table 10-6 demonstrates that given any of the potential alternative 1-hour daily maximum standards in this range, there would be counties in the U.S. expected to have air quality above the level of that standard. However, this does not rule out the possibility that the current standards could still offer some degree of additional protection in some parts of the country not currently monitoring for SO_2.

Based on these considerations, staff finds it reasonable to conclude that if a new 99th percentile 1-hour daily maximum standard is selected with a level from the upper end of the range that staff has identified for consideration, then in addition to setting a 99th percentile 1-hour daily maximum standard, consideration should also be given to retaining the existing 24-hour and/or annual standards. However, if the selected level of a 99th percentile 1-hour daily maximum standard is in the lower end of the range, it could reasonably be concluded that consideration should be given to revoking the current 24-hour and/or annual NAAQS.

10.6 KEY OBSERVATIONS

The following observations reflect staff's views and conclusions:

- The scientific evidence and the risk and exposure information call into question the adequacy of the current standards to protect public health with an adequate margin of safety.
- In considering potential alternative standards, SO_2 remains the most appropriate indicator ambient SO_x.
- A 1-hour daily maximum standard, set at an appropriate level, can provide adequate protection against the range of health outcomes associated with averaging times from 5-minutes to 24-hours.
- Consideration should be given primarily to establishing a new 1-hour daily maximum standard with a 99th percentile or 4th highest daily maximum form.
- The health evidence and the air quality, exposure, and risk information presented above most strongly support consideration of 99th percentile (or 4th highest) 1-hour daily maximum standards in the range of 50- 75 ppb. Consideration should also be given to standard levels above this range, up to 150 ppb, to the extent that significant weight is placed on the uncertainties in the epidemiologic and controlled human exposure evidence, recognizing the questions that would be raised by levels at the higher end of this range.

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Appendix A: Supplement to the SO_2 Air Quality Characterization

Overview

This appendix contains supplementary information on the SO_2 ambient monitoring data used in the air quality characterization described in Chapter 7 of the SO_2 REA. Included in this appendix are spatial and temporal attributes important for understanding the relationship between the ambient monitor and those sources affecting air quality measurements.

In section A.1, important spatial characteristics described include the physical locations of the ambient monitors (e.g., U.S. states, counties, territories, and cities). Temporal attributes of interest include, for example, the number of samples collected, sample averaging times, and years of monitoring data available. Attributes of the monitors that reported both the 5-minute maximum and the 1-hour SO_2 concentrations are given in Tables A.1-1 and A.1-2, while the supplemental characteristics of the broader ambient monitoring network are given in Table A.1-3 and A.1-4. The method for calculating the proximity of the ambient monitors follows, along with the distance and emission results summarized in Table A.1-5.

Section A.2 details the analyses performed on simultaneous concentrations, some of which are the result of co-located monitoring instruments, others the result of duplicate reporting. Simultaneous measurements were identified by staff using monitor IDs and multiple concentrations present given the hour-of-day on each available date. Staff estimated a relative percent difference between the simultaneous measurements at each monitor.

Section A-3 has the tables summarizing the COV and GSD peak-to-mean ratio (PMRs). Section A-4 has tables summarizing the individual factors used in adjusting ambient air quality to just meet the current and potential alternative SO_2 air quality standards. Section A-5 summarizes measured 1-hour concentrations and number of days per year with air quality benchmark exceedances occurring at the 98 monitors reporting 5-minute maximum SO_2 concentrations.

A.1 Spatial and Temporal Attributes of Ambient SO_2 Monitors

Table A.1-1. Meta-data for 98 ambient monitors reporting 5-minute maximum and corresponding 1-hour SO_2 concentrations.

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height (m)	Years n	Years First	Years Last
AR	Pulaski	051190007	34.756111	-92.275833	POP	URB	COM	NEI	4	6	2002	2007
AR	Pulaski	051191002	34.830556	-92.259444	HIC	RUR	FOR	NEI	4	5	1997	2001
AR	Union	051390006	33.215	-92.668889	UNK	URB	COM		4	11	1997	2007
CO	Denver	080310002	39.75119	-104.98762	HIC	URB	COM	NEI	5	10	1997	2006
DC	District of Columbia	110010041	38.897222	-76.952778	POP	URB	RES	NEI		6	2000	2007
DE	New Castle	100031008	39.577778	-75.611111	UNK	RUR	AGR			2	1997	1998
FL	Nassau	120890005	30.658333	-81.463333	HIC	SUB	IND	NEI	2	4	2002	2005
IA	Cerro Gordo	190330018	43.16944	-93.202426	UNK	SUB	RES		4	5	2001	2005
IA	Clinton	190450019	41.823283	-90.211982	UNK	URB	IND	MID		5	2001	2005
IA	Muscatine	191390016	41.419429	-91.070975	UNK	URB	RES		3	5	2001	2005
IA	Muscatine	191390017	41.387969	-91.054504	UNK	SUB	IND		4	5	2001	2005
IA	Muscatine	191390020	41.407796	-91.062646	UNK	SUB	IND		4	5	2001	2005
IA	Scott	191630015	41.530011	-90.587611	HIC	URB	RES	NEI	4	5	2001	2005
IA	Van Buren	191770005	40.689167	-91.994444	UNK	RUR	FOR		3	4	2001	2004
IA	Van Buren	191770006	40.695078	-92.006318	GEN	RUR	FOR		3	2	2004	2005
IA	Woodbury	191930018	42.399444	-96.355833	POP	URB	RES		3	2	2001	2002
LA	West Baton Rouge	221210001	30.501944	-91.209722	HIC	SUB	COM		2	4	1997	2000
MO	Buchanan	290210009	39.731389	-94.8775	GEN	URB	IND	NEI	3	4	1997	2000
MO	Buchanan	290210011	39.731389	-94.868333	GEN	URB	IND	NEI	3	4	2000	2003
MO	Greene	290770026	37.128333	-93.261667	POP	SUB	RES		3	11	1997	2007
MO	Greene	290770037	37.11	-93.251944	POP	RUR	RES		4	11	1997	2007
MO	Iron	290930030	37.466389	-90.69	SRC	RUR	RES	NEI	4	8	1997	2004
MO	Iron	290930031	37.519444	-90.7125	UNK	RUR	AGR		2	8	1997	2004
MO	Jefferson	290990004	38.2633	-90.3785	POP	RUR	IND		3	4	2004	2007
MO	Jefferson	290990014	38.267222	-90.379444	OTH	RUR	RES	NEI	4	5	1997	2001
MO	Jefferson	290990017	38.252778	-90.393333	UNK	SUB	RES		5	4	1998	2001
MO	Jefferson	290990018	38.297694	-90.384333	HIC	SUB	RES	NEI	5	3	2001	2003
MO	Monroe	291370001	39.473056	-91.789167	UNK	RUR	UNK			11	1997	2007
MO	Pike	291630002	39.3726	-90.9144	HIC	RUR	RES	NEI	3	3	2005	2007
MO	Saint Charles	291830010	38.579167	-90.841111	UNK	RUR	AGR		3	2	1997	1998

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height (m)	Years n	Years First	Years Last
MO	Saint Charles	291831002	38.8725	-90.226389	UNK	RUR	AGR		2	4	1997	2000
MT	Yellowstone	301110066	45.788318	-108.459536	SRC	RUR	RES	NEI	3.5	7	1997	2003
MT	Yellowstone	301110079	45.769439	-108.574292	POP	SUB	COM		4.5	4	1997	2003
MT	Yellowstone	301110080	45.777149	-108.47436	UNK	RUR	AGR		4	5	1997	2001
MT	Yellowstone	301110082	45.783889	-108.515	POP	URB	COM	NEI	3	3	2001	2003
MT	Yellowstone	301110083	45.795278	-108.455833	SRC	SUB	AGR		4	5	1999	2003
MT	Yellowstone	301110084	45.831453	-108.449964	POP	SUB	RES	NEI	4.5	4	2003	2006
MT	Yellowstone	301112008	45.786389	-108.523056	UNK	URB	RES		3	1	1997	1997
NC	Forsyth	370670022	36.110556	-80.226667	POP	URB	RES	NEI	3	8	1997	2004
NC	New Hanover	371290006	34.268403	-77.956529	GEN	RUR	IND	URB	3	4	1999	2002
ND	Billings	380070002	46.8943	-103.37853	GEN	RUR	AGR	REG	12.2	10	1998	2007
ND	Billings	380070003	46.9619	-103.356699	HIC	RUR	IND	URB	4	1	1997	1997
ND	Burke	380130002	48.9904	-102.7815	SRC	RUR	AGR	REG	4	7	1999	2005
ND	Burke	380130004	48.64193	-102.4018	REG	RUR	AGR	REG	4	5	2003	2007
ND	Burleigh	380150003	46.825425	-100.76821	POP	SUB	RES	URB	4	3	2005	2007
ND	Cass	380171003	46.910278	-96.795	POP	SUB	RES	URB	4	2	1997	1998
ND	Cass	380171004	46.933754	-96.85535	POP	SUB	AGR	URB	3	10	1998	2007
ND	Dunn	380250003	47.3132	-102.5273	GEN	RUR	AGR	REG	4	11	1997	2007
ND	McKenzie	380530002	47.5812	-103.2995	GEN	RUR	AGR	REG	4	9	1997	2007
ND	McKenzie	380530104	47.575278	-103.968889	SRC	RUR	AGR	URB	3	10	1998	2007
ND	McKenzie	380530111	47.605556	-104.017222	SRC	RUR	IND	URB	3	10	1998	2007
ND	Mercer	380570001	47.258853	-101.783035	POP	SUB	RES	NEI	5	3	1997	1999
ND	Mercer	380570004	47.298611	-101.766944	POP	RUR	AGR	URB	4	9	1999	2007
ND	Morton	380590002	46.84175	-100.870059	SRC	SUB	IND	NEI	4	9	1997	2005
ND	Morton	380590003	46.873075	-100.905039	SRC	SUB	IND	NEI	4	8	1998	2005
ND	Oliver	380650002	47.185833	-101.428056	SRC	RUR	AGR	URB	3	11	1997	2007
ND	Steele	380910001	47.599703	-97.899009	GEN	RUR	AGR	REG	3	4	1997	2000
ND	Williams	381050103	48.408834	-102.90765	SRC	RUR	IND	URB	4	6	2002	2007
ND	Williams	381050105	48.392644	-102.910233	SRC	RUR	IND	URB	4	6	2002	2007
PA	Allegheny	420030002	40.500556	-80.071944	POP	SUB	RES	NEI	6	3	1997	1999
PA	Allegheny	420030021	40.413611	-79.941389	POP	SUB	RES	NEI	6	4	1997	2002
PA	Allegheny	420030031	40.443333	-79.990556	POP	URB	COM	NEI	13	3	1997	1999
PA	Allegheny	420030032	40.414444	-79.942222	UNK	SUB	RES		5	3	1997	1999

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height (m)	Years		
										n	First	Last
PA	Allegheny	420030064	40.323611	-79.868333	POP	SUB	RES	NEI	8	4	1997	2002
PA	Allegheny	420030067	40.381944	-80.185556	GEN	RUR	RES	NEI	9	3	1997	1999
PA	Allegheny	420030116	40.473611	-80.077222	POP	SUB	RES	NEI	5	4	1997	2002
PA	Allegheny	420031301	40.4025	-79.860278	HIC	SUB	RES	NEI	9	3	1997	1999
PA	Allegheny	420033003	40.318056	-79.881111	POP	SUB	IND		5	4	1997	2002
PA	Allegheny	420033004	40.305	-79.888889	UNK	SUB	RES		8	3	1997	1999
PA	Beaver	420070002	40.56252	-80.503948	REG	RUR	AGR	REG	3	2	1997	1998
PA	Beaver	420070005	40.684722	-80.359722	POP	RUR	AGR	URB	3	8	1997	2007
PA	Berks	420110009	40.320278	-75.926667	HIC	SUB	RES	NEI	4	3	1997	1999
PA	Cambria	420210011	40.309722	-78.915	HIC	URB	COM	NEI	12	3	1997	1999
PA	Erie	420490003	42.14175	-80.038611	HIC	SUB	COM	NEI	4	3	1997	1999
PA	Philadelphia	421010022	39.916667	-75.188889	HIC	URB	IND	NEI	7	5	1997	2001
PA	Philadelphia	421010048	39.991389	-75.080833	UNK	RUR	RES		5	3	1997	1999
PA	Philadelphia	421010136	39.9275	-75.222778	POP	URB	RES	NEI	4	7	1997	2003
PA	Warren	421230003	41.857222	-79.1375	HIC	SUB	RES	NEI	4	2	1997	1998
PA	Warren	421230004	41.844722	-79.169722	HIC	RUR	FOR	NEI	4	2	1997	1998
PA	Washington	421250005	40.146667	-79.902222	POP	SUB	COM	NEI	2	3	1997	1999
PA	Washington	421250200	40.170556	-80.261389	POP	SUB	RES	NEI	4	3	1997	1999
PA	Washington	421255001	40.445278	-80.420833	REG	RUR	AGR	REG	4	2	1997	1998
SC	Barnwell	450110001	33.320344	-81.465537	SRC	RUR	FOR	URB	3.1	3	2000	2002
SC	Charleston	450190003	32.882289	-79.977538	POP	URB	COM	NEI	4.3	3	2000	2002
SC	Charleston	450190046	32.941023	-79.657187	SRC	RUR	FOR	REG	4	3	2000	2002
SC	Georgetown	450430006	33.362014	-79.294251	SRC	URB	IND	NEI	2.13	3	2000	2002
SC	Greenville	450450008	34.838814	-82.402918	POP	URB	COM	NEI	4	3	2000	2002
SC	Lexington	450630008	34.051017	-81.15495	SRC	SUB	COM	NEI	3.35	2	2001	2002
SC	Oconee	450730001	34.805261	-83.2377	REG	RUR	FOR	REG	4.3	3	2000	2002
SC	Richland	450790007	34.093959	-80.962304	OTH	SUB	COM	NEI	3	3	2000	2002
SC	Richland	450790021	33.81468	-80.781135	GEN	RUR	FOR	URB	4.42	3	2000	2002
SC	Richland	450791003	34.024497	-81.036248	POP	URB	COM	MID	4	2	2001	2002
UT	Salt Lake	490352004	40.736389	-112.210278	HIC	RUR	IND			2	1997	1998
WV	Wayne	540990002	38.39186	-82.583923	POP	RUR	IND	NEI	4	1	2002	2002
WV	Wayne	540990003	38.390278	-82.585833	HIC	RUR	RES	NEI	3	4	2002	2005
WV	Wayne	540990004	38.380278	-82.583889	HIC	RUR	RES	NEI	3	4	2002	2005

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height (m)	Years		
										n	First	Last
WV	Wayne	540990005	38.372222	-82.588889	HIC	RUR	RES	NEI	3	4	2002	2005
WV	Wood	541071002	39.323533	-81.552367	POP	SUB	IND	URB	4	5	2001	2005

Notes:

[1] Objectives are POP=Population Exposure; HIC=Highest Concentration; SRC=Source Oriented; GEN=General/Background; REG=Regional Transport; OTH=Other; UNK=Unknown

[2] Settings are R=Rural; U=Urban and Center City; S=Suburban

[3] Land Uses are AGR=Agricultural; COM=Commercial; IND=Industrial; FOR=Forest; RES=Residential; UNK=Unknown

[4] Scales are NEI=Neighborhood; MID=Middle; URB=URBAN; REG=Regional

Table A.1-2. Population density, concentration variability, and total SO_2 emissions associated with 98 ambient monitors reporting 5-minute maximum and corresponding 1-hour SO_2 concentrations.

State	County	Monitor ID	Population Residing Within:				Analysis Bins			Emissions (tpy)[4]
			5 km	10 km	15 km	20 km	Population[1]	COV[2]	GSD[3]	
AR	Pulaski	051190007	67784	178348	270266	334649	hi	a	a	20
AR	Pulaski	051191002	45800	109372	230200	310362	mid	a	a	20
AR	Union	051390006	21877	29073	32652	36340	mid	b	a	2527
CO	Denver	080310002	189782	574752	1158644	1608099	hi	b	b	26354
DE	New Castle	100031008	5386	80025	192989	391157	low	b	b	39757
DC	District of Columbia	110010041	216129	813665	1461563	2029936	hi	a	a	18325
FL	Nassau	120890005	17963	21386	38521	48316	mid	c	b	5050
IA	Cerro Gordo	190330018	21247	30341	39284	45105	mid	c	c	10737
IA	Clinton	190450019	24561	37638	42404	45947	mid	b	c	9388
IA	Muscatine	191390016	20360	27101	31886	40248	mid	b	b	31137
IA	Muscatine	191390017	11109	27101	31696	36604	mid	b	b	31054
IA	Muscatine	191390020	20360	27101	31886	40290	mid	c	c	31054
IA	Scott	191630015	90863	201277	268535	293627	hi	b	c	9415
IA	Van Buren	191770005	994	2252	3764	6984	low	b	b	
IA	Van Buren	191770006	994	2252	3764	6984	low	a	b	
IA	Woodbury	191930018	4449	44815	92956	112802	low	b	c	36833
LA	West Baton Rouge	221210001	21249	137455	239718	366741	mid	b	b	31242
MO	Buchanan	290210009	23253	72613	87121	93365	mid	c	b	3563
MO	Buchanan	290210011	28224	75073	86317	93365	mid	b	b	3563
MO	Greene	290770026	41036	146752	224445	256158	mid	c	b	9206
MO	Greene	290770037	21784	110681	210953	254437	mid	c	b	9206
MO	Iron	290930030	1121	1121	4507	8447	low	c	c	43340
MO	Iron	290930031	0	3799	6585	8436	low	c	b	43340
MO	Jefferson	290990004	15049	33379	64516	124301	mid	c	c	55725
MO	Jefferson	290990014	11967	35082	61963	125932	mid	c	b	55725
MO	Jefferson	290990017	19711	36471	60199	116882	mid	c	b	55725
MO	Jefferson	290990018	12258	41709	79196	170110	mid	c	b	32468
MO	Monroe	291370001	0	1439	2093	5612	low	a	a	
MO	Pike	291630002	645	2077	6916	11249	low	b	b	13495
MO	Saint Charles	291830010	2637	6349	34541	90953	low	b	b	47610
MO	Saint Charles	291831002	4587	95765	273147	431484	low	b	b	67735

State	County	Monitor ID	Population Residing Within:				Analysis Bins			Emissions (tpy)[4]
			5 km	10 km	15 km	20 km	Population[1]	COV[2]	GSD[3]	
MT	Yellowstone	301110066	27389	79644	98733	107178	mid	b	c	5480
MT	Yellowstone	301110079	61645	89282	102887	114640	hi	b	a	5480
MT	Yellowstone	301110080	33774	86065	104825	108399	mid	b	b	5480
MT	Yellowstone	301110082	58256	94753	103200	106046	hi	b	a	5480
MT	Yellowstone	301110083	27620	76641	98733	109475	mid	b	b	5480
MT	Yellowstone	301110084	22577	59919	97912	110980	mid	b	b	15298
MT	Yellowstone	301112008	61335	95574	103200	106046	hi	b	b	5480
NC	Forsyth	370670022	61669	170320	258102	325974	hi	b	b	3945
NC	New Hanover	371290006	17957	83529	145330	170260	mid	c	c	30020
ND	Billings	380070002	0	0	1887	1887	low	a	a	283
ND	Billings	380070003	0	888	1887	1887	low	a	a	283
ND	Burke	380130002	0	0	0	625	low	b	b	
ND	Burke	380130004	655	655	655	655	low	b	b	426
ND	Burleigh	380150003	49591	67377	83082	84415	mid	b	a	4592
ND	Cass	380171003	48975	134561	144878	154455	mid	b	a	771
ND	Cass	380171004	2118	91149	145789	148002	low	a	b	756
ND	Dunn	380250003	0	0	0	537	low	a	a	5
ND	McKenzie	380530002	0	596	596	596	low	a	a	210
ND	McKenzie	380530104	0	521	521	2283	low	b	a	
ND	McKenzie	380530111	0	0	2283	5771	low	c	a	823
ND	Mercer	380570001	3280	3280	5902	6465	low	b	b	91617
ND	Mercer	380570004	3280	4428	5902	7455	low	b	a	91617
ND	Morton	380590002	17925	67959	75685	84415	mid	c	c	4592
ND	Morton	380590003	10305	31348	75685	82584	mid	b	b	4592
ND	Oliver	380650002	0	0	2057	2670	low	b	b	28565
ND	Steele	380910001	0	934	934	934	low	a	a	
ND	Williams	381050103	0	1259	1259	1827	low	c	b	1605
ND	Williams	381050105	0	1259	1259	1827	low	b	c	1605
PA	Allegheny	420030002	83332	277442	651551	961378	hi	b	b	1964
PA	Allegheny	420030021	170777	560187	921490	1142754	hi	b	b	52447
PA	Allegheny	420030031	183843	580429	877668	1145039	hi	a	b	46957
PA	Allegheny	420030032	174072	558904	922097	1144558	hi	b	b	52447
PA	Allegheny	420030064	64846	201143	520438	943781	hi	b	c	11490

State	County	Monitor ID	Population Residing Within: 5 km	10 km	15 km	20 km	Analysis Bins: Population[1]	COV[2]	GSD[3]	Emissions (tpy)[4]
PA	Allegheny	420030067	13277	86792	324154	610975	mid	a	b	1167
PA	Allegheny	420030116	96820	331624	704601	996267	hi	b	b	1964
PA	Allegheny	420031301	115432	411867	766188	1088115	hi	b	b	52100
PA	Allegheny	420033003	55221	202092	509708	944188	hi	b	c	11490
PA	Allegheny	420033004	38588	170065	461433	904760	mid	b	b	11501
PA	Beaver	420070002	3434	28961	68617	120780	low	b	b	187257
PA	Beaver	420070005	17292	77240	143738	224631	mid	b	c	41385
PA	Berks	420110009	121330	203799	250610	309553	hi	a	b	14817
PA	Cambria	420210011	50440	79710	102905	124592	hi	a	b	16779
PA	Erie	420490003	81199	150626	190212	209983	hi	b	b	4122
PA	Philadelphia	421010022	316944	985213	1726387	2446142	hi	a	b	18834
PA	Philadelphia	421010048	262592	1102727	1938877	2607877	hi	b	b	6214
PA	Philadelphia	421010136	382995	985957	1718068	2381173	hi	b	b	21700
PA	Warren	421230003	14142	19940	25715	32490	mid	b	b	4890
PA	Warren	421230004	13965	18884	28805	33523	mid	b	c	4890
PA	Washington	421250005	31276	68512	111222	183285	mid	a	b	8484
PA	Washington	421250200	32125	52910	83324	118188	mid	b	b	7
PA	Washington	421255001	1359	15854	43364	126091	low	b	b	2566
SC	Barnwell	450110001	0	4022	13647	21554	low	a	a	65
SC	Charleston	450190003	40872	132716	273298	364953	mid	b	b	34934
SC	Charleston	450190046	1103	1103	9529	22255	low	b	a	
SC	Georgetown	450430006	10567	18215	22467	34357	mid	b	b	40841
SC	Greenville	450450008	70221	173012	284047	379022	hi	a	a	1067
SC	Lexington	450630008	42208	131361	257820	355854	mid	b	b	10433
SC	Oconee	450730001	0	2260	11136	26182	low	a	a	5
SC	Richland	450790007	35872	121006	255135	353072	mid	a	a	613
SC	Richland	450790021	1666	4643	13324	33098	low	b	a	40492
SC	Richland	450791003	87097	213836	300874	396116	hi	a	a	12935
UT	Salt Lake	490352004	0	4074	35159	124394	low	a	a	3735
WV	Wayne	540990002	17320	62645	124477	178576	mid	a	b	10172
WV	Wayne	540990003	17320	59989	123349	177744	mid	b	b	10172
WV	Wayne	540990004	16553	54251	122072	179815	mid	b	b	10172
WV	Wayne	540990005	13314	48330	114824	173807	mid	b	b	10172

State	County	Monitor ID	Population Residing Within:				Analysis Bins			Emissions (tpy)[4]
			5 km	10 km	15 km	20 km	Population[1]	COV[2]	GSD[3]	
WV	Wood	541071002	24917	70324	104458	128127	mid	b	b	48124

Notes:
[1] Population bins: low (≤10,000); mid (10,001 to 50,000); hi (>50,000) using population within 5 km of ambient monitor.
[2] COV bins: a (≤100%); b (>100 to ≤200); c (>200).
[3] GSD bins: a (≤2.17); b (>2.17 to ≤2.94); c (>2.94).
[4] Sum of emissions within 20 km radius of ambient monitor based on 2002 NEI.

Table A.1-3. Meta-data for 809 ambient monitors in the broader SO_2 monitoring network.

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height	Years n	First	Last
AL	Colbert	010330044	34.690556	-87.821389	UNK	RUR	AGR			9	1997	2005
AL	Jackson	010710020	34.876944	-85.720833	UNK	RUR	AGR		4	9	1997	2005
AL	Jefferson	010731003	33.485556	-86.915	HIC	SUB	RES	NEI	4	9	1997	2006
AL	Lawrence	010790003	34.589571	-87.109445	UNK	RUR	AGR	URB		2	1998	1999
AL	MOB	010970028	30.958333	-88.028333	HIC	SUB	IND	NEI	4	3	1997	1999
AL	MOB	010972005	30.474674	-88.14114	POP	RUR	AGR	NEI	1	3	2002	2004
AL	Montgomery	011011002	32.40712	-86.256367	HIC	SUB	COM	NEI	6	1	1997	1997
AZ	Gila	040070009	33.399135	-110.858896	SRC	URB	RES			7	1999	2005
AZ	Gila	040071001	33.006179	-110.785797	SRC	URB	IND		4	7	1999	2005
AZ	Maricopa	040130019	33.48385	-112.14257	UNK	SUB	RES			1	1998	1998
AZ	Maricopa	040133002	33.45793	-112.04601	HIC	URB	RES	NEI	11.3	9	1997	2006
AZ	Maricopa	040133003	33.47968	-111.91721	POP	SUB	RES	NEI	5.8	7	1998	2006
AZ	Pima	040191011	32.208333	-110.872222	POP	SUB	RES	NEI	5	9	1998	2006
AZ	Pinal	040212001	32.600479	-110.633598	POP	SUB	RES		4	4	1998	2005
AR	Pulaski	051190007	34.756111	-92.275833	POP	URB	COM	NEI	4	5	2002	2006
AR	Pulaski	051191002	34.830556	-92.259444	HIC	RUR	FOR	NEI	4	5	1997	2001
AR	Union	051390006	33.215	-92.668889	UNK	URB	COM		4	7	1997	2006
CA	Alameda	060010010	37.7603	-122.1925	POP	SUB	RES	NEI		1	2002	2002
CA	Contra Costa	060130002	37.936	-122.0262	SRC	SUB	RES	NEI	8.3	9	1997	2005
CA	Contra Costa	060130006	37.9478	-122.3651	UNK	URB	IND	NEI	8.5	9	1997	2005
CA	Contra Costa	060130010	38.0313	-122.1318	POP	URB	COM	NEI		1	2002	2002
CA	Contra Costa	060131001	38.055556	-122.219722	SRC	SUB	IND		7	8	1997	2004
CA	Contra Costa	060131002	38.010556	-121.641389	UNK	RUR	AGR		7	9	1997	2005
CA	Contra Costa	060131003	37.964167	-122.339167	UNK	URB	COM		6	4	1998	2001
CA	Contra Costa	060131004	37.96028	-122.35667	POP	URB	COM		20	3	2003	2005
CA	Contra Costa	060132001	38.013056	-122.133611	UNK	URB	RES		9	9	1997	2005
CA	Contra Costa	060133001	38.029167	-121.902222	HIC	URB	RES	NEI	7	9	1997	2005
CA	Imperial	060250005	32.676111	-115.483333	UNK	SUB	RES			6	1999	2005
CA	Los Angeles	060371002	34.17605	-118.31712	UNK	URB	COM		5	7	1998	2005
CA	Los Angeles	060371103	34.06659	-118.22688	UNK	URB	RES		11	6	1997	2005
CA	Los Angeles	060374002	33.82376	-118.18921	POP	SUB	RES	NEI	7	9	1997	2005

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height	Years		
										n	First	Last
CA	Los Angeles	060375001	33.92288	-118.37026	POP	URB	COM	NEI	2	7	1997	2003
CA	Los Angeles	060375005	33.9508	-118.43043	UPW	SUB	RES	NEI	4	1	2005	2005
CA	Orange	060591003	33.67464	-117.92568	UNK	SUB	RES	MID	6	9	1997	2005
CA	Riverside	060658001	33.99958	-117.41601	POP	SUB	RES	NEI	7	7	1997	2005
CA	Sacramento	060670002	38.712778	-121.38	UNK	SUB	RES		5	7	1997	2006
CA	Sacramento	060670006	38.614167	-121.366944	HIC	SUB	RES	NEI	5	9	1997	2006
CA	San Bernardino	060710012	34.426111	-117.563056	UNK	RUR	COM			1	1997	1997
CA	San Bernardino	060710014	34.5125	-117.33	UNK	SUB	RES		4	3	1997	1999
CA	San Bernardino	060710306	34.51	-117.330556	UNK	SUB	RES		4	7	2000	2006
CA	San Bernardino	060711234	35.763889	-117.396111	OTH	RUR	DES		1	8	1998	2006
CA	San Bernardino	060712002	34.10002	-117.49201	POP	SUB	IND	NEI	5	5	1997	2005
CA	San Bernardino	060714001	34.418056	-117.284722	UNK	SUB	RES			1	1997	1997
CA	San Diego	060730001	32.631231	-117.059075	POP	SUB	RES	NEI	7	9	1997	2005
CA	San Diego	060731007	32.709172	-117.153975	POP	URB	COM	NEI	5	8	1997	2004
CA	San Diego	060732007	32.552164	-116.937772	POP	RUR	MOB	NEI	5	8	1997	2004
CA	San Francisco	060750005	37.766	-122.3991	UNK	URB	IND			9	1997	2005
CA	San Luis Obispo	060791005	35.043889	-120.580278	UNK	RUR	COM		4	5	1997	2001
CA	San Luis Obispo	060792001	35.125	-120.633333	UNK	SUB	RES	NEI	5	5	1997	2002
CA	San Luis Obispo	060792004	35.022222	-120.569444	UNK	RUR	IND		4	9	1997	2006
CA	San Luis Obispo	060794002	35.028333	-120.387222	POP	RUR	RES	REG	4	7	2000	2006
CA	Santa Barbara	060830008	34.462222	-120.024444	POP	RUR	UNK	REG	4	9	1997	2005
CA	Santa Barbara	060831012	34.451944	-120.457778	UNK	RUR	AGR	REG		1	1997	1997
CA	Santa Barbara	060831013	34.725556	-120.427778	UNK	RUR	AGR	NEI		9	1997	2005
CA	Santa Barbara	060831015	34.478056	-120.210833	UNK	RUR	AGR	NEI		1	1997	1997
CA	Santa Barbara	060831016	34.477778	-120.205556	UNK	RUR	AGR	NEI		1	1997	1997
CA	Santa Barbara	060831019	34.475278	-120.188889	UNK	RUR	AGR	NEI		1	1997	1997
CA	Santa Barbara	060831020	34.415278	-119.878611	UNK	RUR	AGR	NEI		6	1997	2005
CA	Santa Barbara	060831025	34.489722	-120.045833	UNK	RUR	AGR	NEI		9	1997	2005
CA	Santa Barbara	060831026	34.479444	-120.0325	UNK	RUR	AGR	NEI		2	1997	1998
CA	Santa Barbara	060831027	34.469167	-120.039444	UNK	RUR	AGR	NEI		2	1997	1998
CA	Santa Barbara	060832004	34.6375	-120.456389	POP	URB	COM	NEI		9	1997	2005
CA	Santa Barbara	060832011	34.445278	-119.827778	POP	SUB	RES	NEI		9	1997	2005
CA	Santa Barbara	060834003	34.596111	-120.630278	UNK	RUR	AGR	NEI		8	1997	2005

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height	Years n	First	Last
CA	Santa Cruz	060870003	37.011944	-122.193333	UNK	RUR	RES			9	1997	2006
CA	Solano	060950001	38.052222	-122.144722	UNK	URB	COM		6	1	1997	1997
CA	Solano	060950004	38.1027	-122.2382	UNK	URB	COM		8	9	1997	2005
CA	Ventura	061113001	34.255	-119.1425	HIC	RUR	RES	NEI	4	7	1997	2003
CO	Adams	080010007	39.8	-104.910833	POP	URB	RES	NEI	4	2	2002	2003
CO	Adams	080013001	39.83818	-104.94984	POP	RUR	AGR	NEI	4	9	1997	2005
CO	Denver	080310002	39.75119	-104.98762	HIC	URB	COM	NEI	5	8	1997	2006
CO	El Paso	080416001	38.633611	-104.715556	UNK	RUR	IND		4	4	1997	2000
CO	El Paso	080416004	38.921389	-104.8125	UNK	URB	RES		4	3	1997	1999
CO	El Paso	080416011	38.846667	-104.827222	UNK	URB	RES		3	4	1997	2000
CO	El Paso	080416018	38.811389	-104.751389	UNK	URB	COM		3	3	1998	2000
CT	Fairfield	090010012	41.195	-73.163333	HIC	URB	RES	NEI	3	9	1997	2005
CT	Fairfield	090010017	41.003611	-73.585	UNK	SUB	RES		3	1	1997	1997
CT	Fairfield	090011123	41.399167	-73.443056	UNK	SUB	RES		3	9	1997	2005
CT	Fairfield	090012124	41.063056	-73.528889	HIC	URB	RES	NEI		8	1997	2004
CT	Fairfield	090019003	41.118333	-73.336667	POP	RUR	FOR	NEI		8	1998	2005
CT	Hartford	090031005	42.015833	-72.518056	POP	RUR	AGR	REG	3	2	1997	1998
CT	Hartford	090031018	41.760833	-72.670833	POP	URB	COM	NEI	3	1	1997	1997
CT	Hartford	090032006	41.7425	-72.634444	HIC	SUB	IND	NEI	9	9	1997	2005
CT	New Haven	090090027	41.301111	-72.902778	POP	URB	COM	NEI	3.67	1	2005	2005
CT	New Haven	090091003	41.310556	-72.915556	UNK	SUB	IND		5	1	1997	1997
CT	New Haven	090091123	41.310833	-72.916944	HIC	URB	RES	NEI	5	7	1997	2003
CT	New Haven	090092123	41.550556	-73.043611	POP	URB	MOB	NEI	5	9	1997	2005
CT	New London	090110007	41.361111	-72.08	UNK	SUB	RES		3	2	1997	1998
CT	Tolland	090130003	41.73	-72.213611	UNK	SUB	COM	NEI	3	2	1997	1998
DE	New Castle	100031003	39.761111	-75.491944	HIC	SUB	RES	NEI	4	6	1997	2002
DE	New Castle	100031007	39.551111	-75.730833	UNK	RUR	AGR			3	2002	2006
DE	New Castle	100031008	39.577778	-75.611111	UNK	RUR	AGR			8	1997	2006
DE	New Castle	100031013	39.773889	-75.496389	POP	SUB	RES			2	2004	2006
DE	New Castle	100032002	39.757778	-75.546389	POP	URB	COM	NEI	6	2	1997	1998
DE	New Castle	100032004	39.739444	-75.558056	UNK	URB	COM			6	2000	2006
DC	District of Columbia	110010041	38.897222	-76.952778	POP	URB	RES	NEI		10	1997	2006

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height	Years n	Years First	Years Last
FL	Broward	120110010	26.128611	-80.167222	HIC	SUB	RES	NEI	4	8	1997	2005
FL	Duval	120310032	30.356111	-81.635556	HIC	SUB	COM	NEI	3	8	1997	2004
FL	Duval	120310080	30.308889	-81.6525	HIC	SUB	COM	MID	3	8	1997	2005
FL	Duval	120310081	30.422222	-81.621111	HIC	SUB	RES	MID	4	8	1997	2005
FL	Duval	120310097	30.367222	-81.594167	POP	SUB	COM	NEI	5	8	1997	2005
FL	Escambia	120330004	30.525	-87.204167	POP	SUB	IND	NEI	4	9	1997	2005
FL	Escambia	120330022	30.544722	-87.216111	HIC	SUB	COM	NEI	6	8	1997	2005
FL	Hamilton	120470015	30.411111	-82.783611	UNK	RUR	IND		3	10	1997	2006
FL	Hillsborough	120570021	27.947222	-82.453333	HIC	RUR	RES	NEI	2	3	1997	1999
FL	Hillsborough	120570053	27.886389	-82.481389	POP	SUB	RES	NEI	4	9	1997	2005
FL	Hillsborough	120570081	27.739722	-82.465278	UNK	UNK	UNK		4	8	1997	2005
FL	Hillsborough	120570095	27.9225	-82.401389	HIC	SUB	COM	NEI	4	9	1997	2005
FL	Hillsborough	120570109	27.856389	-82.383667	POP	SUB	COM	NEI	3	9	1997	2005
FL	Hillsborough	120571035	27.928056	-82.454722	POP	SUB	RES	NEI	4	9	1997	2005
FL	Hillsborough	120574004	27.9925	-82.125833	HIC	SUB	RES	NEI	4	6	2000	2005
FL	Manatee	120813002	27.632778	-82.546111	POP	RUR	IND	NEI	4	5	1999	2004
FL	Miami-Dade	120860019	25.8975	-80.38	POP	UNK	UNK	NEI	4	7	1997	2003
FL	Nassau	120890005	30.658333	-81.463333	HIC	SUB	IND	NEI	2	8	1997	2006
FL	Nassau	120890009	30.686389	-81.4475	HIC	SUB	RES	NEI	4	1	1997	1997
FL	Orange	120952002	28.599444	-81.363056	HIC	URB	COM	NEI	4	9	1997	2005
FL	Palm Beach	120993004	26.369722	-80.074444	HIC	SUB	COM	NEI	10	6	1997	2002
FL	Pinellas	121030023	27.863333	-82.623333	POP	RUR	IND	NEI	4	9	1997	2005
FL	Pinellas	121033002	27.871389	-82.691667	HIC	SUB	COM	NEI	3	9	1997	2005
FL	Pinellas	121035002	28.09	-82.700833	HIC	RUR	RES	NEI	4	9	1997	2005
FL	Pinellas	121035003	28.141667	-82.739722	HIC	SUB	RES	NEI	4	7	1999	2005
FL	Polk	121050010	27.856111	-82.017778	HIC	RUR	IND	NEI	2	8	1997	2004
FL	Polk	121052006	27.896944	-81.960278	HIC	SUB	IND	NEI	4	6	1997	2002
FL	Putnam	121071008	29.6875	-81.656667	HIC	RUR	IND	NEI		10	1997	2006
FL	Sarasota	121151002	27.299722	-82.524444	HIC	SUB	RES	NEI	5	1	1997	1997
FL	Sarasota	121151005	27.306944	-82.570556	POP	SUB	RES	URB	4	4	1997	2000
FL	Sarasota	121151006	27.350278	-82.48	POP	SUB	RES	NEI	5	4	2000	2003
GA	Baldwin	130090001	33.153258	-83.235807	SRC	RUR	RES	NEI	5	3	1998	2006
GA	Bartow	130150002	34.103333	-84.915278	POP	SUB	AGR	REG	5	5	1997	2004

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height	Years n	Years First	Years Last
GA	Bibb	130210012	32.805244	-83.543628	POP	RUR	IND	URB	4	3	1998	2003
GA	Chatham	130510019	32.093889	-81.151111	HIC	SUB	IND	URB	4	1	2000	2000
GA	Chatham	130510021	32.06905	-81.048949	SRC	SUB	COM	NEI	10	6	1998	2006
GA	Chatham	130511002	32.090278	-81.130556	POP	URB	IND	NEI	5	3	2004	2006
GA	Dougherty	130950006	31.567778	-84.102778	HIC	SUB	RES	MID	4	1	1998	1998
GA	Fannin	131110091	34.985556	-84.375278	POP	URB	IND	NEI	3	9	1997	2006
GA	Floyd	131150003	34.261113	-85.323018	POP	RUR	RES	NEI	4	10	1997	2006
GA	Fulton	131210048	33.779189	-84.395843	HIC	URB	COM	NEI	5	8	1999	2006
GA	Fulton	131210055	33.720428	-84.357449	POP	SUB	COM	NEI	5	10	1997	2006
GA	Glynn	131270006	31.16953	-81.496046	POP	SUB	RES	NEI	8	1	1999	1999
GA	Muscogee	132150008	32.521099	-84.944695	POP	SUB	RES	NEI	4	2	1999	2005
GA	Richmond	132450003	33.393611	-82.006389	POP	SUB	IND	NEI	4	3	1997	2001
HI	Honolulu	150030010	21.329167	-158.093333	SRC	RUR	IND			9	1997	2005
HI	Honolulu	150030011	21.337222	-158.119167	SRC	RUR	COM	NEI	4	6	2000	2005
HI	Honolulu	150031001	21.310278	-157.858056	POP	URB	COM	NEI	10	7	1998	2004
HI	Honolulu	150031006	21.3475	-158.113333	UNK	RUR	IND			9	1997	2005
ID	Bannock	160050004	42.916389	-112.515833	HIC	RUR	IND	NEI	3	9	1997	2005
ID	Caribou	160290003	42.661298	-111.591443	POP	URB	RES	NEI	3	3	1999	2001
ID	Caribou	160290031	42.695278	-111.593889	SRC	RUR	DES	MIC	4	4	2002	2005
ID	Power	160770011	42.9125	-112.535556	SRC	RUR	IND			1	2004	2004
IL	Adams	170010006	39.93301	-91.404237	POP	URB	COM	NEI	9	10	1997	2006
IL	Champaign	170190004	40.123796	-88.229531	POP	SUB	RES	NEI	5	4	1997	2000
IL	Cook	170310050	41.70757	-87.568574	POP	SUB	IND	NEI	8	10	1997	2006
IL	Cook	170310059	41.6875	-87.536111	HIC	SUB	IND	NEI	10	4	1997	2000
IL	Cook	170310063	41.876969	-87.63433	POP	URB	MOB	NEI	3	10	1997	2006
IL	Cook	170310064	41.790787	-87.601646	POP	SUB	RES	NEI	15	1	1997	1997
IL	Cook	170310076	41.7514	-87.713488	POP	SUB	RES	URB	4	3	2004	2006
IL	Cook	170311018	41.773889	-87.815278	HIC	SUB	IND	NEI	4	8	1997	2004
IL	Cook	170311601	41.66812	-87.99057	POP	SUB	RES	NEI	4	10	1997	2006
IL	Cook	170312001	41.662109	-87.696467	HIC	SUB	IND	NEI	9	7	1997	2003
IL	Cook	170314002	41.855243	-87.75247	POP	SUB	RES	NEI	4	10	1997	2006
IL	Cook	170314201	42.139996	-87.799227	POP	SUB	RES	URB	8	2	2004	2005
IL	Cook	170318003	41.631389	-87.568056	POP	SUB	RES	NEI	4	6	1997	2002

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height	Years		
										n	First	Last
IL	DuPage	170436001	41.813049	-88.072827	POP	SUB	AGR	NEI	14	4	1997	2000
IL	La Salle	170990007	41.293015	-89.049425	SRC	SUB	IND	NEI	5	1	2006	2006
IL	Macon	171150013	39.866834	-88.925594	POP	SUB	IND	NEI	5	10	1997	2006
IL	Macoupin	171170002	39.396075	-89.809739	POP	RUR	AGR	REG	5	10	1997	2006
IL	Madison	171190008	38.890186	-90.148031	SRC	SUB	IND	NEI	15	6	1997	2002
IL	Madison	171190017	38.701944	-90.149167	HIC	URB	MOB	NEI	3	4	1997	2000
IL	Madison	171191010	38.828303	-90.058433	SRC	SUB	IND	NEI	5	10	1997	2006
IL	Madison	171193007	38.860669	-90.105851	POP	SUB	IND	NEI	10	10	1997	2006
IL	Madison	171193009	38.865984	-90.070571	SRC	SUB	COM	NEI	7	9	1997	2006
IL	Peoria	171430024	40.68742	-89.606943	POP	SUB	COM	NEI	5	10	1997	2006
IL	Randolph	171570001	38.176278	-89.788459	GEN	RUR	IND	NEI	5	10	1997	2006
IL	Rock Island	171610003	41.511944	-90.514167	HIC	URB	COM	NEI	8	4	1997	2000
IL	Saint Clair	171630010	38.612034	-90.160477	POP	SUB	IND	NEI	5	10	1997	2006
IL	Saint Clair	171631010	38.592192	-90.165081	HIC	SUB	IND	NEI	7	6	1997	2002
IL	Saint Clair	171631011	38.235	-89.841944	SRC	RUR	IND	NEI	5	5	1997	2001
IL	Sangamon	171670006	39.800614	-89.591225	SRC	SUB	IND	NEI	8	10	1997	2006
IL	Tazewell	171790004	40.55646	-89.654028	SRC	SUB	IND	NEI	6	10	1997	2006
IL	Wabash	171850001	38.397222	-87.773611	HIC	URB	MOB	NEI	2	5	1997	2005
IL	Wabash	171851001	38.369444	-87.834444	HIC	RUR	AGR	NEI	2	6	1997	2005
IL	Will	171970013	41.459963	-88.182019	SRC	RUR	IND	NEI	13	10	1997	2006
IN	Daviess	180270002	38.572778	-87.214722	HIC	RUR	AGR	NEI	2	9	1997	2005
IN	Dearborn	180290004	39.092778	-84.855	HIC	SUB	COM	NEI	5	9	1997	2005
IN	Floyd	180430004	38.367778	-85.833056	HIC	RUR	AGR	NEI	5	5	1997	2005
IN	Floyd	180430007	38.273333	-85.836389	SRC	RUR	RES	NEI	4	5	1997	2005
IN	Floyd	180431004	38.308056	-85.834167	POP	SUB	RES	NEI	5	10	1997	2006
IN	Fountain	180450001	39.964167	-87.421389	HIC	RUR	AGR	NEI	2	6	1997	2005
IN	Gibson	180510001	38.361389	-87.748611	HIC	RUR	AGR	NEI	5	5	1997	2005
IN	Gibson	180510002	38.392778	-87.748333	HIC	RUR	AGR	NEI	9	5	1997	2004
IN	Hendricks	180630001	39.876944	-86.473889	HIC	RUR	IND			2	2004	2005
IN	Hendricks	180630002	39.863361	-86.47075	HIC	SUB	COM			2	2004	2005
IN	Hendricks	180630003	39.880833	-86.542194	HIC	SUB	COM			2	2004	2005
IN	Jasper	180730002	41.187778	-87.053333	HIC	RUR	AGR	NEI	3	10	1997	2006
IN	Jasper	180730003	41.135833	-86.987778	HIC	RUR	AGR	URB	3	6	1997	2002

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height	Years n	Years First	Years Last
IN	Jefferson	180770004	38.776667	-85.407222	HIC	SUB	COM	NEI	5	8	1997	2004
IN	Lake	180890022	41.606667	-87.304722	UNK	URB	IND			8	1998	2005
IN	Lake	180892008	41.639444	-87.493611	HIC	SUB	COM	NEI	5	9	1997	2006
IN	LaPorte	180910005	41.716944	-86.9075	HIC	URB	IND	NEI	4	10	1997	2006
IN	LaPorte	180910007	41.679722	-86.852778	HIC	RUR	RES	NEI	3	6	1997	2002
IN	Marion	180970042	39.646254	-86.248784	POP	RUR	AGR	URB	4	10	1997	2006
IN	Marion	180970054	39.730278	-86.196111	HIC	URB	IND	NEI	9	1	1997	1997
IN	Marion	180970057	39.749019	-86.186314	HIC	URB	RES	NEI	4	10	1997	2006
IN	Marion	180970072	39.768056	-86.16	POP	URB	COM	MID	3	4	1997	2000
IN	Marion	180970073	39.789167	-86.060833	POP	URB	RES	NEI	5	9	1997	2005
IN	Morgan	181091001	39.515	-86.391667	HIC	SUB	RES	NEI	2	2	1997	2005
IN	Perry	181230006	37.99433	-86.763457	UNK	RUR	IND			5	1998	2003
IN	Perry	181230007	37.983773	-86.772202	UNK	RUR	IND			5	1998	2003
IN	Pike	181250005	38.519167	-87.249722	HIC	RUR	AGR	NEI	4	8	1997	2005
IN	Porter	181270011	41.633889	-87.101389	HIC	RUR	IND	NEI	4	10	1997	2006
IN	Porter	181270017	41.621944	-87.116389	HIC	RUR	IND	NEI		6	1997	2002
IN	Porter	181270023	41.616667	-87.145833	HIC	SUB	IND	NEI		6	1997	2002
IN	Spencer	181470002	37.9825	-86.96638	HIC	RUR	AGR	NEI	5	5	1997	2001
IN	Spencer	181470010	37.95536	-87.0318	HIC	RUR	AGR	NEI	5	4	2002	2005
IN	Sullivan	181530004	39.099444	-87.470556	HIC	RUR	AGR	NEI	2	7	1997	2005
IN	Vanderburgh	181630012	38.021667	-87.569444	POP	URB	COM	NEI	5	10	1997	2006
IN	Vanderburgh	181631002	37.9025	-87.671389	UNK	RUR	AGR		9	10	1997	2006
IN	Vigo	181670018	39.486111	-87.401389	POP	URB	RES	NEI	5	10	1997	2006
IN	Vigo	181671014	39.514722	-87.407778	HIC	RUR	COM	NEI	5	8	1997	2005
IN	Warrick	181730002	37.9375	-87.314167	HIC	RUR	IND	NEI	4	5	1997	2006
IN	Warrick	181731001	37.938056	-87.345833	HIC	RUR	IND	NEI	4	4	1997	2002
IN	Wayne	181770006	39.812222	-84.89	HIC	SUB	IND	NEI	5	10	1997	2006
IN	Wayne	181770007	39.795833	-84.880833	HIC	RUR	IND	NEI	9	10	1997	2006
IA	Cerro Gordo	190330018	43.16944	-93.202426	UNK	SUB	RES		4	9	1998	2006
IA	Clinton	190450018	41.824722	-90.212778	UNK	SUB	RES		4	1	1997	1997
IA	Clinton	190450019	41.823283	-90.211982	UNK	URB	IND	MID		10	1997	2006
IA	Clinton	190450020	41.845833	-90.216389	HIC	SUB	COM	URB	7	1	1997	1997
IA	Lee	191110006	40.392222	-91.4	UNK	URB	IND		5	2	1997	1998

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height	Years		
										n	First	Last
IA	Lee	191111007	40.5825	-91.4275	UNK	RUR	IND		15	2	1998	2000
IA	Linn	191130028	41.910556	-91.651944	HIC	SUB	COM	NEI	8	5	1997	2001
IA	Linn	191130029	41.974722	-91.666667	HIC	URB	COM	NEI	16	9	1997	2006
IA	Linn	191130031	41.983333	-91.662778	SRC	URB	RES	MID	4	10	1997	2006
IA	Linn	191130032	41.964722	-91.664722	UNK	URB	RES			2	1998	1999
IA	Linn	191130034	41.971111	-91.645278	UNK	URB	RES			2	1998	1999
IA	Linn	191130038	41.941111	-91.633889	SRC	SUB	IND	MID	4.5	8	1999	2006
IA	Linn	191130039	41.934167	-91.6825	SRC	URB	IND			1	2001	2001
IA	Muscatine	191390016	41.419429	-91.070975	UNK	URB	RES		3	10	1997	2006
IA	Muscatine	191390017	41.387969	-91.054504	UNK	SUB	IND		4	10	1997	2006
IA	Muscatine	191390020	41.407796	-91.062646	UNK	SUB	IND		4	10	1997	2006
IA	Scott	191630015	41.530011	-90.587611	HIC	URB	RES	NEI	4	8	1997	2005
IA	Scott	191630017	41.467236	-90.688451	UNK	RUR	IND	NEI	4	1	1997	1997
IA	Van Buren	191770004	40.711111	-91.975278	HIC	RUR	FOR		3	2	1997	1998
IA	Van Buren	191770005	40.689167	-91.994444	UNK	RUR	FOR		3	4	2000	2003
IA	Van Buren	191770006	40.695078	-92.006318	GEN	RUR	FOR		3	2	2005	2006
IA	Woodbury	191930018	42.399444	-96.355833	POP	URB	RES		3	1	2002	2002
KS	Linn	201070002	38.135833	-94.731944	REG	RUR	AGR	REG	4	6	1999	2004
KS	Montgomery	201250006	37.046944	-95.613333	POP	URB	RES	NEI	4	7	1998	2005
KS	Pawnee	201450001	38.17625	-99.108028	POP	SUB	RES	NEI	3	1	1997	1997
KS	Sedgwick	201730010	37.701111	-97.313889	POP	URB	RES	NEI	4	1	1997	1997
KS	Sumner	201910002	37.476944	-97.366389	REG	RUR	RES	REG	4	3	2001	2005
KS	Trego	201950001	38.770278	-99.763611	GEN	RUR	AGR	REG	4	3	2002	2005
KS	Wyandotte	202090001	39.113056	-94.624444	HIC	URB	COM	NEI	15	2	1997	1998
KS	Wyandotte	202090020	39.151389	-94.6175	POP	URB	IND	NEI	9	1	1997	1997
KS	Wyandotte	202090021	39.1175	-94.635556	POP	URB	RES	NEI	4	4	2000	2005
KY	Boyd	210190015	38.465833	-82.621111	POP	URB	RES	NEI	4	3	1997	2000
KY	Boyd	210190017	38.459167	-82.640556	POP	SUB	RES	NEI	3	4	2002	2005
KY	Boyd	210191003	38.388611	-82.6025	POP	SUB	IND	NEI	5	3	1997	1999
KY	Campbell	210370003	39.065556	-84.451944	POP	SUB	RES	NEI	4	6	2000	2005
KY	Campbell	210371001	39.108611	-84.476111	POP	URB	RES	NEI	4	3	1997	1999
KY	Daviess	210590005	37.780833	-87.075556	POP	SUB	COM	NEI	4	9	1997	2005
KY	Fayette	210670012	38.065	-84.5	POP	SUB	RES	NEI	4	9	1997	2005

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height	Years n	First	Last
KY	Greenup	210890007	38.548333	-82.731667	POP	SUB	RES	NEI	4	9	1997	2005
KY	Hancock	210910012	37.938889	-86.896944	POP	RUR	RES	NEI	4	7	1998	2004
KY	Henderson	211010013	37.858889	-87.575278	POP	SUB	RES	NEI	4	5	1997	2001
KY	Henderson	211010014	37.871389	-87.463333	POP	RUR	COM	NEI	4	2	2004	2005
KY	Jefferson	211110032	38.1825	-85.861667	HIC	SUB	RES	NEI	4	3	1997	2001
KY	Jefferson	211110051	38.060833	-85.896111	POP	SUB	RES	NEI	4	10	1997	2006
KY	Jefferson	211111041	38.23163	-85.82672	POP	SUB	IND	NEI	5	8	1997	2006
KY	Livingston	211390004	37.070833	-88.334167	HIC	RUR	AGR	NEI	4	9	1997	2005
KY	McCracken	211450001	37.131667	-88.813333	HIC	RUR	IND	NEI	5	3	1997	1999
KY	McCracken	211451024	37.058056	-88.5725	POP	SUB	COM	NEI	4	6	2000	2005
KY	McCracken	211451026	37.040833	-88.541111	POP	SUB	RES	NEI	6	2	1997	1998
KY	Warren	212270008	37.036667	-86.250556	POP	RUR	RES	URB	4	3	2003	2005
LA	Bossier	220150008	32.53626	-93.74891	POP	URB	COM		3	10	1997	2006
LA	Calcasieu	220190008	30.261667	-93.284167	POP	RUR	IND	NEI	5	10	1997	2006
LA	East Baton Rouge	220330009	30.46198	-91.17922	HIC	URB	COM	NEI	5	10	1997	2006
LA	Ouachita	220730004	32.509713	-92.046093	GEN	URB	IND		4	10	1997	2006
LA	St. Bernard	220870002	29.981944	-89.998611	SRC	SUB	RES		2	7	1998	2004
LA	West Baton Rouge	221210001	30.501944	-91.209722	HIC	SUB	COM		2	10	1997	2006
ME	Androscoggin	230010011	44.089406	-70.214219	HIC	URB	COM	NEI	4	4	1997	2002
ME	Aroostook	230030009	47.351667	-68.303611	UNK	SUB	RES		1	1	1997	1997
ME	Aroostook	230030012	47.354444	-68.314167	UNK	URB	IND		9	1	1997	1997
ME	Aroostook	230031003	47.351667	-68.311389	UNK	SUB	RES		3	1	1997	1997
ME	Aroostook	230031013	46.123889	-67.829722	UNK	URB	COM		4	1	1997	1997
ME	Aroostook	230031018	46.660899	-67.902066	SRC	RUR	IND	NEI		1	2004	2004
ME	Cumberland	230050014	43.659722	-70.261389	HIC	URB	COM	NEI	4	1	1997	1997
ME	Cumberland	230050027	43.661944	-70.265833	HIC	URB	IND	NEI	4	7	2000	2006
ME	Oxford	230172007	44.543056	-70.545833	UNK	SUB	IND		4	8	1997	2004
MD	Allegany	240010006	39.649722	-78.762778	POP	URB	COM	NEI	5	1	1997	1997
MD	Anne Arundel	240032002	39.159722	-76.511667	POP	SUB	RES	NEI	5	4	1999	2002
MD	Baltimore	240053001	39.310833	-76.474444	POP	SUB	RES	NEI	5	2	2004	2005
MD	Baltimore (City)	245100018	39.314167	-76.613333	POP	URB	RES	NEI	4	2	1997	1998

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height	Years		
										n	First	Last
MD	Baltimore (City)	245100036	39.265	-76.536667	HIC	URB	RES	NEI	5	1	1997	1997
MA	Bristol	250051004	41.683279	-71.169171	HIC	SUB	COM	NEI	5	9	1997	2006
MA	Essex	250090005	42.709444	-71.146389	HIC	URB	RES	NEI	4	5	1997	2001
MA	Essex	250091004	42.515556	-70.931389	UNK	SUB	RES			1	1997	1997
MA	Essex	250091005	42.525	-70.934167	UNK	SUB	RES			1	1997	1997
MA	Essex	250095004	42.772222	-71.061111	OTH	SUB	RES		9	3	1997	2000
MA	Hampden	250130016	42.108581	-72.590614	POP	URB	COM	NEI	4	9	1997	2006
MA	Hampden	250131009	42.085556	-72.579722	HIC	SUB	RES	NEI	5	3	1997	1999
MA	Hampshire	250154002	42.298279	-72.333904	OTH	RUR	FOR	URB	5	9	1998	2006
MA	Middlesex	250171701	42.474444	-71.111111	UNK	SUB	RES			2	1997	1999
MA	Middlesex	250174003	42.383611	-71.213889	POP	RUR	AGR	NEI	4	2	1997	1998
MA	Suffolk	250250002	42.348873	-71.097163	HIC	URB	COM	NEI	5	8	1997	2006
MA	Suffolk	250250019	42.316394	-70.967773	OTH	RUR	RES		5	9	1997	2005
MA	Suffolk	250250020	42.309417	-71.055573	OTH	URB	COM		5	8	1997	2005
MA	Suffolk	250250021	42.377833	-71.027138	HIC	URB	RES	NEI	4	9	1997	2005
MA	Suffolk	250250040	42.340251	-71.03835	POP	URB	IND	NEI	4	9	1997	2005
MA	Suffolk	250250042	42.3294	-71.0825	POP	URB	COM	NEI	5	5	2001	2006
MA	Suffolk	250251003	42.401667	-71.031111	POP	SUB	RES	NEI	4	3	1997	1999
MA	Worcester	250270020	42.267222	-71.798889	HIC	URB	COM	NEI	3	4	1998	2002
MA	Worcester	250270023	42.263877	-71.794186	POP	URB	COM	URB	4	3	2004	2006
MI	Delta	260410902	45.796667	-87.089444	UNK	RUR	IND			7	1997	2003
MI	Genesee	260490021	43.047224	-83.670159	POP	URB	RES	NEI	4	8	1997	2006
MI	Genesee	260492001	43.168336	-83.461541	GEN	RUR	AGR			1	2004	2004
MI	Kent	260810020	42.984173	-85.671339	POP	URB	IND	NEI	5	8	1997	2005
MI	Macomb	260991003	42.51334	-83.005971	POP	SUB	RES	NEI	3	10	1997	2006
MI	Missaukee	261130001	44.310555	-84.891865	GEN	RUR	FOR			1	2003	2003
MI	St. Clair	261470005	42.953336	-82.456229	HIC	SUB	RES	NEI	4	10	1997	2006
MI	Schoolcraft	261530001	46.288877	-85.950227	GEN	RUR	FOR			1	2005	2005
MI	Wayne	261630001	42.22862	-83.2082	POP	SUB	COM	NEI	4	1	1997	1997
MI	Wayne	261630005	42.267231	-83.132086	HIC	SUB	IND	NEI	4	4	1997	2000
MI	Wayne	261630015	42.302786	-83.10653	HIC	URB	COM	NEI	4	9	1997	2006
MI	Wayne	261630016	42.357808	-83.096033	POP	URB	RES	NEI	4	9	1997	2006
MI	Wayne	261630019	42.43084	-83.000138	POP	SUB	RES	NEI	4	7	1997	2006

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height	Years n	Years First	Years Last
MI	Wayne	261630025	42.423063	-83.426263	POP	SUB	COM	NEI	4	1	1997	1997
MI	Wayne	261630027	42.292231	-83.106807	HIC	URB	IND	MID	3	3	1997	1999
MI	Wayne	261630033	42.306674	-83.148754	HIC	SUB	IND	MID	5	2	1997	1998
MI	Wayne	261630062	42.340833	-83.0625	POP	URB	RES	NEI	5	1	1997	1997
MI	Wayne	261630092	42.296111	-83.116944	HIC	URB	RES	MID	7	1	1997	1997
MN	Anoka	270031002	45.13768	-93.20772	POP	SUB	RES	URB	4.57	4	2003	2006
MN	Carlton	270176316	46.733611	-92.418889	SRC	RUR	AGR		3	2	2001	2002
MN	Dakota	270370020	44.76323	-93.03255	UNK	RUR	IND	NEI	3	8	1997	2006
MN	Dakota	270370423	44.77553	-93.06299	UNK	RUR	IND	NEI	3.66	9	1997	2006
MN	Dakota	270370439	44.748039	-93.043266	UNK	RUR	IND		4	1	1999	1999
MN	Dakota	270370441	44.7468	-93.02611	UNK	RUR	IND		3	7	2000	2006
MN	Dakota	270370442	44.73857	-93.00496	UNK	RUR	AGR	NEI	3.5	6	2001	2006
MN	Hennepin	270530954	44.980995	-93.273719	HIC	URB	COM	NEI	3	7	1997	2006
MN	Hennepin	270530957	45.021111	-93.281944	HIC	URB	IND	MID	10	6	1997	2002
MN	Koochiching	270711240	48.605278	-93.402222	UNK	URB	IND		10	2	1997	1999
MN	Ramsey	271230864	44.991944	-93.183056	POP	SUB	RES	NEI	6	6	1997	2002
MN	Sherburne	271410003	45.420278	-93.871667	UNK	RUR	AGR			1	1997	1997
MN	Sherburne	271410011	45.394444	-93.8975	UNK	RUR	IND	NEI		2	1997	1998
MN	Sherburne	271410012	45.394444	-93.885	UNK	URB	MOB	NEI		1	1997	1997
MN	Sherburne	271410013	45.369444	-93.898056	UNK	RUR	IND	NEI		2	1997	1998
MN	Washington	271630436	44.84737	-92.9954	UNK	SUB	IND	MID	4.88	9	1997	2006
MN	Wright	271710007	45.329167	-93.835833	UNK	RUR	AGR			1	1997	1997
MS	Harrison	280470007	30.446806	-89.029139	HIC	SUB	RES	NEI	4	8	1997	2004
MS	Hinds	280490018	32.296806	-90.188306	POP	URB	COM	NEI	4	9	1997	2005
MS	Jackson	280590006	30.378425	-88.533985	POP	URB	COM	NEI		7	1997	2006
MS	Lee	280810004	34.263333	-88.759722	UNK	SUB	COM		4	1	1997	1997
MO	Buchanan	290210009	39.731389	-94.8775	GEN	URB	IND	NEI	3	3	1997	1999
MO	Buchanan	290210011	39.731389	-94.868333	GEN	URB	IND	NEI	3	1	2001	2001
MO	Clay	290470025	39.183889	-94.4975	POP	SUB	RES	NEI	4	5	1997	2001
MO	Greene	290770026	37.128333	-93.261667	POP	SUB	RES		3	10	1997	2006
MO	Greene	290770032	37.205278	-93.283333	UNK	URB	RES		3	10	1997	2006
MO	Greene	290770037	37.11	-93.251944	POP	RUR	RES		4	10	1997	2006
MO	Greene	290770040	37.108889	-93.252778	SRC	SUB	RES			4	2003	2006

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height	Years n	Years First	Years Last
MO	Greene	290770041	37.108611	-93.272222	SRC	SUB	RES			4	2003	2006
MO	Iron	290930030	37.466389	-90.69	SRC	RUR	RES	NEI	4	7	1997	2003
MO	Iron	290930031	37.519444	-90.7125	UNK	RUR	AGR		2	6	1997	2003
MO	Jackson	290950034	39.104722	-94.570556	UNK	URB	COM			9	1997	2006
MO	Jefferson	290990004	38.2633	-90.3785	POP	RUR	IND		3	3	2004	2006
MO	Jefferson	290990014	38.267222	-90.379444	OTH	RUR	RES	NEI	4	4	1997	2000
MO	Jefferson	290990017	38.252778	-90.393333	UNK	SUB	RES		5	2	1999	2000
MO	Jefferson	290990018	38.297694	-90.384333	HIC	SUB	RES	NEI	5	1	2002	2002
MO	Monroe	291370001	39.473056	-91.789167	UNK	RUR	UNK			10	1997	2006
MO	Pike	291630002	39.3726	-90.9144	HIC	RUR	RES	NEI	3	1	2006	2006
MO	Platte	291650023	39.3	-94.7	UNK	SUB	MOB		3	8	1997	2004
MO	Saint Charles	291830010	38.579167	-90.841111	UNK	RUR	AGR		3	1	1997	1997
MO	Saint Charles	291831002	38.8725	-90.226389	UNK	RUR	AGR		2	3	1997	1999
MO	Saint Louis	291890001	38.521667	-90.343611	POP	SUB	RES	NEI	3	1	1997	1997
MO	Saint Louis	291890004	38.5325	-90.382778	POP	SUB	RES	NEI	3	6	1999	2004
MO	Saint Louis	291890006	38.613611	-90.495833	UNK	RUR	RES		4	8	1997	2004
MO	Saint Louis	291890014	38.7109	-90.4759	HIC	RUR	RES	NEI	3	1	2006	2006
MO	Saint Louis	291893001	38.641389	-90.345833	UNK	SUB	COM		4	10	1997	2006
MO	Saint Louis	291895001	38.766111	-90.285833	UNK	SUB	COM		2	8	1997	2004
MO	Saint Louis	291897002	38.727222	-90.379444	POP	SUB	RES	NEI	4	4	1997	2000
MO	Saint Louis	291897003	38.720917	-90.367028	POP	SUB	RES	NEI	4	2	2002	2003
MO	St. Louis City	295100007	38.5425	-90.263611	HIC	URB	RES	NEI	4	10	1997	2006
MO	St. Louis City	295100072	38.624167	-90.198611	POP	URB	COM	NEI	14	4	1997	2000
MO	St. Louis City	295100080	38.682778	-90.246667	UNK	URB	RES		4	3	1997	1999
MO	St. Louis City	295100086	38.672222	-90.238889	POP	URB	RES	NEI	4	7	2000	2006
MT	Cascade	300132000	47.532222	-111.271111	SRC	SUB	AGR		3	3	1997	1999
MT	Cascade	300132001	47.53	-111.283611	SRC	SUB	IND	NEI	3.5	5	2001	2005
MT	Jefferson	300430903	46.557679	-111.918098	UNK	RUR	AGR			4	1997	2000
MT	Jefferson	300430911	46.548056	-111.873333	UNK	RUR	AGR		4	4	1997	2000
MT	Jefferson	300430913	46.534722	-111.861389	UNK	RUR	AGR		4	4	1997	2000
MT	Lewis and Clark	300490702	46.583333	-111.934444	UNK	RUR	AGR		3	4	1997	2000
MT	Lewis and Clark	300490703	46.593889	-111.92	UNK	RUR	RES		3	4	1997	2000
MT	Rosebud	300870700	45.886944	-106.628056	UNK	SUB	RES		4	4	1998	2001

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height	Years n	Years First	Years Last
MT	Rosebud	300870701	45.901944	-106.637778	UNK	RUR	AGR		5	3	1997	1999
MT	Rosebud	300870702	45.863889	-106.557778	UNK	RUR	AGR		5	2	1997	2000
MT	Rosebud	300870760	45.668056	-106.518889	SRC	RUR	FOR		4	5	1998	2003
MT	Rosebud	300870761	45.603056	-106.464167	SRC	RUR	FOR			5	1997	2003
MT	Rosebud	300870762	45.648333	-106.556667	OTH	RUR	FOR			5	1998	2003
MT	Rosebud	300870763	45.976667	-106.660556	UNK	RUR	IND		3	1	1997	1997
MT	Yellowstone	301110016	45.656389	-108.765833	UNK	RUR	AGR		4	9	1997	2005
MT	Yellowstone	301110066	45.788318	-108.459536	SRC	RUR	RES	NEI	3.5	10	1997	2006
MT	Yellowstone	301110079	45.769439	-108.574292	POP	SUB	COM		4.5	2	2002	2003
MT	Yellowstone	301110080	45.777149	-108.47436	UNK	RUR	AGR		4	4	1997	2000
MT	Yellowstone	301110082	45.783889	-108.515	POP	URB	COM	NEI	3	2	2002	2003
MT	Yellowstone	301110083	45.795278	-108.455833	SRC	SUB	AGR		4	3	2000	2002
MT	Yellowstone	301110084	45.831453	-108.449964	POP	SUB	RES	NEI	4.5	3	2004	2006
MT	Yellowstone	301111065	45.801944	-108.426111	UNK	SUB	RES		4	9	1997	2005
MT	Yellowstone	301112005	45.803889	-108.445556	UNK	SUB	IND		4	9	1997	2005
MT	Yellowstone	301112006	45.81	-108.413056	OTH	SUB	AGR		3	8	1997	2004
MT	Yellowstone	301112007	45.832778	-108.377778	OTH	RUR	RES		3	9	1997	2005
NE	Douglas	310550048	41.323889	-95.942778	HIC	URB	RES	NEI	5	1	1997	1997
NE	Douglas	310550050	41.332778	-95.956389	HIC	URB	RES	NEI	6	2	2002	2003
NE	Douglas	310550053	41.297778	-95.9375	POP	URB	IND	NEI	4	4	2002	2006
NE	Douglas	310550055	41.362433	-95.976112	HIC	SUB	RES	NEI	8	2	2005	2006
NV	Clark	320030022	36.390775	-114.90681	REG	RUR	IND	NEI	3.5	5	1998	2002
NV	Clark	320030078	35.46505	-114.919615	REG	RUR	DES	REG	4	2	2001	2002
NV	Clark	320030539	36.144444	-115.085556	POP	SUB	MOB	URB	3.5	8	1998	2005
NV	Clark	320030601	35.978889	-114.844167	POP	SUB	COM	NEI	4	1	2002	2002
NH	Cheshire	330050007	42.930556	-72.277778	UNK	URB	COM	NEI		7	1997	2003
NH	Coos	330070019	44.488611	-71.180278	POP	UNK	UNK	NEI	4	5	1997	2001
NH	Coos	330070022	44.458333	-71.154167	UNK	RUR	IND			1	1997	1997
NH	Coos	330071007	44.596667	-71.516667	POP	URB	IND	NEI	5	4	1997	2001
NH	Hillsborough	330110016	42.992778	-71.459444	HIC	URB	COM	NEI	5	1	1997	1997
NH	Hillsborough	330110019	43.000556	-71.468056	UNK	URB	COM		5	1	2000	2000
NH	Hillsborough	330110020	43.000556	-71.468056	UNK	URB	COM	NEI	5	5	2002	2006
NH	Hillsborough	330111009	42.764444	-71.4675	HIC	URB	COM	NEI	3	3	1997	2001

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height	Years		
										n	First	Last
NH	Hillsborough	330111010	42.701944	-71.445	UNK	SUB	IND	MIC	5	6	1997	2002
NH	Merrimack	330130007	43.206944	-71.534167	UNK	URB	COM	NEI		6	1997	2003
NH	Merrimack	330131003	43.177222	-71.4625	UNK	RUR	RES	NEI	3	7	1997	2003
NH	Merrimack	330131006	43.132444	-71.45827	OTH	SUB	RES	NEI	3	4	2003	2006
NH	Merrimack	330131007	43.218491	-71.45827	OTH	URB	COM	URB	9	1	2005	2005
NH	Rockingham	330150009	43.078056	-70.762778	UNK	SUB	COM		3	3	1997	2000
NH	Rockingham	330150014	43.075278	-70.748056	POP	URB	RES	NEI	2	3	2004	2006
NH	Rockingham	330150015	43.0825	-70.761944	POP	SUB	COM	NEI	4	1	2002	2002
NH	Sullivan	330190003	43.364444	-72.338333	UNK	URB	RES	NEI		5	1997	2001
NJ	Atlantic	340010005	39.53024	-74.46069	UNK	RUR	RES		4	8	1997	2005
NJ	Bergen	340035001	40.88237	-74.04217	POP	URB	COM	NEI	4	9	1997	2005
NJ	Burlington	340051001	40.07806	-74.85772	HIC	URB	COM	NEI	4	9	1997	2005
NJ	Camden	340070003	39.92304	-75.09762	POP	SUB	RES	NEI	5	8	1997	2005
NJ	Camden	340071001	39.68425	-74.86149	GEN	RUR	COM	URB	4	9	1997	2005
NJ	Cumberland	340110007	39.42227	-75.0252	UNK	RUR	IND		4	9	1997	2005
NJ	Essex	340130011	40.726667	-74.144167	UNK	URB	IND		4	2	1997	1998
NJ	Essex	340130016	40.722222	-74.146944	POP	URB	IND	NEI	5	1	2002	2002
NJ	Gloucester	340150002	39.80034	-75.21212	UNK	RUR	AGR		4	9	1997	2005
NJ	Hudson	340170006	40.67025	-74.12608	POP	URB	COM	NEI	5	9	1997	2005
NJ	Hudson	340171002	40.73169	-74.06657	HIC	URB	COM	NEI	4	8	1997	2005
NJ	Middlesex	340232003	40.50888	-74.2682	HIC	URB	COM	NEI	5	9	1997	2005
NJ	Morris	340273001	40.78763	-74.6763	UNK	RUR	AGR		5	9	1997	2005
NJ	Union	340390003	40.66245	-74.21474	POP	URB	COM	MID	5	9	1997	2005
NJ	Union	340390004	40.64144	-74.20836	HIC	SUB	IND	NEI	4	9	1997	2005
NM	Dona Ana	350130008	31.930556	-106.630556	UNK	RUR	AGR		2	6	1997	2002
NM	Dona Ana	350130017	31.795833	-106.5575	SRC	SUB	COM	URB		9	1997	2005
NM	Eddy	350151004	32.855556	-104.411389	SRC	URB	COM	NEI		9	1997	2005
NM	Grant	350170001	32.759444	-108.131389	UNK	SUB	IND		4	5	1997	2001
NM	Grant	350171003	32.691944	-108.124444	SRC	RUR	IND	NEI		5	1999	2005
NM	Hidalgo	350230005	31.783333	-108.497222	UNK	RUR	UNK		3	5	1997	2001
NM	San Juan	350450008	36.735833	-108.238333	UNK	RUR	DES			6	1997	2002
NM	San Juan	350450009	36.742222	-107.976944	SRC	RUR	IND	NEI		3	1997	2005
NM	San Juan	350450017	36.752778	-108.716667	UNK	RUR	UNK		3	1	1997	1997

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height	Years n	Years First	Years Last
NM	San Juan	350451005	36.796667	-108.4725	UNK	UNK	UNK		9	7	1997	2005
NY	Albany	360010012	42.68069	-73.75689	HIC	RUR	AGR	NEI	5	10	1997	2006
NY	Bronx	360050073	40.811389	-73.91	UNK	URB	RES		13	2	1997	1998
NY	Bronx	360050080	40.83608	-73.92021	HIC	URB	RES	MID	12	3	1997	1999
NY	Bronx	360050083	40.86586	-73.88075	UNK	URB	COM			6	2001	2006
NY	Bronx	360050110	40.81616	-73.90207	OTH	URB	RES			5	2000	2006
NY	Chautauqua	360130005	42.29073	-79.58958	POP	URB	IND		5	4	1997	2000
NY	Chautauqua	360130006	42.49945	-79.31888	HIC	URB	IND	NEI	4	7	2000	2006
NY	Chautauqua	360130011	42.29073	-79.58658	POP	RUR	AGR	REG	4	10	1997	2006
NY	Chemung	360150003	42.11105	-76.80249	UNK	URB	COM		4	9	1998	2006
NY	Erie	360290005	42.87684	-78.80988	POP	URB	RES	NEI	4	10	1997	2006
NY	Erie	360294002	42.99549	-78.90157	HIC	SUB	IND	NEI	4	10	1997	2006
NY	Erie	360298001	42.818889	-78.840833	HIC	URB	IND	NEI	4	2	1997	1998
NY	Essex	360310003	44.39309	-73.85892	GEN	RUR	FOR	NEI	4	10	1997	2006
NY	Franklin	360330004	44.434309	-74.24601	GEN	RUR	COM			2	2005	2006
NY	Hamilton	360410005	43.44957	-74.51625	POP	RUR	COM	URB	5	10	1997	2006
NY	Herkimer	360430005	43.68578	-74.98538	POP	RUR	FOR	REG	4	8	1997	2006
NY	Kings	360470011	40.73277	-73.94722	HIC	URB	IND	NEI	13	1	1998	1998
NY	Kings	360470076	40.67185	-73.97824	POP	URB	RES		11	2	1997	1999
NY	Madison	360530006	42.73046	-75.78443	POP	RUR	AGR	REG		10	1997	2006
NY	Monroe	360551004	43.16545	-77.55479	POP	SUB	RES	NEI	4	7	1997	2003
NY	Monroe	360551007	43.146198	-77.54813	POP	URB	RES			2	2005	2006
NY	Monroe	360556001	43.161	-77.60357	HIC	URB	COM	NEI	12	7	1997	2003
NY	Nassau	360590005	40.74316	-73.58549	UNK	SUB	COM	NEI	5	9	1997	2006
NY	New York	360610010	40.739444	-73.986111	HIC	URB	RES	NEI	38	2	1997	1999
NY	New York	360610056	40.75917	-73.96651	HIC	URB	COM	MID	10	8	1997	2006
NY	Niagara	360632008	43.08216	-79.00099	POP	SUB	IND	NEI	4	8	1999	2006
NY	Onondaga	360671015	43.05238	-76.0592	POP	SUB	COM	NEI	5	10	1997	2006
NY	Putnam	360790005	41.44151	-73.70762	UNK	RUR	FOR			10	1997	2006
NY	Queens	360810097	40.75527	-73.75861	GEN	URB	RES		12	3	1999	2001
NY	Queens	360810124	40.7362	-73.82317	POP	SUB	RES			5	2002	2006
NY	Rensselaer	360830004	42.78187	-73.46361	OTH	RUR	FOR			3	2002	2004
NY	Rensselaer	360831005	42.72444	-73.43166	GEN	RUR	FOR		5	3	1998	2000

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height	Years n	Years First	Years Last
NY	Richmond	360850067	40.59733	-74.12619	POP	SUB	RES	NEI	20	3	1997	1999
NY	Schenectady	360930003	42.79963	-73.94019	POP	SUB	RES	NEI	5	10	1997	2006
NY	Suffolk	361030002	40.74529	-73.41919	HIC	SUB	IND	NEI	5	2	1997	1998
NY	Suffolk	361030009	40.8275	-73.05694	UNK	SUB	RES			7	2000	2006
NY	Ulster	361111005	42.1438	-74.49414	POP	RUR	COM	URB	5	9	1997	2006
NC	Alexander	370030003	35.903611	-81.184167	GEN	SUB	COM	URB		2	1999	2003
NC	Beaufort	370130003	35.3575	-76.779722	SRC	RUR	IND	NEI	3	3	1997	1999
NC	Beaufort	370130004	35.377241	-76.748997	HIC	RUR	FOR	NEI	3	2	1997	1998
NC	Beaufort	370130006	35.377778	-76.766944	SRC	RUR	IND	NEI	3	5	2001	2006
NC	Chatham	370370004	35.757222	-79.159722	GEN	RUR	AGR	MIC		2	1998	2001
NC	Cumberland	370511003	34.968889	-78.9625	POP	SUB	COM	NEI		2	1999	2006
NC	Davie	370590002	35.809289	-80.559115	GEN	SUB	IND			2	1997	2000
NC	Duplin	370610002	34.954823	-77.960781	GEN	URB	RES	NEI		1	1999	1999
NC	Edgecombe	370650099	35.988333	-77.582778	GEN	RUR	AGR	REG	4	2	1999	2004
NC	Forsyth	370670022	36.110556	-80.226667	POP	URB	RES	NEI	3	8	1997	2004
NC	Johnston	371010002	35.590833	-78.461944	GEN	RUR	AGR	URB		1	1999	1999
NC	Lincoln	371090004	35.438556	-81.27675	GEN	RUR	RES	NEI		2	1997	2000
NC	Martin	371170001	35.81069	-76.89782	GEN	RUR	AGR	URB	5	2	1998	2001
NC	Mecklenburg	371190034	35.248611	-80.766389	POP	SUB	RES	NEI	5	2	1997	1998
NC	Mecklenburg	371190041	35.2401	-80.785683	POP	URB	RES	NEI	5	6	2000	2006
NC	New Hanover	371290002	34.364167	-77.838611	POP	RUR	AGR	URB	3	1	2005	2005
NC	New Hanover	371290006	34.268403	-77.956529	GEN	RUR	IND	URB	3	10	1997	2006
NC	Northampton	371310002	36.48438	-77.61998	SRC	RUR	COM	URB		2	1997	2000
NC	Person	371450003	36.306965	-79.09197	GEN	RUR	AGR	URB	4	2	1998	2004
NC	Pitt	371470099	35.583333	-77.598889	GEN	RUR	COM	REG		2	1997	2000
NC	Swain	371730002	35.435509	-83.443697	GEN	SUB	RES	NEI		2	1998	2004
ND	Billings	380070002	46.8943	-103.37853	GEN	RUR	AGR	REG	12.2	5	2000	2006
ND	Billings	380070111	47.296667	-103.095556	HIC	RUR	IND	NEI	4	1	1997	1997
ND	Burke	380130002	48.9904	-102.7815	SRC	RUR	AGR	REG	4	6	2000	2005
ND	Burke	380130004	48.64193	-102.4018	REG	RUR	AGR	REG	4	3	2004	2006
ND	Burleigh	380150003	46.825425	-100.76821	POP	SUB	RES	URB	4	1	2006	2006
ND	Cass	380171003	46.910278	-96.795	POP	SUB	RES	URB	4	1	1997	1997
ND	Cass	380171004	46.933754	-96.85535	POP	SUB	AGR	URB	3	8	1999	2006

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height	Years n	Years First	Years Last
ND	Dunn	380250003	47.3132	-102.5273	GEN	RUR	AGR	REG	4	10	1997	2006
ND	McKenzie	380530002	47.5812	-103.2995	GEN	RUR	AGR	REG	4	6	1997	2006
ND	McKenzie	380530104	47.575278	-103.968889	SRC	RUR	AGR	URB	3	9	1998	2006
ND	McKenzie	380530111	47.605556	-104.017222	SRC	RUR	IND	URB	3	7	2000	2006
ND	McLean	380550113	47.606667	-102.036389	POP	RUR	AGR	URB	3	6	1998	2003
ND	Mercer	380570001	47.258853	-101.783035	POP	SUB	RES	NEI	5	1	1997	1997
ND	Mercer	380570004	47.298611	-101.766944	POP	RUR	AGR	URB	4	8	1999	2006
ND	Mercer	380570102	47.325	-101.765833	SRC	RUR	IND	URB	3	10	1997	2006
ND	Mercer	380570118	47.371667	-101.780833	SRC	RUR	IND	URB	3	10	1997	2006
ND	Mercer	380570123	47.385725	-101.862917	SRC	RUR	IND	URB	4	10	1997	2006
ND	Mercer	380570124	47.400619	-101.92865	SRC	RUR	IND	URB	4	10	1997	2006
ND	Morton	380590002	46.84175	-100.870059	SRC	SUB	IND	NEI	4	8	1997	2004
ND	Morton	380590003	46.873075	-100.905039	SRC	SUB	IND	NEI	4	6	1999	2004
ND	Oliver	380650002	47.185833	-101.428056	SRC	RUR	AGR	URB	3	9	1997	2006
ND	Steele	380910001	47.599703	-97.899009	GEN	RUR	AGR	REG	3	2	1997	1999
ND	Williams	381050103	48.408834	-102.90765	SRC	RUR	IND	URB	4	9	1997	2006
ND	Williams	381050105	48.392644	-102.910233	SRC	RUR	IND	URB	4	9	1997	2005
OH	Adams	390010001	38.795	-83.535278	POP	SUB	RES	NEI	5	10	1997	2006
OH	Allen	390030002	40.772222	-84.051944	POP	UNK	AGR	URB	6	10	1997	2006
OH	Ashtabula	390071001	41.959444	-80.5725	POP	SUB	RES	URB	8	10	1997	2006
OH	Belmont	390133002	39.968056	-80.7475	POP	SUB	IND	NEI	6	7	2000	2006
OH	Butler	390170004	39.383333	-84.544167	POP	SUB	COM	NEI	7	10	1997	2006
OH	Butler	390171004	39.53	-84.3925	POP	SUB	COM	NEI	4	10	1997	2006
OH	Clark	390230003	39.855556	-83.9975	POP	RUR	AGR	NEI	4	10	1997	2006
OH	Clermont	390250021	38.961273	-84.09445	HIC	URB	RES	URB	5	8	1997	2004
OH	Columbiana	390290016	40.634722	-80.546389	POP	SUB	RES	NEI	7	1	1997	1997
OH	Columbiana	390290022	40.635	-80.546667	POP	SUB	COM	MIC	6	5	2002	2006
OH	Columbiana	390292001	40.620278	-80.580833	POP	URB	COM	NEI	20	1	1998	1998
OH	Cuyahoga	390350038	41.476944	-81.681944	HIC	URB	IND	NEI	4	9	1997	2006
OH	Cuyahoga	390350045	41.471667	-81.657222	POP	URB	IND	NEI	4	10	1997	2006
OH	Cuyahoga	390350060	41.493955	-81.678542	POP	URB	COM	NEI	4	10	1997	2006
OH	Cuyahoga	390350065	41.446389	-81.661944	HIC	URB	RES	NEI	5	9	1998	2006
OH	Cuyahoga	390356001	41.504722	-81.623889	POP	SUB	COM	NEI	6	6	1997	2002

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height	Years n	Years First	Years Last
OH	Franklin	390490004	39.992222	-83.041667	HIC	SUB	COM	NEI	5	3	1997	1999
OH	Franklin	390490034	40.0025	-82.994444	POP	URB	COM	NEI	4	9	1997	2006
OH	Gallia	390530002	38.944167	-82.112222	POP	SUB	RES	NEI	10	5	2002	2006
OH	Hamilton	390610010	39.214931	-84.690723	POP	RUR	IND	NEI	5	9	1998	2006
OH	Hamilton	390612003	39.228889	-84.448889	HIC	SUB	IND	NEI	3	1	1997	1997
OH	Jefferson	390810016	40.362778	-80.615556	POP	URB	COM	NEI	10	4	1999	2002
OH	Jefferson	390810017	40.366104	-80.615002	HIC	URB	COM	NEI	3	3	2004	2006
OH	Jefferson	390811001	40.321944	-80.606389	HIC	URB	IND	MID	6	6	1998	2003
OH	Lake	390850003	41.673056	-81.4225	UNK	SUB	RES	NEI	5	10	1997	2006
OH	Lake	390853002	41.7225	-81.241944	HIC	SUB	COM	MID	16	10	1997	2006
OH	Lawrence	390870006	38.520278	-82.666667	POP	SUB	RES	NEI	8	9	1998	2006
OH	Lorain	390930017	41.368056	-82.110556	POP	URB	COM	NEI	6	3	2001	2003
OH	Lorain	390930026	41.471667	-82.143611	POP	SUB	IND	NEI	5	6	1997	2002
OH	Lorain	390931003	41.365833	-82.108333	HIC	URB	COM	NEI	9	3	1997	1999
OH	Lucas	390950008	41.663333	-83.476667	HIC	URB	IND	NEI	8	7	1998	2006
OH	Lucas	390950024	41.644167	-83.546667	POP	URB	IND	NEI	8	8	1999	2006
OH	Mahoning	390990009	41.098333	-80.651944	HIC	URB	COM	NEI	6	3	1997	1999
OH	Mahoning	390990013	41.096111	-80.658611	GEN	URB	RES	NEI	6	7	2000	2006
OH	Meigs	391051001	39.037778	-82.045556	POP	SUB	RES	URB	4	10	1997	2006
OH	Montgomery	391130025	39.758333	-84.2	HIC	URB	COM	NEI	3	7	1997	2003
OH	Morgan	391150003	39.631667	-81.673056	HIC	RUR	AGR	URB	5	9	1997	2005
OH	Morgan	391150004	39.634221	-81.670038	SRC	RUR	AGR	URB	4	1	2006	2006
OH	Scioto	391450013	38.754167	-82.9175	HIC	SUB	IND	MID	10	10	1997	2006
OH	Scioto	391450020	38.609048	-82.822911	HIC	RUR	FOR	NEI	4	2	2005	2006
OH	Scioto	391450022	38.588034	-82.834973	UPW	RUR	IND	NEI	4	2	2005	2006
OH	Stark	391510016	40.827778	-81.378611	HIC	SUB	RES	NEI	5	7	1997	2003
OH	Summit	391530017	41.063333	-81.468611	HIC	SUB	IND	NEI	4	10	1997	2006
OH	Summit	391530022	41.080278	-81.516389	POP	URB	COM	NEI	3	10	1997	2006
OH	Tuscarawas	391570003	40.516389	-81.476389	POP	URB	IND	URB	5	6	1997	2002
OH	Tuscarawas	391570006	40.511416	-81.639149	POP	RUR	RES	NEI	10	3	2004	2006
OK	Cherokee	400219002	35.85408	-94.985964	REG	RUR	RES	NEI	3	4	2001	2005
OK	Kay	400710602	36.705328	-97.087656	UNK	URB	RES		4	8	1997	2005
OK	Kay	400719003	36.662778	-97.074444	POP	RUR	RES	NEI	3	2	2002	2003

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OK	Kay	400719010	36.956222	-97.03135	GEN	RUR	AGR	NEI	3	2	2004	2005
OK	Mayes	400979014	36.228408	-95.249943	GEN	RUR	AGR	NEI	3	1	2005	2005
OK	Muskogee	401010167	35.793134	-95.302235	SRC	RUR	COM	NEI	5	9	1997	2005
OK	Oklahoma	401090025	35.553056	-97.623611	POP	SUB	RES	URB	4	4	1999	2002
OK	Oklahoma	401091037	35.614131	-97.475083	POP	SUB	RES	URB	4	2	2004	2005
OK	Ottawa	401159004	36.922222	-94.838889	UNK	RUR	RES	NEI		3	2001	2004
OK	Tulsa	401430175	36.149877	-96.011664	UNK	SUB	IND	NEI	4	9	1997	2005
OK	Tulsa	401430235	36.126945	-95.998941	SRC	URB	IND	MID	4	9	1997	2005
OK	Tulsa	401430501	36.16127	-96.015784	UNK	URB	COM			6	2000	2005
PA	Allegheny	420030002	40.500556	-80.071944	POP	SUB	RES	NEI	6	8	1997	2006
PA	Allegheny	420030010	40.445577	-80.016155	POP	URB	COM	URB	4	9	1998	2006
PA	Allegheny	420030021	40.413611	-79.941389	POP	SUB	RES	NEI	6	7	1997	2006
PA	Allegheny	420030031	40.443333	-79.990556	POP	URB	COM	NEI	13	3	1997	1999
PA	Allegheny	420030032	40.414444	-79.942222	UNK	SUB	RES		5	2	1997	1998
PA	Allegheny	420030064	40.323611	-79.868333	POP	SUB	RES	NEI	8	10	1997	2006
PA	Allegheny	420030067	40.381944	-80.185556	GEN	RUR	RES	NEI	9	9	1997	2006
PA	Allegheny	420030116	40.473611	-80.077222	POP	SUB	RES	NEI	5	7	1997	2005
PA	Allegheny	420031301	40.4025	-79.860278	HIC	SUB	RES	NEI	9	4	1997	2000
PA	Allegheny	420033003	40.318056	-79.881111	POP	SUB	IND		5	7	1997	2005
PA	Allegheny	420033004	40.305	-79.888889	UNK	SUB	RES		8	4	1997	2000
PA	Beaver	420070002	40.56252	-80.503948	REG	RUR	AGR	REG	3	10	1997	2006
PA	Beaver	420070004	40.635575	-80.230605	HIC	URB	IND	NEI	4	2	1997	1998
PA	Beaver	420070005	40.684722	-80.359722	POP	RUR	AGR	URB	3	10	1997	2006
PA	Beaver	420070014	40.747796	-80.316442	POP	URB	RES	URB	4	10	1997	2006
PA	Berks	420110009	40.320278	-75.926667	HIC	SUB	RES	NEI	4	9	1997	2005
PA	Berks	420110100	40.335278	-75.922778	UNK	URB	COM		4	2	1997	1998
PA	Blair	420130801	40.535278	-78.370833	POP	SUB	IND	NEI	6	10	1997	2006
PA	Bucks	420170012	40.107222	-74.882222	POP	SUB	RES	NEI	2	10	1997	2006
PA	Cambria	420210011	40.309722	-78.915	HIC	URB	COM	NEI	12	10	1997	2006
PA	Centre	420270100	40.811389	-77.877028	POP	RUR	AGR	NEI	3	3	2004	2006
PA	Dauphin	420430401	40.245	-76.844722	HIC	RUR	COM	NEI	4	10	1997	2006
PA	Delaware	420450002	39.835556	-75.3725	HIC	URB	IND	NEI	4	10	1997	2006
PA	Delaware	420450109	39.818715	-75.413973	UNK	URB	IND			3	1997	1999

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height	Years n	Years First	Years Last
PA	Erie	420490003	42.14175	-80.038611	HIC	SUB	COM	NEI	4	10	1997	2006
PA	Indiana	420630004	40.56333	-78.919972	POP	RUR	COM	NEI	3	2	2005	2006
PA	Lackawanna	420692006	41.442778	-75.623056	HIC	SUB	RES	NEI	4	10	1997	2006
PA	Lancaster	420710007	40.046667	-76.283333	HIC	SUB	IND	NEI	4	10	1997	2006
PA	Lawrence	420730015	40.995848	-80.346442	POP	SUB	IND	NEI	4	10	1997	2006
PA	Lehigh	420770004	40.611944	-75.4325	POP	SUB	COM	NEI	3	10	1997	2006
PA	Luzerne	420791101	41.265556	-75.846389	POP	SUB	RES	NEI	4	9	1997	2005
PA	Lycoming	420810100	41.2508	-76.9238	POP	URB	RES	URB	3.5	5	2002	2006
PA	Lycoming	420810403	41.246111	-76.989722	POP	URB	COM	NEI	8	4	1997	2000
PA	Mercer	420850100	41.215014	-80.484779	POP	URB	COM	NEI	3	9	1997	2006
PA	Montgomery	420910013	40.112222	-75.309167	POP	SUB	RES	NEI	4	10	1997	2006
PA	Northampton	420950025	40.628056	-75.341111	POP	SUB	COM	NEI	3	9	1998	2006
PA	Northampton	420950100	40.676667	-75.216667	UNK	SUB	IND		3	2	1997	1998
PA	Northampton	420958000	40.692224	-75.237156	POP	SUB	RES	NEI	4	7	2000	2006
PA	Perry	420990301	40.456944	-77.165556	GEN	RUR	UNK	REG	4	10	1997	2006
PA	Philadelphia	421010004	40.008889	-75.097778	POP	URB	RES	NEI	7	8	1997	2004
PA	Philadelphia	421010022	39.916667	-75.188889	HIC	URB	IND	NEI	7	2	1997	1998
PA	Philadelphia	421010024	40.076389	-75.011944	UNK	SUB	IND		4	2	1997	1998
PA	Philadelphia	421010027	40.010556	-75.151944	UNK	URB	MOB		5	2	1997	1998
PA	Philadelphia	421010029	39.957222	-75.173056	POP	URB	COM	NEI	11	8	1997	2004
PA	Philadelphia	421010047	39.944722	-75.166111	POP	URB	RES	NEI	4	2	1997	1998
PA	Philadelphia	421010048	39.991389	-75.080833	UNK	RUR	RES		5	2	1997	1998
PA	Philadelphia	421010055	39.922517	-75.186783	POP	URB	RES	NEI	4	1	2005	2005
PA	Philadelphia	421010136	39.9275	-75.222778	POP	URB	RES	NEI	4	7	1997	2004
PA	Schuylkill	421070003	40.820556	-76.212222	POP	RUR	RES	NEI	4	9	1998	2006
PA	Warren	421230003	41.857222	-79.1375	HIC	SUB	RES	NEI	4	10	1997	2006
PA	Warren	421230004	41.844722	-79.169722	HIC	RUR	FOR	NEI	4	10	1997	2006
PA	Washington	421250005	40.146667	-79.902222	POP	SUB	COM	NEI	2	10	1997	2006
PA	Washington	421250200	40.170556	-80.261389	POP	SUB	RES	NEI	4	10	1997	2006
PA	Washington	421255001	40.445278	-80.420833	REG	RUR	AGR	REG	4	10	1997	2006
PA	Westmoreland	421290008	40.304694	-79.505667	POP	SUB	COM	URB	4	9	1998	2006
PA	York	421330008	39.965278	-76.699444	HIC	SUB	RES	NEI	4	10	1997	2006
RI	Providence	440070012	41.825556	-71.405278	POP	URB	COM	NEI	20	10	1997	2006

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height	Years n	Years First	Years Last
RI	Providence	440071005	41.878333	-71.378889	HIC	URB	RES	NEI	6	1	1997	1997
RI	Providence	440071009	41.823611	-71.411667	HIC	URB	COM	NEI	3	10	1997	2006
SC	Aiken	450030003	33.342226	-81.788731	HIC	SUB	RES	URB	4.02	2	1997	1998
SC	Barnwell	450110001	33.320344	-81.465537	SRC	RUR	FOR	URB	3.1	10	1997	2006
SC	Charleston	450190003	32.882289	-79.977538	POP	URB	COM	NEI	4.3	10	1997	2006
SC	Charleston	450190046	32.941023	-79.657187	SRC	RUR	FOR	REG	4	8	1997	2006
SC	Georgetown	450430006	33.362014	-79.294251	SRC	URB	IND	NEI	2.13	7	1997	2006
SC	Greenville	450450008	34.838814	-82.402918	POP	URB	COM	NEI	4	9	1997	2006
SC	Greenville	450450009	34.899141	-82.31307	WEL	SUB	RES	NEI	4	2	2005	2006
SC	Lexington	450630008	34.051017	-81.15495	SRC	SUB	COM	NEI	3.35	9	1997	2006
SC	Oconee	450730001	34.805261	-83.2377	REG	RUR	FOR	REG	4.3	9	1997	2006
SC	Orangeburg	450750003	33.29959	-80.442218	SRC	RUR	FOR	NEI	3.2	1	2003	2003
SC	Richland	450790007	34.093959	-80.962304	OTH	SUB	COM	NEI	3	7	1999	2006
SC	Richland	450790021	33.81468	-80.781135	GEN	RUR	FOR	URB	4.42	4	2002	2005
SC	Richland	450791003	34.024497	-81.036248	POP	URB	COM	MID	4	10	1997	2006
SC	Richland	450791006	33.817902	-80.826596	GEN	RUR	FOR	MIC	5	2	1997	1999
SD	Custer	460330132	43.5578	-103.4839	REG	RUR	FOR	REG	3.35	2	2005	2006
SD	Jackson	460710001	43.74561	-101.941218	GEN	RUR	AGR	REG	3	2	2005	2006
SD	Minnehaha	460990007	43.537626	-96.682001	POP	URB	RES	NEI	4	3	2004	2006
TN	Anderson	470010028	36.027778	-84.151389	UNK	SUB	RES		3	8	1997	2006
TN	Blount	470090002	35.775	-83.965833	HIC	RUR	COM	MID	4	8	1997	2006
TN	Blount	470090006	35.768056	-83.976667	HIC	SUB	RES	MID	4	8	1997	2006
TN	Blount	470090101	35.63149	-83.943512	GEN	RUR	FOR	REG	10	1	1999	1999
TN	Bradley	470110102	35.283164	-84.759371	UNK	URB	RES			8	1997	2006
TN	Coffee	470310004	35.582222	-86.015556	UNK	RUR	AGR		4	1	1998	1998
TN	Davidson	470370011	36.205	-86.744722	POP	URB	RES	NEI	13	10	1997	2006
TN	Hawkins	470730002	36.366944	-82.977778	UNK	RUR	AGR		1	6	1998	2004
TN	Humphreys	470850020	36.051944	-87.965	UNK	RUR	AGR		4	8	1997	2006
TN	McMinn	471070101	35.29733	-84.75076	HIC	SUB	AGR	NEI	4	8	1997	2005
TN	Montgomery	471250006	36.520056	-87.394167	UNK	RUR	IND	NEI	3	10	1997	2006
TN	Montgomery	471250106	36.504529	-87.396675	HIC	RUR	RES	MID	4	10	1997	2006
TN	Polk	471390003	35.026111	-84.384722	POP	SUB	COM	NEI	8	9	1997	2005
TN	Polk	471390007	34.988333	-84.371667	POP	URB	COM	NEI	1	9	1997	2005

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TN	Polk	471390008	34.995833	-84.368333	UNK	RUR	RES		3	3	1998	2000
TN	Polk	471390009	34.989722	-84.383889	UNK	RUR	IND		4	3	1997	2000
TN	Roane	471450009	35.947222	-84.522222	UNK	SUB	RES		4	6	1998	2005
TN	Shelby	471570034	35.0434	-90.0136	HIC	SUB	RES	NEI	3	4	2002	2005
TN	Shelby	471570043	35.087778	-90.025278	HIC	SUB	COM	NEI	3	2	1997	1998
TN	Shelby	471570046	35.272778	-89.961389	POP	SUB	IND	URB		10	1997	2006
TN	Shelby	471571034	35.087222	-90.133611	UNK	RUR	AGR	MID	3	10	1997	2006
TN	Stewart	471610007	36.389722	-87.633333	OTH	RUR	AGR		3	7	1997	2005
TN	Sullivan	471630007	36.534804	-82.517078	HIC	SUB	RES	NEI	3	9	1998	2006
TN	Sullivan	471630009	36.513971	-82.560968	HIC	RUR	RES	NEI	3	10	1997	2006
TN	Sumner	471651002	36.341667	-86.398333	OTH	RUR	AGR		3	7	1997	2004
TX	Cameron	480610006	25.892509	-97.493824	HIC	URB	COM	NEI		3	1998	2000
TX	Dallas	481130069	32.819952	-96.860082	POP	URB	COM	NEI	6	10	1997	2006
TX	Ellis	481390015	32.436944	-97.025	HIC	SUB	AGR	NEI	4	9	1998	2006
TX	Ellis	481390016	32.482222	-97.026944	GEN	SUB	AGR	NEI	4	7	1998	2006
TX	Ellis	481390017	32.473611	-97.0425	OTH	RUR	RES			1	2005	2005
TX	El Paso	481410037	31.768281	-106.501253	POP	URB	COM	NEI	3	9	1998	2006
TX	El Paso	481410053	31.758504	-106.501023	HIC	URB	COM	NEI	5	8	1999	2006
TX	El Paso	481410058	31.893928	-106.425813	POP	URB	RES	NEI	5	5	2001	2005
TX	Galveston	481670005	29.385236	-94.931526	HIC	URB	RES	NEI		2	2005	2006
TX	Galveston	481671002	29.398611	-94.933333	HIC	SUB	RES	NEI	5	7	1997	2003
TX	Gregg	481830001	32.37871	-94.711834	GEN	RUR	RES	NEI	4	6	2000	2005
TX	Harris	482010046	29.8275	-95.283611	POP	SUB	RES	NEI	4	8	1997	2006
TX	Harris	482010051	29.623611	-95.473611	SRC	SUB	RES	NEI	4	8	1997	2006
TX	Harris	482010059	29.705833	-95.281111	HIC	SUB	RES	NEI	6	1	1997	1997
TX	Harris	482010062	29.625833	-95.2675	POP	SUB	RES	NEI	5	9	1997	2006
TX	Harris	482010070	29.735129	-95.315583	GEN	SUB	RES	NEI	11	6	2001	2006
TX	Harris	482011035	29.733713	-95.257591	POP	SUB	IND	NEI	6	9	1997	2006
TX	Harris	482011050	29.583032	-95.015535	HIC	SUB	RES	MID	11	5	2002	2006
TX	Jefferson	482450009	30.036446	-94.071073	HIC	SUB	RES	NEI	6.31	10	1997	2006
TX	Jefferson	482450011	29.89403	-93.987898	SRC	URB	IND	NEI	4	10	1997	2006
TX	Jefferson	482450020	30.06607	-94.077383	SRC	URB	IND	NEI	5	8	1998	2006
TX	Kaufman	482570005	32.564969	-96.31766	HIC	SUB	COM	NEI	5	6	2001	2006

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height	Years n	Years First	Years Last
TX	Nueces	483550025	27.76534	-97.434272	POP	URB	RES	NEI	4	9	1997	2005
TX	Nueces	483550026	27.832409	-97.555381	HIC	URB	RES	NEI	6	8	1998	2005
TX	Nueces	483550032	27.804482	-97.431553	POP	SUB	RES		4	8	1998	2005
UT	Cache	490050004	41.731111	-111.8375	POP	URB	COM		4	3	2003	2005
UT	Davis	490110001	40.886389	-111.882222	POP	SUB	COM		3	6	1997	2002
UT	Davis	490110004	40.902967	-111.884467	POP	SUB	RES	NEI	4	2	2004	2005
UT	Salt Lake	490350012	40.8075	-111.921111	UNK	SUB	IND		4	6	1999	2004
UT	Salt Lake	490351001	40.708611	-112.094722	HIC	SUB	RES	NEI	6	9	1997	2005
UT	Salt Lake	490352004	40.736389	-112.210278	HIC	RUR	IND			7	1997	2003
VT	Chittenden	500070003	44.478889	-73.211944	HIC	URB	COM	NEI	4	3	1997	1999
VT	Chittenden	500070014	44.4762	-73.2106	POP	URB	COM	MID		1	2004	2004
VT	Rutland	500210002	43.608056	-72.982778	POP	URB	COM	NEI	4	7	1997	2005
VA	Charles	510360002	37.343294	-77.260034	HIC	SUB	RES	NEI	5	10	1997	2006
VA	Fairfax	510590005	38.893889	-77.465278	POP	RUR	AGR	NEI	4	9	1997	2006
VA	Fairfax	510590018	38.7425	-77.0775	UNK	SUB	RES		4	1	1997	1997
VA	Fairfax	510591004	38.868056	-77.143056	UNK	SUB	COM		11	4	1997	2000
VA	Fairfax	510591005	38.837517	-77.163231	POP	SUB	RES			4	2003	2006
VA	Fairfax	510595001	38.931944	-77.198889	UNK	SUB	RES		4	9	1998	2006
VA	Madison	511130003	38.521944	-78.436111	UNK	RUR	FOR			3	2000	2003
VA	Roanoke	511611004	37.285556	-79.884167	HIC	SUB	RES	NEI	4	10	1997	2006
VA	Rockingham	511650002	38.389444	-78.914167	POP	RUR	AGR	NEI	7	6	1998	2003
VA	Rockingham	511650003	38.47732	-78.81904	POP	SUB	COM	NEI	6	2	2005	2006
VA	Alexandria City	515100009	38.810833	-77.044722	POP	URB	RES	NEI	10	10	1997	2006
VA	Hampton City	516500004	37.003333	-76.399167	HIC	SUB	RES	NEI	4	10	1997	2006
VA	Norfolk City	517100023	36.850278	-76.257778	POP	URB	COM	NEI	5	8	1997	2004
VA	Richmond City	517600024	37.562778	-77.465278	HIC	URB	COM	NEI	5	8	1999	2006
WA	Clallam	530090010	48.113333	-123.399167	UNK	SUB	RES		4	1	1997	1997
WA	Clallam	530090012	48.0975	-123.425556	UNK	SUB	RES	NEI	5	5	1999	2004
WA	King	530330057	47.563333	-122.3406	HIC	SUB	IND	NEI	11	2	1997	1998
WA	King	530330080	47.568333	-122.308056	POP	URB	RES	URB	5	4	2001	2004
WA	Pierce	530530021	47.281111	-122.374167	HIC	SUB	RES	NEI	5	1	1997	1997
WA	Pierce	530530031	47.2656	-122.3858	POP	SUB	IND	NEI	5	1	1997	1997
WA	Skagit	530570012	48.493611	-122.551944	UNK	SUB	RES		5	1	1997	1997

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height	Years n	Years First	Years Last
WA	Skagit	530571003	48.486111	-122.549444	UNK	RUR	IND		3	1	1997	1997
WA	Snohomish	530610016	47.983333	-122.209722	UNK	URB	COM		4	1	1997	1997
WA	Whatcom	530730011	48.750278	-122.482778	UNK	URB	IND		12	1	1998	1998
WV	Brooke	540090005	40.341023	-80.596635	POP	SUB	IND	NEI	4	10	1997	2006
WV	Brooke	540090007	40.389655	-80.586235	POP	RUR	RES	NEI	4	10	1997	2006
WV	Cabell	540110006	38.424133	-82.4259	POP	SUB	COM	NEI	13.6	10	1997	2006
WV	Greenbrier	540250001	37.819444	-80.5125	UNK	RUR	AGR		4	1	1997	1997
WV	Hancock	540290005	40.529021	-80.576067	POP	SUB	RES	URB	4	10	1997	2006
WV	Hancock	540290007	40.460138	-80.576567	POP	RUR	RES	URB		10	1997	2006
WV	Hancock	540290008	40.61572	-80.56	POP	SUB	RES	NEI	5	10	1997	2006
WV	Hancock	540290009	40.427372	-80.592318	POP	SUB	RES	NEI		10	1997	2006
WV	Hancock	540290011	40.394583	-80.612017	POP	SUB	RES	NEI		10	1997	2006
WV	Hancock	540290014	40.43552	-80.600579	POP	SUB	RES	MID		7	1997	2003
WV	Hancock	540290015	40.618353	-80.540616	POP	URB	RES	URB	4	10	1997	2006
WV	Hancock	540290016	40.411944	-80.601667	HIC	SUB	RES		4	7	1997	2003
WV	Hancock	540291004	40.421539	-80.580717	HIC	SUB	RES	NEI	3	10	1997	2006
WV	Kanawha	540390004	38.343889	-81.619444	POP	SUB	COM	NEI	8	2	1997	1998
WV	Kanawha	540390010	38.3456	-81.628317	POP	URB	COM	URB	13	6	2001	2006
WV	Kanawha	540392002	38.416944	-81.846389	HIC	SUB	IND	NEI	4	1	1997	1997
WV	Marshall	540511002	39.915961	-80.733858	POP	SUB	RES	URB	4	10	1997	2006
WV	Monongalia	540610003	39.649367	-79.920867	POP	SUB	COM	URB	4.6	10	1997	2006
WV	Monongalia	540610004	39.633056	-79.957222	UNK	SUB	RES			4	1997	2000
WV	Monongalia	540610005	39.648333	-79.957778	UNK	SUB	RES	URB	10.7	9	1997	2005
WV	Ohio	540690007	40.12043	-80.699265	HIC	SUB	RES	NEI	8	6	1997	2002
WV	Wayne	540990002	38.39186	-82.583923	POP	RUR	IND	NEI	4	6	1997	2002
WV	Wayne	540990003	38.390278	-82.585833	HIC	RUR	RES	NEI	3	8	1997	2005
WV	Wayne	540990004	38.380278	-82.583889	HIC	RUR	RES	NEI	3	8	1997	2005
WV	Wayne	540990005	38.372222	-82.588889	HIC	RUR	RES	NEI	3	8	1997	2005
WV	Wood	541071002	39.323533	-81.552367	POP	SUB	IND	URB	4	10	1997	2006
WI	Brown	550090005	44.516667	-87.993889	POP	URB	RES	NEI	11	7	1997	2005
WI	Dane	550250041	43.100833	-89.357222	POP	URB	RES	NEI	5	2	1997	1998
WI	FOR	550410007	45.56498	-88.80859	GEN	RUR	FOR	REG	6	2	2004	2005
WI	Marathon	550730005	45.028333	-89.652222	HIC	RUR	FOR	MID	5	3	1997	1999

State	County	Monitor ID	Latitude	Longitude	Objective[1]	Setting[2]	Land Use[3]	Scale[4]	Height	Years n	Years First	Years Last
WI	Milwaukee	550790007	43.047222	-87.920278	POP	URB	COM	NEI	7	4	1997	2000
WI	Milwaukee	550790026	43.061111	-87.9125	POP	URB	COM	NEI	9	4	2002	2005
WI	Milwaukee	550790041	43.075278	-87.884444	HIC	URB	RES	NEI	7	4	1997	2001
WI	Oneida	550850996	45.645278	-89.4125	UNK	URB	IND		6	9	1997	2005
WI	Sauk	551110007	43.435556	-89.680278	GEN	RUR	FOR	REG	6	1	2003	2003
WI	Vilas	551250001	46.048056	-89.653611	GEN	RUR	FOR	REG	15	1	2003	2003
WI	Wood	551410016	44.3825	-89.819167	POP	URB	RES	NEI	7	2	1998	1999
WY	Campbell	560050857	44.277222	-105.375	SRC	RUR	IND	NEI	4	3	2002	2004
PR	Barceloneta	720170003	18.436111	-66.580556	UNK	RUR	RES		3	5	1997	2005
PR	Bayamon	720210004	18.412778	-66.132778	HIC	SUB	IND	NEI		6	1997	2004
PR	Bayamon	720210006	18.416667	-66.150833	POP	SUB	IND	NEI	3	7	1997	2005
PR	Catano	720330004	18.430556	-66.142222	UNK	SUB	RES		4	7	1997	2005
PR	Catano	720330007	18.444722	-66.116111	POP	URB	RES	NEI	2	1	2002	2002
PR	Catano	720330008	18.440028	-66.127076	POP	URB	COM			1	2005	2005
PR	Catano	720330009	18.449964	-66.149043	POP	URB	RES			1	2005	2005
PR	Guayama	720570009	17.966844	-66.188014	SRC	RUR	COM	NEI	4	4	2002	2005
PR	Salinas	721230001	17.963002	-66.254749	SRC	RUR	AGR			1	2004	2004
VI	St Croix	780100006	17.706944	-64.780556	HIC	RUR	IND	NEI	4	5	1998	2004
VI	St Croix	780100011	17.719167	-64.775	HIC	RUR	IND	NEI	4	5	1997	2004
VI	St Croix	780100013	17.7225	-64.776667	POP	SUB	RES	NEI		5	1999	2004
VI	St Croix	780100014	17.734444	-64.783333	POP	RUR	AGR	NEI	4	5	1999	2004
VI	St Croix	780100015	17.741667	-64.751944	SRC	RUR	AGR	NEI	4	4	2000	2004

Notes:
[1] Objectives are POP=Population Exposure; HIC=Highest Concentration; SRC=Source Oriented; GEN=General/Background; REG=Regional Transport; OTH=Other; UNK=Unknown; UPW=Upwind Background; WEL=Welfare Related Impacts
[2] Settings are R=Rural; U=Urban and Center City; S=Suburban
[3] Land Uses are AGR=Agricultural; COM=Commercial; IND=Industrial; FOR=Forest; RES=Residential; UNK=Unknown; DES=Desert; MOB=Mobile.
[4] Scales are NEI=Neighborhood; MID=Middle; URB=URBAN; REG=Regional; MIC=Micro

Table A.1-4. Population density, concentration variability, and total SO_2 emissions associated with 809 ambient monitors in the broader SO_2 monitoring network.

State	County	Monitor ID	Population Residing within:				Analysis Bins			Emissions (tpy)[4]
			5km	10km	15km	20km	Population[1]	COV[2]	GSD[3]	
AL	Colbert	010330044	2195	7954	25394	62838	low	c	a	50041
AL	Jackson	010710020	1902	8137	19317	29686	low	c	b	45357
AL	Jefferson	010731003	76802	196682	344386	489181	hi	b	b	6478
AL	Lawrence	010790003	3952	28674	73092	91057	low	b	b	8937
AL	Mobile	010970028	5966	7758	17087	39111	low	c	c	66130
AL	Mobile	010972005	3017	18106	52682	111608	low	b	a	1187
AL	Montgomery	011011002	45389	156786	213606	259730	mod	a	a	3650
AR	Pulaski	051190007	67784	178348	270266	334649	hi	a	a	20
AR	Pulaski	051191002	45800	109372	230200	310362	mod	a	a	20
AR	Union	051390006	21877	29073	32652	36340	mod	b	a	2527
AZ	Gila	040070009	7801	14076	17280	17633	low	b	b	
AZ	Gila	040071001	1359	1359	3098	5401	low	c	c	18438
AZ	Maricopa	040130019	197458	613618	1036233	1447648	hi	a	b	186
AZ	Maricopa	040133002	144581	490123	980730	1612687	hi	a	a	185
AZ	Maricopa	040133003	91955	340325	829051	1518806	hi	a	a	180
AZ	Pima	040191011	111215	354473	561487	639921	hi	a	a	3119
AZ	Pinal	040212001	4375	7679	9577	10125	low	c	a	
CA	Alameda	060010010	236320	532827	841443	1342267	hi	a	a	369
CA	Contra Costa	060130002	136288	303088	445297	598861	hi	b	a	15056
CA	Contra Costa	060130006	119088	231479	471471	968983	hi	b	a	5032
CA	Contra Costa	060130010	29809	123220	403137	685185	mod	a	a	17834
CA	Contra Costa	060131001	53051	181259	321500	610171	hi	b	a	19592
CA	Contra Costa	060131002	4033	39708	117118	173196	low	a	a	79
CA	Contra Costa	060131003	146336	256417	420619	856435	hi	a	a	5032
CA	Contra Costa	060131004	125350	233220	433669	876585	hi	a	a	5032
CA	Contra Costa	060132001	34743	155226	433934	807706	mod	a	a	17834
CA	Contra Costa	060133001	64019	152758	303597	478310	hi	b	a	8105
CA	Imperial	060250005	27033	31895	56234	84405	mod	b	c	7
CA	Los Angeles	060371002	167653	827729	2001363	3286038	hi	a	a	51
CA	Los Angeles	060371103	378843	1618324	3027507	4530714	hi	a	a	551

State	County	Monitor ID	Population Residing within:				Analysis Bins			Emissions (tpy)[4]
			5km	10km	15km	20km	Population[1]	COV[2]	GSD[3]	
CA	Los Angeles	060374002	240505	913176	1850549	3218392	hi	a	b	5869
CA	Los Angeles	060375001	276378	890302	2071144	3561110	hi	a	a	6282
CA	Los Angeles	060375005	94836	652173	1628468	2848126	hi	a	a	2304
CA	Orange	060591003	200253	744882	1303743	1829713	hi	a	a	68
CA	Riverside	060658001	78757	360234	734267	1141466	hi	a	a	299
CA	Sacramento	060670002	92433	328190	645533	916197	hi	a	a	5
CA	Sacramento	060670006	132584	472019	866437	1180898	hi	a	a	58
CA	San Bernardino	060710012	6720	17620	29756	69717	low	a	a	8
CA	San Bernardino	060710014	58937	114149	193928	224008	hi	a	a	251
CA	San Bernardino	060710306	59772	114149	193046	224008	hi	a	a	251
CA	San Bernardino	060711234	0	0	1911	1911	low	a	a	290
CA	San Bernardino	060712002	89732	314392	650533	1142460	hi	a	a	203
CA	San Bernardino	060714001	40799	114888	174610	219525	mod	a	a	32
CA	San Diego	060730001	168237	528890	866015	1177835	hi	a	a	21
CA	San Diego	060731007	169117	616102	1097387	1449106	hi	a	a	34
CA	San Diego	060732007	9376	15849	218480	452120	low	a	a	21
CA	San Francisco	060750005	433367	827164	1227784	1729715	hi	a	a	399
CA	San Luis Obispo	060791005	4725	56677	85064	152491	low	c	b	3755
CA	San Luis Obispo	060792001	39236	55657	61709	121393	mod	a	a	3755
CA	San Luis Obispo	060792004	2135	34056	113260	162669	low	b	c	3755
CA	San Luis Obispo	060794002	0	51508	95245	141786	low	b	b	3755
CA	Santa Barbara	060830008	655	1678	17486	67965	low	a	a	118
CA	Santa Barbara	060831012	0	0	960	3201	low	a	a	1109
CA	Santa Barbara	060831013	6617	41576	59590	89777	low	a	a	1109
CA	Santa Barbara	060831015	0	0	2391	17826	low	a	a	18
CA	Santa Barbara	060831016	0	0	4034	17826	low	a	a	18
CA	Santa Barbara	060831019	0	0	4689	17826	low	a	a	18
CA	Santa Barbara	060831020	39222	71015	117832	170206	mod	a	a	118
CA	Santa Barbara	060831025	655	1678	11216	56132	low	a	a	118
CA	Santa Barbara	060831026	655	1678	15659	63963	low	a	a	118
CA	Santa Barbara	060831027	655	1678	13618	62298	low	b	a	118
CA	Santa Barbara	060832004	38688	49356	58271	59279	mod	a	a	1109
CA	Santa Barbara	060832011	55496	105491	170865	181894	hi	a	a	118

State	County	Monitor ID	Population Residing within:				Analysis Bins			Emissions (tpy)[4]
			5km	10km	15km	20km	Population[1]	COV[2]	GSD[3]	
CA	Santa Barbara	060834003	0	0	8430	51692	low	a	a	1109
CA	Santa Cruz	060870003	0	6016	51831	124792	low	a	a	722
CA	Solano	060950001	27872	130319	359105	620107	mod	a	a	17821
CA	Solano	060950004	102003	166693	247861	374613	hi	a	a	17763
CA	Ventura	061113001	47248	227525	401656	427503	mod	a	b	19
CO	Adams	080010007	45071	360261	903964	1344766	mod	b	b	24028
CO	Adams	080013001	81896	334611	784343	1205604	hi	b	b	23817
CO	Denver	080310002	189782	574752	1158644	1608099	hi	b	b	26354
CO	El Paso	080416001	0	24520	54194	111518	low	b	b	5010
CO	El Paso	080416004	84979	242841	368203	430076	hi	a	a	8547
CO	El Paso	080416011	97849	288563	407401	448545	hi	b	b	8547
CO	El Paso	080416018	93065	266008	388801	438812	hi	a	a	8537
CT	Fairfield	090010012	164887	291072	393358	528453	hi	b	b	4671
CT	Fairfield	090010017	30184	188214	330125	672435	mod	b	b	757
CT	Fairfield	090011123	72689	126452	191805	277225	hi	a	b	
CT	Fairfield	090012124	121109	209567	343909	476656	hi	b	b	766
CT	Fairfield	090019003	28181	151905	313449	546288	mod	b	b	5039
CT	Hartford	090031005	33414	147625	319902	484462	mod	a	b	1268
CT	Hartford	090031018	152497	329646	523045	693079	hi	a	b	113
CT	Hartford	090032006	91965	333744	510929	671515	hi	a	b	83
CT	New Haven	090090027	140329	290735	389117	529118	hi	b	b	4761
CT	New Haven	090091003	156879	293853	414381	552021	hi	b	b	5085
CT	New Haven	090091123	154781	292598	417546	557442	hi	b	b	5085
CT	New Haven	090092123	104191	189838	276310	447334	hi	a	b	430
CT	New London	090110007	58457	97870	141173	182476	hi	a	a	3898
CT	Tolland	090130003	23441	47285	78649	115317	mod	a	a	
DC	District of Columbia	110010041	216129	813665	1461563	2029936	hi	a	a	18325
DE	New Castle	100031003	68790	223079	369450	603736	hi	b	b	33133
DE	New Castle	100031007	14297	67478	178295	274942	mod	b	b	34382
DE	New Castle	100031008	5386	80025	192989	391157	low	b	b	39757
DE	New Castle	100031013	79498	221315	386624	618604	hi	b	b	33133
DE	New Castle	100032002	111236	245832	400217	624587	hi	b	b	28868
DE	New Castle	100032004	111609	245173	411000	600168	hi	b	b	59518

State	County	Monitor ID	Population Residing within:				Analysis Bins			Emissions (tpy)[4]
			5km	10km	15km	20km	Population[1]	COV[2]	GSD[3]	
FL	Broward	120110010	173204	475485	953527	1459284	hi	c	a	19178
FL	Duval	120310032	81831	270954	439516	620929	hi	b	b	38010
FL	Duval	120310080	70468	288474	506828	704506	hi	b	b	38015
FL	Duval	120310081	23862	152805	305323	463770	mod	c	b	38001
FL	Duval	120310097	59980	225163	418997	600591	hi	b	b	38010
FL	Escambia	120330004	43464	133022	233520	303319	mod	b	b	43573
FL	Escambia	120330022	32534	122295	223566	291695	mod	c	b	43573
FL	Hamilton	120470015	582	1733	6459	12479	low	b	a	2264
FL	Hillsborough	120570021	90125	287073	539627	762352	hi	c	b	89751
FL	Hillsborough	120570053	54303	140247	307460	668911	hi	b	b	89830
FL	Hillsborough	120570081	5101	24672	48751	228142	low	b	b	122051
FL	Hillsborough	120570095	28554	192630	493886	719140	mod	c	b	65362
FL	Hillsborough	120570109	11493	81649	287436	509661	mod	c	b	65352
FL	Hillsborough	120571035	63839	244436	463185	764479	hi	b	b	89751
FL	Hillsborough	120574004	32134	66598	149341	346648	mod	b	a	8617
FL	Manatee	120813002	2043	18810	82190	281383	low	b	b	365
FL	Miami-Dade	120860019	54755	283528	685044	1386189	hi	a	a	235
FL	Nassau	120890005	17963	21386	38521	48316	mod	c	c	5050
FL	Nassau	120890009	8627	18803	27645	59574	low	b	b	5050
FL	Orange	120952002	85060	389159	808816	1031221	hi	b	a	46
FL	Palm Beach	120993004	54596	222249	446441	718156	hi	b	a	235
FL	Pinellas	121030023	40222	180398	488170	901428	mod	b	c	24819
FL	Pinellas	121033002	74280	310490	633807	907997	hi	b	c	24813
FL	Pinellas	121035002	58164	184586	401002	655181	hi	b	b	30797
FL	Pinellas	121035003	48341	174960	304905	492683	mod	b	b	30797
FL	Polk	121050010	1499	21899	60024	142707	low	b	a	21475
FL	Polk	121052006	8128	49090	125120	198136	low	b	b	21989
FL	Putnam	121071008	10853	21601	35511	44711	mod	b	b	29894
FL	Sarasota	121151002	78620	180672	237782	332704	hi	b	b	
FL	Sarasota	121151005	28895	140026	244918	356779	mod	b	a	
FL	Sarasota	121151006	65360	188269	295631	386824	hi	b	a	143
GA	Baldwin	130090001	7410	22059	44230	50761	low	c	b	73950
GA	Bartow	130150002	1628	15879	50084	91503	low	c	a	162418

State	County	Monitor ID	Population Residing within:				Analysis Bins			Emissions (tpy)[4]
			5km	10km	15km	20km	Population[1]	COV[2]	GSD[3]	
GA	Bibb	130210012	5430	38736	102539	153254	low	b	a	2694
GA	Chatham	130510019	24119	107149	188444	220328	mod	b	b	19069
GA	Chatham	130510021	47852	121273	183343	220814	mod	b	b	19069
GA	Chatham	130511002	40337	113925	186077	222588	mod	c	b	19069
GA	Dougherty	130950006	28572	73138	101552	117779	mod	b	a	6773
GA	Fannin	131110091	3943	9432	19045	24026	low	c	b	1900
GA	Floyd	131150003	2671	22348	46960	74655	low	c	b	32455
GA	Fulton	131210048	139962	429736	806001	1253530	hi	b	b	30375
GA	Fulton	131210055	103612	409533	779857	1209013	hi	b	b	30375
GA	Glynn	131270006	22992	38643	61789	67649	mod	b	a	2464
GA	Muscogee	132150008	63822	167389	234866	254253	hi	b	a	6960
GA	Richmond	132450003	30694	124609	206847	298992	mod	b	a	20025
HI	Honolulu	150030010	24951	89592	181585	344307	mod	a	a	15617
HI	Honolulu	150030011	16119	58440	160177	277456	mod	a	a	15617
HI	Honolulu	150031001	197479	344436	483321	672198	hi	b	a	3130
HI	Honolulu	150031006	16676	66976	180191	300444	mod	b	a	15617
IA	Cerro Gordo	190330018	21247	30341	39284	45105	mod	c	c	10737
IA	Clinton	190450018	24561	37638	42404	45947	mod	b	b	9388
IA	Clinton	190450019	24561	37638	42404	45947	mod	b	c	9388
IA	Clinton	190450020	25544	36227	41370	48214	mod	b	b	9388
IA	Lee	191110006	11675	18308	24246	25010	mod	b	c	29
IA	Lee	191111007	1202	11474	20995	34036	low	b	c	208
IA	Linn	191130028	9112	77687	143283	189856	low	b	a	15400
IA	Linn	191130029	72325	146914	168250	179312	hi	b	b	15400
IA	Linn	191130031	76896	148919	170320	179312	hi	c	b	15400
IA	Linn	191130032	66674	131315	169310	183904	hi	b	a	15400
IA	Linn	191130034	63548	146044	170320	185547	hi	c	b	15400
IA	Linn	191130038	30007	108042	163636	180807	mod	c	c	15400
IA	Linn	191130039	30134	106631	160903	180968	mod	b	a	15400
IA	Muscatine	191390016	20360	27101	31886	40248	mod	c	c	31137
IA	Muscatine	191390017	11109	27101	31696	36604	mod	b	b	31054
IA	Muscatine	191390020	20360	27101	31886	40290	mod	c	c	31054
IA	Scott	191630015	90863	201277	268535	293627	hi	b	c	9415

State	County	Monitor ID	Population Residing within:				Analysis Bins			Emissions (tpy)[4]
			5km	10km	15km	20km	Population[1]	COV[2]	GSD[3]	
IA	Scott	191630017	3486	43003	159186	245960	low	c	a	14841
IA	Van Buren	191770004	0	2252	3764	7809	low	a	b	
IA	Van Buren	191770005	994	2252	3764	6984	low	b	b	
IA	Van Buren	191770006	994	2252	3764	6984	low	a	b	
IA	Woodbury	191930018	4449	44815	92956	112802	low	b	b	36833
ID	Bannock	160050004	16523	57823	64147	69313	mod	b	c	1609
ID	Caribou	160290003	0	1351	3211	4218	low	c	b	12572
ID	Caribou	160290031	0	604	3211	3211	low	c	c	12572
ID	Power	160770011	7702	50773	64147	69313	low	b	a	1609
IL	Adams	170010006	40173	49711	54168	64300	mod	b	b	3859
IL	Champaign	170190004	91239	126127	134689	152309	hi	b	b	362
IL	Cook	170310050	162765	649556	1310508	1997666	hi	b	b	42308
IL	Cook	170310059	67237	496359	1055079	1759830	hi	b	b	36403
IL	Cook	170310063	307232	1205813	2476802	3318024	hi	b	b	23944
IL	Cook	170310064	299183	965573	1758392	2786664	hi	b	b	50763
IL	Cook	170310076	289574	1034471	2000564	2971446	hi	a	b	33488
IL	Cook	170311018	113572	617444	1657665	3102521	hi	b	b	24023
IL	Cook	170311601	23495	167647	466741	1000711	mod	b	b	45681
IL	Cook	170312001	138992	604707	1380464	2117578	hi	b	b	39578
IL	Cook	170314002	406933	1482581	2777797	3752141	hi	b	b	24553
IL	Cook	170314201	63731	232428	627873	1254146	hi	b	b	659
IL	Cook	170318003	111959	456791	1004517	1682955	hi	b	b	30075
IL	DuPage	170436001	83416	401929	787802	1266818	hi	b	b	35837
IL	La Salle	170990007	4862	26956	37974	63052	low	c	c	3561
IL	Macon	171150013	54806	92426	103292	112667	hi	b	b	13757
IL	Macoupin	171170002	0	5005	16518	19043	low	b	a	
IL	Madison	171190008	36580	84254	152472	330907	mod	b	b	67657
IL	Madison	171190017	37113	201161	536687	950679	mod	b	b	35077
IL	Madison	171191010	9382	70816	176153	323143	low	b	b	26719
IL	Madison	171193007	32393	71861	172196	353090	mod	b	b	72660
IL	Madison	171193009	27788	69631	136629	273179	mod	b	b	72512
IL	Peoria	171430024	76341	167513	232727	269180	hi	b	c	73334
IL	Randolph	171570001	5095	10038	16360	29336	low	c	b	26296

State	County	Monitor ID	Population Residing within:				Analysis Bins			Emissions (tpy)[4]
			5km	10km	15km	20km	Population[1]	COV[2]	GSD[3]	
IL	Rock Island	171610003	87160	228445	275180	296786	hi	b	a	9449
IL	Saint Clair	171630010	48405	274406	621019	999843	mod	b	b	13346
IL	Saint Clair	171631010	49630	269778	593969	973751	mod	b	b	13346
IL	Saint Clair	171631011	1148	9915	18231	27769	low	c	b	26296
IL	Sangamon	171670006	41165	123641	154447	171401	mod	c	b	10849
IL	Tazewell	171790004	32800	50160	99136	194767	mod	c	b	73270
IL	Wabash	171850001	8738	9493	13312	27993	low	c	b	127357
IL	Wabash	171851001	1069	10899	11617	21643	low	c	b	127357
IL	Will	171970013	12237	66320	171777	249868	mod	b	b	46347
IN	Daviess	180270002	905	9377	21937	32380	low	b	c	65217
IN	Dearborn	180290004	11932	21347	69595	151228	mod	b	b	151052
IN	Floyd	180430004	17205	86512	201325	363262	mod	b	c	52000
IN	Floyd	180430007	65510	228353	408246	607160	hi	b	b	67211
IN	Floyd	180431004	45432	169258	351938	532952	mod	c	b	66977
IN	Fountain	180450001	788	2536	9505	19361	low	c	b	55655
IN	Gibson	180510001	792	10900	18174	30700	low	c	b	127357
IN	Gibson	180510002	6276	9493	16779	29981	low	c	c	127357
IN	Hendricks	180630001	4657	29661	66108	183728	low	c	b	
IN	Hendricks	180630002	7481	31567	79685	205437	low	b	b	147
IN	Hendricks	180630003	1776	11450	41400	79693	low	b	b	
IN	Jasper	180730002	991	8080	16959	28865	low	b	a	27494
IN	Jasper	180730003	1688	4551	12127	20725	low	b	b	27494
IN	Jefferson	180770004	11228	22061	32050	36387	mod	b	b	38198
IN	Lake	180890022	40318	152401	292371	500754	mod	b	b	50716
IN	Lake	180892008	97669	293157	745205	1339901	hi	b	b	36590
IN	LaPorte	180910005	28928	42982	60818	97304	mod	b	b	12499
IN	LaPorte	180910007	29106	54698	82651	112181	mod	b	b	9198
IN	Marion	180970042	19283	109791	306701	564512	mod	b	b	51880
IN	Marion	180970054	53595	301941	612446	863127	hi	b	b	51077
IN	Marion	180970057	79478	349455	640054	909257	hi	b	b	51077
IN	Marion	180970072	115856	380088	684608	922620	hi	b	b	51096
IN	Marion	180970073	100599	357454	585925	880596	hi	b	b	50949
IN	Morgan	181091001	4178	26279	53331	105208	low	b	c	18019

State	County	Monitor ID	Population Residing within:				Analysis Bins			Emissions (tpy)[4]
			5km	10km	15km	20km	Population[1]	COV[2]	GSD[3]	
IN	Perry	181230006	6348	13158	20298	30372	low	c	c	56262
IN	Perry	181230007	6153	15700	19228	29270	low	b	c	56262
IN	Pike	181250005	3991	7372	12598	29314	low	b	a	65217
IN	Porter	181270011	12202	44110	101993	210946	mod	b	b	39173
IN	Porter	181270017	14162	59080	118122	223900	mod	b	b	29995
IN	Porter	181270023	13645	79678	136098	256849	mod	b	b	29975
IN	Spencer	181470002	1935	4701	13255	32146	low	b	b	109391
IN	Spencer	181470010	2483	5934	14936	32405	low	b	b	60394
IN	Sullivan	181530004	1735	8313	15494	25746	low	a	a	27810
IN	Vanderburgh	181630012	45373	141869	184521	225094	mod	b	b	9032
IN	Vanderburgh	181631002	1289	30177	123286	201383	low	b	b	9032
IN	Vigo	181670018	50963	82314	98561	115726	hi	b	b	65055
IN	Vigo	181671014	25046	72089	100022	118986	mod	b	c	65055
IN	Warrick	181730002	2200	27584	60538	123354	low	b	b	109088
IN	Warrick	181731001	11943	28798	80348	155370	mod	b	b	109088
IN	Wayne	181770006	34483	51601	59606	71062	mod	b	c	12892
IN	Wayne	181770007	31811	48948	59606	72278	mod	b	c	12892
KS	Linn	201070002	1728	3741	4705	6412	low	b	a	
KS	Montgomery	201250006	9331	14142	17807	21677	low	b	b	1873
KS	Pawnee	201450001	5329	6038	6038	6038	low	a	a	
KS	Sedgwick	201730010	102842	276624	380868	426333	hi	a	a	806
KS	Sumner	201910002	1476	13125	56924	120034	low	b	a	806
KS	Trego	201950001	0	0	578	578	low	a	a	
KS	Wyandotte	202090001	63756	288005	588511	868652	hi	b	a	19433
KS	Wyandotte	202090020	41751	237368	491118	742170	mod	b	a	19433
KS	Wyandotte	202090021	61336	271585	571758	840225	hi	b	a	19427
KY	Boyd	210190015	31077	78140	124766	179511	mod	b	b	11909
KY	Boyd	210190017	34804	79205	119732	161810	mod	b	b	11933
KY	Boyd	210191003	14960	58723	117154	181371	mod	b	b	10172
KY	Campbell	210370003	67933	285451	616440	910551	hi	b	b	74986
KY	Campbell	210371001	153388	421973	754366	1016145	hi	b	b	5111
KY	Daviess	210590005	25889	70609	81162	92902	mod	b	b	60963
KY	Fayette	210670012	92980	195446	267016	309266	hi	a	b	626

State	County	Monitor ID	Population Residing within:				Analysis Bins			Emissions (tpy)[4]
			5km	10km	15km	20km	Population[1]	COV[2]	GSD[3]	
KY	Greenup	210890007	19411	45899	85066	109294	mod	b	b	4806
KY	Hancock	210910012	3345	4280	20931	39607	low	b	b	109458
KY	Henderson	211010013	21591	35051	126144	202537	mod	b	b	9026
KY	Henderson	211010014	2594	30452	135741	194289	low	b	b	109476
KY	Jefferson	211110032	49825	208276	375535	586335	mod	b	b	86910
KY	Jefferson	211110051	13446	52332	121743	257453	mod	b	b	39110
KY	Jefferson	211111041	81560	281755	485759	676730	hi	b	b	68947
KY	Livingston	211390004	1695	8508	15337	31298	low	b	b	1775
KY	McCracken	211450001	1336	15733	28279	64951	low	b	b	61380
KY	McCracken	211451024	17904	48907	63098	83436	mod	b	a	1760
KY	McCracken	211451026	9706	42285	62036	82624	low	b	b	1760
KY	Warren	212270008	1865	8137	23083	68407	low	a	a	52
LA	Bossier	220150008	43077	149478	247738	295731	mod	a	a	153
LA	Calcasieu	220190008	12932	68406	137949	154942	mod	b	b	53630
LA	East Baton Rouge	220330009	76518	193981	321486	408305	hi	c	b	39378
LA	Ouachita	220730004	24260	87999	116037	131643	mod	a	a	2166
LA	St. Bernard	220870002	97021	407863	672107	856519	hi	b	b	7543
LA	West Baton Rouge	221210001	21249	137455	239718	366741	mod	b	b	31242
MA	Bristol	250051004	89767	169077	221707	372963	hi	b	b	44817
MA	Essex	250090005	125952	225058	376322	598605	hi	b	b	1626
MA	Essex	250091004	123377	309194	545716	906225	hi	a	b	20202
MA	Essex	250091005	109921	314258	523212	870238	hi	b	b	20170
MA	Essex	250095004	57974	128881	316108	422519	hi	a	a	1235
MA	Hampden	250130016	136483	296109	450050	532663	hi	a	b	7360
MA	Hampden	250131009	127283	278577	447646	541476	hi	b	b	2065
MA	Hampshire	250154002	5182	23547	50329	123102	low	a	b	859
MA	Middlesex	250171701	109401	512228	1210094	1773702	hi	b	b	7670
MA	Middlesex	250174003	164954	629764	1334022	1860034	hi	b	b	7254
MA	Suffolk	250250002	486825	1141656	1582622	1955479	hi	a	b	7999
MA	Suffolk	250250019	6913	437626	1118549	1681211	low	a	a	7791
MA	Suffolk	250250020	320320	899106	1461574	1895175	hi	a	a	8024
MA	Suffolk	250250021	243006	887256	1488386	1966520	hi	a	a	7921
MA	Suffolk	250250040	261273	962956	1475999	1921168	hi	b	a	7952

State	County	Monitor ID	Population Residing within:				Analysis Bins			Emissions (tpy)[4]
			5km	10km	15km	20km	Population[1]	COV[2]	GSD[3]	
MA	Suffolk	250250042	441455	1048879	1536036	1941989	hi	a	a	7987
MA	Suffolk	250251003	260061	829040	1436251	1951612	hi	b	b	22045
MA	Worcester	250270020	155688	248143	316330	404489	hi	a	a	690
MA	Worcester	250270023	151851	252264	318317	403312	hi	a	a	690
MD	Allegany	240010006	28416	49750	66814	79171	mod	a	a	1363
MD	Anne Arundel	240032002	40618	134276	372761	829885	mod	b	b	64947
MD	Baltimore	240053001	99648	383980	785111	1155009	hi	b	b	97428
MD	Baltimore (City)	245100018	360916	823207	1195508	1472306	hi	a	a	65129
MD	Baltimore (City)	245100036	105632	490543	1004531	1351499	hi	a	b	97338
ME	Androscoggin	230010011	46561	61938	83767	101615	mod	b	b	283
ME	Aroostook	230030009	3403	4534	6561	9030	low	b	b	90
ME	Aroostook	230030012	3403	4534	6561	9030	low	b	b	90
ME	Aroostook	230031003	3403	4534	6561	9030	low	c	b	90
ME	Aroostook	230031013	6476	6476	10298	11213	low	b	b	48
ME	Aroostook	230031018	2387	8245	15656	21187	low	b	b	772
ME	Cumberland	230050014	65123	122951	151066	187005	hi	b	b	3201
ME	Cumberland	230050027	67865	124508	153138	190157	hi	b	b	3201
ME	Oxford	230172007	5903	10118	12717	17231	low	a	a	499
MI	Delta	260410902	7503	26225	28725	31746	low	a	a	4222
MI	Genesee	260490021	94710	227235	323367	388490	hi	b	b	166
MI	Genesee	260492001	4058	17555	47495	126929	low	b	b	127
MI	Kent	260810020	122533	294283	453477	553989	hi	a	a	541
MI	Macomb	260991003	116002	549258	1171414	1769656	hi	b	b	718
MI	Missaukee	261130001	0	2308	7840	14456	low	a	a	58
MI	St. Clair	261470005	32599	64545	82832	98014	mod	b	c	1572
MI	Schoolcraft	261530001	0	0	0	1389	low	b	b	
MI	Wayne	261630001	151437	338726	682793	1135095	hi	b	b	64065
MI	Wayne	261630005	86804	350207	804947	1386398	hi	b	b	64412
MI	Wayne	261630015	98193	423093	975303	1647773	hi	b	c	34236
MI	Wayne	261630016	203577	654802	1283000	1934280	hi	b	b	34225
MI	Wayne	261630019	210099	695836	1189529	1756001	hi	b	b	31238
MI	Wayne	261630025	81534	280589	668415	1150319	hi	b	b	81
MI	Wayne	261630027	79205	384693	915619	1574294	hi	b	c	64407

State	County	Monitor ID	Population Residing within:				Analysis Bins			Emissions (tpy)[4]
			5km	10km	15km	20km	Population[1]	COV[2]	GSD[3]	
MI	Wayne	261630033	150194	544634	1115397	1730610	hi	b	b	34236
MI	Wayne	261630062	123532	491879	1104610	1743263	hi	b	b	34225
MI	Wayne	261630092	96517	429048	973432	1618949	hi	b	b	64407
MN	Anoka	270031002	57502	226660	496686	903982	hi	b	a	13324
MN	Carlton	270176316	9236	17582	28511	56009	low	b	a	362
MN	Dakota	270370020	3854	64533	221239	432974	low	b	b	9155
MN	Dakota	270370423	8572	101147	265053	574966	low	b	a	13685
MN	Dakota	270370439	1487	55052	218201	411081	low	b	a	8949
MN	Dakota	270370441	1487	36683	191183	384938	low	b	a	8639
MN	Dakota	270370442	2705	24656	153752	332905	low	b	a	5567
MN	Hennepin	270530954	224357	608888	1082178	1517123	hi	b	b	21921
MN	Hennepin	270530957	157024	542309	1022041	1489863	hi	b	a	18443
MN	Koochiching	270711240	6444	8075	8923	10210	low	c	a	67
MN	Ramsey	271230864	112909	599029	1052764	1510602	hi	b	a	20773
MN	Sherburne	271410003	5629	7667	35016	50427	low	a	a	26742
MN	Sherburne	271410011	5629	9806	29985	51661	low	b	a	26742
MN	Sherburne	271410012	5629	9806	29774	50884	low	a	a	26742
MN	Sherburne	271410013	0	10957	33889	58410	low	a	a	26742
MN	Washington	271630436	46665	149177	354337	679510	mod	b	b	11441
MN	Wright	271710007	5377	28368	39511	77671	low	a	a	26794
MO	Buchanan	290210009	23253	72613	87121	93365	mod	c	b	3563
MO	Buchanan	290210011	28224	75073	86317	93365	mod	b	b	3563
MO	Clay	290470025	40627	163217	366686	617013	mod	b	a	25233
MO	Greene	290770026	41036	146752	224445	256158	mod	c	b	9206
MO	Greene	290770032	96594	180831	208384	244406	hi	a	a	9206
MO	Greene	290770037	21784	110681	210953	254437	mod	c	b	9206
MO	Greene	290770040	18988	109888	210953	254437	mod	b	a	9206
MO	Greene	290770041	24455	120781	213312	256766	mod	a	a	9206
MO	Iron	290930030	1121	1121	4507	8447	low	c	c	43340
MO	Iron	290930031	0	3799	6585	8436	low	c	b	43340
MO	Jackson	290950034	84236	310816	605775	921037	hi	c	b	19433
MO	Jefferson	290990004	15049	33379	64516	124301	mod	c	c	55725
MO	Jefferson	290990014	11967	35082	61963	125932	mod	c	b	55725

State	County	Monitor ID	Population Residing within: 5km	10km	15km	20km	Analysis Bins Population[1]	COV[2]	GSD[3]	Emissions (tpy)[4]
MO	Jefferson	290990017	19711	36471	60199	116882	mod	c	b	55725
MO	Jefferson	290990018	12258	41709	79196	170110	mod	c	b	32468
MO	Monroe	291370001	0	1439	2093	5612	low	a	a	
MO	Pike	291630002	645	2077	6916	11249	low	b	b	13495
MO	Platte	291650023	2159	36438	113990	238276	low	a	a	11030
MO	Saint Charles	291830010	2637	6349	34541	90953	low	b	b	47610
MO	Saint Charles	291831002	4587	95765	273147	431484	low	b	b	67735
MO	Saint Louis	291890001	95190	327257	630767	966432	hi	b	b	24466
MO	Saint Louis	291890004	61422	315539	647834	1020228	hi	b	b	22816
MO	Saint Louis	291890006	68741	235858	488837	927852	hi	b	b	190
MO	Saint Louis	291890014	48016	223506	550275	1005593	mod	b	b	265
MO	Saint Louis	291893001	117492	487564	929037	1305061	hi	b	b	10737
MO	Saint Louis	291895001	108578	358731	617042	941386	hi	b	b	66892
MO	Saint Louis	291897002	82790	336688	729925	1170973	hi	b	b	697
MO	Saint Louis	291897003	88786	383007	764342	1192267	hi	b	b	7262
MO	St. Louis City	295100007	107568	375790	678820	979578	hi	b	b	24933
MO	St. Louis City	295100072	101305	393971	726063	1097105	hi	b	b	13346
MO	St. Louis City	295100080	154740	463092	861774	1168442	hi	b	b	13502
MO	St. Louis City	295100086	145966	473923	857733	1177204	hi	b	b	13486
MS	Harrison	280470007	18607	88520	139495	181694	mod	c	b	25071
MS	Hinds	280490018	54986	171385	273630	332464	hi	b	a	256
MS	Jackson	280590006	39463	49647	65034	75787	mod	b	b	34318
MS	Lee	280810004	24421	44442	61390	74867	mod	a	a	
MT	Cascade	300132000	40281	64778	68296	70181	mod	b	b	702
MT	Cascade	300132001	42971	64778	70181	70181	mod	c	b	702
MT	Jefferson	300430903	1767	25076	47509	49340	low	b	b	234
MT	Jefferson	300430911	0	11616	36425	49340	low	c	b	234
MT	Jefferson	300430913	0	6845	27041	47509	low	c	b	234
MT	Lewis and Clark	300490702	10126	38881	49340	49340	mod	c	c	234
MT	Lewis and Clark	300490703	7706	31421	48723	49340	low	b	c	234
MT	Rosebud	300870700	2353	2353	2353	3131	low	b	a	16735
MT	Rosebud	300870701	2353	2353	3131	3131	low	b	a	16735
MT	Rosebud	300870702	0	2353	2353	3131	low	b	a	16735

State	County	Monitor ID	Population Residing within:				Analysis Bins			Emissions (tpy)[4]
			5km	10km	15km	20km	Population[1]	COV[2]	GSD[3]	
MT	Rosebud	300870760	0	0	643	2928	low	c	a	
MT	Rosebud	300870761	0	643	3524	3524	low	b	a	
MT	Rosebud	300870762	0	0	2928	2928	low	a	a	
MT	Rosebud	300870763	0	1536	3131	3131	low	a	a	16735
MT	Yellowstone	301110016	8526	9747	14953	39121	low	b	c	
MT	Yellowstone	301110066	27389	79644	98733	107178	mod	b	c	5480
MT	Yellowstone	301110079	61645	89282	102887	114640	hi	b	a	5480
MT	Yellowstone	301110080	33774	86065	104825	108399	mod	b	b	5480
MT	Yellowstone	301110082	58256	94753	103200	106046	hi	b	a	5480
MT	Yellowstone	301110083	27620	76641	98733	109475	mod	b	b	5480
MT	Yellowstone	301110084	22577	59919	97912	110980	mod	b	b	15298
MT	Yellowstone	301111065	13350	59574	97912	110980	mod	b	b	5480
MT	Yellowstone	301112005	24420	68288	97912	109475	mod	b	b	5480
MT	Yellowstone	301112006	11205	46767	86788	110980	mod	b	c	15298
MT	Yellowstone	301112007	5391	26316	69446	104067	low	b	c	15298
NC	Alexander	370030003	7574	16738	40689	80547	low	a	a	
NC	Beaufort	370130003	1085	1762	5519	8488	low	a	a	4730
NC	Beaufort	370130004	0	1762	6616	8488	low	b	a	4730
NC	Beaufort	370130006	0	1762	6616	8488	low	b	b	4730
NC	Chatham	370370004	4146	12138	23134	72477	low	a	a	474
NC	Cumberland	370511003	32970	108671	203822	280713	mod	a	a	1477
NC	Davie	370590002	4799	16224	44277	93569	low	a	a	7795
NC	Duplin	370610002	850	6058	12866	29813	low	a	a	414
NC	Edgecombe	370650099	0	11321	25673	51492	low	a	a	325
NC	Forsyth	370670022	61669	170320	258102	325974	hi	b	b	3945
NC	Johnston	371010002	9854	32163	67759	129979	low	a	a	29
NC	Lincoln	371090004	10568	32515	62768	125735	mod	a	a	10
NC	Martin	371170001	573	5282	14427	26518	low	a	a	3426
NC	Mecklenburg	371190034	90874	276915	474624	629520	hi	b	a	1030
NC	Mecklenburg	371190041	105796	295729	494494	647110	hi	b	b	821
NC	New Hanover	371290002	2584	20636	67021	127088	low	b	a	29923
NC	New Hanover	371290006	17957	83529	145330	170260	mod	b	b	30020
NC	Northampton	371310002	12284	29917	38134	46966	mod	a	a	2416

State	County	Monitor ID	Population Residing within:				Analysis Bins			Emissions (tpy)[4]
			5km	10km	15km	20km	Population[1]	COV[2]	GSD[3]	
NC	Person	371450003	2620	8081	24203	41995	low	b	b	96752
NC	Pitt	371470099	5860	10688	23742	72588	low	a	a	28
NC	Swain	371730002	3268	8992	15036	18230	low	a	a	
ND	Billings	380070002	0	0	1887	1887	low	a	a	283
ND	Billings	380070111	0	0	0	0	low	b	a	
ND	Burke	380130002	0	0	0	625	low	b	b	
ND	Burke	380130004	655	655	655	655	low	b	b	426
ND	Burleigh	380150003	49591	67377	83082	84415	mod	b	a	4592
ND	Cass	380171003	48975	134561	144878	154455	mod	b	a	771
ND	Cass	380171004	2118	91149	145789	148002	low	a	b	756
ND	Dunn	380250003	0	0	0	537	low	a	a	5
ND	McKenzie	380530002	0	596	596	596	low	a	a	210
ND	McKenzie	380530104	0	521	521	2283	low	c	a	
ND	McKenzie	380530111	0	0	2283	5771	low	c	a	823
ND	McLean	380550113	0	632	698	698	low	b	a	
ND	Mercer	380570001	3280	3280	5902	6465	low	b	b	91617
ND	Mercer	380570004	3280	4428	5902	7455	low	b	a	91617
ND	Mercer	380570102	1574	4428	5902	7455	low	b	b	91617
ND	Mercer	380570118	0	1574	6898	7455	low	b	b	91617
ND	Mercer	380570123	0	557	3837	5981	low	b	b	91617
ND	Mercer	380570124	557	557	557	3903	low	b	b	91617
ND	Morton	380590002	17925	67959	75685	84415	mod	c	c	4592
ND	Morton	380590003	10305	31348	75685	82584	mod	b	b	4592
ND	Oliver	380650002	0	0	2057	2670	low	b	b	28565
ND	Steele	380910001	0	934	934	934	low	a	a	
ND	Williams	381050103	0	1259	1259	1827	low	b	a	1605
ND	Williams	381050105	0	1259	1259	1827	low	b	c	1605
NE	Douglas	310550048	50168	209209	371395	532173	hi	c	b	31850
NE	Douglas	310550050	45166	187855	367828	525602	mod	b	a	31850
NE	Douglas	310550053	82663	264396	424100	578351	hi	c	b	31850
NE	Douglas	310550055	13902	109385	299381	473231	mod	b	a	11535
NH	Cheshire	330050007	16719	30003	39998	53389	mod	a	b	81
NH	Coos	330070019	9280	13603	14203	14928	low	b	c	638

State	County	Monitor ID	Population Residing within:				Analysis Bins			Emissions (tpy)[4]
			5km	10km	15km	20km	Population[1]	COV[2]	GSD[3]	
NH	Coos	330070022	8360	12552	14928	14928	low	b	b	638
NH	Coos	330071007	2438	2438	6025	8364	low	c	b	18
NH	Hillsborough	330110016	107911	145660	196209	270491	hi	b	b	30806
NH	Hillsborough	330110019	104650	140235	189502	266391	hi	b	b	30806
NH	Hillsborough	330110020	104650	140235	189502	266391	hi	b	b	30806
NH	Hillsborough	330111009	72131	130360	219169	438168	hi	a	a	454
NH	Hillsborough	330111010	37423	145620	333540	467236	mod	b	b	772
NH	Merrimack	330130007	27595	54309	75576	101847	mod	b	b	30833
NH	Merrimack	330131003	8787	45710	74945	138179	low	c	c	30833
NH	Merrimack	330131006	8066	35862	104656	218207	low	b	c	30833
NH	Merrimack	330131007	9351	43118	73240	98696	low	b	b	30833
NH	Rockingham	330150009	25227	48762	88743	157669	mod	b	b	13706
NH	Rockingham	330150014	25984	48762	78775	148875	mod	b	b	13706
NH	Rockingham	330150015	25227	48762	92738	152363	mod	b	b	13706
NH	Sullivan	330190003	11339	17306	34644	48414	mod	a	a	220
NJ	Atlantic	340010005	6123	33910	71617	160179	low	a	a	
NJ	Bergen	340035001	209619	973093	3404473	5751193	hi	a	b	27848
NJ	Burlington	340051001	71953	261206	561157	1133142	hi	b	b	15099
NJ	Camden	340070003	193686	806251	1761045	2534030	hi	b	b	10733
NJ	Camden	340071001	8015	46392	121996	262931	low	a	b	17
NJ	Cumberland	340110007	26454	77939	109030	160091	mod	a	b	646
NJ	Essex	340130011	209592	1133321	2811759	5933785	hi	a	b	27424
NJ	Essex	340130016	200779	1136145	2763272	5837087	hi	b	b	27638
NJ	Gloucester	340150002	32432	107924	537340	1392192	mod	b	b	26452
NJ	Hudson	340170006	158136	930071	3370494	5894707	hi	a	b	27538
NJ	Hudson	340171002	343775	1754575	5021807	8159098	hi	a	b	29856
NJ	Middlesex	340232003	95281	371119	839280	1615249	hi	a	b	1675
NJ	Morris	340273001	13515	60394	181888	361716	mod	b	b	38
NJ	Union	340390003	221266	868022	1790660	3314852	hi	a	b	23181
NJ	Union	340390004	194256	750485	1727936	3277263	hi	a	a	23146
NM	Dona Ana	350130008	10195	49347	114220	181522	mod	a	a	37
NM	Dona Ana	350130017	40832	158545	258940	387481	mod	c	b	574
NM	Eddy	350151004	12050	12050	14785	16465	mod	b	b	4233

State	County	Monitor ID	Population Residing within:				Analysis Bins			Emissions (tpy)[4]
			5km	10km	15km	20km	Population[1]	COV[2]	GSD[3]	
NM	Grant	350170001	4292	6951	21790	23982	low	c	b	263
NM	Grant	350171003	1429	5721	9904	24316	low	c	b	263
NM	Hidalgo	350230005	0	0	0	0	low	c	c	
NM	San Juan	350450008	22921	41258	51483	68906	mod	b	a	17344
NM	San Juan	350450009	2930	18431	32213	58595	low	b	a	585
NM	San Juan	350450017	0	6492	10898	10936	low	b	b	
NM	San Juan	350451005	491	2247	11772	16909	low	b	c	50191
NV	Clark	320030022	0	0	0	10778	low	a	a	178
NV	Clark	320030078	0	0	2836	2836	low	a	a	
NV	Clark	320030539	226197	557934	933583	1236711	hi	a	a	
NV	Clark	320030601	13570	22316	71616	97845	mod	a	a	
NY	Albany	360010012	108841	255221	371301	484970	hi	b	b	362
NY	Bronx	360050073	1215989	3522226	5762144	8036800	hi	a	b	27101
NY	Bronx	360050080	1278526	3040232	5159927	7489995	hi	a	b	26825
NY	Bronx	360050083	1162835	2294809	4245952	6315293	hi	a	b	6659
NY	Bronx	360050110	1205886	3444711	5621679	7878863	hi	a	a	26965
NY	Chautauqua	360130005	3605	6928	15645	22519	low	b	c	
NY	Chautauqua	360130006	14144	29535	39906	47684	mod	c	b	52177
NY	Chautauqua	360130011	3605	6928	15645	22519	low	b	c	
NY	Chemung	360150003	41915	68619	82014	101244	mod	a	a	404
NY	Erie	360290005	150194	458758	680793	839570	hi	b	b	40734
NY	Erie	360294002	80118	328976	575596	768392	hi	c	c	41722
NY	Erie	360298001	66153	237799	503575	729503	hi	b	b	40659
NY	Essex	360310003	492	2054	7005	10934	low	b	b	
NY	Franklin	360330004	0	2880	5697	11358	low	b	b	
NY	Hamilton	360410005	0	0	454	2054	low	b	c	
NY	Herkimer	360430005	2043	2043	2043	2043	low	b	c	
NY	Kings	360470011	1301071	3958499	6872002	8807020	hi	a	b	29050
NY	Kings	360470076	1173879	3316779	5595972	7596057	hi	a	b	28686
NY	Madison	360530006	806	4985	7448	17313	low	b	b	
NY	Monroe	360551004	149439	384621	579436	665760	hi	b	b	50379
NY	Monroe	360551007	129608	381741	570995	669909	hi	b	a	50379
NY	Monroe	360556001	222716	407438	582031	678777	hi	b	b	50379

State	County	Monitor ID	Population Residing within:				Analysis Bins			Emissions (tpy)[4]
			5km	10km	15km	20km	Population[1]	COV[2]	GSD[3]	
NY	Nassau	360590005	172837	677944	1424915	2365352	hi	b	b	1806
NY	New York	360610010	1062324	3421130	6487922	8988411	hi	a	b	28873
NY	New York	360610056	1289280	3673609	6607580	8980807	hi	a	a	29021
NY	Niagara	360632008	60505	96530	176040	348603	hi	b	a	40748
NY	Onondaga	360671015	56156	207136	329787	395331	hi	a	a	3280
NY	Putnam	360790005	15437	57790	111398	223357	mod	b	c	
NY	Queens	360810097	378415	1589364	3438261	7138176	hi	a	b	8183
NY	Queens	360810124	823992	2441512	5839274	8419326	hi	b	b	8043
NY	Rensselaer	360830004	1987	5975	22806	118285	low	b	c	379
NY	Rensselaer	360831005	1222	6357	19071	69278	low	b	c	188
NY	Richmond	360850067	282277	653196	2026407	4371801	hi	a	b	24733
NY	Schenectady	360930003	100404	157970	233426	383092	hi	a	a	96
NY	Suffolk	361030002	80740	526254	950326	1417428	hi	a	b	1404
NY	Suffolk	361030009	101641	341308	551178	802861	hi	a	b	7344
NY	Ulster	361111005	755	1541	7851	10684	low	b	c	
OH	Adams	390010001	4630	6792	15822	22444	low	b	b	19670
OH	Allen	390030002	15401	67353	90874	114512	mod	b	b	3977
OH	Ashtabula	390071001	11409	17288	23848	42433	mod	b	b	8655
OH	Belmont	390133002	17529	41346	95392	120821	mod	b	c	138904
OH	Butler	390170004	68823	163124	276076	487924	hi	b	b	9979
OH	Butler	390171004	47209	96458	152032	287701	mod	b	b	13912
OH	Clark	390230003	19786	66337	175311	410155	mod	b	b	2034
OH	Clermont	390250021	7297	20144	53435	96496	low	b	b	91822
OH	Columbiana	390290016	21336	46769	67377	101068	mod	b	b	186262
OH	Columbiana	390290022	21336	46769	67377	101068	mod	b	c	186262
OH	Columbiana	390292001	25779	43920	64319	92597	mod	b	b	179205
OH	Cuyahoga	390350038	136697	547523	932680	1214114	hi	b	b	7403
OH	Cuyahoga	390350045	151001	564795	962245	1221356	hi	b	b	7403
OH	Cuyahoga	390350060	116933	512974	907112	1201852	hi	b	b	7403
OH	Cuyahoga	390350065	132176	562942	968826	1244026	hi	b	b	7403
OH	Cuyahoga	390356001	191842	529243	883601	1165619	hi	b	b	74869
OH	Franklin	390490004	133697	467572	806703	1042146	hi	b	b	450
OH	Franklin	390490034	157233	482749	868013	1090438	hi	b	b	450

State	County	Monitor ID	Population Residing within:				Analysis Bins			Emissions (tpy)[4]
			5km	10km	15km	20km	Population[1]	COV[2]	GSD[3]	
OH	Gallia	390530002	1087	13134	30170	49474	low	b	b	190311
OH	Hamilton	390610010	15310	124569	345879	632705	mod	b	c	92654
OH	Hamilton	390612003	71390	325799	683493	1079723	hi	b	b	7257
OH	Jefferson	390810016	28019	70995	96550	122094	mod	b	c	223185
OH	Jefferson	390810017	30069	71838	96408	122094	mod	b	c	223185
OH	Jefferson	390811001	21833	53684	91514	119322	mod	b	c	78071
OH	Lake	390850003	48791	145694	238216	407417	mod	b	b	72266
OH	Lake	390853002	40430	92415	141902	209471	mod	b	c	4799
OH	Lawrence	390870006	26563	71376	94538	131453	mod	b	b	11400
OH	Lorain	390930017	58361	129195	249878	362235	hi	b	b	495
OH	Lorain	390930026	54867	114602	202571	298148	hi	b	b	53
OH	Lorain	390931003	58580	124277	251182	365323	hi	b	b	495
OH	Lucas	390950008	62606	205665	356815	487567	hi	b	b	37337
OH	Lucas	390950024	134960	319708	466184	528531	hi	b	b	37450
OH	Mahoning	390990009	79207	210961	293714	378289	hi	b	b	21074
OH	Mahoning	390990013	78376	214611	294367	375287	hi	b	b	21074
OH	Meigs	391051001	5440	15029	21812	31834	low	b	b	190311
OH	Montgomery	391130025	123978	304826	511565	645130	hi	b	b	9652
OH	Morgan	391150003	1122	3168	9162	22426	low	c	c	115526
OH	Morgan	391150004	1122	3168	9871	24252	low	c	b	115526
OH	Scioto	391450013	15699	47369	61292	77940	mod	b	b	
OH	Scioto	391450020	4530	11216	45697	87756	low	b	c	4351
OH	Scioto	391450022	3469	12081	40548	82103	low	b	c	4351
OH	Stark	391510016	99075	208779	291216	350367	hi	a	b	1269
OH	Summit	391530017	104817	292059	470747	574282	hi	b	c	11053
OH	Summit	391530022	140332	329963	454363	570258	hi	b	b	11053
OH	Tuscarawas	391570003	26914	40238	61526	85938	mod	b	b	2579
OH	Tuscarawas	391570006	2710	15439	38518	72765	low	b	b	2556
OK	Cherokee	400219002	993	22584	28182	36130	low	c	a	
OK	Kay	400710602	25029	31461	31461	36740	mod	b	b	7003
OK	Kay	400719003	6614	29697	32746	35459	low	b	b	7003
OK	Kay	400719010	1123	3516	16273	20121	low	b	a	
OK	Mayes	400979014	1947	14224	26265	29243	low	a	b	19079

State	County	Monitor ID	Population Residing within:				Analysis Bins			Emissions (tpy)[4]
			5km	10km	15km	20km	Population[1]	COV[2]	GSD[3]	
OK	Muskogee	401010167	5633	39252	56271	64455	low	b	b	30011
OK	Oklahoma	401090025	78654	254952	384825	552894	hi	a	a	182
OK	Oklahoma	401091037	46197	141934	258441	459371	mod	a	a	182
OK	Ottawa	401159004	6272	22614	29716	37508	low	b	a	62
OK	Tulsa	401430175	53094	207546	357175	485641	hi	b	c	9377
OK	Tulsa	401430235	65020	235972	405434	515780	hi	b	c	9377
OK	Tulsa	401430501	46840	187023	333482	468989	mod	b	b	9377
PA	Allegheny	420030002	83332	277442	651551	961378	hi	b	b	1964
PA	Allegheny	420030010	168140	536314	842237	1114184	hi	a	b	4688
PA	Allegheny	420030021	170777	560187	921490	1142754	hi	b	b	52447
PA	Allegheny	420030031	183843	580429	877668	1145039	hi	a	b	46957
PA	Allegheny	420030032	174072	558904	922097	1144558	hi	b	b	52447
PA	Allegheny	420030064	64846	201143	520438	943781	hi	b	b	11490
PA	Allegheny	420030067	13277	86792	324154	610975	mod	a	b	1167
PA	Allegheny	420030116	96820	331624	704601	996267	hi	b	b	1964
PA	Allegheny	420031301	115432	411867	766188	1088115	hi	b	b	52100
PA	Allegheny	420033003	55221	202092	509708	944188	hi	b	c	11490
PA	Allegheny	420033004	38588	170065	461433	904760	mod	b	b	11501
PA	Beaver	420070002	3434	28961	68617	120780	low	b	b	187257
PA	Beaver	420070004	35152	104660	203430	317823	mod	a	a	41170
PA	Beaver	420070005	17292	77240	143738	224631	mod	b	c	41385
PA	Beaver	420070014	36335	82468	134467	220614	mod	b	b	44003
PA	Berks	420110009	121330	203799	250610	309553	hi	b	b	14817
PA	Berks	420110100	118553	202746	254794	310286	hi	a	b	14774
PA	Blair	420130801	44392	72996	94779	124536	mod	b	b	441
PA	Bucks	420170012	85719	324327	638218	1212911	hi	a	b	15117
PA	Cambria	420210011	50440	79710	102905	124592	hi	b	b	16779
PA	Centre	420270100	60659	76595	96267	107078	hi	a	b	4359
PA	Dauphin	420430401	86638	219394	324647	384070	hi	a	b	857
PA	Delaware	420450002	74840	237232	510590	1091830	hi	a	b	38833
PA	Delaware	420450109	59762	209503	446058	812243	hi	a	b	38470
PA	Erie	420490003	81199	150626	190212	209983	hi	a	a	4122
PA	Indiana	420630004	1110	8662	23057	57759	low	b	b	14389

State	County	Monitor ID	Population Residing within: 5km	10km	15km	20km	Analysis Bins: Population[1]	COV[2]	GSD[3]	Emissions (tpy)[4]
PA	Lackawanna	420692006	68522	144913	189515	246604	hi	a	b	66
PA	Lancaster	420710007	97205	174296	254789	344292	hi	b	b	375
PA	Lawrence	420730015	40803	57962	81815	118770	mod	b	b	28854
PA	Lehigh	420770004	133092	298181	395772	501878	hi	a	b	9143
PA	Luzerne	420791101	68639	157363	215050	265123	hi	a	b	467
PA	Lycoming	420810100	15088	60400	83910	108961	mod	b	b	83
PA	Lycoming	420810403	41897	69102	80935	103969	mod	a	b	83
PA	Mercer	420850100	40443	69465	96468	184589	mod	b	b	28
PA	Montgomery	420910013	91275	239337	706445	1623890	hi	a	b	4794
PA	Northampton	420950025	79756	173911	398867	513651	hi	a	b	12167
PA	Northampton	420950100	71422	118395	209567	317220	hi	a	b	32680
PA	Northampton	420958000	71626	133639	228524	330629	hi	b	b	32714
PA	Perry	420990301	6450	13169	26326	49400	low	b	b	
PA	Philadelphia	421010004	400078	1147634	1971579	2631448	hi	b	b	6228
PA	Philadelphia	421010022	316944	985213	1726387	2446142	hi	a	b	18834
PA	Philadelphia	421010024	197076	588104	1351349	2063868	hi	b	b	1663
PA	Philadelphia	421010027	472813	1348135	2026206	2632847	hi	a	b	6246
PA	Philadelphia	421010029	484661	1229942	1999611	2574304	hi	b	b	17550
PA	Philadelphia	421010047	410380	1153434	1989848	2573573	hi	a	b	17536
PA	Philadelphia	421010048	262592	1102727	1938877	2607877	hi	b	b	6214
PA	Philadelphia	421010055	341893	1020004	1774411	2476647	hi	a	b	18848
PA	Philadelphia	421010136	382995	985957	1718068	2381173	hi	b	b	21700
PA	Schuylkill	421070003	19152	30388	59370	100508	mod	a	b	4987
PA	Warren	421230003	14142	19940	25715	32490	mod	b	b	4890
PA	Warren	421230004	13965	18884	28805	33523	mod	b	c	4890
PA	Washington	421250005	31276	68512	111222	183285	mod	a	a	8484
PA	Washington	421250200	32125	52910	83324	118188	mod	a	b	7
PA	Washington	421255001	1359	15854	43364	126091	low	b	b	2566
PA	Westmoreland	421290008	35656	82661	148990	213978	mod	a	b	72
PA	York	421330008	85574	156166	216656	284208	hi	b	b	80487
PR	Barceloneta	720170003	29823	83433	134176	243828	mod	b	a	
PR	Bayamon	720210004	192976	679576	1002864	1292141	hi	b	b	
PR	Bayamon	720210006	208167	587003	956783	1256603	hi	b	b	

State	County	Monitor ID	Population Residing within:				Analysis Bins			Emissions (tpy)[4]
			5km	10km	15km	20km	Population[1]	COV[2]	GSD[3]	
PR	Catano	720330004	154575	583552	958456	1233122	hi	b	b	
PR	Catano	720330007	95500	576841	983702	1219701	hi	b	b	
PR	Catano	720330008	99778	594607	972270	1238188	hi	b	b	
PR	Catano	720330009	110439	457427	883511	1164315	hi	b	b	
PR	Guayama	720570009	12086	49373	90444	174005	mod	a	a	
PR	Salinas	721230001	20645	31312	68199	174332	mod	b	b	
RI	Providence	440070012	223521	487990	638092	816597	hi	a	b	2228
RI	Providence	440071005	148802	390751	615465	809993	hi	b	b	2265
RI	Providence	440071009	226940	493584	646894	821476	hi	a	b	2253
SC	Aiken	450030003	752	6505	18533	55485	low	a	a	21498
SC	Barnwell	450110001	0	4022	13647	21554	low	a	a	65
SC	Charleston	450190003	40872	132716	273298	364953	mod	b	b	34934
SC	Charleston	450190046	1103	1103	9529	22255	low	b	a	
SC	Georgetown	450430006	10567	18215	22467	34357	mod	b	b	40841
SC	Greenville	450450008	70221	173012	284047	379022	hi	a	b	1067
SC	Greenville	450450009	56686	151862	279293	356410	hi	b	a	1082
SC	Lexington	450630008	42208	131361	257820	355854	mod	b	b	10433
SC	Oconee	450730001	0	2260	11136	26182	low	a	a	5
SC	Orangeburg	450750003	2904	7856	14446	24656	low	b	a	7166
SC	Richland	450790007	35872	121006	255135	353072	mod	a	a	613
SC	Richland	450790021	1666	4643	13324	33098	low	b	b	40492
SC	Richland	450791003	87097	213836	300874	396116	hi	b	a	12935
SC	Richland	450791006	1666	5435	15920	47548	low	b	a	42894
SD	Custer	460330132	0	0	3940	4686	low	b	a	
SD	Jackson	460710001	0	0	0	0	low	a	a	
SD	Minnehaha	460990007	65647	119287	138918	147218	hi	b	a	496
TN	Anderson	470010028	11872	59225	153931	292415	mod	c	b	44761
TN	Blount	470090002	28887	70731	105939	198408	mod	b	c	4263
TN	Blount	470090006	36020	72290	104178	189214	mod	b	b	4263
TN	Blount	470090101	0	12650	44702	81010	low	b	a	4263
TN	Bradley	470110102	2540	11940	46188	84762	low	b	a	5437
TN	Coffee	470310004	1286	9718	23113	35158	low	b	a	
TN	Davidson	470370011	77459	228349	410925	583532	hi	a	b	8019

State	County	Monitor ID	Population Residing within:				Analysis Bins			Emissions (tpy)[4]
			5km	10km	15km	20km	Population[1]	COV[2]	GSD[3]	
TN	Hawkins	470730002	6748	14441	22457	39857	low	c	c	35493
TN	Humphreys	470850020	2474	6672	13621	23460	low	c	b	111597
TN	McMinn	471070101	2540	11940	37322	84929	low	b	a	5501
TN	Montgomery	471250006	21032	79399	112883	139621	mod	a	a	1330
TN	Montgomery	471250106	16569	74449	109087	138438	mod	a	a	1330
TN	Polk	471390003	1613	9042	14124	24537	low	b	a	1900
TN	Polk	471390007	2491	9432	19726	24026	low	c	b	1900
TN	Polk	471390008	2491	9432	17401	25902	low	a	a	1900
TN	Polk	471390009	2491	10239	17235	24026	low	b	a	1900
TN	Roane	471450009	8848	21677	37175	57683	low	c	a	77881
TN	Shelby	471570034	74216	277713	497847	695164	hi	a	a	21675
TN	Shelby	471570043	94449	325228	534950	751299	hi	a	b	21675
TN	Shelby	471570046	18782	113964	273306	473443	mod	b	a	3945
TN	Shelby	471571034	886	97506	277857	484234	low	b	b	21847
TN	Stewart	471610007	787	4566	8854	20362	low	b	a	16682
TN	Sullivan	471630007	28689	78826	112565	153445	mod	b	c	30097
TN	Sullivan	471630009	28254	77403	117095	151856	mod	b	c	30156
TN	Sumner	471651002	5070	38555	53602	119241	low	c	b	34373
TX	Cameron	480610006	70071	151247	160048	167993	hi	a	a	
TX	Dallas	481130069	93552	455917	991123	1609774	hi	a	a	307
TX	Ellis	481390015	6089	13876	35210	113413	low	b	b	7972
TX	Ellis	481390016	7883	18193	68740	191352	low	b	c	7972
TX	Ellis	481390017	5723	17592	50332	152699	low	c	b	7972
TX	El Paso	481410037	56009	182473	337222	522824	hi	b	b	574
TX	El Paso	481410053	49083	163206	325118	519008	mod	b	b	574
TX	El Paso	481410058	78658	126481	299419	524259	hi	b	a	614
TX	Galveston	481670005	37427	62491	98724	182464	mod	b	b	7976
TX	Galveston	481671002	38619	65658	98768	196215	mod	b	b	7976
TX	Gregg	481830001	1349	17138	52116	105781	low	c	b	66443
TX	Harris	482010046	65125	350122	756166	1283440	hi	b	a	17583
TX	Harris	482010051	123431	372470	896497	1380154	hi	b	a	26
TX	Harris	482010059	151412	475338	902121	1392348	hi	b	c	25608
TX	Harris	482010062	73770	352818	695432	1108749	hi	b	b	25677

State	County	Monitor ID	Population Residing within:				Analysis Bins			Emissions (tpy)[4]
			5km	10km	15km	20km	Population[1]	COV[2]	GSD[3]	
TX	Harris	482010070	153479	511407	991134	1610993	hi	b	b	24501
TX	Harris	482011035	99581	451485	891195	1287766	hi	b	b	25635
TX	Harris	482011050	23794	83705	224120	405297	mod	a	a	11195
TX	Jefferson	482450009	33143	87386	182005	237033	mod	b	c	13807
TX	Jefferson	482450011	13164	93985	121116	140687	mod	b	c	26962
TX	Jefferson	482450020	35739	101563	177284	223336	mod	b	c	1362
TX	Kaufman	482570005	6583	9190	28396	43226	low	a	a	
TX	Nueces	483550025	99888	186846	231717	280479	hi	b	b	7954
TX	Nueces	483550026	16215	28033	92841	177008	mod	b	a	8056
TX	Nueces	483550032	48320	128230	228351	272861	mod	b	b	7954
UT	Cache	490050004	49600	64094	80592	86020	mod	a	a	5
UT	Davis	490110001	56718	82741	178141	311810	hi	b	b	2807
UT	Davis	490110004	52464	83909	154925	295333	hi	b	a	2807
UT	Salt Lake	490350012	57910	183684	370433	630857	hi	b	a	2807
UT	Salt Lake	490351001	31709	107346	260423	522228	mod	b	a	5832
UT	Salt Lake	490352004	0	4074	35159	124394	low	b	a	3735
VA	Charles	510360002	3370	32169	76679	176978	low	b	b	86717
VA	Fairfax	510590005	34561	183637	408647	687195	mod	a	b	156
VA	Fairfax	510590018	87725	293189	730360	1388941	hi	a	b	18204
VA	Fairfax	510591004	215952	660586	1410007	2092422	hi	a	a	18303
VA	Fairfax	510591005	203219	670880	1238334	1844099	hi	a	a	18405
VA	Fairfax	510595001	80603	358173	1098236	2041931	hi	a	a	17221
VA	Madison	511130003	1316	4823	13930	28417	low	b	c	7
VA	Roanoke	511611004	33161	123148	197615	235072	mod	a	a	677
VA	Rockingham	511650002	17897	58020	76316	85276	mod	a	a	277
VA	Rockingham	511650003	13821	47577	71219	92912	mod	a	a	235
VA	Alexandria City	515100009	137533	622283	1320784	1894197	hi	b	b	18293
VA	Hampton City	516500004	73011	182507	356676	601943	hi	b	b	4274
VA	Norfolk City	517100023	124263	379455	703082	871632	hi	b	b	36499
VA	Richmond City	517600024	109306	309672	524083	656099	hi	b	b	2675
VI	St Croix	780100006	0	0	0	0	low	b	c	
VI	St Croix	780100011	0	0	0	0	low	b	c	
VI	St Croix	780100013	0	0	0	0	low	c	c	

State	County	Monitor ID	Population Residing within:				Analysis Bins			Emissions (tpy)[4]
			5km	10km	15km	20km	Population[1]	COV[2]	GSD[3]	
VI	St Croix	780100014	0	0	0	0	low	c	c	
VI	St Croix	780100015	0	0	0	0	low	c	c	
VT	Chittenden	500070003	50990	89229	110853	133530	hi	b	a	6
VT	Chittenden	500070014	54166	87471	110853	133749	hi	a	a	6
VT	Rutland	500210002	21330	30052	35316	46525	mod	b	c	
WA	Clallam	530090010	17871	26073	30255	37672	mod	b	b	756
WA	Clallam	530090012	20830	27014	30036	36843	mod	b	a	756
WA	King	530330057	131605	394412	730218	1093083	hi	a	a	1203
WA	King	530330080	116769	423064	811856	1157199	hi	b	a	1203
WA	Pierce	530530021	68072	250876	548806	839357	hi	b	b	538
WA	Pierce	530530031	55628	275358	555755	820805	hi	b	a	538
WA	Skagit	530570012	3580	22573	32120	70660	low	b	b	8951
WA	Skagit	530571003	1733	21622	32120	75069	low	b	b	8951
WA	Snohomish	530610016	46071	152230	303720	432356	mod	a	a	381
WA	Whatcom	530730011	60525	83632	111425	126291	hi	a	a	4391
WI	Brown	550090005	79060	158940	201226	215144	hi	b	b	23888
WI	Dane	550250041	79610	189421	306132	353861	hi	b	b	9049
WI	Forest	550410007	1330	3913	5514	6669	low	b	a	5
WI	Marathon	550730005	5095	42173	61417	93151	low	c	a	12120
WI	Milwaukee	550790007	248317	606921	865925	1037293	hi	b	b	15753
WI	Milwaukee	550790026	214859	572784	834939	1014161	hi	b	a	15753
WI	Milwaukee	550790041	137816	455868	765734	964876	hi	b	b	15753
WI	Oneida	550850996	8351	17018	17018	23821	low	c	c	2304
WI	Sauk	551110007	2743	15039	24240	43368	low	b	a	63
WI	Vilas	551250001	934	934	8639	10755	low	a	a	
WI	Wood	551410016	19525	33790	43315	50360	mod	c	b	14245
WV	Brooke	540090005	25010	64711	92813	118070	mod	b	b	78071
WV	Brooke	540090007	30794	70187	95823	120385	mod	b	b	223185
WV	Cabell	540110006	50835	88879	125923	164495	hi	b	b	7504
WV	Greenbrier	540250001	2158	9273	18280	23902	low	a	a	
WV	Hancock	540290005	6006	23418	77160	125873	low	b	b	176554
WV	Hancock	540290007	14924	44311	83167	128126	mod	b	b	148520
WV	Hancock	540290008	24095	49351	63727	91485	mod	b	b	186262

State	County	Monitor ID	Population Residing within:				Analysis Bins			Emissions (tpy)[4]
			5km	10km	15km	20km	Population[1]	COV[2]	GSD[3]	
WV	Hancock	540290009	20946	61117	90717	115283	mod	b	b	148404
WV	Hancock	540290011	31890	76198	95992	115162	mod	b	b	223185
WV	Hancock	540290014	22857	58620	89998	120724	mod	b	b	148520
WV	Hancock	540290015	20793	45848	65851	102031	mod	b	b	186262
WV	Hancock	540290016	19278	70483	96151	114992	mod	b	b	169771
WV	Hancock	540291004	24761	63677	91977	115615	mod	b	b	169771
WV	Kanawha	540390004	46977	80511	120631	164476	mod	b	b	6115
WV	Kanawha	540390010	48231	83340	123101	172217	mod	b	b	6115
WV	Kanawha	540392002	21694	61059	111812	164912	mod	b	b	113491
WV	Marshall	540511002	13403	32048	55054	95735	mod	b	c	138904
WV	Monongalia	540610003	43902	65672	80405	98315	mod	b	b	91984
WV	Monongalia	540610004	44079	63708	80385	98966	mod	b	b	97887
WV	Monongalia	540610005	46591	61019	77800	99544	mod	b	b	96396
WV	Ohio	540690007	20818	60048	91967	126981	mod	b	b	74781
WV	Wayne	540990002	17320	62645	124477	178576	mod	a	b	10172
WV	Wayne	540990003	17320	59989	123349	177744	mod	b	b	10172
WV	Wayne	540990004	16553	54251	122072	179815	mod	b	b	10172
WV	Wayne	540990005	13314	48330	114824	173807	mod	b	b	10172
WV	Wood	541071002	24917	70324	104458	128127	mod	b	b	48124
WY	Campbell	560050857	3288	11413	23902	25752	low	b	b	10106

Notes:

[1] Population bins: low (≤10,000); mid (10,001 to 50,000); hi (>50,000) using population within 5 km of ambient monitor.

[2] COV bins: a (≤100%); b (>100 to ≤200); c (>200).

[3] GSD bins: a (≤2.17); b (>2.17 to ≤2.94); c (>2.94).

[4] Sum of emissions within 20 km radius of ambient monitor based on 2002 NEI.

A.1.2 Analysis of SO_2 Emission Sources Surrounding Ambient Monitors

Distances of the 5-minute and 1-hour ambient monitoring sites to stationary sources emitting SO_2 were estimated using data from the 2002 National Emissions Inventory[1] (NEI). The NEI database reports emissions of SO_2 in tons per year (tpy) for 98,667 unique emission sources at various points of release. The release locations were all taken from the latitude longitude values within the NEI. First, all SO_2 emissions were summed for identical latitude and longitude entries while retaining source codes for the emissions (e.g., Standard Industrial Code (SIC), or North American Industrial Classification System (NAICS)). Therefore, any facility containing similar emission processes were summed at the stack location, resulting in 32,521 observations. These data were then screened for sources with emissions greater than 5 tpy, yielding 6,104 unique SO_2 emission sources. Locations of these stationary source emissions were compared with ambient monitoring locations using the following formula:

$$d = \arccos(\sin(lat_1) \times \sin(lat_2) + \cos(lat_1) \times \cos(lat_2) \times \cos(lon_2 - lon_1)) \times r$$

where

d	=	distance (kilometers)
lat_1	=	latitude of a monitor (radians)
lat_2	=	latitude of source emission (radians)
lon_1	=	longitude of monitor (radians)
lon_2	=	longitude of source emission (radians)
r	=	approximate radius of the earth (or 6,371 km)

Location data for monitors and sources provided in the AQS and NEI data bases were given in units of degrees therefore, these were first converted to radians by dividing by 180/π. For each monitor, source emissions within 20 km of the monitor were retained.

Table A.1-5 contains the summary of the distance of stationary source emissions to each of the monitors in the broader SO_2 monitoring network. There were varying numbers of sources emitting >5 tpy of SO_2 and located within a 20 km radius for many of the monitors. Some of the monitors are point-source oriented, that is, sited to measure ambient concentrations potentially

[1] 2002 National Emissions Inventory Data & Documentation. Office of Air Quality Planning and Standards, Research Triangle Park, NC. Available at: http://www.epa.gov/ttn/chief/net/2002inventory html.

influenced by a specific single sources (e.g., Missouri monitor IDs 290210009, 290210011, 290930030), or by several sources (e.g., Pennsylvania monitor IDs 420030021, 420030031) of varying emission strength. A few of the monitors contained no source emissions >5 tpy (e.g., Iowa monitor IDs 191770005, 191770006).

Table A.1-5. Distance of ambient SO_2 monitors (all used in analysis) to stationary sources emitting > 5 tons of SO_2 per year, within a 20 kilometer distance of monitoring site, and SO_2 emissions associated with those stationary sources.

		SO_2 emissions (tpy) from sources within 20 km of monitor[1]							Distance of monitor to SO_2 emission source (km)[1]						
Monitor ID	n	mean	std	min	p2.5	p50	p97.5	p100	mean	std	min	p2.5	p50	p97.5	p100
010330044	3	16680	28821	30	30	51	49960	49960	6.0	0.7	5.5	5.5	5.9	6.8	6.8
010710020	3	15119	25004	98	98	1276	43983	43983	5.7	2.4	3.1	3.1	6.2	7.8	7.8
010731003	43	151	227	5	5	38	786	982	11.4	5.5	1.1	1.2	13.1	16.8	19.8
010790003	5	1787	3416	6	6	58	7852	7852	8.4	1.7	5.5	5.5	8.6	9.8	9.8
010970028	10	6613	13057	14	14	214	38917	38917	7.5	5.8	1.4	1.4	6.1	19.1	19.1
010972005	9	132	154	5	5	72	440	440	7.7	2.1	4.3	4.3	7.2	10.1	10.1
011011002	4	913	1183	180	180	403	2663	2663	12.7	7.2	4.5	4.5	13.2	19.9	19.9
040070009	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
040071001	2	9219	10723	1637	1637	9219	16801	16801	1.3	0.5	0.9	0.9	1.3	1.6	1.6
040130019	8	23	19	10	10	19	69	69	11.0	3.6	5.6	5.6	10.2	16.9	16.9
040133002	9	21	19	10	10	14	69	69	10.8	6.6	1.9	1.9	11.2	19.2	19.2
040133003	9	20	19	6	6	14	69	69	12.5	4.7	5.5	5.5	12.4	18.5	18.5
040191011	1	3119		3119	3119	3119	3119	3119	6.1	0.0	6.1	6.1	6.1	6.1	6.1
040212001	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
051190007	1	20		20	20	20	20	20	6.3	0.0	6.3	6.3	6.3	6.3	6.3
051191002	1	20		20	20	20	20	20	13.7	0.0	13.7	13.7	13.7	13.7	13.7
051390006	6	421	689	8	8	22	1689	1689	7.7	4.2	1.9	1.9	8.8	11.7	11.7
060010010	7	53	66	5	5	14	187	187	8.9	5.4	1.2	1.2	9.0	16.8	16.8
060130002	15	1004	2007	6	6	58	7009	7009	13.5	2.8	9.6	9.6	13.3	17.8	17.8
060130006	9	559	789	5	5	38	1829	1829	13.0	6.4	2.5	2.5	15.0	19.3	19.3
060130010	15	1189	1977	6	6	419	7009	7009	8.3	5.6	1.6	1.6	6.4	19.7	19.7
060131001	13	1507	2036	6	6	793	7009	7009	10.1	5.9	0.2	0.2	9.9	19.8	19.8
060131002	3	26	21	6	6	25	48	48	11.7	1.4	10.1	10.1	12.4	12.7	12.7
060131003	9	559	789	5	5	38	1829	1829	12.6	4.8	5.4	5.4	12.2	19.0	19.0
060131004	9	559	789	5	5	38	1829	1829	12.8	5.7	4.1	4.1	13.5	19.1	19.1
060132001	15	1189	1977	6	6	419	7009	7009	8.8	5.4	2.3	2.3	6.7	19.9	19.9
060133001	16	507	1104	6	6	48	4337	4337	9.8	6.1	0.7	0.7	11.4	18.6	18.6
060250005	1	7		7	7	7	7	7	18.0	0.0	18.0	18.0	18.0	18.0	18.0
060371002	3	17	7	10	10	17	24	24	6.8	2.1	4.7	4.7	6.9	8.8	8.8
060371103	15	37	36	7	7	29	119	119	13.8	5.1	6.3	6.3	12.5	19.8	19.8
060374002	32	183	313	5	5	46	1503	1503	10.4	5.2	4.1	4.1	9.3	19.5	19.5
060375001	31	203	342	5	5	61	1503	1503	13.4	5.9	3.7	3.7	16.4	19.6	19.6

		SO_2 emissions (tpy) from sources within 20 km of monitor[1]							Distance of monitor to SO_2 emission source (km)[1]						
Monitor ID	**n**	**mean**	**std**	**min**	**p2.5**	**p50**	**p97.5**	**p100**	**mean**	**std**	**min**	**p2.5**	**p50**	**p97.5**	**p100**
060375005	12	192	332	6	6	33	1119	1119	9.1	5.9	2.3	2.3	6.0	19.8	19.8
060591003	7	10	5	5	5	7	18	18	13.9	5.7	5.3	5.3	15.6	19.7	19.7
060658001	4	75	76	17	17	50	181	181	16.8	4.7	9.8	9.8	18.8	19.6	19.6
060670002	1	5		5	5	5	5	5	14.8	0.0	14.8	14.8	14.8	14.8	14.8
060670006	1	58		58	58	58	58	58	9.7	0.0	9.7	9.7	9.7	9.7	9.7
060710012	1	8		8	8	8	8	8	11.9	0.0	11.9	11.9	11.9	11.9	11.9
060710014	2	126	132	32	32	126	219	219	8.0	3.0	5.9	5.9	8.0	10.1	10.1
060710306	2	126	132	32	32	126	219	219	8.1	3.3	5.7	5.7	8.1	10.4	10.4
060711234	3	97	85	6	6	110	175	175	4.9	5.8	1.3	1.3	1.9	11.7	11.7
060712002	2	102	112	22	22	102	181	181	13.2	2.9	11.2	11.2	13.2	15.3	15.3
060714001	1	32		32	32	32	32	32	6.5	0.0	6.5	6.5	6.5	6.5	6.5
060730001	1	21		21	21	21	21	21	4.0	0.0	4.0	4.0	4.0	4.0	4.0
060731007	3	11	9	5	5	7	21	21	12.9	1.3	11.8	11.8	12.5	14.4	14.4
060732007	1	21		21	21	21	21	21	16.4	0.0	16.4	16.4	16.4	16.4	16.4
060750005	6	66	83	5	5	39	224	224	13.3	6.2	1.8	1.8	15.2	18.3	18.3
060791005	7	536	1369	6	6	24	3642	3642	1.0	0.2	0.8	0.8	1.0	1.5	1.5
060792001	7	536	1369	6	6	24	3642	3642	10.5	0.2	10.2	10.2	10.4	10.9	10.9
060792004	7	536	1369	6	6	24	3642	3642	2.5	0.1	2.3	2.3	2.6	2.7	2.7
060794002	7	536	1369	6	6	24	3642	3642	18.4	0.1	18.3	18.3	18.5	18.5	18.5
060830008	3	39	43	10	10	18	89	89	9.7	6.2	2.8	2.8	11.3	14.9	14.9
060831012	2	554	357	302	302	554	807	807	16.5	0.1	16.4	16.4	16.5	16.5	16.5
060831013	2	554	357	302	302	554	807	807	14.1	0.1	14.1	14.1	14.1	14.2	14.2
060831015	1	18		18	18	18	18	18	15.6	0.0	15.6	15.6	15.6	15.6	15.6
060831016	1	18		18	18	18	18	18	15.2	0.0	15.2	15.2	15.2	15.2	15.2
060831019	1	18		18	18	18	18	18	13.7	0.0	13.7	13.7	13.7	13.7	13.7
060831020	3	39	43	10	10	18	89	89	7.3	8.2	2.0	2.0	3.2	16.7	16.7
060831025	3	39	43	10	10	18	89	89	10.9	8.9	0.8	0.8	14.2	17.7	17.7
060831026	3	39	43	10	10	18	89	89	9.9	8.0	0.9	0.9	12.6	16.2	16.2
060831027	3	39	43	10	10	18	89	89	10.3	7.7	1.7	1.7	12.8	16.4	16.4
060832004	2	554	357	302	302	554	807	807	4.2	0.1	4.2	4.2	4.2	4.2	4.2
060832011	3	39	43	10	10	18	89	89	10.4	8.4	3.9	3.9	7.5	20.0	20.0
060834003	2	554	357	302	302	554	807	807	16.4	0.1	16.4	16.4	16.4	16.5	16.5
060870003	1	722		722	722	722	722	722	0.8	0.0	0.8	0.8	0.8	0.8	0.8
060950001	13	1371	2071	6	6	790	7009	7009	7.1	3.3	2.1	2.1	7.5	13.8	13.8
060950004	12	1480	2124	6	6	791	7009	7009	13.0	4.9	5.5	5.5	13.6	19.6	19.6
061113001	2	9	3	7	7	9	11	11	10.4	5.1	6.8	6.8	10.4	14.0	14.0

		SO_2 emissions (tpy) from sources within 20 km of monitor[1]							Distance of monitor to SO_2 emission source (km)[1]						
Monitor ID	**n**	**mean**	**std**	**min**	**p2.5**	**p50**	**p97.5**	**p100**	**mean**	**std**	**min**	**p2.5**	**p50**	**p97.5**	**p100**
080010007	24	1001	3352	8	8	25	15958	15958	9.8	6.1	2.4	2.4	8.2	19.7	19.7
080013001	20	1191	3657	8	8	28	15958	15958	8.3	5.8	1.6	1.6	5.9	19.8	19.8
080310002	24	1098	3356	6	6	28	15958	15958	9.2	4.5	3.9	3.9	7.0	19.5	19.5
080416001	3	1670	2857	7	7	34	4969	4969	6.2	8.6	0.8	0.8	1.8	16.1	16.1
080416004	3	2849	4920	7	7	10	8530	8530	13.0	3.9	10.7	10.7	10.9	17.6	17.6
080416011	3	2849	4920	7	7	10	8530	8530	9.9	7.6	2.5	2.5	9.6	17.7	17.7
080416018	2	4268	6026	7	7	4268	8530	8530	6.8	0.5	6.5	6.5	6.8	7.2	7.2
090010012	11	425	1198	5	5	21	4024	4024	6.1	4.9	2.1	2.1	4.8	19.7	19.7
090010017	3	252	423	5	5	11	741	741	9.6	6.4	5.7	5.7	6.2	17.0	17.0
090011123	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
090012124	4	192	366	5	5	10	741	741	7.4	6.0	2.3	2.3	6.5	14.4	14.4
090019003	10	504	1257	5	5	10	4024	4024	13.2	5.1	4.0	4.0	14.0	19.5	19.5
090031005	28	45	106	5	5	12	522	522	14.2	3.6	3.0	3.0	14.2	19.9	19.9
090031018	7	16	9	5	5	15	30	30	7.7	6.3	1.9	1.9	3.7	18.4	18.4
090032006	6	14	7	5	5	15	25	25	4.5	5.1	0.5	0.5	1.8	11.4	11.4
090090027	8	595	1388	5	5	32	4012	4012	6.3	7.3	1.0	1.0	3.1	18.6	18.6
090091003	9	565	1302	5	5	43	4012	4012	7.4	8.2	0.7	0.7	2.6	19.7	19.7
090091123	9	565	1302	5	5	43	4012	4012	7.3	8.2	0.8	0.8	2.7	19.7	19.7
090092123	5	86	96	9	9	28	198	198	9.0	5.7	0.8	0.8	8.9	15.2	15.2
090110007	6	650	1088	7	7	110	2755	2755	8.4	3.0	3.3	3.3	8.7	12.7	12.7
090130003	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
100031003	34	975	1619	5	5	112	6720	6720	9.0	5.2	1.5	1.5	8.1	19.8	19.8
100031007	11	3126	6528	15	15	103	19923	19923	10.5	2.2	9.1	9.1	9.8	16.2	16.2
100031008	24	1657	4554	5	5	60	19923	19923	10.9	6.9	2.2	2.2	13.9	19.7	19.7
100031013	34	975	1619	5	5	112	6720	6720	9.1	4.8	2.8	2.8	8.3	18.9	18.9
100032002	36	802	1272	5	5	97	5051	5051	10.2	6.2	1.1	1.1	9.4	19.7	19.7
100032004	39	1526	3681	5	5	116	19923	19923	10.9	6.2	1.3	1.3	11.1	19.8	19.8
110010041	13	1410	4437	7	7	24	16141	16141	11.7	6.5	0.6	0.6	11.5	19.8	19.8
120110010	8	2397	6653	17	17	41	18861	18861	11.0	6.1	5.1	5.1	7.5	19.2	19.2
120310032	14	2715	5784	5	5	287	20908	20908	9.0	4.2	1.3	1.3	9.1	18.5	18.5
120310080	15	2534	5617	5	5	257	20908	20908	12.0	4.7	1.1	1.1	13.3	19.7	19.7
120310081	13	2923	5965	5	5	317	20908	20908	7.9	4.6	1.3	1.3	6.5	15.5	15.5
120310097	14	2715	5784	5	5	287	20908	20908	9.2	4.7	3.1	3.1	7.7	19.5	19.5
120330004	6	7262	14101	6	6	330	35417	35417	9.3	4.2	4.9	4.9	8.9	14.6	14.6
120330022	6	7262	14101	6	6	330	35417	35417	7.6	4.4	2.4	2.4	8.4	12.3	12.3
120470015	3	755	1268	18	18	27	2218	2218	3.0	0.5	2.6	2.6	2.7	3.6	3.6

Monitor ID	n	SO_2 emissions (tpy) from sources within 20 km of monitor[1]							Distance of monitor to SO_2 emission source (km)[1]						
		mean	std	min	p2.5	p50	p97.5	p100	mean	std	min	p2.5	p50	p97.5	p100
120570021	18	4986	11445	6	6	341	47103	47103	11.6	6.5	1.4	1.4	14.3	18.2	18.2
120570053	19	4728	11180	6	6	104	47103	47103	10.8	3.5	5.9	5.9	12.1	17.3	17.3
120570081	18	6781	13097	6	6	1116	47103	47103	14.4	4.5	8.1	8.1	15.1	19.6	19.6
120570095	17	3845	11285	6	6	61	47103	47103	10.1	6.2	2.5	2.5	14.2	19.3	19.3
120570109	16	4084	11610	6	6	83	47103	47103	9.9	4.0	6.7	6.7	7.4	19.9	19.9
120571035	18	4986	11445	6	6	341	47103	47103	10.6	5.8	1.6	1.6	12.9	16.3	16.3
120574004	3	2872	4949	11	11	19	8587	8587	14.2	8.5	4.4	4.4	18.9	19.3	19.3
120813002	5	73	93	6	6	9	208	208	7.2	8.3	0.7	0.7	2.2	16.5	16.5
120860019	7	34	45	5	5	12	130	130	9.6	5.8	2.6	2.6	6.9	19.1	19.1
120890005	4	1262	1594	11	11	765	3509	3509	4.5	5.0	1.1	1.1	2.5	12.0	12.0
120890009	4	1262	1594	11	11	765	3509	3509	4.2	4.6	1.1	1.1	2.4	11.0	11.0
120952002	5	9	4	5	5	10	14	14	13.8	2.8	10.1	10.1	13.6	17.6	17.6
120993004	6	39	38	5	5	32	103	103	12.0	3.1	7.0	7.0	12.0	16.7	16.7
121030023	7	3546	7041	6	6	104	18822	18822	7.4	6.4	2.3	2.3	3.7	19.6	19.6
121033002	6	4136	7521	23	23	156	18822	18822	10.3	4.2	3.5	3.5	10.0	15.4	15.4
121035002	2	15398	21767	7	7	15398	30790	30790	13.6	0.1	13.5	13.5	13.6	13.7	13.7
121035003	2	15398	21767	7	7	15398	30790	30790	9.8	4.0	7.0	7.0	9.8	12.6	12.6
121050010	9	2386	2929	6	6	1210	8587	8587	10.4	3.1	3.7	3.7	10.8	14.4	14.4
121052006	13	1691	2627	6	6	230	8587	8587	11.9	6.2	2.7	2.7	13.7	19.9	19.9
121071008	3	9965	12565	12	12	5799	24083	24083	5.8	3.4	2.6	2.6	5.6	9.3	9.3
121151002	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
121151005	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
121151006	2	71	90	7	7	71	135	135	15.8	0.8	15.2	15.2	15.8	16.4	16.4
130090001	2	36975	52282	6	6	36975	73943	73943	11.3	5.4	7.5	7.5	11.3	15.1	15.1
130150002	4	40604	80047	21	21	862	160673	160673	10.4	5.2	2.5	2.5	13.0	13.0	13.0
130210012	11	245	468	6	6	17	1576	1576	10.1	5.2	1.5	1.5	8.8	19.9	19.9
130510019	14	1362	2664	8	8	235	7969	7969	7.1	4.1	0.4	0.4	6.6	12.0	12.0
130510021	14	1362	2664	8	8	235	7969	7969	6.8	4.4	1.4	1.4	7.2	14.0	14.0
130511002	14	1362	2664	8	8	235	7969	7969	6.2	3.4	1.6	1.6	6.6	10.0	10.0
130950006	4	1693	2220	5	5	932	4905	4905	6.3	5.3	2.2	2.2	4.4	14.1	14.1
131110091	1	1900		1900	1900	1900	1900	1900	1.6	0.0	1.6	1.6	1.6	1.6	1.6
131150003	8	4057	9625	5	5	101	27594	27594	1.4	0.4	1.1	1.1	1.2	2.3	2.3
131210048	7	4339	10445	68	68	169	27993	27993	10.3	2.1	8.4	8.4	9.2	14.0	14.0
131210055	7	4339	10445	68	68	169	27993	27993	15.1	3.3	8.0	8.0	15.6	18.1	18.1
131270006	3	821	948	14	14	586	1865	1865	3.6	2.8	1.8	1.8	2.2	6.8	6.8
132150008	4	1740	3214	8	8	197	6559	6559	12.5	2.6	10.1	10.1	12.4	15.1	15.1

		SO_2 emissions (tpy) from sources within 20 km of monitor[1]							Distance of monitor to SO_2 emission source (km)[1]						
Monitor ID	**n**	**mean**	**std**	**min**	**p2.5**	**p50**	**p97.5**	**p100**	**mean**	**std**	**min**	**p2.5**	**p50**	**p97.5**	**p100**
132450003	15	1335	2379	8	8	545	8275	8275	8.0	1.4	4.7	4.7	8.2	10.0	10.0
150030010	7	2231	2339	79	79	1566	6978	6978	5.0	4.6	2.5	2.5	3.3	15.3	15.3
150030011	7	2231	2339	79	79	1566	6978	6978	5.7	5.3	2.2	2.2	4.1	17.5	17.5
150031001	3	1043	1509	6	6	350	2774	2774	10.1	8.2	0.7	0.7	13.8	15.7	15.7
150031006	7	2231	2339	79	79	1566	6978	6978	6.1	4.8	1.8	1.8	5.0	16.5	16.5
160050004	2	804	606	376	376	804	1233	1233	1.3	0.1	1.2	1.2	1.3	1.4	1.4
160290003	13	967	2904	7	7	33	10544	10544	2.9	0.4	2.7	2.7	2.8	4.3	4.3
160290031	13	967	2904	7	7	33	10544	10544	1.4	1.1	0.8	0.8	1.2	4.9	4.9
160770011	2	804	606	376	376	804	1233	1233	0.8	0.1	0.7	0.7	0.8	0.8	0.8
170010006	4	965	614	392	392	817	1834	1834	4.8	4.5	1.9	1.9	2.9	11.5	11.5
170190004	3	121	182	10	10	21	331	331	1.8	0.9	0.8	0.8	2.3	2.4	2.4
170310050	47	900	1775	5	5	65	5951	8443	11.0	5.0	2.1	3.4	10.2	19.7	19.8
170310059	40	910	1928	5	5	65	7381	8443	7.5	5.2	1.5	1.5	5.8	19.3	19.5
170310063	23	1041	1800	5	5	17	6229	6229	11.0	6.8	0.9	0.9	9.3	19.7	19.7
170310064	50	1015	1902	5	5	51	6229	8443	14.6	4.1	3.9	6.4	16.4	19.9	19.9
170310076	36	930	1976	5	5	26	8443	8443	13.2	4.0	4.9	4.9	13.3	19.7	19.7
170311018	26	924	1721	5	5	16	6229	6229	10.7	6.8	0.5	0.5	11.6	19.8	19.8
170311601	12	3807	5540	7	7	1090	15934	15934	14.1	6.4	4.0	4.0	18.5	19.3	19.3
170312001	43	920	1807	5	5	64	6229	8443	16.5	3.2	3.4	8.4	17.7	19.3	19.9
170314002	25	982	1738	5	5	17	6229	6229	9.0	3.1	3.9	3.9	9.5	18.5	18.5
170314201	4	165	230	7	7	77	498	498	18.0	3.0	13.4	13.4	19.4	19.7	19.7
170318003	36	835	1797	5	5	70	8443	8443	8.8	2.4	2.9	2.9	8.4	14.7	14.7
170436001	12	2986	5690	6	6	17	15934	15934	16.5	5.1	1.5	1.5	18.1	19.8	19.8
170990007	4	890	1527	6	6	189	3178	3178	7.2	6.1	0.5	0.5	6.7	14.8	14.8
171150013	11	1251	2596	22	22	164	8032	8032	3.3	2.3	1.8	1.8	3.2	9.9	9.9
171170002	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
171190008	15	4510	11972	6	6	111	45960	45960	10.1	3.7	3.2	3.2	9.5	19.7	19.7
171190017	40	877	2339	6	6	117	9663	12063	9.5	6.6	0.5	0.7	11.2	19.0	19.6
171191010	28	954	2564	6	6	183	12063	12063	10.5	6.8	0.7	0.7	15.6	18.4	18.4
171193007	28	2595	8875	6	6	214	45960	45960	12.2	6.9	2.4	2.4	16.1	18.9	18.9
171193009	26	2789	9193	6	6	247	45960	45960	12.4	7.5	2.9	2.9	14.7	19.8	19.8
171430024	10	7333	11752	5	5	67	35748	35748	13.2	5.8	1.3	1.3	15.5	18.8	18.8
171570001	2	13148	18554	28	28	13148	26268	26268	6.4	0.4	6.0	6.0	6.4	6.7	6.7
171610003	10	945	1612	7	7	169	4963	4963	11.4	5.6	2.3	2.3	12.3	17.2	17.2
171630010	30	445	1152	6	6	68	6250	6250	9.3	4.1	1.3	1.3	9.6	18.5	18.5
171631010	30	445	1152	6	6	68	6250	6250	10.4	4.3	1.1	1.1	11.7	19.4	19.4

		SO_2 emissions (tpy) from sources within 20 km of monitor[1]							Distance of monitor to SO_2 emission source (km)[1]						
Monitor ID	**n**	**mean**	**std**	**min**	**p2.5**	**p50**	**p97.5**	**p100**	**mean**	**std**	**min**	**p2.5**	**p50**	**p97.5**	**p100**
171631011	2	13148	18554	28	28	13148	26268	26268	4.0	0.6	3.6	3.6	4.0	4.4	4.4
171670006	5	2170	3169	9	9	202	7210	7210	7.3	3.6	4.9	4.9	5.6	13.5	13.5
171790004	6	12212	13311	22	22	10290	35748	35748	5.4	5.2	0.8	0.8	3.6	13.8	13.8
171850001	3	42452	25439	27097	27097	28443	71817	71817	2.9	0.1	2.8	2.8	2.9	3.1	3.1
171851001	3	42452	25439	27097	27097	28443	71817	71817	5.9	0.1	5.8	5.8	5.8	6.0	6.0
171970013	19	2439	6269	6	6	37	25224	25224	6.6	4.8	1.1	1.1	5.2	18.6	18.6
180270002	6	10869	16456	9	9	2241	41536	41536	6.3	0.6	5.8	5.8	6.0	7.3	7.3
180290004	7	21579	32930	174	174	1574	85699	85699	4.2	4.1	1.2	1.2	3.4	12.8	12.8
180430004	8	6500	10778	12	12	484	23995	23995	13.4	3.1	8.8	8.8	12.3	17.7	17.7
180430007	10	6721	10131	12	12	516	23995	23995	9.2	6.4	1.1	1.1	7.3	19.9	19.9
180431004	9	7442	10470	12	12	798	23995	23995	10.0	3.5	5.0	5.0	9.8	14.7	14.7
180450001	3	18552	32099	10	10	28	55617	55617	9.8	8.7	4.5	4.5	5.1	19.8	19.8
180510001	3	42452	25439	27097	27097	28443	71817	71817	2.0	0.1	1.8	1.8	2.0	2.1	2.1
180510002	3	42452	25439	27097	27097	28443	71817	71817	2.9	0.0	2.9	2.9	2.9	3.0	3.0
180630001	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
180630002	1	147		147	147	147	147	147	19.2	0.0	19.2	19.2	19.2	19.2	19.2
180630003	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
180730002	4	6874	1422	6085	6085	6204	9002	9002	4.3	1.0	3.5	3.5	4.0	5.8	5.8
180730003	4	6874	1422	6085	6085	6204	9002	9002	10.2	1.2	9.5	9.5	9.7	12.1	12.1
180770004	2	19099	1297	18182	18182	19099	20016	20016	4.3	0.1	4.3	4.3	4.3	4.4	4.4
180890022	50	1014	1502	5	6	188	5951	6318	14.1	4.0	0.8	1.8	14.6	19.8	19.9
180892008	39	938	1945	5	5	72	8443	8443	6.4	4.1	1.6	1.6	5.6	17.6	17.6
180910005	3	4166	4640	20	20	3301	9178	9178	9.1	9.7	0.4	0.4	7.3	19.6	19.6
180910007	2	4599	6476	20	20	4599	9178	9178	6.0	0.8	5.4	5.4	6.0	6.5	6.5
180970042	22	2358	6820	5	5	36	30896	30896	11.2	2.9	7.8	7.8	11.0	17.0	17.0
180970054	20	2554	7138	5	5	23	30896	30896	3.3	2.3	0.9	0.9	2.4	9.2	9.2
180970057	20	2554	7138	5	5	23	30896	30896	4.2	2.0	0.9	0.9	4.3	9.8	9.8
180970072	21	2433	6980	5	5	19	30896	30896	6.9	3.5	0.8	0.8	6.6	18.7	18.7
180970073	20	2547	7141	5	5	18	30896	30896	13.7	2.3	6.2	6.2	14.5	15.3	15.3
181091001	3	6006	9709	242	242	561	17216	17216	4.3	2.4	2.1	2.1	4.0	6.9	6.9
181230006	8	7033	17145	7	7	38	49028	49028	7.7	4.3	2.8	2.8	7.0	14.3	14.3
181230007	8	7033	17145	7	7	38	49028	49028	6.8	4.2	2.1	2.1	5.7	13.1	13.1
181250005	6	10869	16456	9	9	2241	41536	41536	3.0	4.7	0.9	0.9	1.1	12.7	12.7
181270011	23	1703	2266	20	20	1062	9178	9178	6.7	6.2	2.2	2.2	3.6	18.7	18.7
181270017	22	1363	1612	20	20	1029	6318	6318	5.4	5.7	2.0	2.0	2.6	17.8	17.8
181270023	21	1427	1623	23	23	1062	6318	6318	4.1	4.4	1.1	1.1	2.4	14.6	14.6

Monitor ID	n	SO_2 emissions (tpy) from sources within 20 km of monitor[1]							Distance of monitor to SO_2 emission source (km)[1]						
		mean	std	min	p2.5	p50	p97.5	p100	mean	std	min	p2.5	p50	p97.5	p100
181470002	7	15627	24405	7	7	66	53196	53196	13.0	3.6	8.0	8.0	15.0	16.6	16.6
181470010	4	15099	25616	20	20	3589	53196	53196	12.3	6.6	3.3	3.3	14.0	17.9	17.9
181530004	3	9270	8089	10	10	12846	14955	14955	12.1	6.4	4.8	4.8	14.7	16.8	16.8
181630012	5	1806	2589	5	5	382	6004	6004	13.1	7.7	3.1	3.1	18.0	19.6	19.6
181631002	5	1806	2589	5	5	382	6004	6004	8.5	5.3	3.4	3.4	9.5	16.5	16.5
181670018	6	10842	25028	12	12	417	61901	61901	6.8	3.6	5.0	5.0	5.5	14.1	14.1
181671014	6	10842	25028	12	12	417	61901	61901	6.8	5.9	1.9	1.9	5.5	17.3	17.3
181730002	8	13636	16457	50	50	3559	41049	41049	2.9	0.4	2.5	2.5	3.0	3.3	3.3
181731001	8	13636	16457	50	50	3559	41049	41049	3.0	0.5	2.5	2.5	2.9	3.7	3.7
181770006	2	6446	9089	19	19	6446	12873	12873	2.1	1.4	1.1	1.1	2.1	3.1	3.1
181770007	2	6446	9089	19	19	6446	12873	12873	3.2	2.5	1.4	1.4	3.2	5.0	5.0
190330018	4	2684	3305	20	20	1934	6850	6850	3.9	3.7	0.4	0.4	3.2	8.8	8.8
190450018	2	4694	839	4101	4101	4694	5287	5287	1.4	0.9	0.7	0.7	1.4	2.0	2.0
190450019	2	4694	839	4101	4101	4694	5287	5287	1.3	1.0	0.6	0.6	1.3	2.0	2.0
190450020	2	4694	839	4101	4101	4694	5287	5287	3.4	0.6	3.0	3.0	3.4	3.8	3.8
191110006	1	29		29	29	29	29	29	3.7	0.0	3.7	3.7	3.7	3.7	3.7
191111007	2	104	105	29	29	104	179	179	13.3	6.3	8.8	8.8	13.3	17.7	17.7
191130028	7	2200	2428	12	12	1954	5480	5480	5.8	2.4	2.8	2.8	6.7	8.8	8.8
191130029	7	2200	2428	12	12	1954	5480	5480	3.8	3.1	0.5	0.5	4.0	9.2	9.2
191130031	7	2200	2428	12	12	1954	5480	5480	4.3	3.2	0.5	0.5	4.7	9.3	9.3
191130032	7	2200	2428	12	12	1954	5480	5480	3.5	2.7	0.6	0.6	3.1	8.8	8.8
191130034	7	2200	2428	12	12	1954	5480	5480	3.6	2.5	0.2	0.2	2.9	7.4	7.4
191130038	7	2200	2428	12	12	1954	5480	5480	3.9	1.9	0.6	0.6	4.2	6.2	6.2
191130039	7	2200	2428	12	12	1954	5480	5480	4.6	3.0	1.1	1.1	4.2	10.3	10.3
191390016	5	6227	6934	83	83	3790	15901	15901	8.7	6.9	2.4	2.4	7.4	19.2	19.2
191390017	4	7763	6956	463	463	7345	15901	15901	3.8	3.6	0.6	0.6	3.1	8.5	8.5
191390020	4	7763	6956	463	463	7345	15901	15901	4.9	4.4	0.9	0.9	4.0	10.4	10.4
191630015	7	1345	1810	17	17	336	4963	4963	9.5	5.0	1.1	1.1	11.7	15.1	15.1
191630017	7	2120	3515	17	17	303	8983	8983	9.6	4.2	1.1	1.1	11.2	13.6	13.6
191770004	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
191770005	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
191770006	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
191930018	4	9208	10818	15	15	7845	21127	21127	6.4	4.3	0.7	0.7	7.1	10.7	10.7
201070002	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
201250006	4	468	464	11	11	428	1006	1006	5.8	9.3	0.5	0.5	1.6	19.7	19.7
201450001	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0

		SO_2 emissions (tpy) from sources within 20 km of monitor[1]							Distance of monitor to SO_2 emission source (km)[1]						
Monitor ID	n	mean	std	min	p2.5	p50	p97.5	p100	mean	std	min	p2.5	p50	p97.5	p100
201730010	3	269	448	6	6	15	785	785	11.4	3.1	9.0	9.0	10.2	14.9	14.9
201910002	3	269	448	6	6	15	785	785	16.3	2.4	13.6	13.6	17.3	18.0	18.0
201950001	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
202090001	14	1388	2341	6	6	34	7625	7625	9.2	5.9	3.5	3.5	7.1	19.8	19.8
202090020	14	1388	2341	6	6	34	7625	7625	9.0	6.1	0.6	0.6	7.7	18.9	18.9
202090021	13	1494	2402	6	6	40	7625	7625	8.6	5.5	3.4	3.4	6.6	19.1	19.1
210190015	9	1323	2058	25	25	401	6285	6285	12.3	5.5	1.6	1.6	14.6	17.7	17.7
210190017	10	1193	1983	25	25	343	6285	6285	12.8	5.4	2.9	2.9	13.8	19.5	19.5
210191003	8	1271	2194	25	25	343	6285	6285	9.3	5.4	1.3	1.3	9.9	15.4	15.4
210370003	11	6817	20950	12	12	268	69953	69953	12.0	3.0	8.1	8.1	10.8	17.8	17.8
210371001	11	465	664	12	12	213	1848	1848	8.5	3.4	4.2	4.2	7.5	15.5	15.5
210590005	4	15241	25506	26	26	3871	53196	53196	7.4	6.8	2.2	2.2	5.5	16.5	16.5
210670012	3	209	316	12	12	42	573	573	3.2	2.2	1.2	1.2	2.7	5.6	5.6
210890007	5	961	1147	25	25	401	2589	2589	10.9	6.2	5.1	5.1	7.6	19.8	19.8
210910012	9	12162	22226	7	7	38	53196	53196	10.4	5.1	1.2	1.2	10.6	18.9	18.9
211010013	4	2256	2755	5	5	1508	6004	6004	10.2	5.5	2.0	2.0	12.7	13.3	13.3
211010014	10	10948	15581	5	5	2980	41049	41049	12.9	1.4	11.5	11.5	12.8	16.6	16.6
211110032	14	6208	8948	38	38	516	23995	23995	11.4	5.6	2.4	2.4	13.7	18.3	18.3
211110051	12	3259	5326	38	38	168	14977	14977	10.6	7.5	1.6	1.6	14.6	18.7	18.7
211111041	11	6268	9779	12	12	234	23995	23995	9.1	7.3	1.3	1.3	7.7	19.3	19.3
211390004	4	444	869	6	6	11	1747	1747	8.0	6.9	3.1	3.1	5.4	17.9	17.9
211450001	7	8769	13010	174	174	7435	37077	37077	7.5	3.4	2.0	2.0	9.4	11.2	11.2
211451024	3	587	1005	6	6	7	1747	1747	18.2	2.1	15.8	15.8	19.3	19.5	19.5
211451026	3	587	1005	6	6	7	1747	1747	15.3	2.2	12.7	12.7	16.5	16.7	16.7
212270008	1	52		52	52	52	52	52	19.1	0.0	19.1	19.1	19.1	19.1	19.1
220150008	2	77	21	62	62	77	91	91	8.7	0.1	8.6	8.6	8.7	8.8	8.8
220190008	16	3352	5531	6	6	184	18851	18851	7.6	6.1	1.2	1.2	5.8	16.7	16.7
220330009	28	1406	3913	6	6	45	18680	18680	5.8	5.6	1.5	1.5	3.2	20.0	20.0
220730004	1	2166		2166	2166	2166	2166	2166	10.1	0.0	10.1	10.1	10.1	10.1	10.1
220870002	18	419	846	8	8	52	3009	3009	8.8	4.2	0.5	0.5	7.8	19.0	19.0
221210001	28	1116	3650	6	6	33	18680	18680	5.4	4.7	2.4	2.4	3.4	18.1	18.1
230010011	9	31	41	5	5	23	140	140	6.6	4.3	1.3	1.3	6.5	13.3	13.3
230030009	1	90		90	90	90	90	90	1.9	0.0	1.9	1.9	1.9	1.9	1.9
230030012	1	90		90	90	90	90	90	1.0	0.0	1.0	1.0	1.0	1.0	1.0
230031003	1	90		90	90	90	90	90	1.3	0.0	1.3	1.3	1.3	1.3	1.3
230031013	3	16	17	5	5	7	36	36	4.7	4.5	1.4	1.4	2.8	9.9	9.9

		SO_2 emissions (tpy) from sources within 20 km of monitor[1]							Distance of monitor to SO_2 emission source (km)[1]						
Monitor ID	**n**	**mean**	**std**	**min**	**p2.5**	**p50**	**p97.5**	**p100**	**mean**	**std**	**min**	**p2.5**	**p50**	**p97.5**	**p100**
230031018	4	193	233	7	7	133	499	499	8.5	5.6	0.3	0.3	10.3	13.0	13.0
230050014	12	267	628	5	5	16	2091	2091	6.1	4.8	1.2	1.2	5.0	16.8	16.8
230050027	12	267	628	5	5	16	2091	2091	6.0	4.7	0.8	0.8	4.8	16.6	16.6
230172007	2	249	344	6	6	249	492	492	1.0	0.1	1.0	1.0	1.0	1.1	1.1
240010006	2	681	685	197	197	681	1166	1166	8.9	4.0	6.0	6.0	8.9	11.7	11.7
240032002	20	3247	9622	5	5	21	39974	39974	11.9	4.5	2.7	2.7	13.3	19.9	19.9
240053001	22	4429	11101	5	5	27	39974	39974	11.9	3.3	4.6	4.6	12.1	19.2	19.2
245100018	21	3101	9402	5	5	22	39974	39974	9.1	4.6	1.4	1.4	7.6	16.7	16.7
245100036	21	4635	11331	5	5	22	39974	39974	6.6	3.3	1.6	1.6	6.8	16.0	16.0
250051004	24	1867	8085	6	6	31	39593	39593	7.5	6.7	0.1	0.1	3.8	18.9	18.9
250090005	25	65	148	6	6	26	762	762	9.6	6.6	0.3	0.3	9.2	19.9	19.9
250091004	23	878	3071	5	5	16	14132	14132	11.3	6.3	0.8	0.8	12.8	20.0	20.0
250091005	22	917	3137	5	5	16	14132	14132	11.2	6.3	0.7	0.7	11.9	18.6	18.6
250095004	14	88	197	8	8	25	762	762	8.6	4.2	0.7	0.7	10.1	14.7	14.7
250130016	34	216	907	5	5	14	5282	5282	7.6	5.2	0.5	0.5	7.4	19.2	19.2
250131009	32	65	148	5	5	13	671	671	8.4	4.7	1.7	1.7	7.4	18.9	18.9
250154002	12	72	113	6	6	29	363	363	15.8	3.4	9.1	9.1	16.8	19.7	19.7
250171701	55	139	678	5	5	15	640	5007	13.3	4.6	0.4	2.9	15.0	19.4	20.0
250174003	57	127	663	5	5	13	460	5007	12.2	4.0	0.6	5.6	12.4	19.5	19.7
250250002	62	129	639	5	5	14	640	5007	9.6	6.1	0.7	1.1	8.6	19.5	19.7
250250019	50	156	710	5	5	14	640	5007	12.0	3.8	0.7	4.2	12.0	18.1	18.4
250250020	58	138	660	5	5	15	640	5007	10.0	5.0	1.1	3.0	9.1	19.2	19.2
250250021	58	137	660	5	5	14	640	5007	10.6	4.7	1.8	3.4	9.3	19.5	20.0
250250040	59	135	654	5	5	14	640	5007	10.2	5.3	1.0	1.4	9.5	19.5	19.8
250250042	60	133	649	5	5	14	640	5007	9.4	5.8	0.5	0.7	9.1	19.1	19.3
250251003	58	380	1952	5	5	15	5007	14132	11.0	4.6	1.0	2.1	10.4	19.3	19.4
250270020	28	25	35	6	6	12	178	178	5.0	5.9	0.1	0.1	2.8	19.5	19.5
250270023	28	25	35	6	6	12	178	178	5.1	5.8	0.6	0.6	2.9	19.1	19.1
260410902	3	1407	1264	671	671	685	2867	2867	2.5	1.5	0.8	0.8	3.3	3.4	3.4
260490021	4	42	24	7	7	48	63	63	10.9	4.5	4.2	4.2	13.1	13.1	13.1
260492001	2	64	79	7	7	64	120	120	19.0	0.4	18.8	18.8	19.0	19.3	19.3
260810020	9	60	96	9	9	12	280	280	10.5	5.6	4.3	4.3	10.6	19.4	19.4
260991003	3	239	287	10	10	148	560	560	14.0	3.4	10.2	10.2	15.2	16.7	16.7
261130001	1	58		58	58	58	58	58	10.3	0.0	10.3	10.3	10.3	10.3	10.3
261470005	3	524	431	31	31	715	826	826	8.7	5.9	3.8	3.8	6.9	15.2	15.2
261530001	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0

Monitor ID	n	SO_2 emissions (tpy) from sources within 20 km of monitor[1]							Distance of monitor to SO_2 emission source (km)[1]						
		mean	std	min	p2.5	p50	p97.5	p100	mean	std	min	p2.5	p50	p97.5	p100
261630001	36	1780	5390	5	5	109	30171	30171	10.9	4.0	5.4	5.4	9.6	20.0	20.0
261630005	34	1894	5529	5	5	117	30171	30171	6.1	5.4	1.2	1.2	4.4	19.0	19.0
261630015	32	1070	2436	5	5	117	8913	8913	5.5	4.2	1.5	1.5	3.8	17.9	17.9
261630016	31	1104	2469	5	5	121	8913	8913	9.0	2.7	3.6	3.6	8.6	17.0	17.0
261630019	23	1358	2828	10	10	121	8913	8913	17.3	4.5	3.7	3.7	18.9	19.8	19.8
261630025	6	13	14	5	5	9	42	42	14.8	2.4	11.2	11.2	15.2	17.8	17.8
261630027	33	1952	5605	5	5	121	30171	30171	5.5	5.2	0.4	0.4	3.9	19.7	19.7
261630033	32	1070	2436	5	5	117	8913	8913	5.0	4.5	0.4	0.4	4.2	15.8	15.8
261630062	31	1104	2469	5	5	121	8913	8913	9.0	2.9	3.1	3.1	8.5	17.2	17.2
261630092	33	1952	5605	5	5	121	30171	30171	5.4	5.1	0.9	0.9	3.0	19.9	19.9
270031002	10	1332	4067	5	5	11	12904	12904	14.3	4.4	4.7	4.7	15.5	18.9	18.9
270176316	5	72	84	5	5	26	190	190	13.7	6.8	2.2	2.2	16.4	19.7	19.7
270370020	15	610	1015	9	9	104	3071	3071	11.9	6.1	0.9	0.9	12.4	19.6	19.6
270370423	17	805	1227	9	9	205	3821	3821	11.6	5.5	0.4	0.4	12.4	18.8	18.8
270370439	14	639	1047	9	9	79	3071	3071	12.5	5.8	2.6	2.6	13.1	20.0	20.0
270370441	12	720	1114	9	9	79	3071	3071	11.6	5.7	1.6	1.6	12.6	19.0	19.0
270370442	11	506	873	9	9	54	2869	2869	12.2	5.5	2.3	2.3	13.8	18.8	18.8
270530954	24	913	2729	5	5	48	12904	12904	10.9	5.8	0.6	0.6	12.2	19.0	19.0
270530957	21	878	2877	5	5	12	12904	12904	10.7	5.3	0.9	0.9	10.9	18.3	18.3
270711240	1	67		67	67	67	67	67	0.3	0.0	0.3	0.3	0.3	0.3	0.3
271230864	27	769	2540	5	5	46	12904	12904	12.0	4.8	3.9	3.9	12.6	19.7	19.7
271410003	1	26742		26742	26742	26742	26742	26742	4.9	0.0	4.9	4.9	4.9	4.9	4.9
271410011	1	26742		26742	26742	26742	26742	26742	1.7	0.0	1.7	1.7	1.7	1.7	1.7
271410012	1	26742		26742	26742	26742	26742	26742	1.8	0.0	1.8	1.8	1.8	1.8	1.8
271410013	1	26742		26742	26742	26742	26742	26742	1.1	0.0	1.1	1.1	1.1	1.1	1.1
271630436	21	545	997	7	7	104	3821	3821	11.1	5.6	0.9	0.9	11.4	18.4	18.4
271710007	2	13397	18873	52	52	13397	26742	26742	11.8	6.5	7.2	7.2	11.8	16.3	16.3
280470007	2	12535	17718	6	6	12535	25064	25064	6.5	7.9	0.9	0.9	6.5	12.1	12.1
280490018	5	51	45	15	15	30	128	128	7.3	5.4	3.2	3.2	6.0	16.6	16.6
280590006	7	4903	10049	12	12	96	27207	27207	7.0	4.9	3.3	3.3	5.4	17.3	17.3
280810004	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
290210009	1	3563		3563	3563	3563	3563	3563	0.7	0.0	0.7	0.7	0.7	0.7	0.7
290210011	1	3563		3563	3563	3563	3563	3563	0.9	0.0	0.9	0.9	0.9	0.9	0.9
290470025	15	1682	2364	6	6	105	7625	7625	11.9	4.8	2.8	2.8	10.8	18.2	18.2
290770026	4	2302	2728	5	5	1772	5657	5657	8.2	4.5	2.3	2.3	9.3	11.8	11.8
290770032	4	2302	2728	5	5	1772	5657	5657	7.8	3.9	3.0	3.0	8.5	11.0	11.0

		SO_2 emissions (tpy) from sources within 20 km of monitor[1]							Distance of monitor to SO_2 emission source (km)[1]						
Monitor ID	**n**	**mean**	**std**	**min**	**p2.5**	**p50**	**p97.5**	**p100**	**mean**	**std**	**min**	**p2.5**	**p50**	**p97.5**	**p100**
290770037	4	2302	2728	5	5	1772	5657	5657	9.2	6.1	0.6	0.6	11.0	14.0	14.0
290770040	4	2302	2728	5	5	1772	5657	5657	9.2	6.2	0.5	0.5	11.0	14.1	14.1
290770041	4	2302	2728	5	5	1772	5657	5657	8.6	5.5	1.2	1.2	9.7	13.8	13.8
290930030	1	43340		43340	43340	43340	43340	43340	1.7	0.0	1.7	1.7	1.7	1.7	1.7
290930031	1	43340		43340	43340	43340	43340	43340	4.6	0.0	4.6	4.6	4.6	4.6	4.6
290950034	14	1388	2341	6	6	34	7625	7625	8.7	4.9	1.4	1.4	8.1	15.4	15.4
290990004	5	11145	10277	243	243	15223	23258	23258	9.7	7.4	0.2	0.2	11.4	17.1	17.1
290990014	5	11145	10277	243	243	15223	23258	23258	9.8	7.4	0.7	0.7	11.9	17.5	17.5
290990017	5	11145	10277	243	243	15223	23258	23258	10.2	7.1	1.6	1.6	10.6	17.3	17.3
290990018	4	8117	8927	243	243	7889	16447	16447	8.3	6.6	1.4	1.4	8.2	15.3	15.3
291370001	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
291630002	2	6747	934	6087	6087	6747	7408	7408	7.3	6.6	2.7	2.7	7.3	12.0	12.0
291650023	4	2757	3602	19	19	1693	7625	7625	17.8	1.3	16.0	16.0	18.1	19.1	19.1
291830010	1	47610		47610	47610	47610	47610	47610	1.7	0.0	1.7	1.7	1.7	1.7	1.7
291831002	15	4516	11970	6	6	136	45960	45960	12.6	3.4	4.3	4.3	13.5	17.3	17.3
291890001	14	1748	4547	8	8	35	16447	16447	14.8	4.4	6.4	6.4	15.9	19.7	19.7
291890004	9	2535	5610	8	8	13	16447	16447	14.0	3.1	9.8	9.8	15.2	18.2	18.2
291890006	7	27	48	6	6	8	136	136	14.7	4.6	8.4	8.4	15.7	19.9	19.9
291890014	8	33	47	6	6	10	136	136	11.9	6.2	3.2	3.2	11.3	19.7	19.7
291893001	29	370	1164	6	6	60	6250	6250	15.2	4.2	5.1	5.1	16.0	20.0	20.0
291895001	35	1911	7823	6	6	111	45960	45960	15.1	3.1	6.7	6.7	15.9	20.0	20.0
291897002	14	50	75	6	6	16	277	277	13.2	5.7	3.9	3.9	14.6	20.0	20.0
291897003	18	403	1461	6	6	37	6250	6250	14.1	5.4	3.5	3.5	16.2	19.4	19.4
295100007	19	1312	3936	8	8	50	16447	16447	12.5	6.0	0.5	0.5	14.0	19.6	19.6
295100072	30	445	1152	6	6	68	6250	6250	8.8	3.8	2.0	2.0	9.7	19.2	19.2
295100080	34	397	1088	6	6	61	6250	6250	10.7	4.3	0.4	0.4	10.5	19.7	19.7
295100086	32	421	1118	6	6	68	6250	6250	9.8	3.9	1.7	1.7	10.0	18.6	18.6
300132000	2	351	481	11	11	351	691	691	4.1	3.6	1.5	1.5	4.1	6.7	6.7
300132001	2	351	481	11	11	351	691	691	4.1	4.9	0.7	0.7	4.1	7.5	7.5
300430903	1	234		234	234	234	234	234	3.3	0.0	3.3	3.3	3.3	3.3	3.3
300430911	1	234		234	234	234	234	234	4.5	0.0	4.5	4.5	4.5	4.5	4.5
300430913	1	234		234	234	234	234	234	4.9	0.0	4.9	4.9	4.9	4.9	4.9
300490702	1	234		234	234	234	234	234	6.2	0.0	6.2	6.2	6.2	6.2	6.2
300490703	1	234		234	234	234	234	234	7.3	0.0	7.3	7.3	7.3	7.3	7.3
300870700	1	16735		16735	16735	16735	16735	16735	19.8	0.0	19.8	19.8	19.8	19.8	19.8
300870701	1	16735		16735	16735	16735	16735	16735	19.0	0.0	19.0	19.0	19.0	19.0	19.0

		SO_2 emissions (tpy) from sources within 20 km of monitor[1]							Distance of monitor to SO_2 emission source (km)[1]						
Monitor ID	**n**	**mean**	**std**	**min**	**p2.5**	**p50**	**p97.5**	**p100**	**mean**	**std**	**min**	**p2.5**	**p50**	**p97.5**	**p100**
300870702	1	16735		16735	16735	16735	16735	16735	19.8	0.0	19.8	19.8	19.8	19.8	19.8
300870760	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
300870761	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
300870762	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
300870763	1	16735		16735	16735	16735	16735	16735	15.2	0.0	15.2	15.2	15.2	15.2	15.2
301110016	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
301110066	4	1370	1322	75	75	1135	3135	3135	3.1	0.5	2.6	2.6	3.1	3.7	3.7
301110079	4	1370	1322	75	75	1135	3135	3135	7.8	3.0	5.8	5.8	6.7	12.2	12.2
301110080	4	1370	1322	75	75	1135	3135	3135	2.4	1.8	0.9	0.9	1.9	5.0	5.0
301110082	4	1370	1322	75	75	1135	3135	3135	3.4	2.7	1.7	1.7	2.3	7.3	7.3
301110083	4	1370	1322	75	75	1135	3135	3135	3.4	0.7	2.7	2.7	3.4	4.4	4.4
301110084	6	2550	2627	75	75	1976	7415	7415	10.3	6.6	3.1	3.1	7.4	18.6	18.6
301111065	4	1370	1322	75	75	1135	3135	3135	4.7	2.7	0.7	0.7	5.7	6.7	6.7
301112005	4	1370	1322	75	75	1135	3135	3135	4.1	1.8	1.5	1.5	4.6	5.7	5.7
301112006	6	2550	2627	75	75	1976	7415	7415	10.1	7.2	1.1	1.1	7.6	18.8	18.8
301112007	6	2550	2627	75	75	1976	7415	7415	11.4	3.9	4.7	4.7	11.2	15.3	15.3
310550048	5	6370	9218	6	6	58	20257	20257	12.7	7.5	0.5	0.5	13.6	19.3	19.3
310550050	5	6370	9218	6	6	58	20257	20257	13.4	7.5	1.0	1.0	14.7	19.6	19.6
310550053	5	6370	9218	6	6	58	20257	20257	11.3	5.7	3.3	3.3	10.6	18.0	18.0
310550055	3	3845	6637	6	6	20	11509	11509	13.0	7.3	4.7	4.7	16.1	18.2	18.2
320030022	4	45	27	16	16	44	75	75	3.9	0.0	3.8	3.8	3.9	3.9	3.9
320030078	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
320030539	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
320030601	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
330050007	1	81		81	81	81	81	81	0.3	0.0	0.3	0.3	0.3	0.3	0.3
330070019	1	638		638	638	638	638	638	1.7	0.0	1.7	1.7	1.7	1.7	1.7
330070022	1	638		638	638	638	638	638	2.3	0.0	2.3	2.3	2.3	2.3	2.3
330071007	2	9	4	6	6	9	12	12	0.6	0.1	0.6	0.6	0.6	0.7	0.7
330110016	3	10269	10386	149	149	9754	20902	20902	17.3	1.3	16.5	16.5	16.6	18.8	18.8
330110019	3	10269	10386	149	149	9754	20902	20902	17.0	2.3	15.7	15.7	15.7	19.6	19.6
330110020	3	10269	10386	149	149	9754	20902	20902	17.0	2.3	15.7	15.7	15.7	19.6	19.6
330111009	11	41	42	6	6	20	149	149	12.7	6.0	4.4	4.4	14.7	19.0	19.0
330111010	16	48	42	6	6	38	149	149	13.0	3.0	7.2	7.2	12.0	19.0	19.0
330130007	4	7708	9906	41	41	4945	20902	20902	7.3	3.9	1.4	1.4	9.0	9.6	9.6
330131003	4	7708	9906	41	41	4945	20902	20902	7.7	5.4	4.0	4.0	5.6	15.4	15.4
330131006	4	7708	9906	41	41	4945	20902	20902	8.2	8.8	1.3	1.3	5.8	19.8	19.8

		SO_2 emissions (tpy) from sources within 20 km of monitor[1]							Distance of monitor to SO_2 emission source (km)[1]						
Monitor ID	**n**	**mean**	**std**	**min**	**p2.5**	**p50**	**p97.5**	**p100**	**mean**	**std**	**min**	**p2.5**	**p50**	**p97.5**	**p100**
330131007	4	7708	9906	41	41	4945	20902	20902	9.3	2.1	7.5	7.5	8.6	12.3	12.3
330150009	9	1523	2990	6	6	52	8057	8057	9.0	6.9	2.0	2.0	4.4	19.2	19.2
330150014	9	1523	2990	6	6	52	8057	8057	9.6	7.0	1.0	1.0	5.5	19.9	19.9
330150015	9	1523	2990	6	6	52	8057	8057	8.9	7.1	1.9	1.9	4.1	19.5	19.5
330190003	2	110	81	53	53	110	168	168	2.5	1.7	1.3	1.3	2.5	3.7	3.7
340010005	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
340035001	61	457	2442	6	6	22	2302	18958	14.8	3.7	2.2	5.2	15.7	19.7	19.9
340051001	21	719	3104	5	5	35	14266	14266	10.7	6.7	1.5	1.5	12.3	19.9	19.9
340070003	60	179	644	5	5	25	2378	4450	9.7	3.4	2.0	2.8	9.6	17.2	19.9
340071001	2	8	1	8	8	8	9	9	10.2	0.5	9.9	9.9	10.2	10.5	10.5
340110007	4	161	198	28	28	81	456	456	7.5	6.6	1.8	1.8	5.7	16.8	16.8
340130011	59	465	2471	5	6	25	1845	18958	13.1	4.9	1.6	2.2	14.2	19.2	19.4
340130016	61	453	2431	5	6	25	1845	18958	13.4	5.0	1.8	2.7	14.3	19.8	19.9
340150002	50	529	1281	5	6	44	4450	6720	13.2	3.7	2.1	4.6	12.9	19.2	19.7
340170006	59	467	2471	5	5	25	1845	18958	13.0	4.6	2.0	3.2	13.5	19.9	19.9
340171002	71	421	2267	5	5	18	2302	18958	11.9	5.0	0.8	0.8	11.6	19.7	19.8
340232003	21	80	206	6	6	16	958	958	8.6	4.6	1.8	1.8	9.2	15.8	15.8
340273001	2	19	8	13	13	19	25	25	17.7	3.1	15.5	15.5	17.7	19.8	19.8
340390003	38	610	3074	5	5	19	18958	18958	11.5	5.3	2.3	2.3	12.4	20.0	20.0
340390004	38	609	3075	5	5	19	18958	18958	11.2	5.6	0.7	0.7	12.1	19.9	19.9
350130008	1	37		37	37	37	37	37	17.9	0.0	17.9	17.9	17.9	17.9	17.9
350130017	13	44	92	5	5	11	345	345	14.8	4.0	1.7	1.7	15.7	17.7	17.7
350151004	4	1058	973	168	168	983	2099	2099	8.6	8.4	0.9	0.9	8.7	16.1	16.1
350170001	1	263		263	263	263	263	263	6.1	0.0	6.1	6.1	6.1	6.1	6.1
350171003	1	263		263	263	263	263	263	1.5	0.0	1.5	1.5	1.5	1.5	1.5
350230005	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
350450008	7	2478	2496	11	11	2554	5919	5919	17.2	3.5	11.9	11.9	19.2	19.3	19.3
350450009	2	293	378	25	25	293	560	560	3.3	2.0	2.0	2.0	3.3	4.7	4.7
350450017	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
350451005	8	6274	10983	11	11	2630	32847	32847	6.1	3.8	3.2	3.2	3.5	11.9	11.9
360010012	9	40	46	7	7	20	153	153	10.8	5.2	3.5	3.5	9.0	18.0	18.0
360050073	68	399	2309	5	6	22	2302	18958	10.0	4.9	3.4	3.4	9.1	19.2	19.7
360050080	66	406	2344	5	6	18	2302	18958	10.6	5.0	1.8	3.0	9.6	19.5	19.9
360050083	56	119	355	6	6	19	1129	2302	11.2	5.6	1.6	1.8	11.3	19.6	19.6
360050110	67	402	2326	5	6	21	2302	18958	10.1	4.9	2.7	2.8	9.0	19.2	19.7
360130005	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0

Monitor ID	n	SO_2 emissions (tpy) from sources within 20 km of monitor[1]							Distance of monitor to SO_2 emission source (km)[1]						
		mean	std	min	p2.5	p50	p97.5	p100	mean	std	min	p2.5	p50	p97.5	p100
360130006	1	52177		52177	52177	52177	52177	52177	2.0	0.0	2.0	2.0	2.0	2.0	2.0
360130011	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
360150003	2	202	270	11	11	202	393	393	10.2	13.6	0.6	0.6	10.2	19.9	19.9
360290005	10	4073	12273	8	8	182	38999	38999	10.2	4.7	2.5	2.5	11.1	15.4	15.4
360294002	16	2608	9706	8	8	166	38999	38999	10.4	6.2	1.6	1.6	12.3	18.3	18.3
360298001	9	4518	12932	8	8	247	38999	38999	13.5	5.6	4.6	4.6	14.7	19.0	19.0
360310003	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
360330004	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
360410005	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
360430005	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
360470011	77	377	2178	5	5	18	2302	18958	10.3	5.5	0.7	1.9	10.8	19.2	19.7
360470076	67	428	2333	5	5	17	2302	18958	11.6	4.8	2.3	3.1	11.5	19.4	19.9
360530006	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
360551004	4	12595	14519	8	8	11988	26395	26395	11.0	4.2	7.6	7.6	10.0	16.5	16.5
360551007	4	12595	14519	8	8	11988	26395	26395	11.3	4.1	6.4	6.4	11.9	15.0	15.0
360556001	4	12595	14519	8	8	11988	26395	26395	10.5	6.8	5.2	5.2	8.5	19.8	19.8
360590005	12	151	301	6	6	26	1057	1057	11.8	4.8	1.9	1.9	11.8	19.1	19.1
360610010	77	375	2178	5	5	17	2302	18958	10.4	5.4	0.3	1.4	11.1	19.4	19.6
360610056	76	382	2192	5	5	18	2302	18958	9.9	5.4	0.3	1.4	10.6	19.9	19.9
360632008	13	3134	10777	8	8	118	38999	38999	9.3	7.3	0.3	0.3	12.2	19.8	19.8
360671015	4	820	1602	8	8	24	3223	3223	5.9	4.3	1.9	1.9	5.2	11.5	11.5
360790005	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
360810097	60	136	358	5	6	22	1129	2302	14.8	4.0	2.9	5.0	15.5	19.9	20.0
360810124	66	122	342	5	6	21	1129	2302	12.5	4.0	2.1	2.3	12.4	19.5	20.0
360830004	3	126	106	10	10	153	217	217	18.4	1.8	16.3	16.3	19.3	19.6	19.6
360831005	2	94	124	6	6	94	182	182	17.6	1.6	16.5	16.5	17.6	18.8	18.8
360850067	48	515	2737	5	6	17	1845	18958	14.0	4.0	5.5	6.2	14.2	19.6	19.9
360930003	4	24	26	6	6	14	62	62	9.5	6.6	2.0	2.0	9.7	16.5	16.5
361030002	9	156	344	6	6	19	1057	1057	9.3	5.8	1.9	1.9	7.3	18.2	18.2
361030009	10	734	2013	11	11	42	6453	6453	11.3	5.7	2.0	2.0	11.9	19.3	19.3
361111005	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
370030003	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
370130003	1	4730		4730	4730	4730	4730	4730	2.2	0.0	2.2	2.2	2.2	2.2	2.2
370130004	1	4730		4730	4730	4730	4730	4730	2.7	0.0	2.7	2.7	2.7	2.7	2.7
370130006	1	4730		4730	4730	4730	4730	4730	1.1	0.0	1.1	1.1	1.1	1.1	1.1
370370004	4	119	71	12	12	148	165	165	17.2	3.7	11.8	11.8	18.6	19.9	19.9

		SO_2 emissions (tpy) from sources within 20 km of monitor[1]							Distance of monitor to SO_2 emission source (km)[1]						
Monitor ID	**n**	**mean**	**std**	**min**	**p2.5**	**p50**	**p97.5**	**p100**	**mean**	**std**	**min**	**p2.5**	**p50**	**p97.5**	**p100**
370511003	5	295	264	17	17	173	675	675	15.8	2.5	11.5	11.5	16.5	17.9	17.9
370590002	4	1949	3658	13	13	175	7432	7432	15.3	4.3	10.4	10.4	15.6	19.6	19.6
370610002	5	83	132	6	6	36	317	317	12.3	4.9	4.1	4.1	13.1	17.0	17.0
370650099	1	325		325	325	325	325	325	16.1	0.0	16.1	16.1	16.1	16.1	16.1
370670022	9	438	848	5	5	46	2591	2591	6.3	5.7	1.2	1.2	3.9	17.8	17.8
371010002	2	15	4	12	12	15	17	17	10.3	7.5	5.0	5.0	10.3	15.6	15.6
371090004	1	10		10	10	10	10	10	10.7	0.0	10.7	10.7	10.7	10.7	10.7
371170001	2	1713	2329	66	66	1713	3360	3360	6.6	7.8	1.1	1.1	6.6	12.2	12.2
371190034	12	86	121	5	5	11	320	320	13.3	4.7	6.3	6.3	12.8	19.8	19.8
371190041	12	68	103	5	5	11	320	320	12.7	5.0	6.3	6.3	12.2	19.8	19.8
371290002	9	3325	6800	6	6	313	20865	20865	14.5	4.9	2.3	2.3	15.4	19.0	19.0
371290006	12	2502	5987	6	6	50	20865	20865	6.9	4.8	0.6	0.6	7.1	14.5	14.5
371310002	3	805	759	16	16	871	1529	1529	4.2	1.8	2.1	2.1	5.1	5.3	5.3
371450003	3	32251	54874	5	5	1136	95610	95610	18.8	0.5	18.4	18.4	18.7	19.3	19.3
371470099	2	14	3	12	12	14	16	16	1.3	0.0	1.3	1.3	1.3	1.3	1.3
371730002	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
380070002	1	283		283	283	283	283	283	11.4	0.0	11.4	11.4	11.4	11.4	11.4
380070111	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
380130002	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
380130004	1	426		426	426	426	426	426	18.6	0.0	18.6	18.6	18.6	18.6	18.6
380150003	1	4592		4592	4592	4592	4592	4592	9.8	0.0	9.8	9.8	9.8	9.8	9.8
380171003	3	257	226	15	15	294	462	462	7.7	6.9	3.0	3.0	4.6	15.7	15.7
380171004	2	378	119	294	294	378	462	462	9.0	1.1	8.2	8.2	9.0	9.7	9.7
380250003	1	5		5	5	5	5	5	13.9	0.0	13.9	13.9	13.9	13.9	13.9
380530002	1	210		210	210	210	210	210	17.3	0.0	17.3	17.3	17.3	17.3	17.3
380530104	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
380530111	2	411	522	42	42	411	781	781	16.1	0.1	16.1	16.1	16.1	16.2	16.2
380550113	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
380570001	2	45808	55924	6264	6264	45808	85352	85352	2.5	2.6	0.7	0.7	2.5	4.3	4.3
380570004	2	45808	55924	6264	6264	45808	85352	85352	2.7	2.0	1.3	1.3	2.7	4.1	4.1
380570102	2	45808	55924	6264	6264	45808	85352	85352	5.4	2.3	3.8	3.8	5.4	7.0	7.0
380570118	2	45808	55924	6264	6264	45808	85352	85352	10.7	2.2	9.1	9.1	10.7	12.2	12.2
380570123	2	45808	55924	6264	6264	45808	85352	85352	14.3	1.4	13.3	13.3	14.3	15.3	15.3
380570124	2	45808	55924	6264	6264	45808	85352	85352	18.6	1.0	17.9	17.9	18.6	19.3	19.3
380590002	1	4592		4592	4592	4592	4592	4592	2.6	0.0	2.6	2.6	2.6	2.6	2.6
380590003	1	4592		4592	4592	4592	4592	4592	5.1	0.0	5.1	5.1	5.1	5.1	5.1

Monitor ID	n	SO_2 emissions (tpy) from sources within 20 km of monitor[1]							Distance of monitor to SO_2 emission source (km)[1]						
		mean	std	min	p2.5	p50	p97.5	p100	mean	std	min	p2.5	p50	p97.5	p100
380650002	1	28565		28565	28565	28565	28565	28565	8.5	0.0	8.5	8.5	8.5	8.5	8.5
380910001	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
381050103	1	1605		1605	1605	1605	1605	1605	2.8	0.0	2.8	2.8	2.8	2.8	2.8
381050105	1	1605		1605	1605	1605	1605	1605	1.8	0.0	1.8	1.8	1.8	1.8	1.8
390010001	1	19670		19670	19670	19670	19670	19670	11.4	0.0	11.4	11.4	11.4	11.4	11.4
390030002	9	442	535	16	16	45	1469	1469	8.5	0.4	7.9	7.9	8.3	9.3	9.3
390071001	5	1731	3761	12	12	34	8458	8458	17.3	0.6	16.6	16.6	17.2	18.2	18.2
390133002	5	27781	23029	795	795	35454	56009	56009	14.5	5.1	6.0	6.0	15.8	19.8	19.8
390170004	11	907	1265	56	56	233	3998	3998	14.7	6.9	0.9	0.9	18.5	19.3	19.3
390171004	9	1546	2186	56	56	309	6275	6275	6.5	6.5	1.7	1.7	3.3	19.8	19.8
390230003	4	509	349	105	105	492	946	946	12.2	6.1	5.8	5.8	12.0	19.2	19.2
390250021	6	15304	28111	26	26	145	69953	69953	15.0	2.7	12.7	12.7	14.1	18.7	18.7
390290016	9	20696	19955	18	18	24766	59928	59928	12.7	3.6	7.2	7.2	13.5	18.1	18.1
390290022	9	20696	19955	18	18	24766	59928	59928	12.7	3.6	7.2	7.2	13.6	18.2	18.2
390292001	8	22401	20621	18	18	25596	59928	59928	11.4	4.1	4.6	4.6	10.8	19.3	19.3
390350038	10	740	916	15	15	382	2453	2453	9.8	4.9	1.9	1.9	11.7	14.3	14.3
390350045	10	740	916	15	15	382	2453	2453	10.1	5.5	1.2	1.2	10.4	15.8	15.8
390350060	10	740	916	15	15	382	2453	2453	10.4	5.7	1.0	1.0	13.3	15.5	15.5
390350065	10	740	916	15	15	382	2453	2453	9.8	4.3	2.0	2.0	9.8	14.5	14.5
390356001	13	5759	16867	8	8	382	61629	61629	13.8	7.1	1.7	1.7	16.8	20.0	20.0
390490004	6	75	74	5	5	64	192	192	8.7	3.4	2.9	2.9	9.2	12.9	12.9
390490034	6	75	74	5	5	64	192	192	9.5	3.0	3.4	3.4	10.4	11.5	11.5
390530002	6	31718	26583	9	9	29551	74452	74452	7.0	7.4	1.0	1.0	3.6	16.5	16.5
390610010	10	9265	26865	12	12	537	85699	85699	16.1	3.0	8.6	8.6	16.8	19.7	19.7
390612003	11	660	817	12	12	268	2164	2164	8.7	5.5	0.4	0.4	8.0	19.4	19.4
390810016	17	13129	20063	10	10	361	59928	59928	9.5	7.1	1.7	1.7	5.6	19.0	19.0
390810017	17	13129	20063	10	10	361	59928	59928	9.6	6.9	2.0	2.0	5.9	18.6	18.6
390811001	13	6005	15392	10	10	234	53414	53414	4.9	5.6	0.3	0.3	2.9	18.0	18.0
390850003	6	12044	24426	8	8	2390	61629	61629	9.1	4.2	5.6	5.6	7.4	15.2	15.2
390853002	3	1600	2615	18	18	163	4618	4618	5.3	6.0	1.1	1.1	2.6	12.3	12.3
390870006	8	1425	2178	25	25	343	6285	6285	13.7	6.0	2.2	2.2	15.5	19.3	19.3
390930017	3	165	241	6	6	47	442	442	11.4	2.2	8.9	8.9	12.5	12.8	12.8
390930026	2	27	29	6	6	27	47	47	3.3	0.5	3.0	3.0	3.3	3.6	3.6
390931003	3	165	241	6	6	47	442	442	11.6	2.1	9.2	9.2	12.5	13.1	13.1
390950008	9	4149	4513	204	204	3712	13581	13581	8.1	5.5	2.5	2.5	4.5	14.6	14.6
390950024	10	3745	4443	113	113	2406	13581	13581	11.4	6.4	3.9	3.9	9.5	18.6	18.6

		SO_2 emissions (tpy) from sources within 20 km of monitor[1]							Distance of monitor to SO_2 emission source (km)[1]						
Monitor ID	**n**	**mean**	**std**	**min**	**p2.5**	**p50**	**p97.5**	**p100**	**mean**	**std**	**min**	**p2.5**	**p50**	**p97.5**	**p100**
390990009	10	2107	5350	6	6	353	17244	17244	12.4	7.3	2.0	2.0	15.6	19.6	19.6
390990013	10	2107	5350	6	6	353	17244	17244	12.4	7.5	1.7	1.7	15.8	19.6	19.6
391051001	6	31718	26583	9	9	29551	74452	74452	13.6	2.2	11.6	11.6	13.0	17.8	17.8
391130025	6	1609	2326	105	105	753	6275	6275	13.4	5.4	7.3	7.3	13.4	19.4	19.4
391150003	2	57763	38696	30401	30401	57763	85125	85125	4.8	0.2	4.6	4.6	4.8	4.9	4.9
391150004	2	57763	38696	30401	30401	57763	85125	85125	5.1	0.3	4.9	4.9	5.1	5.3	5.3
391450013	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
391450020	3	1450	1306	25	25	1737	2589	2589	9.6	6.9	4.6	4.6	6.7	17.5	17.5
391450022	3	1450	1306	25	25	1737	2589	2589	8.4	7.5	2.8	2.8	5.4	16.9	16.9
391510016	7	181	213	10	10	43	510	510	6.6	1.5	4.5	4.5	5.9	8.7	8.7
391530017	4	2763	2244	863	863	2091	6009	6009	5.0	2.4	1.4	1.4	6.0	6.6	6.6
391530022	4	2763	2244	863	863	2091	6009	6009	3.9	0.7	3.0	3.0	4.1	4.6	4.6
391570003	7	368	741	15	15	38	2017	2017	12.0	6.4	0.6	0.6	13.3	18.6	18.6
391570006	6	426	795	15	15	38	2017	2017	6.4	6.1	0.4	0.4	5.3	14.2	14.2
400219002	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
400710602	2	3502	457	3178	3178	3502	3825	3825	3.4	2.3	1.8	1.8	3.4	5.0	5.0
400719003	2	3502	457	3178	3178	3502	3825	3825	1.8	2.0	0.4	0.4	1.8	3.2	3.2
400719010	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
400979014	6	3180	5200	173	173	713	13428	13428	4.7	1.3	2.7	2.7	5.5	5.7	5.7
401010167	8	3751	4529	23	23	1130	9866	9866	5.9	4.2	3.7	3.7	3.7	15.8	15.8
401090025	2	91	110	13	13	91	169	169	8.7	4.5	5.6	5.6	8.7	11.9	11.9
401091037	2	91	110	13	13	91	169	169	8.8	7.9	3.2	3.2	8.8	14.4	14.4
401159004	1	62		62	62	62	62	62	5.2	0.0	5.2	5.2	5.2	5.2	5.2
401430175	10	938	1088	9	9	263	2729	2729	11.8	6.9	1.4	1.4	13.9	18.3	18.3
401430235	10	938	1088	9	9	263	2729	2729	10.7	6.9	1.5	1.5	13.4	18.1	18.1
401430501	10	938	1088	9	9	263	2729	2729	12.6	6.8	2.7	2.7	14.2	19.2	19.2
420030002	19	103	137	7	7	30	468	468	7.4	5.9	0.6	0.6	8.6	18.1	18.1
420030010	55	85	101	5	7	49	407	468	14.2	5.6	2.5	2.5	15.5	20.0	20.0
420030021	64	819	5274	5	7	47	5395	42018	11.7	3.3	3.2	4.8	13.1	18.0	18.7
420030031	62	757	5327	5	7	46	468	42018	13.9	5.1	1.3	1.4	14.4	18.7	19.8
420030032	64	819	5274	5	7	47	5395	42018	11.7	3.3	3.1	4.7	13.2	18.1	18.7
420030064	54	213	741	5	6	52	1164	5395	6.0	5.2	2.0	2.0	3.1	17.9	18.2
420030067	16	73	105	7	7	29	407	407	15.1	3.5	6.1	6.1	15.7	19.7	19.7
420030116	19	103	137	7	7	30	468	468	7.4	5.1	2.1	2.1	7.7	17.0	17.0
420031301	57	914	5587	5	7	47	5395	42018	9.9	4.6	1.1	1.1	11.0	17.5	17.8
420033003	54	213	741	5	6	52	1164	5395	5.6	5.4	1.0	1.0	2.3	17.8	17.8

Monitor ID	n	SO_2 emissions (tpy) from sources within 20 km of monitor[1]							Distance of monitor to SO_2 emission source (km)[1]						
		mean	std	min	p2.5	p50	p97.5	p100	mean	std	min	p2.5	p50	p97.5	p100
420033004	55	209	735	5	6	49	1164	5395	5.9	6.0	0.6	0.7	3.3	18.8	18.8
420070002	10	18726	19819	18	18	15912	59928	59928	13.0	3.2	9.2	9.2	11.4	18.6	18.6
420070004	7	5881	11104	9	9	118	30312	30312	14.5	5.1	7.4	7.4	16.0	19.8	19.8
420070005	8	5173	10474	9	9	157	30312	30312	9.6	5.6	2.5	2.5	8.8	17.1	17.1
420070014	10	4400	9400	8	8	157	30312	30312	12.0	3.1	7.1	7.1	12.0	17.2	17.2
420110009	13	1140	3818	14	14	37	13841	13841	9.8	7.1	1.3	1.3	10.3	19.8	19.8
420110100	12	1231	3973	14	14	34	13841	13841	8.7	6.3	1.5	1.5	7.5	17.2	17.2
420130801	1	441		441	441	441	441	441	1.3	0.0	1.3	1.3	1.3	1.3	1.3
420170012	22	687	3033	5	5	27	14266	14266	11.1	6.5	1.2	1.2	12.4	19.6	19.6
420210011	4	4195	5171	34	34	3004	10738	10738	8.5	7.4	1.5	1.5	8.9	14.9	14.9
420270100	4	1090	1267	53	53	834	2638	2638	10.4	6.2	2.3	2.3	11.4	16.6	16.6
420430401	8	107	99	10	10	78	313	313	5.4	4.0	0.8	0.8	3.7	12.1	12.1
420450002	57	681	1415	5	5	47	5051	6720	13.6	5.5	1.3	1.9	15.8	19.8	19.8
420450109	45	855	1553	5	5	91	5051	6720	12.4	6.4	0.5	1.6	13.3	19.9	20.0
420490003	5	824	1068	10	10	228	2398	2398	3.1	1.9	1.2	1.2	2.6	5.4	5.4
420630004	3	4796	5156	1497	1497	2154	10738	10738	18.4	1.4	17.0	17.0	18.4	19.8	19.8
420692006	5	13	5	6	6	15	18	18	10.9	7.4	2.1	2.1	8.2	19.6	19.6
420710007	5	75	109	6	6	23	264	264	3.7	3.7	0.6	0.6	2.7	10.1	10.1
420730015	9	3206	8423	6	6	28	25551	25551	12.5	5.6	0.6	0.6	13.2	18.0	18.0
420770004	13	703	1041	7	7	120	2888	2888	12.5	5.8	0.3	0.3	12.0	19.3	19.3
420791101	4	117	160	9	9	53	351	351	12.3	3.4	7.8	7.8	12.9	15.8	15.8
420810100	3	28	28	6	6	18	59	59	11.3	0.7	10.6	10.6	11.2	12.0	12.0
420810403	3	28	28	6	6	18	59	59	15.8	1.1	14.9	14.9	15.4	16.9	16.9
420850100	2	14	4	11	11	14	17	17	10.8	11.8	2.4	2.4	10.8	19.1	19.1
420910013	28	171	704	5	5	15	3753	3753	15.3	4.5	1.4	1.4	16.2	20.0	20.0
420950025	18	676	1020	7	7	86	2888	2888	13.1	4.3	4.0	4.0	14.1	19.7	19.7
420950100	15	2179	5602	7	7	120	22057	22057	10.4	5.5	2.5	2.5	10.7	19.3	19.3
420958000	16	2045	5439	7	7	86	22057	22057	10.1	5.9	0.6	0.6	9.1	18.8	18.8
420990301	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
421010004	61	102	316	5	6	20	560	2378	10.5	5.2	1.0	1.3	10.9	19.2	19.7
421010022	66	285	1022	5	5	26	4450	6720	8.0	5.6	0.9	1.0	7.0	19.4	20.0
421010024	36	46	77	5	5	13	407	407	13.0	3.8	6.3	6.3	12.6	19.9	19.9
421010027	63	99	311	5	6	20	560	2378	9.8	4.6	0.8	1.7	11.0	19.7	19.7
421010029	67	262	1007	5	5	24	4450	6720	8.3	4.7	1.1	1.8	6.8	18.9	19.6
421010047	65	270	1022	5	5	26	4450	6720	7.9	4.5	0.6	0.8	6.4	17.6	17.9
421010048	60	104	318	5	6	22	560	2378	10.4	4.9	0.9	1.7	10.7	18.6	19.2

		SO_2 emissions (tpy) from sources within 20 km of monitor[1]							Distance of monitor to SO_2 emission source (km)[1]						
Monitor ID	**n**	**mean**	**std**	**min**	**p2.5**	**p50**	**p97.5**	**p100**	**mean**	**std**	**min**	**p2.5**	**p50**	**p97.5**	**p100**
421010055	66	286	1022	5	5	26	4450	6720	7.9	5.4	1.3	1.4	6.8	18.8	20.0
421010136	68	319	1042	5	5	27	4450	6720	8.8	5.4	1.1	1.4	9.3	18.7	19.8
421070003	6	831	687	8	8	674	1743	1743	10.4	7.4	3.3	3.3	8.8	19.2	19.2
421230003	2	2445	659	1979	1979	2445	2911	2911	4.0	1.2	3.2	3.2	4.0	4.9	4.9
421230004	2	2445	659	1979	1979	2445	2911	2911	3.0	1.6	1.9	1.9	3.0	4.1	4.1
421250005	33	257	945	5	5	47	5395	5395	15.7	4.7	1.1	1.1	17.5	18.7	18.7
421250200	1	7		7	7	7	7	7	1.1	0.0	1.1	1.1	1.1	1.1	1.1
421255001	8	321	439	7	7	82	1017	1017	15.9	4.1	9.3	9.3	17.2	19.7	19.7
421290008	3	24	9	16	16	22	34	34	9.8	1.4	8.7	8.7	9.3	11.5	11.5
421330008	9	8943	22698	14	14	171	68932	68932	9.3	5.8	0.8	0.8	10.1	17.7	17.7
440070012	54	41	90	5	5	13	392	521	8.4	5.8	0.3	0.4	5.9	18.9	19.0
440071005	55	41	89	5	5	13	392	521	9.1	5.5	0.9	1.0	8.4	18.5	19.0
440071009	55	41	89	5	5	13	392	521	8.6	6.0	0.1	0.4	6.3	19.5	19.9
450030003	13	1654	2599	8	8	549	8275	8275	15.3	1.5	11.4	11.4	15.3	17.5	17.5
450110001	1	65		65	65	65	65	65	13.2	0.0	13.2	13.2	13.2	13.2	13.2
450190003	16	2183	6339	6	6	28	25544	25544	7.2	5.0	1.1	1.1	6.2	16.3	16.3
450190046	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
450430006	7	5834	14038	6	6	24	37622	37622	4.6	4.3	0.2	0.2	3.4	13.2	13.2
450450008	12	89	136	6	6	20	411	411	11.7	4.5	2.1	2.1	10.7	17.4	17.4
450450009	13	83	132	6	6	19	411	411	10.1	5.7	4.0	4.0	5.4	17.3	17.3
450630008	11	948	2944	5	5	9	9820	9820	11.5	5.4	0.5	0.5	13.0	19.2	19.2
450730001	1	5		5	5	5	5	5	14.9	0.0	14.9	14.9	14.9	14.9	14.9
450750003	5	1433	1913	5	5	211	4088	4088	8.5	5.1	3.4	3.4	9.6	15.8	15.8
450790007	10	61	103	5	5	18	343	343	14.0	4.1	6.4	6.4	15.9	18.7	18.7
450790021	8	5061	12720	7	7	89	36378	36378	14.7	1.2	12.3	12.3	15.3	15.6	15.6
450791003	13	995	2730	5	5	52	9820	9820	10.9	5.9	1.4	1.4	10.9	18.5	18.5
450791006	10	4289	11350	7	7	89	36378	36378	17.5	3.3	8.2	8.2	18.9	19.1	19.1
460330132	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
460710001	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
460990007	1	496		496	496	496	496	496	17.5	0.0	17.5	17.5	17.5	17.5	17.5
470010028	8	5595	14808	7	7	34	42188	42188	12.2	6.5	0.9	0.9	12.8	18.8	18.8
470090002	3	1421	2325	6	6	153	4104	4104	5.7	5.7	0.7	0.7	4.5	11.9	11.9
470090006	3	1421	2325	6	6	153	4104	4104	5.4	5.3	1.4	1.4	3.3	11.3	11.3
470090101	3	1421	2325	6	6	153	4104	4104	12.1	6.9	4.2	4.2	15.4	16.7	16.7
470110102	2	2719	3687	112	112	2719	5326	5326	2.5	1.2	1.6	1.6	2.5	3.4	3.4
470310004	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0

Monitor ID	n	SO_2 emissions (tpy) from sources within 20 km of monitor[1]							Distance of monitor to SO_2 emission source (km)[1]						
		mean	std	min	p2.5	p50	p97.5	p100	mean	std	min	p2.5	p50	p97.5	p100
470370011	9	891	2248	9	9	60	6842	6842	10.4	3.6	5.6	5.6	10.7	17.6	17.6
470730002	3	11831	10420	6	6	15822	19666	19666	2.9	2.1	1.7	1.7	1.7	5.2	5.2
470850020	6	18599	44191	12	12	281	108788	108788	3.2	1.8	1.6	1.6	2.6	6.3	6.3
471070101	3	1834	3024	64	64	112	5326	5326	7.6	10.2	0.5	0.5	3.0	19.3	19.3
471250006	6	222	401	8	8	35	1025	1025	6.2	6.9	1.0	1.0	2.5	15.0	15.0
471250106	6	222	401	8	8	35	1025	1025	7.1	7.3	1.5	1.5	3.5	16.3	16.3
471390003	1	1900		1900	1900	1900	1900	1900	3.1	0.0	3.1	3.1	3.1	3.1	3.1
471390007	1	1900		1900	1900	1900	1900	1900	1.6	0.0	1.6	1.6	1.6	1.6	1.6
471390008	1	1900		1900	1900	1900	1900	1900	1.4	0.0	1.4	1.4	1.4	1.4	1.4
471390009	1	1900		1900	1900	1900	1900	1900	1.0	0.0	1.0	1.0	1.0	1.0	1.0
471450009	4	19470	22311	9	9	19188	39495	39495	10.9	6.7	5.3	5.3	9.5	19.1	19.1
471570034	18	1204	2391	5	5	32	6540	6540	11.4	2.2	4.8	4.8	11.8	15.3	15.3
471570043	18	1204	2391	5	5	32	6540	6540	9.6	1.7	5.3	5.3	10.0	11.4	11.4
471570046	2	1973	2640	106	106	1973	3839	3839	6.0	6.7	1.3	1.3	6.0	10.8	10.8
471571034	19	1150	2336	5	5	35	6540	6540	3.5	5.6	0.5	0.5	0.7	18.0	18.0
471610007	3	5561	5107	21	21	6580	10081	10081	1.8	0.2	1.7	1.7	1.7	1.9	1.9
471630007	10	3010	5303	22	22	495	16855	16855	3.7	2.6	1.7	1.7	2.6	10.7	10.7
471630009	12	2513	4935	13	13	286	16855	16855	5.7	6.0	2.0	2.0	2.7	18.7	18.7
471651002	4	8593	10129	88	88	7029	20226	20226	4.2	1.8	2.9	2.9	3.5	6.9	6.9
480610006	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
481130069	9	34	25	9	9	18	69	69	12.1	5.7	2.0	2.0	12.9	20.0	20.0
481390015	12	664	993	13	13	57	3003	3003	9.5	5.8	2.3	2.3	9.4	16.6	16.6
481390016	12	664	993	13	13	57	3003	3003	9.0	6.3	2.9	2.9	6.1	17.4	17.4
481390017	12	664	993	13	13	57	3003	3003	9.6	6.9	1.9	1.9	7.6	18.6	18.6
481410037	13	44	92	5	5	11	345	345	9.7	1.8	4.5	4.5	10.0	12.0	12.0
481410053	13	44	92	5	5	11	345	345	9.7	1.6	5.1	5.1	9.9	11.9	11.9
481410058	16	38	83	5	5	12	345	345	13.9	2.3	9.5	9.5	14.7	16.0	16.0
481670005	43	185	611	5	6	22	1937	3599	2.3	1.3	1.2	1.3	2.0	3.3	9.5
481671002	43	185	611	5	6	22	1937	3599	3.6	1.1	2.5	2.5	3.3	4.6	9.5
481830001	5	13289	12287	6	6	19024	24837	24837	18.9	0.5	18.6	18.6	18.7	19.9	19.9
482010046	29	606	1182	6	6	161	5097	5097	12.8	3.1	6.2	6.2	13.1	19.6	19.6
482010051	2	13	8	7	7	13	18	18	19.1	0.6	18.7	18.7	19.1	19.5	19.5
482010059	38	674	1486	6	6	48	6968	6968	10.3	5.9	1.8	1.8	8.5	19.5	19.5
482010062	37	694	1503	6	6	49	6968	6968	14.8	3.8	7.8	7.8	15.7	20.0	20.0
482010070	31	790	1622	6	6	161	6968	6968	10.7	5.3	2.2	2.2	8.7	19.5	19.5
482011035	39	657	1470	6	6	46	6968	6968	8.6	5.4	1.6	1.6	7.7	17.6	17.6

Monitor ID	n	SO_2 emissions (tpy) from sources within 20 km of monitor[1]							Distance of monitor to SO_2 emission source (km)[1]						
		mean	std	min	p2.5	p50	p97.5	p100	mean	std	min	p2.5	p50	p97.5	p100
482011050	46	243	1028	6	7	36	829	6968	16.5	3.9	5.0	5.3	17.9	19.1	19.9
482450009	16	863	2732	6	6	80	11064	11064	14.8	6.8	0.4	0.4	18.7	19.7	19.7
482450011	27	999	2362	6	6	45	11064	11064	9.0	5.3	2.8	2.8	7.0	18.1	18.1
482450020	8	170	306	6	6	64	908	908	10.8	8.1	1.8	1.8	11.3	19.9	19.9
482570005	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
483550025	17	468	1086	6	6	43	3955	3955	6.7	3.0	4.2	4.2	5.2	16.4	16.4
483550026	19	424	1032	6	6	43	3955	3955	10.0	3.3	4.6	4.6	11.0	13.6	13.6
483550032	17	468	1086	6	6	43	3955	3955	3.9	4.1	0.4	0.4	1.7	16.0	16.0
490050004	1	5		5	5	5	5	5	1.8	0.0	1.8	1.8	1.8	1.8	1.8
490110001	6	468	500	8	8	366	1332	1332	8.2	5.8	1.5	1.5	8.1	17.7	17.7
490110004	6	468	500	8	8	366	1332	1332	9.7	6.0	2.3	2.3	9.8	19.2	19.2
490350012	6	468	500	8	8	366	1332	1332	4.9	3.7	0.6	0.6	4.5	8.9	8.9
490351001	7	833	1006	8	8	712	2788	2788	13.0	6.5	2.1	2.1	13.0	19.6	19.6
490352004	3	1245	1415	8	8	939	2788	2788	9.8	8.0	2.4	2.4	8.9	18.3	18.3
500070003	1	6		6	6	6	6	6	1.6	0.0	1.6	1.6	1.6	1.6	1.6
500070014	1	6		6	6	6	6	6	1.9	0.0	1.9	1.9	1.9	1.9	1.9
500210002	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
510360002	18	4818	17274	7	7	35	73839	73839	12.1	7.2	2.0	2.0	13.6	19.9	19.9
510590005	5	31	46	8	8	11	114	114	17.2	1.6	15.0	15.0	17.3	19.4	19.4
510590018	10	1820	5043	8	8	74	16141	16141	13.5	3.9	8.4	8.4	15.7	17.5	17.5
510591004	11	1664	4813	7	7	59	16141	16141	10.9	3.5	3.7	3.7	11.2	16.3	16.3
510591005	13	1416	4435	7	7	59	16141	16141	13.6	4.3	4.6	4.6	13.8	19.0	19.0
510595001	11	1566	4837	6	6	24	16141	16141	14.8	4.4	5.1	5.1	16.0	19.8	19.8
511130003	1	7		7	7	7	7	7	10.8	0.0	10.8	10.8	10.8	10.8	10.8
511611004	8	85	117	5	5	34	341	341	9.3	5.5	2.9	2.9	9.7	19.1	19.1
511650002	7	40	36	8	8	32	108	108	12.3	5.1	5.1	5.1	13.9	17.8	17.8
511650003	6	39	40	5	5	25	108	108	11.4	5.4	6.3	6.3	10.3	17.9	17.9
515100009	11	1663	4813	7	7	59	16141	16141	9.6	5.1	1.1	1.1	8.6	17.9	17.9
516500004	15	285	505	6	6	92	1983	1983	11.1	4.9	4.0	4.0	11.3	17.9	17.9
517100023	21	1738	7026	5	5	85	32344	32344	8.3	3.4	3.6	3.6	8.3	18.8	18.8
517600024	14	191	363	6	6	16	1148	1148	9.4	5.8	1.2	1.2	10.3	20.0	20.0
530090010	1	756		756	756	756	756	756	5.6	0.0	5.6	5.6	5.6	5.6	5.6
530090012	1	756		756	756	756	756	756	5.3	0.0	5.3	5.3	5.3	5.3	5.3
530330057	5	241	301	63	63	117	771	771	4.0	6.0	0.6	0.6	1.3	14.7	14.7
530330080	5	241	301	63	63	117	771	771	5.0	4.2	2.5	2.5	3.1	12.5	12.5
530530021	3	179	213	11	11	109	419	419	3.2	1.1	2.1	2.1	3.2	4.3	4.3

Monitor ID	n	SO_2 emissions (tpy) from sources within 20 km of monitor[1]							Distance of monitor to SO_2 emission source (km)[1]						
		mean	std	min	p2.5	p50	p97.5	p100	mean	std	min	p2.5	p50	p97.5	p100
530530031	3	179	213	11	11	109	419	419	1.8	0.9	1.2	1.2	1.3	2.8	2.8
530570012	4	2238	2630	21	21	1793	5345	5345	2.2	0.8	1.3	1.3	2.3	3.1	3.1
530571003	4	2238	2630	21	21	1793	5345	5345	1.7	0.6	1.1	1.1	1.7	2.4	2.4
530610016	2	191	194	53	53	191	328	328	0.5	0.1	0.4	0.4	0.5	0.6	0.6
530730011	9	488	695	8	8	349	2286	2286	16.9	6.2	0.5	0.5	19.3	19.7	19.7
540090005	13	6005	15392	10	10	234	53414	53414	5.3	5.3	0.9	0.9	2.7	16.8	16.8
540090007	17	13129	20063	10	10	361	59928	59928	10.7	5.3	3.9	3.9	8.3	18.8	18.8
540110006	5	1501	2677	124	124	401	6285	6285	13.2	7.1	0.5	0.5	16.2	17.2	17.2
540250001	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
540290005	8	22069	20983	18	18	25596	59928	59928	9.3	5.3	4.7	4.7	7.5	17.6	17.6
540290007	16	9282	17668	10	10	238	59928	59928	13.1	3.8	4.8	4.8	13.1	18.3	18.3
540290008	9	20696	19955	18	18	24766	59928	59928	12.1	4.2	6.3	6.3	11.2	19.8	19.8
540290009	15	9894	18112	10	10	243	59928	59928	11.0	3.5	1.0	1.0	12.0	17.7	17.7
540290011	17	13129	20063	10	10	361	59928	59928	10.7	5.2	3.2	3.2	8.8	18.8	18.8
540290014	16	9282	17668	10	10	238	59928	59928	11.8	4.0	1.5	1.5	11.1	19.4	19.4
540290015	9	20696	19955	18	18	24766	59928	59928	12.1	3.5	7.1	7.1	12.4	18.2	18.2
540290016	16	10611	17732	10	10	302	59928	59928	10.8	4.3	1.1	1.1	10.6	18.3	18.3
540291004	16	10611	17732	10	10	302	59928	59928	11.5	3.9	1.8	1.8	11.8	19.8	19.8
540390004	4	1529	1146	854	854	1008	3245	3245	10.2	4.3	6.0	6.0	10.0	14.8	14.8
540390010	4	1529	1146	854	854	1008	3245	3245	9.7	4.6	5.2	5.2	9.8	14.0	14.0
540392002	5	22698	47491	750	750	1009	107633	107633	9.1	5.6	2.3	2.3	6.7	15.5	15.5
540511002	5	27781	23029	795	795	35454	56009	56009	10.1	4.7	2.2	2.2	11.4	15.0	15.0
540610003	2	45992	63840	850	850	45992	91134	91134	4.6	1.4	3.6	3.6	4.6	5.6	5.6
540610004	4	24472	44468	850	850	2952	91134	91134	11.8	8.9	0.8	0.8	13.5	19.4	19.4
540610005	3	32132	51128	850	850	4412	91134	91134	9.2	9.7	1.0	1.0	6.7	19.9	19.9
540690007	2	37391	22660	21367	21367	37391	53414	53414	13.9	1.8	12.7	12.7	13.9	15.2	15.2
540990002	8	1271	2194	25	25	343	6285	6285	9.7	5.5	1.7	1.7	10.6	16.0	16.0
540990003	8	1271	2194	25	25	343	6285	6285	9.6	5.5	1.5	1.5	10.7	15.8	15.8
540990004	8	1271	2194	25	25	343	6285	6285	9.6	6.0	1.0	1.0	11.3	15.8	15.8
540990005	8	1271	2194	25	25	343	6285	6285	9.5	6.4	0.9	0.9	11.4	16.2	16.2
541071002	11	4375	9095	7	7	1517	31006	31006	8.5	5.4	2.7	2.7	8.8	17.0	17.0
550090005	7	3413	5045	9	9	850	13470	13470	4.2	3.4	1.1	1.1	3.1	9.7	9.7
550250041	7	1293	2743	7	7	71	7417	7417	7.4	4.7	2.8	2.8	5.2	14.7	14.7
550410007	1	5		5	5	5	5	5	8.3	0.0	8.3	8.3	8.3	8.3	8.3
550730005	3	4040	6715	24	24	303	11792	11792	10.7	9.2	0.1	0.1	15.8	16.2	16.2
550790007	9	1750	4858	5	5	28	14686	14686	6.5	3.4	1.8	1.8	5.9	12.9	12.9

Monitor ID	n	SO_2 emissions (tpy) from sources within 20 km of monitor[1]							Distance of monitor to SO_2 emission source (km)[1]						
		mean	std	min	p2.5	p50	p97.5	p100	mean	std	min	p2.5	p50	p97.5	p100
550790026	9	1750	4858	5	5	28	14686	14686	7.6	3.0	3.5	3.5	7.5	12.8	12.8
550790041	9	1750	4858	5	5	28	14686	14686	10.1	3.0	5.9	5.9	10.2	14.5	14.5
550850996	2	1152	1617	9	9	1152	2295	2295	0.9	0.1	0.9	0.9	0.9	1.0	1.0
551110007	2	31	35	7	7	31	56	56	14.7	7.4	9.5	9.5	14.7	19.9	19.9
551250001	0								0.0	0.0	0.0	0.0	0.0	0.0	0.0
551410016	6	2374	2368	6	6	2032	5782	5782	5.3	2.6	2.3	2.3	4.9	9.8	9.8
560050857	4	2527	3868	23	23	896	8291	8291	4.6	6.5	1.1	1.1	1.6	14.4	14.4

Notes:

[1] Mean, std , min, p2.5, p50, p97.5, max are the arithmetic average, standard deviation, minimum, 2.5^{th}, 50^{th}, 97.5^{th} percentiles, and maximum distances and emissions.

[2] There were no emissions above 5 tpy for sources located within 20 km of the monitors sited in Puerto Rico and the Virgin Islands.

A.2 Analysis of Duplicate SO_2 Values at Ambient Monitor Locations

During the screening of each of the ambient monitoring data sets, it became evident that simultaneous measurements were present. Staff analyzed the duplicate SO_2 measurements to discern if there were any differences in the reported/measured values because ultimately only one value would be selected for use in each of the final screened data sets. Staff was not interested in whether multiple monitors were present at a particular monitoring site or if there were duplicate reporting of SO_2 concentrations, only to determine that the selection of a particular value used in the final data sets were not biased.

In selecting which of the duplicate concentrations to use for final REA data sets, staff made the following judgements. First, the ambient monitor POC containing the greatest number of samples was used to populate the max-5 data set. Second, where continous-5 measurements were available and coincided with max-5 measurements, staff selected the 5-minute maximum SO_2 concentration from the continuous-5 data set. And finally, where continuous-5 data were available and used to estimate a 1-hour average SO_2 concentration that coincided with a reported 1-hour ambient monitor concentration, the continuous-5 1-hour average concentration was used. Staff designed the following analyses to explore the effect the selection of one concentration over another may have on the final data set used.

Staff calculated the relative percent difference (RPD) for each duplicate concentration, considering measurements within the 5-max data set (n=300,438), duplicate reporting between the continuous-5 and the max-5 data sets (n=29,058), and duplicate values between the 1-hour and the continuous-5 data sets (n=258,457), separately. We anticipated that small fluctuations in concentration between the duplicate data would have a greater influence on the RPD at lower concentrations than at higher concentrations. Therefore, staff separated the duplicate values into concentration groups for this analysis. Two groups were constructed; one with concentrations ≤ 10 ppb and the other conrtaining concentrations > 10 ppb. The following formula calculates the RPD for each duplicate value:

$$RPD = \frac{(C_1 - C_2)}{(C_1 + C_2)} \times 200 \qquad \text{equation A.2-1}$$

where,

RPD = Relative percent difference (%)

C_1 = First SO_2 concentration value

C_2 = Second SO_2 concentration value

Depending on the difference in concentration, the value for the calculated RPD could be as low as -200 or as high +200, indicating the maximum difference between any two values, while an RPD of zero indicates no difference. The sign of the value can also indicate the direction of bias when comparing the first concentration to the second.

In the first comparison (i.e., the within max-5 duplicates), C_1 was selected as the ambient monitor containing the overall greater sample size/duration. Table A.2-1 summarizes the distribution of RPDs for where duplicate values of SO_2 concentrations were less than 10 ppb within the max-5 monitoring data set. On average, there were relatively small differences in the duplicate values reported at each of the monitoring locations. Most duplicate values were within +/-67% of one another, although some were noted at or above 100% (absolute difference). In considering that these maximum 5-minute SO_2 concentrations are well below that of potential interest in the exposure and risk analysis, this degree of agreement between the two values at these concentration levels is acceptable.

Table A.2-1. Distribution of the relative percent difference (RPD) between duplicate 5-minute maximum SO_2 values at max-5 monitors, where concentrations were ≤ 10 ppb.

Monitor ID	n	Relative Percent Difference (%)[1]						
		mean	std	min	p5	p50	p95	max
290210009	25868	0	34	-196	-50	0	67	100
290210011	22247	-7	22	-143	-40	0	18	67
290930030	54904	8	34	-181	-40	0	67	100
290930031	48417	-14	29	-122	-67	0	67	67
290990004	22788	-8	27	-120	-50	0	67	100
290990014	33245	-12	29	-133	-67	0	29	67
290990017	21460	2	30	-120	-50	0	67	120
290990018	17025	2	25	-156	-40	0	67	100
291630002	11528	-3	34	-164	-40	0	67	67

Notes:
[1] the mean, std, min, p5, p50, p95, max are the arithmetic average, standard deviation, minimum, 5th, median, 95th, and maximum, respectively.

When considering duplicate values > 10 ppb, the RPD was much lower at each of the monitors (Table A.2-2). Most of the RPDs are within +/-10%, indicating excellent agreement among the duplicate values. A small negative bias may exist with selection of the monitor with the greatest number of samples as the base monitor, but on average the difference was typically less than 3%.

Table A.2-2. Distribution of the relative percent difference (RPD) between duplicate 5-minute maximum SO_2 values at max-5 monitors, where concentrations were > 10 ppb.

Monitor ID	n	Relative Percent Difference (%)[1]						
		mean	std	min	p5	p50	p95	max
290210009	2333	-2	6	-133	-10	0	6	18
290210011	2344	0	3	-66	-6	0	5	18
290930030	8068	-1	6	-120	-9	0	4	24
290930031	7652	-3	6	-134	-13	-2	0	10
290990004	8627	-1	4	-100	-7	0	5	20
290990014	4973	2	16	-17	-8	0	9	184
290990017	5138	-1	7	-137	-11	0	10	32
290990018	2626	0	6	-81	-7	0	10	32
291630002	1195	-6	32	-137	-133	0	11	29

Notes:
[1] the mean, std, min, p5, p50, p95, max are the arithmetic average, standard deviation, minimum, 5th, median, 95th, and maximum, respectively.

Staff also analyzed data where the max-5 sampling times corresponded with the continuous-5 monitoring at the same location. Of the 29,058 duplicate measurement values, only 312 contained different values among the two sample types (i.e, a non-zero RPD). This indicates that the majority of the data are duplicate values reported in each of the two data sets. Since there were very few samples with RPDs deviating from zero (i.e., 1.1%), the following analysis included only the samples that had a non-zero difference and at any concentration levels. The distribution for the RPD given these monitors and duplicate monitoring events is provided in Table A.2-3. On average there may be a small positive bias in selecting the continuous-5 monitoring concentrations where differences existed, however given that there were only 1% of samples that differed among the two data sets, the overall impact to the below estimation procedure is determined as negligible. In addition, selection of the continuous-5 measurement preserves the relationship between the actual 5-minute maximum and the calculated 1-hour concentration derived from the multiple 5-minute measurements that occurred within the hour, not adding to uncertainty regarding the true relationship between the 1-hour and 5-minute maximum concentrations.

Table A.2-3. Distribution of the relative percent difference (RPD) between simultaneous 5-minute SO_2 maximum values in the max-5 and continuous-5 data sets, where concentrations > 0 ppb.

Monitor ID	n [1]	Relative Percent Difference (%) [2]						
		mean	std	min	p5	p50	p95	max
301110066	76	26	57	-143	-117	16	133	160
301110079	149	27	48	-178	-67	29	67	164
301110082	47	25	52	-67	-67	29	67	186
301110083	40	78	64	-120	-53	67	160	160

Notes:
[1] This distribution is for the number of samples where the RPD was non-zero. The majority of the duplicate measures (n=28,746) were identical.
[2] the mean, std, min, p5, p50, p95, max are the arithmetic average, standard deviation, minimum, 5th, median, 95th, and maximum, respectively.

In the last comparison (i.e., the 1-hour concentration duplicates), the 1-hour concentration from the continous-5 ambient monitors was selected as C_1 in equation A.2-1. Table A.2-4 summarizes the distribution of RPDs for where duplicate measurements of SO_2 concentrations were less than 10 ppb within the max-5 monitoring data set. While nearly 20% had no difference between the duplicate values, on average, there were greater differences in the duplicate 1-hour values at most of the monitors than was observed for the 5-minute duplicates. Nearly 20% of the concentrations were noted at or above 100% one another (absolute difference), however all of these were due to where reported values were zero at the 1-hour monitor and concentrations of 1 ppb were reported for the continuous-5 monitor. This factor contributes to the observed positive bias at most of the monitors, however in considering that these 1-hour SO_2 concentrations are below that of potential interest in the exposure and risk analysis, this degree of limited agreement between the two data sets at these concentration levels should be acceptable.

Table A.2-4. Distribution of the relative percent difference (RPD) between duplicate 1-hour SO_2 values in the continuous-5 and 1-hour data sets, where concentrations were ≤ 10 ppb.

Monitor ID	n	Relative Percent Difference (%)[1]						
		mean	std	min	p5	p50	p95	max
110010041	2049	0	7	-34	-12	0	12	45
120890005	25163	88	99	-175	-11	15	200	200
290770026	24286	91	99	-105	-9	15	200	200
290770037	24822	41	80	-46	-13	0	200	200
301110066	6640	24	62	-100	-13	0	200	200
301110079	7906	119	95	-133	-9	200	200	200
301110082	7930	69	92	-165	-13	12	200	200
301110083	4757	82	96	-105	-9	15	200	200
371290006	27954	-45	83	-193	-133	-59	200	200

Monitor ID	n	Relative Percent Difference (%)[1]						
		mean	std	min	p5	p50	p95	max
420030021	4594	34	81	-175	-18	2	200	200
420030064	5174	20	71	-172	-29	-4	200	200
420030116	4231	3	25	-61	-18	0	19	200
420033003	4640	23	69	-67	-23	-1	200	200
420070005	30386	63	91	-133	-10	6	200	200
540990002	6592	1	10	-40	-13	0	19	90
541071002	23864	1	11	-156	-13	0	17	200

Notes:
[1] the mean, std, min, p5, p50, p95, max are the arithmetic average, standard deviation, minimum, 5th, median, 95th, and maximum, respectively.

When considering duplicate 1-hour concentrations > 10 ppb, the RPD was much lower at each of these same monitors (Table A.2-5). Most RPD distributions were within +/-5%, indicating excellent agreement among the duplicate 1-hour values at concentrations above 10 ppb. A very small positive bias may exist with selection of the continuous-5 monitor data for use in the air quality characterization when compared with the reported 1-hour concentrations, but on average, the difference was typically less than 1% when considering concentrations above 10 ppb.

Table A.2-5. Distribution of the relative percent difference (RPD) between duplicate 1-hour SO_2 values in the continuous-5 and 1-hour data sets, where concentrations were > 10 ppb.

Monitor ID	n	Relative Percent Difference (%)[1]						
		mean	std	min	p5	p50	p95	max
110010041	202	0	2	-5	-4	0	4	5
120890005	2400	0	4	-90	-3	0	3	34
290770026	1906	0	2	-10	-3	0	3	7
290770037	1373	0	2	-5	-3	0	3	7
301110066	1616	0	5	-50	-3	0	4	173
301110079	71	0	3	-6	-4	-1	4	6
301110082	176	0	2	-5	-3	0	4	6
301110083	85	1	3	-4	-3	1	5	20
371290006	3747	1	25	-108	-15	-2	12	186
420030021	1852	1	14	-59	-4	0	4	200
420030064	2892	-2	2	-10	-6	-2	0	11
420030116	1145	0	9	-34	-4	0	4	200
420033003	2625	-1	5	-36	-5	-1	2	187
420070005	15034	0	2	-23	-3	0	3	73
540990002	2062	0	2	-5	-3	0	4	10
541071002	10283	0	2	-87	-3	0	3	65

Notes:
[1] the mean, std, min, p5, p50, p95, max are the arithmetic average, standard deviation, minimum, 5th, median, 95th, and maximum, respectively.

A.3 Peak-To-Mean Ratio Distributions

Peak-to-mean ratios (PMR) were calculated using the measured values for each the 5-minute maximum and 1-hour SO_2 concentrations. PMRs were seperated into 19 groups[2] based on the observed variability (3 bins) and concentrations ranges (7 bins) in measured 1-hour ambient monitor concentrations (n=2,367,686). Table A.3-1 summarizes the PMR distributions used for estimating 5-minute maximum concentrations from 1-hour measurements where ambient monitors were characterized by the 1-hour coefficient of variation (COV). These are the PMR distributions used in the statistical modeling of 5-minute maximum SO_2 concentrations in the air quality characterization and in the exposure modeling.3 Table A.3-2 summarizes the PMR distributions used for estimating 5-minute maximum SO_2 concentrations from 1-hour measurements where ambient monitors were characterized by the 1-hour coefficient of variation (GSD). Peak-to-mean ratios estimated by categorizing the ambient monitors by GSD were used only in evaluating an alternative method of estimating 5-minute SO_2 concentrations.

[2] Although there are 21 PMR distributions possible (i.e., 3 × 7), the COV < 100% and GSD <2.17 categories had only three 1-hour concentrations above 150 ppb. Therefore, the two highest concentration bins do not have a distribution, and concentrations > 75 ppb constituted the highest concentration bin in the low COV or low GSD bins
[3] Note that the minimum and maximum values of each distribution were not used in the final statistical model to estimate 5-minute maximum concentrations. This was determined in the model evaluations described in section 7.2.5 of the SO_2 REA.

Table A.3-1. Distribution of 5-minute maximum peak to 1-hour mean SO_2 concentration ratios (PMRs) using ambient monitors categorized by 1-hour coefficient of variation (COV) and 1-hour mean concentration.

	COV ≤ 100%					100% < COV ≤ 200%							COV > 200 %						
Concbin[1]	**0**	**1**	**2**	**3**	**4**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**0**	**1**	**2**	**3**	**4**	**5**	**6**
Pct[2] - 0	1.00	1.00	1.00	1.00	1.01	1.00	1.00	1.00	1.00	1.00	1.05	1.02	1.00	1.00	1.00	1.00	1.00	1.08	1.13
- 1	1.00	1.00	1.00	1.03	1.02	1.00	1.00	1.00	1.00	1.05	1.08	1.04	1.00	1.00	1.00	1.12	1.14	1.18	1.25
- 2	1.00	1.00	1.00	1.03	1.02	1.00	1.00	1.00	1.03	1.07	1.12	1.14	1.00	1.00	1.06	1.17	1.18	1.21	1.28
- 3	1.00	1.00	1.00	1.04	1.04	1.00	1.00	1.00	1.04	1.08	1.14	1.14	1.00	1.00	1.08	1.21	1.21	1.22	1.29
- 4	1.00	1.00	1.00	1.04	1.04	1.00	1.00	1.05	1.06	1.10	1.16	1.15	1.00	1.00	1.08	1.24	1.24	1.25	1.30
- 5	1.00	1.00	1.05	1.05	1.05	1.00	1.00	1.06	1.06	1.11	1.20	1.16	1.00	1.00	1.09	1.26	1.26	1.28	1.33
- 6	1.00	1.00	1.06	1.06	1.06	1.00	1.00	1.06	1.07	1.12	1.21	1.18	1.00	1.00	1.10	1.29	1.28	1.31	1.34
- 7	1.00	1.00	1.06	1.06	1.07	1.00	1.00	1.07	1.08	1.13	1.21	1.18	1.00	1.00	1.11	1.31	1.30	1.34	1.37
- 8	1.00	1.00	1.06	1.07	1.08	1.00	1.00	1.08	1.09	1.14	1.22	1.22	1.00	1.00	1.14	1.33	1.32	1.37	1.38
- 9	1.00	1.00	1.07	1.07	1.09	1.00	1.00	1.08	1.10	1.15	1.23	1.24	1.00	1.00	1.15	1.36	1.33	1.40	1.43
- 10	1.00	1.00	1.07	1.07	1.09	1.00	1.00	1.08	1.10	1.16	1.23	1.24	1.00	1.00	1.17	1.38	1.35	1.42	1.47
- 11	1.00	1.00	1.08	1.07	1.10	1.00	1.05	1.09	1.11	1.17	1.25	1.24	1.00	1.00	1.18	1.40	1.37	1.44	1.48
- 12	1.00	1.00	1.08	1.08	1.10	1.00	1.08	1.09	1.12	1.18	1.27	1.30	1.00	1.00	1.20	1.42	1.38	1.47	1.50
- 13	1.00	1.00	1.08	1.08	1.11	1.00	1.11	1.10	1.12	1.19	1.27	1.30	1.00	1.06	1.20	1.44	1.40	1.49	1.51
- 14	1.00	1.00	1.08	1.09	1.11	1.00	1.11	1.10	1.13	1.19	1.28	1.32	1.00	1.11	1.22	1.46	1.42	1.51	1.53
- 15	1.00	1.00	1.08	1.09	1.11	1.00	1.11	1.10	1.14	1.20	1.28	1.33	1.00	1.11	1.24	1.48	1.43	1.54	1.54
- 16	1.00	1.00	1.08	1.10	1.12	1.00	1.13	1.10	1.15	1.21	1.29	1.34	1.00	1.13	1.26	1.50	1.45	1.57	1.57
- 17	1.00	1.00	1.09	1.10	1.13	1.00	1.13	1.11	1.15	1.22	1.30	1.36	1.00	1.13	1.27	1.52	1.46	1.59	1.58
- 18	1.00	1.04	1.09	1.11	1.14	1.00	1.13	1.13	1.16	1.23	1.31	1.36	1.00	1.14	1.30	1.53	1.48	1.60	1.59
- 19	1.00	1.11	1.09	1.11	1.15	1.00	1.13	1.13	1.17	1.24	1.32	1.37	1.00	1.14	1.30	1.55	1.50	1.64	1.59
- 20	1.00	1.11	1.09	1.11	1.15	1.00	1.14	1.14	1.17	1.24	1.32	1.38	1.00	1.14	1.33	1.57	1.51	1.65	1.61
- 21	1.00	1.11	1.10	1.12	1.16	1.00	1.14	1.14	1.18	1.25	1.34	1.39	1.00	1.14	1.34	1.59	1.53	1.68	1.61
- 22	1.00	1.11	1.10	1.12	1.17	1.00	1.14	1.15	1.19	1.26	1.34	1.43	1.00	1.17	1.36	1.61	1.54	1.72	1.63
- 23	1.00	1.13	1.10	1.12	1.17	1.00	1.14	1.16	1.20	1.27	1.35	1.45	1.00	1.17	1.38	1.62	1.56	1.75	1.64
- 24	1.00	1.13	1.10	1.13	1.18	1.00	1.15	1.17	1.20	1.28	1.36	1.45	1.00	1.17	1.40	1.64	1.57	1.76	1.64
- 25	1.00	1.13	1.10	1.13	1.18	1.00	1.17	1.17	1.21	1.29	1.37	1.46	1.00	1.17	1.42	1.66	1.59	1.78	1.67
- 26	1.00	1.13	1.11	1.13	1.19	1.00	1.17	1.18	1.22	1.30	1.38	1.46	1.00	1.17	1.44	1.68	1.60	1.80	1.69
- 27	1.00	1.13	1.12	1.14	1.19	1.00	1.17	1.18	1.23	1.30	1.38	1.46	1.00	1.18	1.46	1.70	1.62	1.81	1.71
- 28	1.00	1.13	1.13	1.14	1.20	1.00	1.17	1.19	1.23	1.31	1.38	1.47	1.00	1.20	1.50	1.71	1.64	1.83	1.73
- 29	1.00	1.14	1.13	1.15	1.20	1.00	1.17	1.20	1.24	1.32	1.39	1.47	1.00	1.20	1.50	1.73	1.65	1.87	1.73

	COV ≤ 100%					100% < COV ≤ 200%							COV > 200 %						
Concbin[1]	**0**	**1**	**2**	**3**	**4**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**0**	**1**	**2**	**3**	**4**	**5**	**6**
- 30	1.00	1.14	1.13	1.15	1.23	1.00	1.17	1.20	1.25	1.33	1.40	1.48	1.00	1.20	1.53	1.75	1.67	1.90	1.76
- 31	1.00	1.14	1.14	1.16	1.23	1.00	1.18	1.20	1.26	1.34	1.42	1.49	1.00	1.20	1.55	1.76	1.69	1.91	1.77
- 32	1.00	1.14	1.14	1.16	1.23	1.00	1.20	1.20	1.27	1.35	1.42	1.51	1.00	1.20	1.57	1.78	1.70	1.93	1.78
- 33	1.00	1.14	1.15	1.16	1.24	1.00	1.20	1.21	1.28	1.36	1.43	1.51	1.00	1.20	1.60	1.80	1.73	1.96	1.79
- 34	1.00	1.14	1.15	1.17	1.24	1.00	1.20	1.22	1.28	1.36	1.44	1.51	1.00	1.20	1.62	1.81	1.74	1.97	1.79
- 35	1.00	1.15	1.16	1.17	1.24	1.00	1.20	1.23	1.29	1.38	1.44	1.54	1.00	1.20	1.64	1.83	1.77	1.99	1.80
- 36	1.00	1.17	1.17	1.18	1.24	1.00	1.20	1.24	1.30	1.38	1.46	1.54	1.00	1.22	1.67	1.85	1.78	2.02	1.81
- 37	1.00	1.17	1.17	1.18	1.25	1.00	1.20	1.25	1.31	1.39	1.46	1.55	1.00	1.24	1.69	1.87	1.80	2.05	1.82
- 38	1.00	1.17	1.17	1.19	1.26	1.04	1.20	1.26	1.32	1.40	1.48	1.55	1.00	1.25	1.71	1.88	1.82	2.08	1.82
- 39	1.00	1.17	1.18	1.19	1.29	1.08	1.20	1.27	1.33	1.41	1.49	1.56	1.00	1.27	1.74	1.90	1.84	2.10	1.83
- 40	1.00	1.17	1.18	1.19	1.29	1.11	1.22	1.27	1.34	1.42	1.50	1.57	1.00	1.29	1.76	1.92	1.86	2.14	1.84
- 41	1.00	1.17	1.18	1.20	1.29	1.13	1.22	1.29	1.35	1.43	1.51	1.57	1.00	1.29	1.80	1.94	1.88	2.16	1.84
- 42	1.00	1.17	1.18	1.21	1.30	1.18	1.24	1.29	1.36	1.44	1.52	1.58	1.00	1.33	1.82	1.96	1.90	2.18	1.87
- 43	1.00	1.17	1.19	1.21	1.30	1.22	1.25	1.30	1.37	1.45	1.53	1.60	1.00	1.33	1.84	1.98	1.93	2.20	1.89
- 44	1.00	1.17	1.20	1.22	1.31	1.25	1.25	1.30	1.38	1.46	1.55	1.64	1.00	1.33	1.87	2.00	1.95	2.21	1.91
- 45	1.00	1.20	1.20	1.22	1.31	1.25	1.27	1.31	1.39	1.47	1.57	1.64	1.00	1.34	1.90	2.02	1.97	2.23	1.91
- 46	1.00	1.20	1.20	1.23	1.32	1.25	1.29	1.33	1.40	1.48	1.57	1.65	1.00	1.38	1.92	2.04	1.99	2.24	1.93
- 47	1.00	1.20	1.20	1.23	1.32	1.25	1.29	1.33	1.41	1.49	1.58	1.67	1.00	1.40	1.94	2.06	2.01	2.26	1.94
- 48	1.00	1.20	1.20	1.24	1.34	1.25	1.29	1.35	1.42	1.50	1.59	1.68	1.00	1.40	2.00	2.08	2.04	2.28	1.96
- 49	1.00	1.20	1.21	1.24	1.35	1.29	1.33	1.36	1.43	1.51	1.61	1.68	1.00	1.40	2.00	2.10	2.06	2.30	1.96
- 50	1.00	1.20	1.21	1.25	1.35	1.33	1.33	1.36	1.44	1.52	1.62	1.69	1.00	1.40	2.03	2.12	2.09	2.31	1.97
- 51	1.00	1.20	1.22	1.25	1.36	1.33	1.33	1.38	1.46	1.54	1.62	1.72	1.00	1.43	2.07	2.14	2.12	2.34	1.97
- 52	1.00	1.20	1.23	1.26	1.37	1.33	1.33	1.40	1.47	1.55	1.63	1.72	1.00	1.44	2.09	2.17	2.15	2.36	1.98
- 53	1.00	1.20	1.24	1.27	1.39	1.33	1.33	1.40	1.48	1.56	1.64	1.74	1.00	1.50	2.11	2.19	2.18	2.38	2.01
- 54	1.00	1.20	1.25	1.27	1.40	1.33	1.37	1.41	1.50	1.57	1.65	1.74	1.00	1.50	2.15	2.21	2.21	2.41	2.02
- 55	1.00	1.20	1.25	1.28	1.41	1.33	1.38	1.42	1.51	1.58	1.67	1.76	1.00	1.50	2.18	2.24	2.24	2.43	2.04
- 56	1.00	1.20	1.25	1.28	1.42	1.42	1.40	1.44	1.52	1.60	1.68	1.78	1.00	1.56	2.20	2.26	2.27	2.44	2.06
- 57	1.00	1.22	1.27	1.29	1.42	1.43	1.40	1.45	1.54	1.61	1.70	1.81	1.00	1.57	2.24	2.29	2.30	2.47	2.08
- 58	1.05	1.22	1.27	1.30	1.45	1.50	1.40	1.47	1.55	1.62	1.71	1.82	1.04	1.60	2.27	2.31	2.34	2.50	2.09
- 59	1.11	1.24	1.27	1.31	1.45	1.50	1.40	1.49	1.57	1.63	1.73	1.82	1.11	1.60	2.30	2.34	2.36	2.53	2.13
- 60	1.20	1.25	1.29	1.31	1.46	1.50	1.40	1.50	1.58	1.65	1.74	1.83	1.17	1.63	2.34	2.37	2.40	2.57	2.14
- 61	1.25	1.25	1.29	1.32	1.46	1.50	1.43	1.50	1.60	1.66	1.75	1.83	1.25	1.67	2.38	2.39	2.44	2.60	2.15
- 62	1.25	1.25	1.30	1.32	1.47	1.50	1.43	1.53	1.61	1.67	1.75	1.86	1.25	1.67	2.41	2.42	2.48	2.62	2.17

	COV ≤ 100%					100% < COV ≤ 200%							COV > 200 %						
Concbin[1]	0	1	2	3	4	0	1	2	3	4	5	6	0	1	2	3	4	5	6
- 63	1.25	1.29	1.30	1.33	1.52	1.50	1.45	1.55	1.63	1.69	1.77	1.90	1.25	1.74	2.45	2.45	2.52	2.64	2.17
- 64	1.25	1.29	1.31	1.34	1.54	1.50	1.50	1.56	1.65	1.70	1.79	1.93	1.33	1.78	2.50	2.48	2.56	2.67	2.19
- 65	1.30	1.29	1.31	1.35	1.55	1.50	1.50	1.58	1.67	1.71	1.81	1.93	1.33	1.80	2.53	2.51	2.60	2.70	2.21
- 66	1.33	1.33	1.33	1.36	1.57	1.50	1.50	1.60	1.68	1.72	1.82	1.93	1.33	1.83	2.56	2.54	2.66	2.73	2.24
- 67	1.33	1.33	1.33	1.37	1.58	1.58	1.55	1.62	1.70	1.74	1.83	1.96	1.33	1.86	2.60	2.57	2.71	2.77	2.27
- 68	1.33	1.33	1.35	1.38	1.58	1.67	1.57	1.64	1.72	1.76	1.86	1.99	1.42	1.89	2.64	2.61	2.76	2.80	2.28
- 69	1.33	1.33	1.36	1.39	1.60	1.67	1.58	1.67	1.74	1.78	1.88	2.02	1.50	2.00	2.69	2.64	2.80	2.84	2.30
- 70	1.33	1.33	1.36	1.40	1.64	1.67	1.60	1.68	1.76	1.79	1.90	2.02	1.50	2.00	2.73	2.68	2.85	2.88	2.31
- 71	1.43	1.33	1.38	1.42	1.64	1.75	1.60	1.70	1.78	1.81	1.92	2.04	1.50	2.00	2.77	2.72	2.89	2.90	2.33
- 72	1.50	1.38	1.39	1.42	1.65	1.85	1.63	1.73	1.80	1.83	1.93	2.06	1.50	2.10	2.82	2.76	2.95	2.93	2.33
- 73	1.50	1.38	1.40	1.44	1.65	2.00	1.67	1.75	1.82	1.84	1.96	2.07	1.50	2.14	2.87	2.80	3.01	2.97	2.35
- 74	1.50	1.40	1.40	1.44	1.65	2.00	1.67	1.78	1.85	1.86	1.98	2.07	1.50	2.18	2.92	2.84	3.06	2.99	2.37
- 75	1.50	1.40	1.42	1.46	1.66	2.00	1.71	1.80	1.87	1.88	2.00	2.08	1.50	2.22	2.96	2.89	3.11	3.02	2.41
- 76	1.50	1.40	1.43	1.47	1.67	2.00	1.75	1.83	1.90	1.90	2.02	2.09	1.60	2.29	3.00	2.93	3.16	3.06	2.44
- 77	1.50	1.40	1.45	1.48	1.68	2.00	1.78	1.86	1.92	1.93	2.05	2.11	1.67	2.34	3.07	2.97	3.22	3.10	2.49
- 78	1.50	1.40	1.46	1.50	1.69	2.00	1.80	1.90	1.96	1.95	2.06	2.13	1.71	2.40	3.13	3.03	3.30	3.16	2.52
- 79	1.50	1.43	1.48	1.52	1.70	2.00	1.83	1.92	1.98	1.97	2.08	2.16	1.85	2.46	3.18	3.09	3.35	3.19	2.53
- 80	1.50	1.44	1.50	1.52	1.71	2.00	1.86	1.96	2.01	2.00	2.14	2.20	2.00	2.56	3.25	3.14	3.41	3.24	2.55
- 81	1.58	1.50	1.50	1.54	1.74	2.00	1.89	2.00	2.05	2.02	2.15	2.23	2.00	2.60	3.31	3.20	3.47	3.26	2.57
- 82	1.67	1.50	1.53	1.57	1.75	2.00	2.00	2.05	2.08	2.05	2.17	2.25	2.00	2.67	3.38	3.26	3.57	3.32	2.60
- 83	1.75	1.50	1.55	1.59	1.77	2.00	2.00	2.09	2.12	2.08	2.22	2.29	2.00	2.78	3.46	3.33	3.65	3.38	2.64
- 84	2.00	1.55	1.58	1.61	1.77	2.00	2.00	2.14	2.15	2.11	2.25	2.29	2.00	2.83	3.54	3.41	3.72	3.42	2.65
- 85	2.00	1.57	1.60	1.64	1.82	2.00	2.11	2.19	2.20	2.14	2.27	2.31	2.00	3.00	3.62	3.48	3.80	3.49	2.67
- 86	2.00	1.60	1.63	1.67	1.85	2.11	2.17	2.24	2.24	2.17	2.39	2.32	2.00	3.00	3.70	3.57	3.90	3.55	2.70
- 87	2.00	1.60	1.65	1.70	1.86	2.33	2.20	2.30	2.29	2.20	2.47	2.39	2.00	3.17	3.80	3.67	4.00	3.62	2.71
- 88	2.00	1.63	1.69	1.72	1.88	2.50	2.29	2.36	2.35	2.23	2.50	2.39	2.00	3.29	3.90	3.77	4.10	3.69	2.74
- 89	2.00	1.67	1.71	1.76	1.91	2.50	2.35	2.43	2.40	2.27	2.53	2.39	2.00	3.40	4.00	3.90	4.21	3.80	2.82
- 90	2.00	1.71	1.75	1.80	1.98	2.94	2.43	2.50	2.46	2.31	2.58	2.50	2.00	3.56	4.12	4.04	4.35	3.88	2.84
- 91	2.00	1.78	1.80	1.85	2.10	3.00	2.56	2.60	2.54	2.37	2.66	2.51	2.44	3.68	4.25	4.18	4.44	3.94	2.94
- 92	2.00	1.80	1.83	1.89	2.25	3.00	2.65	2.70	2.62	2.43	2.73	2.57	2.67	3.86	4.39	4.35	4.62	4.07	2.98
- 93	2.00	1.86	1.90	1.96	2.26	3.00	2.80	2.81	2.71	2.48	2.77	2.59	3.00	4.00	4.56	4.55	4.82	4.18	3.03
- 94	2.00	2.00	1.95	2.02	2.30	3.33	3.00	2.94	2.81	2.56	2.81	2.65	3.00	4.29	4.76	4.77	5.03	4.28	3.09
- 95	2.00	2.00	2.05	2.10	2.50	4.00	3.14	3.10	2.93	2.66	2.91	2.65	3.75	4.57	5.00	5.03	5.24	4.40	3.13

	COV ≤ 100%					100% < COV ≤ 200%							COV > 200 %						
Concbin[1]	**0**	**1**	**2**	**3**	**4**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**0**	**1**	**2**	**3**	**4**	**5**	**6**
- 96	2.33	2.14	2.14	2.22	2.53	4.00	3.38	3.30	3.08	2.82	3.11	2.66	4.75	4.88	5.27	5.37	5.48	4.48	3.33
- 97	2.67	2.29	2.27	2.37	2.56	5.00	3.67	3.56	3.28	3.01	3.25	2.71	6.00	5.29	5.69	5.80	5.94	4.63	3.38
- 98	3.00	2.50	2.50	2.63	3.12	6.00	4.17	3.93	3.56	3.33	3.30	3.16	10.00	5.86	6.30	6.51	6.48	5.06	3.48
- 99	4.00	2.89	2.91	3.02	3.61	10.00	5.00	4.64	4.07	3.77	3.82	3.27	10.00	6.86	7.27	7.50	7.29	5.36	3.70
- 100	11.67	10.60	10.08	6.81	6.10	11.75	11.67	11.94	11.41	8.51	6.63	3.51	11.75	11.50	11.93	11.45	11.39	6.48	5.39
n[3]	352735	74053	42876	6895	147	802624	259701	179452	53053	3807	398	104	475572	55341	35502	20077	4019	989	341

Notes:

[1] 1-hour SO_2 concentration bins are: 0 = 1-hour mean < 5 ppb; 2 = 5 ≤ 1-hour mean < 10 ppb; 2 = 10 ≤ 1-hour mean < 25 ppb; 3 = 25 ≤ 1-hour mean < 75 ppb; 4 = 75 ≤ 1-hour mean < 150 ppb ; 5 = 150 ≤ 1-hour mean 250 ppb; 6 = 1-hour mean > 250 ppb.

[2] pct – *x* indicates the percentile of the distribution.

[3] *n* is the number of 5-minute maximum and 1-hour SO_2 measurements used to develop distribution.

Table A.3-2. Distribution of 5-minute maximum peak to 1-hour mean SO_2 concentration ratios (PMRs) using ambient monitors categorized by 1-hour geometric standard deviation (GSD) and 1-hour mean concentration.

	GSD ≤ 2.17					2.17 < GSD ≤ 2.94							GSD > 2.94						
Concbin[1]	**0**	**1**	**2**	**3**	**4**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**0**	**1**	**2**	**3**	**4**	**5**	**6**
Pct[2] - 0	1.00	1.00	1.00	1.00	1.01	1.00	1.00	1.00	1.00	1.00	1.05	1.13	1.00	1.00	1.00	1.00	1.00	1.07	1.02
- 1	1.00	1.00	1.00	1.03	1.07	1.00	1.00	1.00	1.00	1.05	1.13	1.19	1.00	1.00	1.00	1.05	1.08	1.14	1.14
- 2	1.00	1.00	1.00	1.04	1.17	1.00	1.00	1.00	1.03	1.08	1.21	1.26	1.00	1.00	1.04	1.07	1.10	1.17	1.16
- 3	1.00	1.00	1.00	1.04	1.21	1.00	1.00	1.00	1.04	1.10	1.23	1.28	1.00	1.00	1.06	1.08	1.12	1.20	1.18
- 4	1.00	1.00	1.00	1.06	1.22	1.00	1.00	1.05	1.05	1.12	1.26	1.29	1.00	1.00	1.07	1.09	1.14	1.21	1.24
- 5	1.00	1.00	1.00	1.07	1.24	1.00	1.00	1.06	1.06	1.14	1.28	1.30	1.00	1.00	1.08	1.10	1.15	1.21	1.25
- 6	1.00	1.00	1.00	1.08	1.25	1.00	1.00	1.06	1.07	1.16	1.29	1.33	1.00	1.00	1.08	1.12	1.17	1.22	1.29
- 7	1.00	1.00	1.04	1.10	1.27	1.00	1.00	1.07	1.08	1.17	1.31	1.34	1.00	1.03	1.09	1.13	1.18	1.23	1.30
- 8	1.00	1.00	1.06	1.11	1.29	1.00	1.00	1.07	1.08	1.18	1.32	1.35	1.00	1.05	1.10	1.14	1.19	1.25	1.31
- 9	1.00	1.00	1.06	1.12	1.30	1.00	1.00	1.08	1.09	1.20	1.34	1.37	1.00	1.07	1.10	1.15	1.20	1.27	1.33
- 10	1.00	1.00	1.07	1.13	1.30	1.00	1.00	1.08	1.10	1.21	1.35	1.38	1.00	1.09	1.11	1.16	1.21	1.28	1.36
- 11	1.00	1.00	1.07	1.14	1.31	1.00	1.00	1.08	1.11	1.23	1.38	1.43	1.00	1.10	1.12	1.17	1.22	1.30	1.37
- 12	1.00	1.00	1.07	1.14	1.32	1.00	1.05	1.09	1.12	1.24	1.39	1.45	1.00	1.11	1.13	1.18	1.24	1.32	1.38
- 13	1.00	1.00	1.08	1.15	1.32	1.00	1.10	1.09	1.12	1.25	1.40	1.46	1.00	1.11	1.14	1.19	1.25	1.35	1.45
- 14	1.00	1.00	1.08	1.16	1.33	1.00	1.11	1.10	1.13	1.26	1.42	1.47	1.00	1.13	1.15	1.20	1.26	1.36	1.46
- 15	1.00	1.00	1.08	1.17	1.34	1.00	1.11	1.10	1.14	1.28	1.43	1.48	1.00	1.13	1.16	1.21	1.27	1.38	1.46
- 16	1.00	1.00	1.08	1.19	1.35	1.00	1.11	1.10	1.15	1.29	1.44	1.50	1.00	1.13	1.17	1.22	1.29	1.39	1.47
- 17	1.00	1.00	1.09	1.19	1.36	1.00	1.13	1.10	1.15	1.30	1.46	1.51	1.00	1.14	1.18	1.23	1.30	1.42	1.49
- 18	1.00	1.00	1.09	1.20	1.36	1.00	1.13	1.11	1.16	1.31	1.47	1.52	1.00	1.14	1.18	1.24	1.31	1.43	1.51
- 19	1.00	1.00	1.09	1.21	1.37	1.00	1.13	1.12	1.17	1.32	1.49	1.53	1.00	1.14	1.19	1.25	1.32	1.44	1.54
- 20	1.00	1.00	1.09	1.22	1.40	1.00	1.13	1.13	1.17	1.34	1.50	1.54	1.00	1.15	1.20	1.26	1.33	1.46	1.55
- 21	1.00	1.00	1.10	1.23	1.43	1.00	1.14	1.13	1.18	1.35	1.52	1.54	1.00	1.16	1.20	1.27	1.34	1.49	1.57
- 22	1.00	1.07	1.10	1.24	1.44	1.00	1.14	1.14	1.19	1.36	1.53	1.56	1.00	1.17	1.21	1.29	1.35	1.50	1.58
- 23	1.00	1.11	1.10	1.25	1.44	1.00	1.14	1.15	1.20	1.38	1.55	1.58	1.00	1.17	1.23	1.30	1.36	1.53	1.60
- 24	1.00	1.11	1.10	1.26	1.46	1.00	1.14	1.15	1.21	1.39	1.57	1.58	1.00	1.17	1.24	1.31	1.37	1.56	1.61
- 25	1.00	1.11	1.10	1.27	1.47	1.00	1.14	1.16	1.21	1.40	1.57	1.58	1.00	1.18	1.25	1.32	1.39	1.58	1.64
- 26	1.00	1.13	1.11	1.28	1.48	1.00	1.17	1.17	1.22	1.41	1.59	1.59	1.00	1.19	1.25	1.33	1.40	1.60	1.64
- 27	1.00	1.13	1.12	1.29	1.49	1.00	1.17	1.17	1.23	1.42	1.60	1.59	1.00	1.20	1.27	1.34	1.41	1.62	1.64
- 28	1.00	1.13	1.13	1.30	1.50	1.00	1.17	1.18	1.24	1.43	1.61	1.61	1.00	1.20	1.27	1.35	1.42	1.64	1.68
- 29	1.00	1.14	1.14	1.30	1.50	1.00	1.17	1.18	1.25	1.44	1.64	1.63	1.00	1.20	1.29	1.37	1.43	1.65	1.68

	GSD ≤ 2.17					2.17 < GSD ≤ 2.94							GSD > 2.94						
Concbin[1]	**0**	**1**	**2**	**3**	**4**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**0**	**1**	**2**	**3**	**4**	**5**	**6**
- 30	1.00	1.14	1.14	1.31	1.52	1.00	1.17	1.18	1.26	1.46	1.65	1.64	1.00	1.20	1.30	1.38	1.45	1.67	1.74
- 31	1.00	1.14	1.15	1.32	1.53	1.00	1.17	1.19	1.27	1.47	1.68	1.65	1.00	1.20	1.30	1.39	1.46	1.71	1.76
- 32	1.00	1.14	1.16	1.33	1.55	1.00	1.17	1.20	1.28	1.48	1.70	1.66	1.00	1.22	1.32	1.40	1.47	1.73	1.77
- 33	1.00	1.14	1.17	1.34	1.57	1.00	1.18	1.20	1.29	1.50	1.72	1.68	1.00	1.23	1.33	1.42	1.48	1.75	1.79
- 34	1.00	1.15	1.17	1.35	1.58	1.00	1.20	1.20	1.30	1.51	1.74	1.69	1.00	1.25	1.34	1.43	1.50	1.76	1.81
- 35	1.00	1.17	1.18	1.36	1.59	1.00	1.20	1.21	1.31	1.52	1.75	1.69	1.00	1.25	1.36	1.44	1.51	1.77	1.83
- 36	1.00	1.17	1.18	1.37	1.60	1.00	1.20	1.21	1.32	1.54	1.76	1.70	1.00	1.26	1.36	1.46	1.52	1.80	1.83
- 37	1.00	1.17	1.18	1.39	1.60	1.00	1.20	1.23	1.32	1.55	1.78	1.72	1.00	1.28	1.38	1.47	1.53	1.82	1.84
- 38	1.00	1.17	1.20	1.40	1.62	1.00	1.20	1.23	1.33	1.57	1.80	1.73	1.03	1.29	1.39	1.49	1.54	1.85	1.90
- 39	1.00	1.17	1.20	1.40	1.63	1.00	1.20	1.25	1.35	1.58	1.82	1.73	1.05	1.29	1.40	1.50	1.56	1.90	1.91
- 40	1.00	1.17	1.20	1.42	1.63	1.00	1.20	1.25	1.36	1.60	1.83	1.74	1.11	1.32	1.42	1.52	1.57	1.92	1.91
- 41	1.00	1.17	1.20	1.43	1.64	1.00	1.20	1.26	1.37	1.61	1.85	1.76	1.11	1.33	1.43	1.53	1.58	1.94	1.93
- 42	1.00	1.18	1.21	1.44	1.65	1.00	1.20	1.27	1.38	1.63	1.86	1.77	1.11	1.33	1.45	1.55	1.60	1.96	1.96
- 43	1.00	1.20	1.22	1.44	1.66	1.00	1.22	1.27	1.39	1.64	1.89	1.78	1.15	1.33	1.46	1.56	1.61	1.99	1.96
- 44	1.00	1.20	1.23	1.46	1.67	1.00	1.22	1.29	1.40	1.66	1.90	1.78	1.18	1.35	1.47	1.58	1.62	2.02	1.96
- 45	1.00	1.20	1.25	1.47	1.70	1.00	1.25	1.29	1.42	1.67	1.91	1.79	1.21	1.37	1.50	1.59	1.64	2.03	1.97
- 46	1.00	1.20	1.25	1.48	1.70	1.04	1.25	1.30	1.43	1.69	1.93	1.80	1.25	1.38	1.50	1.61	1.65	2.08	1.98
- 47	1.00	1.20	1.27	1.50	1.71	1.11	1.25	1.30	1.44	1.70	1.95	1.80	1.25	1.40	1.53	1.63	1.67	2.12	1.98
- 48	1.00	1.20	1.27	1.51	1.72	1.13	1.29	1.31	1.45	1.72	1.97	1.81	1.25	1.40	1.54	1.64	1.68	2.16	2.00
- 49	1.00	1.20	1.27	1.52	1.74	1.20	1.29	1.33	1.47	1.74	1.99	1.82	1.25	1.40	1.56	1.66	1.69	2.17	2.01
- 50	1.00	1.20	1.29	1.54	1.74	1.25	1.29	1.33	1.48	1.75	2.00	1.82	1.29	1.41	1.58	1.68	1.71	2.21	2.03
- 51	1.00	1.20	1.30	1.56	1.75	1.25	1.29	1.35	1.49	1.77	2.02	1.82	1.33	1.43	1.59	1.69	1.72	2.22	2.04
- 52	1.00	1.20	1.30	1.57	1.76	1.25	1.33	1.36	1.51	1.79	2.05	1.83	1.33	1.44	1.61	1.71	1.74	2.24	2.06
- 53	1.00	1.20	1.31	1.59	1.76	1.25	1.33	1.37	1.52	1.81	2.06	1.84	1.33	1.47	1.63	1.73	1.77	2.26	2.08
- 54	1.00	1.20	1.32	1.61	1.77	1.25	1.33	1.38	1.54	1.83	2.09	1.84	1.33	1.50	1.65	1.75	1.78	2.28	2.09
- 55	1.00	1.22	1.33	1.63	1.78	1.29	1.33	1.40	1.56	1.84	2.11	1.87	1.38	1.50	1.67	1.77	1.80	2.31	2.11
- 56	1.00	1.25	1.35	1.65	1.80	1.33	1.33	1.40	1.57	1.86	2.14	1.88	1.43	1.50	1.69	1.79	1.82	2.37	2.14
- 57	1.00	1.25	1.36	1.67	1.81	1.33	1.38	1.42	1.59	1.88	2.15	1.89	1.43	1.54	1.71	1.80	1.84	2.38	2.15
- 58	1.00	1.27	1.37	1.69	1.81	1.33	1.38	1.43	1.61	1.90	2.17	1.91	1.48	1.57	1.73	1.82	1.86	2.41	2.16
- 59	1.07	1.29	1.38	1.71	1.83	1.33	1.40	1.45	1.62	1.92	2.19	1.91	1.50	1.58	1.76	1.84	1.88	2.43	2.18
- 60	1.14	1.29	1.40	1.72	1.83	1.33	1.40	1.46	1.64	1.94	2.21	1.93	1.50	1.60	1.79	1.86	1.91	2.47	2.19
- 61	1.22	1.32	1.40	1.74	1.84	1.33	1.40	1.47	1.66	1.96	2.22	1.94	1.50	1.60	1.81	1.88	1.93	2.50	2.20
- 62	1.25	1.33	1.42	1.75	1.91	1.43	1.40	1.50	1.68	1.98	2.25	1.95	1.50	1.63	1.83	1.90	1.96	2.52	2.26

	GSD ≤ 2.17					2.17 < GSD ≤ 2.94							GSD > 2.94						
Concbin[1]	0	1	2	3	4	0	1	2	3	4	5	6	0	1	2	3	4	5	6
- 63	1.25	1.33	1.44	1.78	1.93	1.50	1.40	1.50	1.70	1.99	2.27	1.96	1.50	1.67	1.86	1.92	1.98	2.56	2.28
- 64	1.29	1.33	1.45	1.80	1.93	1.50	1.43	1.52	1.72	2.02	2.29	2.00	1.54	1.67	1.89	1.95	2.01	2.59	2.29
- 65	1.33	1.33	1.47	1.81	1.99	1.50	1.43	1.54	1.74	2.04	2.31	2.02	1.62	1.70	1.92	1.97	2.04	2.62	2.31
- 66	1.33	1.38	1.50	1.84	2.00	1.50	1.44	1.56	1.76	2.07	2.32	2.04	1.67	1.72	1.94	2.00	2.07	2.63	2.31
- 67	1.33	1.40	1.50	1.87	2.05	1.50	1.50	1.58	1.79	2.10	2.35	2.06	1.67	1.76	1.99	2.02	2.10	2.67	2.33
- 68	1.33	1.40	1.53	1.89	2.08	1.50	1.50	1.60	1.81	2.12	2.37	2.07	1.71	1.80	2.00	2.04	2.14	2.70	2.35
- 69	1.36	1.40	1.55	1.91	2.09	1.50	1.50	1.62	1.83	2.15	2.41	2.08	1.80	1.80	2.03	2.07	2.18	2.72	2.36
- 70	1.50	1.40	1.58	1.94	2.11	1.50	1.56	1.64	1.85	2.17	2.43	2.11	1.86	1.83	2.07	2.10	2.21	2.77	2.37
- 71	1.50	1.40	1.60	1.97	2.15	1.50	1.57	1.67	1.88	2.20	2.44	2.13	2.00	1.86	2.10	2.13	2.24	2.81	2.39
- 72	1.50	1.43	1.62	2.00	2.18	1.50	1.60	1.69	1.91	2.23	2.49	2.14	2.00	1.89	2.14	2.15	2.29	2.85	2.41
- 73	1.50	1.43	1.64	2.02	2.19	1.67	1.60	1.71	1.94	2.26	2.51	2.15	2.00	1.98	2.18	2.18	2.33	2.90	2.44
- 74	1.50	1.49	1.67	2.04	2.23	1.67	1.60	1.73	1.97	2.30	2.55	2.17	2.00	2.00	2.21	2.21	2.37	2.93	2.50
- 75	1.50	1.50	1.69	2.07	2.26	1.68	1.67	1.77	2.00	2.33	2.61	2.17	2.00	2.00	2.25	2.25	2.42	2.98	2.51
- 76	1.50	1.50	1.71	2.10	2.27	1.75	1.67	1.80	2.03	2.36	2.63	2.21	2.00	2.03	2.29	2.28	2.48	3.01	2.53
- 77	1.50	1.56	1.73	2.12	2.28	2.00	1.71	1.82	2.06	2.41	2.69	2.23	2.00	2.13	2.33	2.32	2.54	3.03	2.53
- 78	1.50	1.57	1.77	2.15	2.31	2.00	1.75	1.86	2.10	2.46	2.73	2.24	2.00	2.17	2.38	2.36	2.60	3.09	2.54
- 79	1.67	1.60	1.80	2.19	2.40	2.00	1.80	1.90	2.13	2.49	2.75	2.27	2.00	2.20	2.43	2.40	2.68	3.12	2.56
- 80	1.75	1.60	1.83	2.22	2.46	2.00	1.80	1.93	2.17	2.54	2.79	2.27	2.00	2.24	2.49	2.44	2.77	3.17	2.58
- 81	2.00	1.63	1.87	2.27	2.47	2.00	1.83	2.00	2.22	2.60	2.84	2.30	2.00	2.31	2.54	2.48	2.85	3.21	2.60
- 82	2.00	1.67	1.91	2.30	2.47	2.00	1.86	2.00	2.26	2.67	2.87	2.31	2.29	2.37	2.60	2.53	2.95	3.25	2.64
- 83	2.00	1.71	1.94	2.36	2.49	2.00	1.96	2.08	2.31	2.72	2.89	2.33	2.50	2.40	2.65	2.58	3.05	3.30	2.65
- 84	2.00	1.77	2.00	2.43	2.53	2.00	2.00	2.11	2.36	2.78	2.92	2.37	2.50	2.50	2.71	2.63	3.13	3.35	2.69
- 85	2.00	1.80	2.00	2.48	2.68	2.00	2.00	2.18	2.41	2.85	2.97	2.44	2.75	2.57	2.79	2.69	3.24	3.39	2.71
- 86	2.00	1.83	2.09	2.56	2.74	2.00	2.11	2.23	2.47	2.90	3.00	2.48	3.00	2.63	2.87	2.75	3.35	3.46	2.73
- 87	2.00	1.86	2.13	2.63	2.78	2.00	2.17	2.30	2.54	2.97	3.11	2.56	3.00	2.73	2.94	2.82	3.47	3.54	2.81
- 88	2.00	1.97	2.20	2.69	2.81	2.00	2.20	2.38	2.60	3.06	3.19	2.59	3.33	2.83	3.00	2.89	3.62	3.59	2.84
- 89	2.00	2.00	2.27	2.79	2.85	2.00	2.30	2.45	2.68	3.14	3.25	2.62	3.33	2.94	3.10	2.96	3.73	3.68	2.84
- 90	2.00	2.00	2.33	2.88	2.96	2.25	2.40	2.54	2.76	3.26	3.31	2.66	4.00	3.00	3.20	3.06	3.86	3.78	2.94
- 91	2.00	2.14	2.42	2.97	3.06	2.50	2.50	2.64	2.86	3.36	3.41	2.67	4.67	3.18	3.31	3.16	4.03	3.88	2.97
- 92	2.00	2.20	2.54	3.08	3.24	2.50	2.60	2.75	2.96	3.44	3.55	2.68	5.00	3.33	3.46	3.28	4.22	3.98	3.02
- 93	2.00	2.29	2.64	3.24	3.39	3.00	2.78	2.89	3.08	3.59	3.67	2.70	5.50	3.50	3.61	3.41	4.41	4.10	3.06
- 94	2.25	2.40	2.79	3.50	3.55	3.00	2.92	3.02	3.22	3.74	3.84	2.71	10.00	3.71	3.77	3.57	4.65	4.18	3.12
- 95	2.50	2.56	2.93	3.61	3.68	3.00	3.14	3.21	3.40	3.92	3.92	3.01	10.00	4.00	4.00	3.78	4.94	4.35	3.16

	GSD ≤ 2.17					2.17 < GSD ≤ 2.94							GSD > 2.94						
Concbin[1]	**0**	**1**	**2**	**3**	**4**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**0**	**1**	**2**	**3**	**4**	**5**	**6**
- 96	3.00	2.71	3.13	3.91	3.93	3.50	3.40	3.44	3.62	4.12	4.22	3.11	10.00	4.25	4.23	4.07	5.23	4.44	3.27
- 97	3.00	3.00	3.40	4.23	4.13	4.00	3.75	3.73	3.93	4.35	4.38	3.41	10.00	4.67	4.57	4.48	5.59	4.58	3.33
- 98	3.50	3.29	3.85	4.71	4.49	5.00	4.20	4.17	4.37	4.84	4.52	3.44	10.00	5.22	5.04	5.06	6.11	4.89	3.35
- 99	4.00	4.00	4.68	5.58	5.09	6.00	5.14	5.00	5.20	5.50	5.13	3.79	10.00	6.20	5.91	6.19	6.89	5.45	3.51
- 100	11.75	11.57	11.94	10.14	6.10	11.75	11.50	11.93	11.41	9.67	6.48	5.39	11.67	11.67	11.93	11.45	11.39	6.63	3.62
n[3]	456580	54454	16117	1925	150	876986	271059	186098	49555	3888	613	219	297365	63582	55615	28545	3952	759	224

Notes:

[1] 1-hour SO_2 concentration bins are: 0 = 1-hour mean < 5 ppb; 2 = 5 ≤ 1-hour mean < 10 ppb; 2 = 10 ≤ 1-hour mean < 25 ppb; 3 = 25 ≤ 1-hour mean < 75 ppb; 4 = 75 ≤ 1-hour mean < 150 ppb ; 5 = 150 ≤ 1-hour mean 250 ppb; 6 = 1-hour mean > 250 ppb.

[2] pct – *x* indicates the percentile of the distribution.

[3] *n* is the number of 5-minute maximum and 1-hour SO_2 measurements used to develop distribution.

A.4 Factors Used in Adjusting Air Quality to Just Meet the Current and Potential Alternative SO_2 Air Quality Standards

The adjustment factors used for simulating just meeting particular forms and levels of SO_2 standards are described here in two sections. This was done given the difference in how the adjustment factors were derived and applied to each of the air quality scenarios and given the number of factors generated for the potential alternative standards. The first section includes the factors used for adjusting air quality to just meet the current standards (either the 24-hour or annual average), while the second section note the concentrations used in deriving the factors applied to simulate just meeting potential alternative standards.

A.4.1 Adjustment factors for just meeting the current standard

Both annual and daily adjustment factors were calculated for all selected counties in evaluating the current annual and daily standards however, the lowest value of the two was selected for use in adjusting concentrations (see REA section 7.2.4). The adjustment factors for each county, year, and the standard from which the factors were derived is given in Table A.4-1. In addion, the coefficient of variation (i.e., COV) was used as a measure to indicate the variability associated with each of the calculated factors when considering all of the monitors in a county. Within a given year, the COV generally indicates the extent of spatial variability in ambient concentrations, considering the number of monitors in operation. Variation in the COV across different years can indicate the temporal variability in a county however, year-to-year differences in the number and location of ambient monitors may confound this comparison. Lower COVs indicate similarity in that concentration metric in the county, while higher values indicate less homogeneity in concentrations (whether spatially or temporally).

Table A.4-1. Adjustment factors used in simulating air quality just meeting the current SO_2 NAAQS in selected counties by year.

State Abbreviation	County	Year	Monitors (n)	Adjustment Factor	COV	Closest Standard[1]
AZ	Gila	2001	2	3.12	4	D
AZ	Gila	2002	2	3.53	5	A
AZ	Gila	2003	2	3.82	12	A
AZ	Gila	2004	2	3.04	21	A
AZ	Gila	2005	2	3.33	5	D
AZ	Gila	2006	2	4.40	1	D
DE	New Castle	2001	4	3.38	16	D
DE	New Castle	2002	4	2.67	9	D

State Abbreviation	County	Year	Monitors (n)	Adjustment Factor	COV	Closest Standard[1]
DE	New Castle	2003	5	2.75	9	D
DE	New Castle	2004	4	2.58	13	D
DE	New Castle	2005	4	2.73	11	D
DE	New Castle	2006	4	2.68	14	D
FL	Hillsborough	2001	7	3.14	13	D
FL	Hillsborough	2002	7	3.09	16	D
FL	Hillsborough	2003	6	3.09	19	D
FL	Hillsborough	2004	6	4.95	32	D
FL	Hillsborough	2005	6	4.40	25	D
FL	Hillsborough	2006	6	4.19	29	D
IL	Madison	2001	4	3.51	7	D
IL	Madison	2002	4	2.88	12	D
IL	Madison	2003	3	3.60	6	D
IL	Madison	2004	3	3.61	18	D
IL	Madison	2005	3	4.19	11	D
IL	Madison	2006	3	4.90	16	D
IL	Wabash	2001	2	3.25	1	D
IL	Wabash	2002	2	3.33	3	D
IL	Wabash	2003	2	2.95	5	D
IL	Wabash	2004	2	3.98	1	D
IL	Wabash	2005	2	3.80	7	D
IL	Wabash	2006	2	3.01	5	D
IN	Floyd	2001	3	3.98	2	D
IN	Floyd	2002	3	4.85	6	D
IN	Floyd	2003	3	4.14	5	D
IN	Floyd	2004	2	5.04	6	A
IN	Floyd	2005	3	3.98	11	A
IN	Floyd	2006	3	3.64	5	D
IN	Gibson	2001	2	2.34	6	D
IN	Gibson	2002	2	2.68	19	D
IN	Gibson	2003	2	1.17	13	D
IN	Gibson	2004	2	2.99	10	D
IN	Gibson	2005	2	4.78	3	D
IN	Gibson	2006	2	1.67	16	D
IN	Lake	2001	2	4.87	0	D
IN	Lake	2002	2	4.43	17	D
IN	Lake	2003	2	4.94	7	D
IN	Lake	2004	2	4.39	14	D
IN	Lake	2005	2	3.39	16	D
IN	Lake	2006	1	8.12	0	A
IN	Vigo	2001	2	2.47	16	D
IN	Vigo	2002	2	4.65	18	A
IN	Vigo	2003	2	4.06	13	A
IN	Vigo	2004	2	5.28	1	D
IN	Vigo	2005	2	4.57	5	D
IN	Vigo	2006	2	6.97	5	D
IA	Linn	2001	5	3.53	18	D
IA	Linn	2002	3	4.70	5	D

State Abbreviation	County	Year	Monitors (n)	Adjustment Factor	COV	Closest Standard[1]
IA	Linn	2003	3	3.45	5	D
IA	Linn	2004	3	2.29	10	D
IA	Linn	2005	3	3.41	9	D
IA	Linn	2006	3	4.10	35	D
IA	Muscatine	2001	3	4.20	12	D
IA	Muscatine	2002	3	3.87	11	D
IA	Muscatine	2003	3	4.09	11	D
IA	Muscatine	2004	3	2.78	16	D
IA	Muscatine	2005	3	2.90	17	D
IA	Muscatine	2006	3	2.94	10	D
MI	Wayne	2001	6	3.21	9	D
MI	Wayne	2002	3	2.97	15	D
MI	Wayne	2003	3	3.30	5	D
MI	Wayne	2004	3	2.99	12	D
MI	Wayne	2005	3	3.35	7	D
MI	Wayne	2006	3	2.95	13	D
MO	Greene	2001	3	3.57	17	D
MO	Greene	2002	5	3.47	32	D
MO	Greene	2003	5	5.12	26	D
MO	Greene	2004	5	5.29	29	D
MO	Greene	2005	5	4.87	34	D
MO	Greene	2006	5	4.46	19	D
MO	Iron	2001	2	2.26	0	D
MO	Iron	2002	2	2.11	2	D
MO	Iron	2003	2	2.44	2	D
MO	Iron	2004	2	7.96	22	A
MO	Jefferson	2001	3	5.74	10	D
MO	Jefferson	2002	1	3.89	0	D
MO	Jefferson	2003	1	5.65	0	D
MO	Jefferson	2004	1	1.87	0	D
MO	Jefferson	2005	1	2.13	0	D
MO	Jefferson	2006	1	1.93	0	D
NH	Merrimack	2001	2	3.07	21	D
NH	Merrimack	2002	3	3.71	18	D
NH	Merrimack	2003	3	3.31	10	D
NH	Merrimack	2004	2	2.59	17	D
NH	Merrimack	2005	2	2.70	18	D
NH	Merrimack	2006	2	2.51	28	D
NJ	Hudson	2001	2	3.39	6	A
NJ	Hudson	2002	1	5.26	0	A
NJ	Hudson	2003	2	3.52	6	A
NJ	Hudson	2004	2	3.67	4	A
NJ	Hudson	2005	2	3.67	1	A
NJ	Hudson	2006	2	6.25	5	D
NJ	Union	2001	2	3.71	7	A
NJ	Union	2002	2	3.52	11	A
NJ	Union	2003	2	3.70	8	A
NJ	Union	2004	2	3.99	8	A

State Abbreviation	County	Year	Monitors (n)	Adjustment Factor	COV	Closest Standard[1]
NJ	Union	2005	2	4.12	7	A
NJ	Union	2006	2	7.98	4	D
NY	Bronx	2001	1	2.95	0	A
NY	Bronx	2002	2	3.04	3	A
NY	Bronx	2003	2	2.82	1	D
NY	Bronx	2004	2	2.96	3	A
NY	Bronx	2005	1	3.26	0	A
NY	Bronx	2006	2	3.44	6	A
NY	Chautauqua	2001	3	1.85	12	D
NY	Chautauqua	2002	2	2.34	18	D
NY	Chautauqua	2003	2	2.30	13	D
NY	Chautauqua	2004	2	3.42	16	D
NY	Chautauqua	2005	2	5.78	11	D
NY	Chautauqua	2006	2	9.47	2	D
NY	Erie	2001	2	2.66	13	D
NY	Erie	2002	2	2.01	16	D
NY	Erie	2003	2	1.85	16	D
NY	Erie	2004	2	3.65	20	D
NY	Erie	2005	2	4.14	14	D
NY	Erie	2006	2	4.72	17	D
OH	Cuyahoga	2001	5	4.05	6	D
OH	Cuyahoga	2002	5	5.10	11	A
OH	Cuyahoga	2003	5	3.98	5	D
OH	Cuyahoga	2004	4	4.54	11	D
OH	Cuyahoga	2005	4	3.43	6	D
OH	Cuyahoga	2006	4	4.25	8	D
OH	Lake	2001	2	3.78	8	A
OH	Lake	2002	2	3.34	15	A
OH	Lake	2003	2	2.79	10	D
OH	Lake	2004	2	3.05	13	D
OH	Lake	2005	2	1.87	13	D
OH	Lake	2006	2	2.51	16	D
OH	Summit	2001	2	3.25	3	D
OH	Summit	2002	2	2.39	8	D
OH	Summit	2003	2	2.65	2	D
OH	Summit	2004	2	2.75	11	D
OH	Summit	2005	2	3.76	14	A
OH	Summit	2006	2	3.79	9	D
OK	Tulsa	2001	3	4.16	10	A
OK	Tulsa	2002	3	4.51	2	D
OK	Tulsa	2003	3	3.65	6	D
OK	Tulsa	2004	3	4.07	3	D
OK	Tulsa	2005	3	4.57	4	A
OK	Tulsa	2006	4	5.69	59	D
PA	Allegheny	2001	7	2.72	5	D
PA	Allegheny	2002	5	2.80	4	A
PA	Allegheny	2003	7	2.23	5	D
PA	Allegheny	2004	7	2.81	6	D

State Abbreviation	County	Year	Monitors (n)	Adjustment Factor	COV	Closest Standard[1]
PA	Allegheny	2005	7	2.17	7	D
PA	Allegheny	2006	6	2.97	8	D
PA	Beaver	2001	3	2.01	5	D
PA	Beaver	2002	3	1.91	6	D
PA	Beaver	2003	3	1.73	6	D
PA	Beaver	2004	3	2.64	6	A
PA	Beaver	2005	3	2.42	7	A
PA	Beaver	2006	3	2.67	8	D
PA	Northampton	2001	2	2.15	28	A
PA	Northampton	2002	2	5.01	0	A
PA	Northampton	2003	2	3.73	18	A
PA	Northampton	2004	2	2.28	21	A
PA	Northampton	2005	2	3.55	3	A
PA	Northampton	2006	2	0.98	19	D
PA	Warren	2001	2	1.66	11	D
PA	Warren	2002	2	1.45	15	D
PA	Warren	2003	2	1.40	11	D
PA	Warren	2004	2	2.37	15	D
PA	Warren	2005	2	1.91	17	D
PA	Warren	2006	2	1.68	19	D
PA	Washington	2001	3	2.95	6	A
PA	Washington	2002	3	3.11	6	A
PA	Washington	2003	3	2.99	8	A
PA	Washington	2004	3	3.42	2	A
PA	Washington	2005	3	3.07	5	D
PA	Washington	2006	3	3.48	6	A
TN	Blount	2001	2	1.62	18	D
TN	Blount	2002	2	2.05	10	D
TN	Blount	2003	2	1.88	12	D
TN	Blount	2004	2	2.22	1	D
TN	Blount	2005	2	1.61	7	D
TN	Blount	2006	2	1.79	10	D
TN	Shelby	2001	3	3.47	19	D
TN	Shelby	2002	3	4.79	20	D
TN	Shelby	2003	3	3.75	21	D
TN	Shelby	2004	3	4.46	20	D
TN	Shelby	2005	4	3.90	46	D
TN	Shelby	2006	3	4.12	44	D
TN	Sullivan	2001	2	2.95	8	A
TN	Sullivan	2002	2	3.26	10	D
TN	Sullivan	2003	2	3.28	4	D
TN	Sullivan	2004	2	3.33	3	D
TN	Sullivan	2005	2	3.72	4	D
TN	Sullivan	2006	2	3.33	3	D
TX	Jefferson	2001	3	2.68	8	D
TX	Jefferson	2002	3	4.82	4	D
TX	Jefferson	2003	3	4.30	4	D
TX	Jefferson	2004	3	4.47	13	D

State Abbreviation	County	Year	Monitors (n)	Adjustment Factor	COV	Closest Standard[1]
TX	Jefferson	2005	3	5.67	7	D
TX	Jefferson	2006	3	4.31	4	D
VA	Fairfax	2001	2	4.50	18	A
VA	Fairfax	2002	2	4.49	14	A
VA	Fairfax	2003	3	4.89	15	A
VA	Fairfax	2004	3	4.80	19	A
VA	Fairfax	2005	3	4.79	19	A
VA	Fairfax	2006	3	5.35	18	A
WV	Brooke	2001	2	2.13	5	A
WV	Brooke	2002	2	2.49	4	A
WV	Brooke	2003	2	2.63	3	A
WV	Brooke	2004	2	2.02	6	A
WV	Brooke	2005	2	2.16	5	A
WV	Brooke	2006	2	2.50	8	A
WV	Hancock	2001	9	2.20	3	A
WV	Hancock	2002	9	2.38	3	D
WV	Hancock	2003	9	2.30	3	D
WV	Hancock	2004	7	2.38	4	A
WV	Hancock	2005	7	2.22	5	A
WV	Hancock	2006	7	2.34	4	A
WV	Monongalia	2001	3	2.37	3	D
WV	Monongalia	2002	2	2.22	2	D
WV	Monongalia	2003	2	3.26	1	D
WV	Monongalia	2004	2	3.25	1	D
WV	Monongalia	2005	2	3.13	3	A
WV	Monongalia	2006	2	3.20	1	D
WV	Wayne	2001	4	2.85	4	D
WV	Wayne	2002	4	3.31	3	A
WV	Wayne	2003	4	3.41	7	D
WV	Wayne	2004	3	2.87	9	D
WV	Wayne	2005	3	2.02	11	D
VI	St Croix	2001	5	3.41	83	D
VI	St Croix	2002	5	3.46	64	D
VI	St Croix	2003	5	3.66	66	D
VI	St Croix	2004	5	3.26	56	D
VI	St Croix	2005	5	9.25	15	D
VI	St Croix	2006	5	4.59	25	D

Notes:
[1] Ambient SO_2 concentrations were closest to either the annual (A) or daily (D) NAAQS level.

A.4.2 Adjustment factors for just meeting the potential alternative standards

Five potential alternative standards (i.e., 50, 100, 150, 200, and 250 ppb daily maximum 1-hour) given a 99th percentile form and one alternative standard (200 ppb daily maximum 1-hour) given a 98th percentile form were selected for evaluation (for details, see REA chapter 5). Adjustment factors were derived for each of two 3-year groups of recent air quality (i.e., 2001-2003 and 2004-2006). For the sake of brevity, only the maximum 3-year averaged concentrations for each of the percentile forms are provided in Table A.4-2, rather than all of the adjustment factors. The actual adjustment factors used in simulating air quality can be derived for each of the concentration levels by dividing by the county concentration for each year goup. For example, the adjustement factor applied to the 2002 hourly mean concentrations in New Castle DE to simulate just meeting a 99th percentile daily maximum 1-hour of 100 ppb is 100/164 = 0.61. That is to say, to meet this particular standard, the hourly concentrations need to be adjusted downward by a factor of 0.61. The COV is also used to represent the temporal variability over the three years of monitoring (where such data exist).

Table A.4-2. Concentrations used in developing adjustment factors when simulating air quality just meeting potential alternative SO_2 NAAQS in selected counties by year.

State Abbreviation	County	Year Group	98th Percentile Years (n)	98th Percentile Conc (ppb)	98th Percentile COV (%)	99th Percentile Years (n)	99th Percentile Conc (ppb)	99th Percentile COV (%)
AZ	Gila	2001-2003	3	226	10	3	260	10
AZ	Gila	2004-2006	2	222	6	2	294	1
DE	New Castle	2001-2003	2	138	5	2	164	0
DE	New Castle	2004-2006	3	123	20	3	147	31
FL	Hillsborough	2001-2003	3	117	12	3	146	2
FL	Hillsborough	2004-2006	2	93	8	2	128	8
IA	Linn	2001-2003	3	82	21	3	105	12
IA	Linn	2004-2006	3	96	17	3	111	27
IA	Muscatine	2001-2003	3	92	13	3	113	9
IA	Muscatine	2004-2006	3	120	10	3	135	8
IL	Madison	2001-2003	3	110	22	3	144	24
IL	Madison	2004-2006	3	123	5	3	144	7
IL	Wabash	2001-2003	1	139		1	216	
IL	Wabash	2004-2006	1	131		1	187	
IN	Floyd	2001-2003	3	124	17	1	151	
IN	Floyd	2004-2006	3	129	14	3	170	6
IN	Gibson	2001-2003	2	185	12	2	235	19

State Abbreviation	County	Year Group	98th Percentile Years (n)	98th Percentile Conc (ppb)	98th Percentile COV (%)	99th Percentile Years (n)	99th Percentile Conc (ppb)	99th Percentile COV (%)
IN	Gibson	2004-2006	1	199		1	226	
IN	Lake	2001-2003	3	68	5	2	84	52
IN	Lake	2004-2006	2	87	1	2	113	3
IN	Vigo	2001-2003	3	114	7	3	159	25
IN	Vigo	2004-2006	2	110	8	2	136	2
MI	Wayne	2001-2003	2	102	3	2	126	4
MI	Wayne	2004-2006	3	115	2	3	128	2
MO	Greene	2001-2003	3	81	13	3	94	13
MO	Greene	2004-2006	3	63	29	3	81	25
MO	Iron	2001-2003	3	289	20	3	341	9
MO	Iron	2004-2006	1	20		1	22	
MO	Jefferson	2001-2003	1	230		1	234	
MO	Jefferson	2004-2006	3	244	10	3	346	16
NH	Merrimack	2001-2003	3	110	30	3	125	34
NH	Merrimack	2004-2006	3	127	2	3	151	9
NJ	Hudson	2001-2003	2	54	9	2	61	1
NJ	Hudson	2004-2006	2	51	3	2	65	1
NJ	Union	2001-2003	3	52	13	3	57	7
NJ	Union	2004-2006	2	49	10	2	60	9
NY	Bronx	2001-2003	2	64	1	2	71	7
NY	Bronx	2004-2006	2	59	7	2	68	2
NY	Chautauqua	2001-2003	3	238	2	3	285	12
NY	Chautauqua	2004-2006	3	84	47	3	101	54
NY	Erie	2001-2003	3	206	10	3	225	8
NY	Erie	2004-2006	3	114	33	3	129	24
OH	Cuyahoga	2001-2003	2	76	1	2	101	1
OH	Cuyahoga[1]	2004-2006	3	67	8	3	80	9
OH	Cuyahoga[1]	2004-2006	3	67	18			
OH	Lake	2001-2003	3	129	10	3	145	4
OH	Lake	2004-2006	3	146	5	3	175	9
OH	Summit	2001-2003	3	131	12	3	148	12
OH	Summit	2004-2006	3	133	9	3	150	13
OK	Tulsa	2001-2003	3	63	22	3	76	7
OK	Tulsa	2004-2006	2	82	32	2	93	33
PA	Allegheny	2001-2003	1	149		1	164	
PA	Allegheny	2004-2006	2	144	16	2	183	36
PA	Beaver	2001-2003	3	200	28	3	245	31
PA	Beaver	2004-2006	3	188	6	3	228	8
PA	Northampton	2001-2003	3	55	9	3	65	3
PA	Northampton	2004-2006	3	92	41	3	146	65
PA	Warren	2001-2003	3	218	6	3	270	12
PA	Warren	2004-2006	3	180	22	3	226	15
PA	Washington	2001-2003	3	99	10	3	111	11
PA	Washington	2004-2006	3	89	10	3	102	11
TN	Blount	2001-2003	1	189		1	204	
TN	Blount	2004-2006	3	168	5	3	194	6
TN	Shelby	2001-2003	3	70	29	3	101	35

State Abbreviation	County	Year Group	98th Percentile Years (n)	98th Percentile Conc (ppb)	98th Percentile COV (%)	99th Percentile Years (n)	99th Percentile Conc (ppb)	99th Percentile COV (%)
TN	Shelby[1]	2004-2006	3	72	35	3	85	33
TN	Shelby[1]	2004-2006	3	72	2			
TN	Sullivan	2001-2003	3	157	13	3	195	19
TN	Sullivan	2004-2006	3	145	7	3	208	17
TX	Jefferson	2001-2003	3	92	20	3	103	16
TX	Jefferson	2004-2006	3	109	49	3	129	46
VA	Fairfax	2001-2003	3	38	15	3	48	24
VA	Fairfax	2004-2006	3	37	8	3	41	11
VI	St Croix	2001-2003	2	103	6	2	126	18
VI	St Croix	2004-2006	1	70		1	130	
WV	Brooke	2001-2003	3	154	20	3	180	17
WV	Brooke	2004-2006	3	125	8	3	158	19
WV	Hancock	2001-2003	3	182	17	3	217	23
WV	Hancock	2004-2006	3	134	24	3	159	19
WV	Monongalia	2001-2003	3	163	22	3	218	26
WV	Monongalia	2004-2006	2	148	3	2	188	16
WV	Wayne	2001-2003	3	93	7	3	109	14
WV	Wayne	2004-2006	2	67	11	2	75	0

Notes:
[1] Two monitors in the county had the same average 98th percentile daily 1-hour maximum concentrations. Concentrations, monitoring years, and COVs for both monitors are indicated.

A.5 Supplementary Results Tables for 5-minute Measurement Data

Table A.5-1. Annual average SO_2 concentrations and number of measured 5-minute daily maximum SO_2 concentrations above potential health effect benchmark levels. Data used were from 98 monitors that reported both the 5-minute maximum and 1-hour SO_2 concentrations for years 1997 through 2007.

State	County	Monitor ID	Year	Days (n)	Hours (n)	Annual Hourly (ppb)				Number of 5-minute Daily Maximum			
						Mean	std	GM	GSD	> 100 ppb	> 200 ppb	> 300 ppb	> 400 ppb
AR	Pulaski	051190007	2002	339	7138	2.76	1.43	2.44	1.65	1	0	0	0
AR	Pulaski	051190007	2003	365	7799	2.47	1.3	2.18	1.64	0	0	0	0
AR	Pulaski	051190007	2004	359	7687	2.08	1.61	1.69	1.84	0	0	0	0
AR	Pulaski	051190007	2005	350	6702	1.91	1.17	1.65	1.69	0	0	0	0
AR	Pulaski	051190007	2006	365	8356	3.2	1.13	3.03	1.39	0	0	0	0
AR	Pulaski	051190007	2007	90	2062	2.88	1.12	2.71	1.39	0	0	0	0
AR	Pulaski	051191002	1997	365	6607	2.33	1.5	1.99	1.74	0	0	0	0
AR	Pulaski	051191002	1998	329	5997	1.62	1.3	1.35	1.74	0	0	0	0
AR	Pulaski	051191002	1999	275	3833	2.31	1.51	1.85	2.04	0	0	0	0
AR	Pulaski	051191002	2000	352	5596	2.38	1.63	1.77	2.44	0	0	0	0
AR	Pulaski	051191002	2001	364	6529	2.28	1.18	2.02	1.63	0	0	0	0
AR	Union	051390006	1997	365	7624	5.27	11.3	3.28	2.15	30	11	5	0
AR	Union	051390006	1998	313	6766	6.4	7.45	5.14	1.73	17	3	1	0
AR	Union	051390006	1999	275	5101	5.39	6.94	3.66	2.44	12	1	0	0
AR	Union	051390006	2000	357	5792	6.21	10.95	3.76	2.29	44	7	2	0
AR	Union	051390006	2001	364	7474	3.09	3.86	2.28	2.06	5	1	1	1
AR	Union	051390006	2002	275	6296	2.92	2.27	2.5	1.65	1	0	0	0
AR	Union	051390006	2003	364	7239	2.14	5.13	1.59	1.88	2	2	2	1
AR	Union	051390006	2004	334	4267	2.15	2.74	1.63	1.89	3	2	0	0
AR	Union	051390006	2005	249	4922	2.36	2.58	1.94	1.76	2	1	0	0
AR	Union	051390006	2006	365	8364	2.89	2.19	2.61	1.49	1	1	1	0
AR	Union	051390006	2007	90	2061	2.99	1.3	2.81	1.39	0	0	0	0
CO	Denver	080310002	1997	365	7014	6.77	9.36	3.75	2.86	23	0	0	0
CO	Denver	080310002	1998	360	4311	7.37	9.45	4.29	2.79	18	2	0	0
CO	Denver	080310002	1999	156	1626	6.77	8.21	4.01	2.76	3	0	0	0
CO	Denver	080310002	2000	137	2434	6.53	8.62	3.84	2.69	4	0	0	0
CO	Denver	080310002	2001	360	5575	6.63	8.85	3.84	2.75	8	0	0	0
CO	Denver	080310002	2002	365	6830	5.36	7.27	3.11	2.67	6	0	0	0
CO	Denver	080310002	2003	362	6250	3.83	4.62	2.54	2.34	1	0	0	0
CO	Denver	080310002	2004	337	4412	3.68	4.09	2.48	2.31	0	0	0	0

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						Mean	std	GM	GSD	> 100 ppb	> 200 ppb	> 300 ppb	> 400 ppb
CO	Denver	080310002	2005	337	3599	3.92	4.2	2.57	2.42	0	0	0	0
CO	Denver	080310002	2006	349	6199	3.38	3.62	2.33	2.26	1	0	0	0
DE	New Castle	100031008	1997	330	7490	10.29	17.99	5.23	2.86	103	33	1	0
DE	New Castle	100031008	1998	257	4898	8.86	14.99	4.35	3.03	64	16	2	0
DC	District of Columbia	110010041	2000	160	3731	8.64	6.17	7.25	1.77	1	0	0	0
DC	District of Columbia	110010041	2001	358	7774	7	6.51	4.83	2.45	3	1	1	0
DC	District of Columbia	110010041	2002	365	8365	6.89	5.62	5.29	2.11	1	0	0	0
DC	District of Columbia	110010041	2003	181	4267	8.63	5.92	7.28	1.75	5	1	1	1
DC	District of Columbia	110010041	2004	119	2765	7.88	5.51	6.3	2.06	1	0	0	0
DC	District of Columbia	110010041	2007	268	6394	5.05	3.74	4.24	1.76	1	1	1	0
FL	Nassau	120890005	2002	357	8415	6.39	15.33	2.65	2.95	69	23	6	2
FL	Nassau	120890005	2003	365	8662	3.44	8.95	1.6	2.5	26	5	1	0
FL	Nassau	120890005	2004	275	6507	3.2	7.18	1.68	2.37	11	5	1	1
FL	Nassau	120890005	2005	175	4120	4.06	10.16	1.65	2.71	26	4	0	0
IA	Cerro Gordo	190330018	2001	38	513	1.22	3.38	0.44	3.16	0	0	0	0
IA	Cerro Gordo	190330018	2002	254	3325	1.16	3.83	0.33	4.07	0	0	0	0
IA	Cerro Gordo	190330018	2003	296	5032	1.88	7.57	0.27	4.83	4	0	0	0
IA	Cerro Gordo	190330018	2004	366	8141	0.8	2.84	0.23	3.4	0	0	0	0
IA	Cerro Gordo	190330018	2005	173	3528	0.69	1.49	0.31	3.16	0	0	0	0
IA	Clinton	190450019	2001	70	1276	2.14	1.69	1.52	2.54	0	0	0	0
IA	Clinton	190450019	2002	345	6516	3.29	3.37	1.96	3.02	3	0	0	0
IA	Clinton	190450019	2003	333	5939	2.89	3.2	1.68	3.14	4	1	0	0
IA	Clinton	190450019	2004	353	7093	2.83	3.06	1.67	3.12	3	0	0	0
IA	Clinton	190450019	2005	177	3323	3.99	4.31	2.35	3.11	2	0	0	0
IA	Muscatine	191390016	2001	91	1733	3.27	4.61	1.89	2.93	0	0	0	0
IA	Muscatine	191390016	2002	365	7391	4.07	5.36	2.78	2.39	4	0	0	0
IA	Muscatine	191390016	2003	353	6570	3.87	7.01	2.21	2.86	4	0	0	0
IA	Muscatine	191390016	2004	365	6664	3.92	5.67	2.43	2.7	5	0	0	0
IA	Muscatine	191390016	2005	181	3629	4.22	7.55	2.34	2.79	9	0	0	0
IA	Muscatine	191390017	2001	83	1373	2.14	1.86	1.42	2.66	0	0	0	0
IA	Muscatine	191390017	2002	364	7242	3.12	3.82	2.05	2.62	3	1	0	0
IA	Muscatine	191390017	2003	365	7586	3.93	4.26	2.69	2.51	4	0	0	0
IA	Muscatine	191390017	2004	363	7322	3.56	3.92	2.24	2.79	2	0	0	0
IA	Muscatine	191390017	2005	181	3441	3.16	4.14	2.03	2.59	4	0	0	0

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IA	Muscatine	191390020	2001	92	1909	5.36	9.76	2.04	3.95	1	0	0	0
IA	Muscatine	191390020	2002	363	7682	5.27	10.27	2.22	3.61	31	1	0	0
IA	Muscatine	191390020	2003	365	7695	5.31	11.2	2.11	3.71	42	5	0	0
IA	Muscatine	191390020	2004	366	7757	7.36	15.39	3.02	3.2	60	14	0	0
IA	Muscatine	191390020	2005	181	3931	5.55	13.61	2.02	3.64	27	12	1	0
IA	Scott	191630015	2001	85	1345	1.15	2.13	0.45	4	0	0	0	0
IA	Scott	191630015	2002	364	7505	2.28	3.17	0.87	4.7	0	0	0	0
IA	Scott	191630015	2003	364	7451	2.09	2.68	1.02	3.79	0	0	0	0
IA	Scott	191630015	2004	336	6696	2.11	2.65	1.06	3.68	0	0	0	0
IA	Scott	191630015	2005	177	3436	2.56	3.05	1.17	4.17	0	0	0	0
IA	Van Buren	191770005	2001	65	597	0.9	0.92	0.64	2.33	0	0	0	0
IA	Van Buren	191770005	2002	353	6350	1.03	0.92	0.72	2.48	0	0	0	0
IA	Van Buren	191770005	2003	358	7118	1.1	0.91	0.78	2.48	0	0	0	0
IA	Van Buren	191770005	2004	305	5011	0.88	1.45	0.5	2.87	0	0	0	0
IA	Van Buren	191770006	2004	53	877	0.85	0.94	0.55	2.53	0	0	0	0
IA	Van Buren	191770006	2005	181	3349	0.9	0.79	0.69	2.09	0	0	0	0
IA	Woodbury	191930018	2001	85	1578	1.32	2.28	0.77	2.45	0	0	0	0
IA	Woodbury	191930018	2002	280	3875	1.5	2.94	0.7	3.14	0	0	0	0
LA	West Baton Rouge	221210001	1997	277	4966	7.04	12.51	3.94	2.65	42	13	4	1
LA	West Baton Rouge	221210001	1998	353	7566	7.52	10.67	5.03	2.29	50	18	2	1
LA	West Baton Rouge	221210001	1999	354	7272	6.4	9.59	4.01	2.44	55	12	1	1
LA	West Baton Rouge	221210001	2000	361	7360	7.3	11.13	4.51	2.46	76	26	7	1
MO	Buchanan	290210009	1997	361	8484	8.3	31.64	2.77	2.8	94	79	57	39
MO	Buchanan	290210009	1998	364	8161	7.06	24.17	2.8	2.64	92	67	44	19
MO	Buchanan	290210009	1999	362	7415	2.77	3.07	2.08	2	3	0	0	0
MO	Buchanan	290210009	2000	264	5297	2.37	3.04	1.81	1.88	7	0	0	0
MO	Buchanan	290210011	2000	72	1672	5.27	8.53	3.45	2.15	8	0	0	0
MO	Buchanan	290210011	2001	329	6412	3.7	5.3	2.52	2.15	6	0	0	0
MO	Buchanan	290210011	2002	331	6457	4.01	7.33	2.52	2.23	21	0	0	0
MO	Buchanan	290210011	2003	253	5141	4.06	7.04	2.59	2.25	13	0	0	0
MO	Greene	290770026	1997	339	4763	4.32	9.65	2.02	2.69	20	2	0	0
MO	Greene	290770026	1998	350	5810	5.73	11.66	2.35	3.07	39	1	0	0
MO	Greene	290770026	1999	362	7242	4.09	7.53	2.22	2.5	13	1	0	0
MO	Greene	290770026	2000	366	8721	4.97	10.21	2.41	2.67	52	1	0	0

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MO	Greene	290770026	2001	365	8304	4.52	9.62	2.17	2.63	36	0	0	0
MO	Greene	290770026	2002	360	7054	4.28	9.08	1.94	2.72	27	0	0	0
MO	Greene	290770026	2003	362	7935	3.5	6.16	2.02	2.36	5	0	0	0
MO	Greene	290770026	2004	274	6574	3.21	6.41	1.64	2.45	3	0	0	0
MO	Greene	290770026	2005	365	8756	2.95	5.94	1.58	2.35	5	0	0	0
MO	Greene	290770026	2006	365	8753	3.15	6.77	1.58	2.42	8	0	0	0
MO	Greene	290770026	2007	272	6520	3.2	7.07	1.59	2.43	9	0	0	0
MO	Greene	290770037	1997	356	6559	4.98	14.73	1.89	2.78	52	21	8	5
MO	Greene	290770037	1998	361	8134	4.27	7.37	2.76	2.18	30	2	0	0
MO	Greene	290770037	1999	363	8554	3.13	7.72	1.72	2.23	31	3	0	0
MO	Greene	290770037	2000	341	5318	6.36	17.9	2.13	3.04	46	23	3	0
MO	Greene	290770037	2001	355	6707	4.04	10.65	1.91	2.49	37	9	2	0
MO	Greene	290770037	2002	335	6373	4	9.68	2.15	2.27	40	11	1	0
MO	Greene	290770037	2003	363	8179	3.32	6.96	1.93	2.21	19	1	0	0
MO	Greene	290770037	2004	274	6575	2.71	4.79	1.79	2.05	13	0	0	0
MO	Greene	290770037	2005	365	8760	3.05	6.06	1.93	2.11	20	1	0	0
MO	Greene	290770037	2006	365	8745	3.26	8.44	1.57	2.38	37	4	0	0
MO	Greene	290770037	2007	272	6496	2.42	6.03	1.37	2.08	16	0	0	0
MO	Iron	290930030	1997	365	8575	8.24	26.43	3.12	2.89	93	78	63	54
MO	Iron	290930030	1998	365	8475	7.9	25.09	2.73	2.99	85	70	62	52
MO	Iron	290930030	1999	356	6546	9.33	28.07	3.29	3.09	83	74	63	49
MO	Iron	290930030	2000	324	4071	14.3	46.11	3.2	3.95	95	77	69	55
MO	Iron	290930030	2001	356	5388	9.32	32.18	2.37	3.41	88	74	64	56
MO	Iron	290930030	2002	354	7960	6.95	23.55	2.2	2.98	99	73	58	52
MO	Iron	290930030	2003	363	6963	7.58	23.2	2.69	2.94	99	81	64	48
MO	Iron	290930030	2004	90	1846	2.47	2.56	1.76	2.11	0	0	0	0
MO	Iron	290930031	1997	352	6177	8.09	24.57	2.92	3.17	77	55	37	27
MO	Iron	290930031	1998	363	7991	7.56	22.94	3.03	2.94	88	57	37	22
MO	Iron	290930031	1999	341	7918	8.41	25.99	3.93	2.63	92	54	37	23
MO	Iron	290930031	2000	332	5170	8.27	24.93	2.81	3.21	86	53	35	23
MO	Iron	290930031	2001	365	8426	6.62	23.42	2.47	2.79	95	60	40	22
MO	Iron	290930031	2002	365	8665	6.32	18.53	3.19	2.35	88	54	28	19
MO	Iron	290930031	2003	350	8230	6.6	21.05	2.89	2.64	88	54	39	23
MO	Iron	290930031	2004	91	2172	3.82	2.74	3.2	1.74	0	0	0	0

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MO	Jefferson	290990004	2004	346	8033	10.32	22.63	4.78	2.96	106	41	26	13
MO	Jefferson	290990004	2005	351	7144	11.41	24.87	4.62	3.34	118	68	47	28
MO	Jefferson	290990004	2006	343	6524	13.12	27.2	4.3	4.02	134	78	53	41
MO	Jefferson	290990004	2007	90	2125	6.31	11.92	3.08	2.88	21	8	4	1
MO	Jefferson	290990014	1997	359	7174	8.38	19	4.14	2.79	87	54	31	23
MO	Jefferson	290990014	1998	365	7770	4.57	9.67	2.62	2.48	37	23	13	6
MO	Jefferson	290990014	1999	363	7591	4.6	9.49	2.48	2.57	32	19	11	5
MO	Jefferson	290990014	2000	361	6588	3.87	7.06	2.36	2.35	28	7	4	2
MO	Jefferson	290990014	2001	132	2433	3.15	5.64	1.95	2.25	7	1	0	0
MO	Jefferson	290990017	1998	289	5721	7.37	18.87	3.47	2.87	59	33	22	16
MO	Jefferson	290990017	1999	360	7289	8.65	22.19	3.8	3.01	90	57	42	29
MO	Jefferson	290990017	2000	355	7153	6.06	16.54	2.87	2.77	59	40	26	17
MO	Jefferson	290990017	2001	74	1044	7.72	16.53	3.69	3.02	13	9	5	3
MO	Jefferson	290990018	2001	219	3492	5.33	11.74	2.53	2.84	34	18	9	6
MO	Jefferson	290990018	2002	352	6305	5.51	14.84	2.59	2.75	56	36	24	18
MO	Jefferson	290990018	2003	272	6009	4.41	10.38	2.4	2.54	27	18	10	9
MO	Monroe	291370001	1997	364	8280	2.92	2.86	2.38	1.79	0	0	0	0
MO	Monroe	291370001	1998	364	8411	2.35	2.25	1.86	1.87	0	0	0	0
MO	Monroe	291370001	1999	365	8714	3.58	2.36	3.13	1.63	0	0	0	0
MO	Monroe	291370001	2000	366	8617	2.93	2.06	2.54	1.65	0	0	0	0
MO	Monroe	291370001	2001	309	4346	1.78	1.44	1.47	1.74	0	0	0	0
MO	Monroe	291370001	2002	321	5358	1.81	1.48	1.48	1.75	0	0	0	0
MO	Monroe	291370001	2003	336	5948	1.82	1.48	1.51	1.73	0	0	0	0
MO	Monroe	291370001	2004	316	5123	2.29	2.31	1.77	1.91	0	0	0	0
MO	Monroe	291370001	2005	348	6518	2.03	1.81	1.63	1.81	0	0	0	0
MO	Monroe	291370001	2006	338	6169	1.73	1.26	1.47	1.68	0	0	0	0
MO	Monroe	291370001	2007	51	526	1.86	2	1.48	1.8	0	0	0	0
MO	Pike	291630002	2005	311	4879	4.37	5.43	2.89	2.33	5	0	0	0
MO	Pike	291630002	2006	348	6469	3.94	4.67	2.78	2.2	3	0	0	0
MO	Pike	291630002	2007	68	1019	3.08	3.69	2.09	2.24	0	0	0	0
MO	Saint Charles	291830010	1997	365	8152	4.35	7.95	2.6	2.45	5	1	1	1
MO	Saint Charles	291830010	1998	230	4810	4.32	5.69	2.77	2.38	1	0	0	0
MO	Saint Charles	291831002	1997	365	8514	5.72	6.95	3.65	2.5	23	2	1	0
MO	Saint Charles	291831002	1998	362	8122	6.31	7.9	4.02	2.5	25	0	0	0

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MO	Saint Charles	291831002	1999	363	7969	5.61	7.24	3.58	2.5	17	2	0	0
MO	Saint Charles	291831002	2000	331	6421	4.6	5.45	3.01	2.42	5	0	0	0
MT	Yellowstone	301110066	1997	362	6873	8.06	10.76	4.4	3	45	7	1	1
MT	Yellowstone	301110066	1998	357	7198	7.14	9.49	4	2.9	42	5	1	0
MT	Yellowstone	301110066	1999	352	5767	7.75	9.65	4.31	2.99	34	5	0	0
MT	Yellowstone	301110066	2000	355	6099	7.72	10.26	4.25	2.97	66	7	2	1
MT	Yellowstone	301110066	2001	365	6872	7.77	10.46	4.13	3.06	56	4	0	0
MT	Yellowstone	301110066	2002	364	8347	6.81	11.61	3.46	3.04	52	4	2	1
MT	Yellowstone	301110066	2003	347	5691	7.37	9.92	4.06	2.93	39	2	0	0
MT	Yellowstone	301110079	1997	180	3166	3.84	4.06	2.65	2.28	1	0	0	0
MT	Yellowstone	301110079	2001	55	837	4.64	3.71	3.43	2.23	0	0	0	0
MT	Yellowstone	301110079	2002	353	8034	1.9	1.91	1.48	1.83	0	0	0	0
MT	Yellowstone	301110079	2003	350	5107	3.02	2.55	2.3	2.06	0	0	0	0
MT	Yellowstone	301110080	1997	363	5433	7.54	10.11	4.29	2.86	59	11	3	0
MT	Yellowstone	301110080	1998	358	5371	6.85	9.12	3.98	2.79	38	14	6	0
MT	Yellowstone	301110080	1999	350	5588	6.36	7.81	3.79	2.75	47	7	4	2
MT	Yellowstone	301110080	2000	360	5999	6.22	7.65	3.68	2.74	59	10	1	0
MT	Yellowstone	301110080	2001	150	2015	5.55	6.3	3.54	2.56	12	2	1	1
MT	Yellowstone	301110082	2001	169	2605	4.19	4.62	2.87	2.32	1	0	0	0
MT	Yellowstone	301110082	2002	365	8212	2.32	2.77	1.7	1.99	0	0	0	0
MT	Yellowstone	301110082	2003	361	5173	2.93	3.25	2.11	2.11	1	1	0	0
MT	Yellowstone	301110083	1999	112	2087	8.07	8.01	5.01	2.81	4	0	0	0
MT	Yellowstone	301110083	2000	341	3845	4.68	5.36	3	2.49	10	1	1	1
MT	Yellowstone	301110083	2001	357	5604	4.36	5.59	2.71	2.51	11	1	0	0
MT	Yellowstone	301110083	2002	360	6847	2.31	3.21	1.65	1.98	1	0	0	0
MT	Yellowstone	301110083	2003	166	1641	2.29	3.08	1.62	1.99	0	0	0	0
MT	Yellowstone	301110084	2003	99	759	2.99	4.51	1.99	2.19	0	0	0	0
MT	Yellowstone	301110084	2004	294	2465	3.48	5.45	2.14	2.37	2	0	0	0
MT	Yellowstone	301110084	2005	291	2577	2.96	4.98	1.79	2.28	2	0	0	0
MT	Yellowstone	301110084	2006	273	1983	2.75	4.56	1.71	2.23	1	0	0	0
MT	Yellowstone	301112008	1997	177	2579	3.96	4.57	2.65	2.35	2	0	0	0
NC	Forsyth	370670022	1997	362	7822	7.06	6.91	5.13	2.2	10	0	0	0
NC	Forsyth	370670022	1998	364	7122	6.98	7.54	4.72	2.48	13	1	1	1
NC	Forsyth	370670022	1999	352	6428	5.85	5.92	4.13	2.29	3	0	0	0

State	County	Monitor ID	Year	Days (n)	Hours (n)	Annual Hourly (ppb)				Number of 5-minute Daily Maximum			
						Mean	std	GM	GSD	> 100 ppb	> 200 ppb	> 300 ppb	> 400 ppb
NC	Forsyth	370670022	2000	266	5203	5.52	5.58	3.77	2.39	1	0	0	0
NC	Forsyth	370670022	2001	361	7634	5.12	5.64	3.46	2.38	5	0	0	0
NC	Forsyth	370670022	2002	362	7022	6.12	8.19	3.87	2.51	15	3	0	0
NC	Forsyth	370670022	2003	363	8075	5.87	6.19	4.17	2.24	11	0	0	0
NC	Forsyth	370670022	2004	259	4710	5.56	8.21	3.37	2.55	6	1	0	0
NC	New Hanover	371290006	1999	360	8208	4.1	8.34	1.92	2.73	54	8	4	3
NC	New Hanover	371290006	2000	335	7980	4.67	8.92	2.13	2.87	76	6	3	0
NC	New Hanover	371290006	2001	358	8168	5.71	13.73	2.08	3.09	109	54	10	3
NC	New Hanover	371290006	2002	352	8028	6.44	13.85	2.61	3.12	127	39	7	2
ND	Billings	380070002	1998	143	1940	1.31	1.04	1.16	1.48	0	0	0	0
ND	Billings	380070002	1999	276	3216	1.38	1.04	1.21	1.53	0	0	0	0
ND	Billings	380070002	2000	248	2724	1.42	1.1	1.24	1.56	0	0	0	0
ND	Billings	380070002	2001	283	2860	1.37	1.12	1.2	1.51	0	0	0	0
ND	Billings	380070002	2002	275	3113	1.43	1.11	1.26	1.53	0	0	0	0
ND	Billings	380070002	2003	26	341	1.48	0.87	1.32	1.54	0	0	0	0
ND	Billings	380070002	2004	164	1256	1.24	0.85	1.13	1.41	0	0	0	0
ND	Billings	380070002	2005	128	835	1.44	0.92	1.27	1.55	0	0	0	0
ND	Billings	380070002	2006	106	418	1.53	1.25	1.29	1.64	0	0	0	0
ND	Billings	380070002	2007	43	221	1.5	1.26	1.29	1.6	0	0	0	0
ND	Billings	380070003	1997	167	2657	1.72	1.52	1.43	1.7	0	0	0	0
ND	Burke	380130002	1999	297	3852	2.79	4.61	1.65	2.31	3	0	0	0
ND	Burke	380130002	2000	347	5268	2.96	5.77	1.77	2.27	7	1	1	0
ND	Burke	380130002	2001	338	5653	2.72	4.97	1.62	2.25	3	1	0	0
ND	Burke	380130002	2002	346	5367	2.64	4.72	1.58	2.24	4	0	0	0
ND	Burke	380130002	2003	353	6328	2.6	4.77	1.62	2.16	7	1	0	0
ND	Burke	380130002	2004	340	5229	2.77	5.03	1.65	2.26	6	0	0	0
ND	Burke	380130002	2005	263	3098	2.88	4.99	1.67	2.33	4	0	0	0
ND	Burke	380130004	2003	63	882	2.89	3.99	1.84	2.26	0	0	0	0
ND	Burke	380130004	2004	315	3198	2.76	3.59	1.83	2.21	0	0	0	0
ND	Burke	380130004	2005	244	2238	2.47	3.18	1.72	2.09	0	0	0	0
ND	Burke	380130004	2006	302	3152	2.27	3.16	1.59	2.02	1	0	0	0
ND	Burke	380130004	2007	99	1227	3.8	5.18	2.27	2.53	1	0	0	0
ND	Burleigh	380150003	2005	60	683	3.4	2.97	2.47	2.2	0	0	0	0
ND	Burleigh	380150003	2006	294	3686	2.33	2.6	1.68	2.04	0	0	0	0

State	County	Monitor ID	Year	Days (n)	Hours (n)	Annual Hourly (ppb)				Number of 5-minute Daily Maximum			
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ND	Burleigh	380150003	2007	97	947	3.77	4.32	2.49	2.36	0	0	0	0
ND	Cass	380171003	1997	206	2254	1.74	2.31	1.32	1.79	0	0	0	0
ND	Cass	380171003	1998	132	2943	1.88	1.83	1.5	1.8	0	0	0	0
ND	Cass	380171004	1998	162	2501	1.11	0.43	1.07	1.27	0	0	0	0
ND	Cass	380171004	1999	246	3325	1.32	0.75	1.2	1.46	0	0	0	0
ND	Cass	380171004	2000	213	1868	1.37	0.84	1.23	1.5	0	0	0	0
ND	Cass	380171004	2001	203	1686	1.34	0.93	1.2	1.49	0	0	0	0
ND	Cass	380171004	2002	274	2476	1.12	0.43	1.08	1.27	0	0	0	0
ND	Cass	380171004	2003	200	1297	1.25	0.82	1.15	1.41	0	0	0	0
ND	Cass	380171004	2004	256	3140	1.21	0.6	1.13	1.37	0	0	0	0
ND	Cass	380171004	2005	146	928	1.24	0.68	1.15	1.41	0	0	0	0
ND	Cass	380171004	2006	358	7385	0.39	0.42	0.28	2.19	0	0	0	0
ND	Cass	380171004	2007	116	2256	0.55	0.74	0.33	2.6	0	0	0	0
ND	Dunn	380250003	1997	224	3313	1.38	1.14	1.2	1.54	0	0	0	0
ND	Dunn	380250003	1998	242	2688	1.78	2.07	1.39	1.79	0	0	0	0
ND	Dunn	380250003	1999	323	5099	1.5	1.56	1.26	1.62	0	0	0	0
ND	Dunn	380250003	2000	353	7455	1.4	1.44	1.2	1.55	0	0	0	0
ND	Dunn	380250003	2001	276	3575	1.6	1.48	1.34	1.66	0	0	0	0
ND	Dunn	380250003	2002	334	4484	1.31	1.09	1.16	1.48	0	0	0	0
ND	Dunn	380250003	2003	355	7289	1.5	1.28	1.29	1.58	0	0	0	0
ND	Dunn	380250003	2004	347	6019	1.34	1.13	1.17	1.51	0	0	0	0
ND	Dunn	380250003	2005	183	1314	1.48	1.53	1.23	1.62	0	0	0	0
ND	Dunn	380250003	2006	262	2213	1.53	1.57	1.26	1.65	0	0	0	0
ND	Dunn	380250003	2007	79	667	1.65	1.5	1.37	1.69	0	0	0	0
ND	McKenzie	380530002	1997	238	2552	1.5	1.23	1.28	1.61	0	0	0	0
ND	McKenzie	380530002	1998	144	1989	1.66	1.57	1.36	1.7	0	0	0	0
ND	McKenzie	380530002	2001	108	754	1.31	0.84	1.18	1.47	0	0	0	0
ND	McKenzie	380530002	2002	262	3361	1.23	0.77	1.13	1.4	0	0	0	0
ND	McKenzie	380530002	2003	305	5345	1.5	1.29	1.28	1.6	0	0	0	0
ND	McKenzie	380530002	2004	303	4614	1.4	1.19	1.22	1.55	0	0	0	0
ND	McKenzie	380530002	2005	225	2515	1.29	0.82	1.17	1.46	0	0	0	0
ND	McKenzie	380530002	2006	276	2896	1.28	0.85	1.16	1.45	0	0	0	0
ND	McKenzie	380530002	2007	73	511	1.64	1.34	1.38	1.67	0	0	0	0
ND	McKenzie	380530104	1998	224	1525	2.38	4.92	1.59	2.04	4	0	0	0

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						Mean	std	GM	GSD	> 100 ppb	> 200 ppb	> 300 ppb	> 400 ppb
ND	McKenzie	380530104	1999	240	1500	2.3	3.7	1.66	1.97	3	3	1	0
ND	McKenzie	380530104	2000	294	2755	1.96	4.07	1.44	1.85	5	2	1	1
ND	McKenzie	380530104	2001	283	2281	1.68	1.75	1.38	1.72	1	0	0	0
ND	McKenzie	380530104	2002	236	1526	1.9	4.04	1.34	1.83	9	2	0	0
ND	McKenzie	380530104	2003	293	2333	1.98	5.29	1.3	1.84	15	3	1	0
ND	McKenzie	380530104	2004	271	2231	1.34	1.34	1.19	1.49	1	0	0	0
ND	McKenzie	380530104	2005	245	1900	1.32	2.32	1.14	1.46	2	0	0	0
ND	McKenzie	380530104	2006	234	1827	1.32	1.78	1.14	1.46	4	1	0	0
ND	McKenzie	380530104	2007	71	764	1.44	1.13	1.26	1.56	0	0	0	0
ND	McKenzie	380530111	1998	258	2063	3.11	7.34	1.8	2.29	7	2	0	0
ND	McKenzie	380530111	1999	294	2379	2.36	5.4	1.56	2.02	7	2	1	1
ND	McKenzie	380530111	2000	329	2805	2.68	8.27	1.65	2.1	7	5	4	2
ND	McKenzie	380530111	2001	336	3183	1.81	2.09	1.4	1.81	0	0	0	0
ND	McKenzie	380530111	2002	297	2255	1.87	3.52	1.38	1.8	8	3	1	0
ND	McKenzie	380530111	2003	288	2243	2.03	3.84	1.44	1.87	7	2	1	0
ND	McKenzie	380530111	2004	308	2857	1.82	5.94	1.27	1.72	3	1	1	0
ND	McKenzie	380530111	2005	296	2790	1.39	3.28	1.14	1.5	5	2	0	0
ND	McKenzie	380530111	2006	304	2896	1.35	2.43	1.16	1.48	4	1	0	0
ND	McKenzie	380530111	2007	78	722	1.61	1.89	1.3	1.69	1	1	0	0
ND	Mercer	380570001	1997	243	2824	2.93	4.29	1.87	2.26	0	0	0	0
ND	Mercer	380570001	1998	319	4735	3.33	6.47	2.09	2.28	5	2	0	0
ND	Mercer	380570001	1999	14	320	5.18	3.12	4.43	1.73	0	0	0	0
ND	Mercer	380570004	1999	334	5584	2.6	3.94	1.66	2.2	3	1	0	0
ND	Mercer	380570004	2000	362	7348	2.29	3.8	1.55	2.06	3	1	0	0
ND	Mercer	380570004	2001	338	4647	2.9	5.34	1.76	2.26	8	0	0	0
ND	Mercer	380570004	2002	336	3701	2.65	4.59	1.73	2.17	2	1	0	0
ND	Mercer	380570004	2003	351	5555	2.21	3.11	1.55	2.01	1	0	0	0
ND	Mercer	380570004	2004	344	4678	2.62	3.57	1.73	2.19	1	0	0	0
ND	Mercer	380570004	2005	273	3037	2.43	3.25	1.68	2.08	0	0	0	0
ND	Mercer	380570004	2006	301	2755	2.77	3.37	1.86	2.21	0	0	0	0
ND	Mercer	380570004	2007	107	1133	2.48	3.44	1.7	2.1	0	0	0	0
ND	Morton	380590002	1997	346	6547	9.31	20.26	2.93	3.67	102	19	1	0
ND	Morton	380590002	1998	290	4696	9.3	22.47	2.78	3.75	75	8	0	0
ND	Morton	380590002	1999	359	6837	7.7	16.99	2.53	3.55	90	4	0	0

State	County	Monitor ID	Year	Days (n)	Hours (n)	Annual Hourly (ppb)				Number of 5-minute Daily Maximum			
						Mean	std	GM	GSD	> 100 ppb	> 200 ppb	> 300 ppb	> 400 ppb
ND	Morton	380590002	2000	363	7964	6.47	14.58	2.22	3.31	73	3	0	0
ND	Morton	380590002	2001	346	5947	7.48	13.57	2.81	3.5	66	2	0	0
ND	Morton	380590002	2002	355	6258	6.26	12.03	2.49	3.25	59	1	0	0
ND	Morton	380590002	2003	365	8033	6.25	13.66	2.33	3.18	82	3	1	0
ND	Morton	380590002	2004	363	7532	6.74	13.2	2.62	3.29	76	2	0	0
ND	Morton	380590002	2005	111	1450	4.85	6.08	2.7	2.82	1	0	0	0
ND	Morton	380590003	1998	95	1924	3.71	7.47	2.01	2.48	8	0	0	0
ND	Morton	380590003	1999	353	6522	5.06	8.84	2.48	2.88	41	2	1	0
ND	Morton	380590003	2000	351	5984	4.71	8.04	2.44	2.74	24	0	0	0
ND	Morton	380590003	2001	357	6345	4.94	8.17	2.54	2.81	27	1	0	0
ND	Morton	380590003	2002	342	5245	4.41	7.53	2.35	2.68	26	1	0	0
ND	Morton	380590003	2003	364	7991	3.55	6.34	1.96	2.49	27	0	0	0
ND	Morton	380590003	2004	344	6338	4.44	7.03	2.5	2.59	24	0	0	0
ND	Morton	380590003	2005	106	1012	3.84	5.1	2.42	2.39	1	0	0	0
ND	Oliver	380650002	1997	244	2356	4.28	7.23	2.3	2.63	7	0	0	0
ND	Oliver	380650002	1998	319	4175	3.92	7.23	2.1	2.58	12	1	0	0
ND	Oliver	380650002	1999	349	4856	3.47	6.94	1.93	2.42	15	1	0	0
ND	Oliver	380650002	2000	351	4765	3.14	5.54	1.89	2.32	8	0	0	0
ND	Oliver	380650002	2001	214	2404	3.42	5.86	1.96	2.42	1	0	0	0
ND	Oliver	380650002	2002	350	4482	2.71	4.75	1.69	2.21	4	0	0	0
ND	Oliver	380650002	2003	357	6953	2.37	5.58	1.47	2.05	10	1	0	0
ND	Oliver	380650002	2004	354	6138	2.76	5.16	1.65	2.24	7	1	1	0
ND	Oliver	380650002	2005	275	2443	3.86	6.7	2.05	2.62	6	2	0	0
ND	Oliver	380650002	2006	325	3369	2.85	4.32	1.77	2.28	1	0	0	0
ND	Oliver	380650002	2007	101	780	4.12	6.99	2.35	2.53	2	0	0	0
ND	Steele	380910001	1997	216	3134	1.41	0.74	1.28	1.5	0	0	0	0
ND	Steele	380910001	1998	202	2804	2.22	2.1	1.72	1.91	0	0	0	0
ND	Steele	380910001	1999	152	1845	1.25	0.79	1.14	1.42	0	0	0	0
ND	Steele	380910001	2000	83	805	1.11	0.4	1.07	1.26	0	0	0	0
ND	Williams	381050103	2002	319	2724	3.18	7.56	1.68	2.36	8	3	1	0
ND	Williams	381050103	2003	339	3323	2.48	3.71	1.64	2.13	3	0	0	0
ND	Williams	381050103	2004	348	3438	2.52	5.21	1.62	2.12	5	3	1	0
ND	Williams	381050103	2005	301	2331	3.51	8	1.85	2.45	20	3	1	0
ND	Williams	381050103	2006	322	2976	1.88	2.32	1.4	1.87	0	0	0	0

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ND	Williams	381050103	2007	86	834	3.35	4.62	2.07	2.4	0	0	0	0
ND	Williams	381050105	2002	302	2843	6.77	10.88	2.93	3.34	35	4	1	0
ND	Williams	381050105	2003	342	3523	5.67	9.39	2.55	3.12	13	1	0	0
ND	Williams	381050105	2004	346	4129	5.64	10.64	2.55	3.1	19	2	2	1
ND	Williams	381050105	2005	349	4492	6.79	13	2.49	3.46	52	12	1	0
ND	Williams	381050105	2006	262	2938	3.74	6.66	1.91	2.62	14	1	0	0
ND	Williams	381050105	2007	24	263	3.59	5.63	1.99	2.53	1	0	0	0
PA	Allegheny	420030002	1997	357	7821	12.57	15.05	7.69	2.68	70	8	2	0
PA	Allegheny	420030002	1998	3	72	43.18	32.27	31.63	2.43	3	1	0	0
PA	Allegheny	420030002	1999	325	6986	11.04	11.16	7.36	2.53	31	2	0	0
PA	Allegheny	420030021	1997	355	7830	18.11	18.87	11.07	2.93	87	19	5	2
PA	Allegheny	420030021	1998	3	72	10.22	8.23	7.48	2.27	0	0	0	0
PA	Allegheny	420030021	1999	362	8279	9	7.94	6.64	2.2	3	0	0	0
PA	Allegheny	420030021	2002	313	7291	7.32	7.33	4.49	2.85	3	0	0	0
PA	Allegheny	420030031	1997	362	8000	10.98	9.63	8.05	2.24	12	1	0	0
PA	Allegheny	420030031	1998	3	68	11.38	9.36	8.2	2.3	0	0	0	0
PA	Allegheny	420030031	1999	360	7443	8.98	7.84	6.43	2.33	1	0	0	0
PA	Allegheny	420030032	1997	364	7951	15.4	19.34	9.39	2.73	84	15	6	4
PA	Allegheny	420030032	1998	3	60	35.2	20.65	27.51	2.26	2	0	0	0
PA	Allegheny	420030032	1999	210	4326	8.18	7.8	5.66	2.41	2	0	0	0
PA	Allegheny	420030064	1997	361	7526	11.9	13.08	7.16	2.86	17	2	0	0
PA	Allegheny	420030064	1998	3	71	20.11	7.99	18.41	1.56	0	0	0	0
PA	Allegheny	420030064	1999	355	7232	12.11	14.34	7.35	2.78	18	3	2	1
PA	Allegheny	420030064	2002	350	8239	10.9	13.26	5.91	3.15	18	5	1	0
PA	Allegheny	420030067	1997	364	8231	10.43	11.13	6.69	2.62	12	2	1	1
PA	Allegheny	420030067	1998	3	72	17.01	12.54	12.63	2.25	0	0	0	0
PA	Allegheny	420030067	1999	257	5891	10.05	8.81	7.35	2.22	1	0	0	0
PA	Allegheny	420030116	1997	361	7767	13.26	17.76	8.33	2.6	60	19	12	8
PA	Allegheny	420030116	1998	3	70	17	11.04	12.59	2.46	0	0	0	0
PA	Allegheny	420030116	1999	299	5684	12.12	16.01	7.82	2.54	50	26	13	8
PA	Allegheny	420030116	2002	232	5403	7	7.96	4.56	2.5	3	0	0	0
PA	Allegheny	420031301	1997	363	7663	9.37	9.8	6.25	2.48	21	4	1	1
PA	Allegheny	420031301	1998	3	70	12.66	6.88	11.29	1.58	0	0	0	0
PA	Allegheny	420031301	1999	363	8161	9.64	9.62	6.57	2.44	21	3	1	1

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PA	Allegheny	420033003	1997	356	7422	11.8	13.86	7.01	2.85	27	1	0	0
PA	Allegheny	420033003	1998	2	45	11.47	6.31	9.35	2.09	0	0	0	0
PA	Allegheny	420033003	1999	350	6998	13.59	19.91	7.86	2.86	37	2	2	2
PA	Allegheny	420033003	2002	316	7363	12.66	18.25	6.32	3.29	53	8	5	3
PA	Allegheny	420033004	1997	362	7461	9.18	9.66	6.17	2.47	12	2	0	0
PA	Allegheny	420033004	1998	3	66	13.12	6.01	11.71	1.65	0	0	0	0
PA	Allegheny	420033004	1999	361	7408	8.55	9.09	5.79	2.47	6	3	2	0
PA	Beaver	420070002	1997	351	7889	11.83	15.38	6.83	2.84	91	11	1	1
PA	Beaver	420070002	1998	270	6205	12.96	16.48	7.8	2.71	74	6	2	0
PA	Beaver	420070005	1997	359	7447	16.57	25.11	8.65	3.14	98	39	17	11
PA	Beaver	420070005	1998	277	6388	16.14	26.85	8.36	3.01	92	39	21	13
PA	Beaver	420070005	2002	361	8491	14.24	26.51	5.28	4.12	113	49	23	13
PA	Beaver	420070005	2003	365	8706	10.79	17.07	4.38	3.83	75	16	3	2
PA	Beaver	420070005	2004	364	8656	11.59	17.68	5.55	3.39	74	22	10	3
PA	Beaver	420070005	2005	362	8578	12.57	18.18	6.82	3.04	75	26	12	7
PA	Beaver	420070005	2006	361	8457	9.26	18.5	3.49	3.78	71	30	11	5
PA	Beaver	420070005	2007	324	7556	9.79	13.98	4.94	3.26	45	12	4	1
PA	Berks	420110009	1997	350	7805	8.66	8.87	5.87	2.44	35	4	0	0
PA	Berks	420110009	1998	365	8641	8.93	7.56	7.11	1.92	33	3	0	0
PA	Berks	420110009	1999	119	2790	9.22	8.38	6.86	2.17	9	1	0	0
PA	Cambria	420210011	1997	361	8129	9.76	9.15	6.72	2.47	8	0	0	0
PA	Cambria	420210011	1998	356	7908	8.78	9.69	5.65	2.62	16	1	0	0
PA	Cambria	420210011	1999	120	2835	9.74	7.99	7.61	1.99	1	0	0	0
PA	Erie	420490003	1997	363	8169	9.76	11.22	6.68	2.33	60	9	1	0
PA	Erie	420490003	1998	363	8416	10.57	13.5	7.09	2.35	60	12	1	0
PA	Erie	420490003	1999	120	2778	11.48	15.12	7.46	2.48	26	7	3	0
PA	Philadelphia	421010022	1997	364	8297	8.56	8.74	5.63	2.57	7	1	0	0
PA	Philadelphia	421010022	1998	363	8065	7.3	7.04	4.82	2.56	2	0	0	0
PA	Philadelphia	421010022	1999	137	2665	7.79	8.26	4.76	2.79	4	1	0	0
PA	Philadelphia	421010022	2000	179	3630	7.63	6.88	5.05	2.62	1	0	0	0
PA	Philadelphia	421010022	2001	98	2094	7.53	7.17	5.16	2.44	0	0	0	0
PA	Philadelphia	421010048	1997	365	8456	8.88	18.38	4.96	2.74	59	40	27	23
PA	Philadelphia	421010048	1998	356	7285	6.27	6.03	4.21	2.48	0	0	0	0
PA	Philadelphia	421010048	1999	178	3939	6.08	6.57	3.95	2.53	1	1	0	0

State	County	Monitor ID	Year	Days (n)	Hours (n)	Annual Hourly (ppb)				Number of 5-minute Daily Maximum			
						Mean	std	GM	GSD	> 100 ppb	> 200 ppb	> 300 ppb	> 400 ppb
PA	Philadelphia	421010136	1997	360	7532	4.99	5.52	3.29	2.43	1	0	0	0
PA	Philadelphia	421010136	1998	339	6491	5.25	5.52	3.5	2.44	2	0	0	0
PA	Philadelphia	421010136	1999	337	7144	5.63	6.04	3.71	2.48	2	1	0	0
PA	Philadelphia	421010136	2000	351	7044	5.76	5.97	3.74	2.54	0	0	0	0
PA	Philadelphia	421010136	2001	266	5149	6.77	7.43	4.38	2.55	2	0	0	0
PA	Philadelphia	421010136	2002	359	7271	5.38	5.7	3.57	2.47	3	0	0	0
PA	Philadelphia	421010136	2003	119	2585	6.74	6.71	4.62	2.42	2	0	0	0
PA	Warren	421230003	1997	346	7157	10.53	11.59	6.64	2.68	26	3	0	0
PA	Warren	421230003	1998	89	2126	7.62	7.38	5.41	2.26	0	0	0	0
PA	Warren	421230004	1997	355	7022	17.14	28.18	7.47	3.66	148	44	14	8
PA	Warren	421230004	1998	89	1966	13.97	21.76	6.8	3.18	30	6	2	0
PA	Washington	421250005	1997	364	8374	8.95	8.41	6.45	2.25	7	0	0	0
PA	Washington	421250005	1998	362	8540	8.88	7.78	6.68	2.14	4	0	0	0
PA	Washington	421250005	1999	120	2821	8.32	7.68	6.36	2.02	1	0	0	0
PA	Washington	421250200	1997	364	8369	10.52	11.23	6.99	2.45	17	0	0	0
PA	Washington	421250200	1998	365	8656	10.46	10.49	7.18	2.37	15	1	0	0
PA	Washington	421250200	1999	120	2829	10.15	9.81	7	2.4	3	1	0	0
PA	Washington	421255001	1997	365	8425	12.71	15.24	8.39	2.36	57	5	1	0
PA	Washington	421255001	1998	277	6559	13.46	13.09	10.28	1.97	42	3	0	0
SC	Barnwell	450110001	2000	100	789	3.95	2.83	3.39	1.66	0	0	0	0
SC	Barnwell	450110001	2001	267	2625	2.72	2.61	2.13	1.93	1	0	0	0
SC	Barnwell	450110001	2002	202	2544	2.11	1.72	1.67	1.88	0	0	0	0
SC	Charleston	450190003	2000	114	1703	6.24	5.36	4.77	2.02	1	0	0	0
SC	Charleston	450190003	2001	344	4806	4.16	4.12	2.95	2.22	1	0	0	0
SC	Charleston	450190003	2002	201	3509	2.85	3.49	1.97	2.16	0	0	0	0
SC	Charleston	450190046	2000	100	1252	4.61	3.9	3.71	1.84	0	0	0	0
SC	Charleston	450190046	2001	269	3497	2.64	2.6	1.99	2	0	0	0	0
SC	Charleston	450190046	2002	189	2927	2.34	2.89	1.68	2.02	0	0	0	0
SC	Georgetown	450430006	2000	71	604	4.92	4.35	3.97	1.82	0	0	0	0
SC	Georgetown	450430006	2001	241	2218	4.76	6.11	3.13	2.33	3	0	0	0
SC	Georgetown	450430006	2002	140	1169	2.5	4.33	1.67	2.08	1	0	0	0
SC	Greenville	450450008	2000	113	1987	4.84	3.75	3.95	1.82	0	0	0	0
SC	Greenville	450450008	2001	356	6418	4.24	3.86	3.18	2.1	3	0	0	0
SC	Greenville	450450008	2002	212	4679	3.06	2.8	2.29	2.09	1	0	0	0

State	County	Monitor ID	Year	Days (n)	Hours (n)	Annual Hourly (ppb)				Number of 5-minute Daily Maximum			
						Mean	std	GM	GSD	> 100 ppb	> 200 ppb	> 300 ppb	> 400 ppb
SC	Lexington	450630008	2001	263	3941	4.2	7.8	2.37	2.44	26	3	0	0
SC	Lexington	450630008	2002	211	4242	4.5	8.74	2.33	2.61	22	3	0	0
SC	Oconee	450730001	2000	89	1218	3.85	2.87	3.26	1.7	0	0	0	0
SC	Oconee	450730001	2001	288	4304	2.9	2.1	2.35	1.89	0	0	0	0
SC	Oconee	450730001	2002	188	3063	1.82	1.52	1.43	1.95	0	0	0	0
SC	Richland	450790007	2000	110	1808	4.48	2.81	3.86	1.69	0	0	0	0
SC	Richland	450790007	2001	365	6419	3.88	3.47	2.99	2.02	0	0	0	0
SC	Richland	450790007	2002	210	4335	2.95	2.71	2.23	2.04	0	0	0	0
SC	Richland	450790021	2000	109	911	4.43	5.47	3.4	1.85	0	0	0	0
SC	Richland	450790021	2001	283	2700	3.73	4.89	2.64	2.1	0	0	0	0
SC	Richland	450790021	2002	202	2505	2.94	4.85	1.92	2.16	0	0	0	0
SC	Richland	450791003	2001	193	3346	3.14	2.8	2.46	1.96	0	0	0	0
SC	Richland	450791003	2002	212	4323	2.87	2.8	2.16	2.04	0	0	0	0
UT	Salt Lake	490352004	1997	335	4524	2.31	2.5	1.76	1.94	6	1	0	0
UT	Salt Lake	490352004	1998	354	5792	1.94	1.66	1.58	1.78	0	0	0	0
WV	Wayne	540990002	2002	365	8711	7.49	7.14	5.13	2.42	1	0	0	0
WV	Wayne	540990003	2002	361	7417	8.48	9.1	5.21	2.75	7	2	1	1
WV	Wayne	540990003	2003	362	8057	8.76	9.73	5.56	2.58	8	0	0	0
WV	Wayne	540990003	2004	366	8659	9.21	9.46	6.38	2.31	5	1	0	0
WV	Wayne	540990003	2005	365	8141	9.58	11.8	5.96	2.61	6	0	0	0
WV	Wayne	540990004	2002	362	8560	9.21	9.18	6.37	2.37	22	1	1	1
WV	Wayne	540990004	2003	365	8570	8.53	9.77	5.84	2.35	26	4	3	1
WV	Wayne	540990004	2004	366	8673	7.22	6.66	5.36	2.12	6	0	0	0
WV	Wayne	540990004	2005	363	8586	7.67	6.39	5.97	2	7	0	0	0
WV	Wayne	540990005	2002	365	8283	8.44	9.75	5.38	2.58	67	3	0	0
WV	Wayne	540990005	2003	365	7927	8.31	11.03	5.02	2.7	52	20	5	0
WV	Wayne	540990005	2004	366	8681	7.03	5.92	5.25	2.16	2	0	0	0
WV	Wayne	540990005	2005	365	8453	6.68	5.52	4.89	2.26	4	1	0	0
WV	Wood	541071002	2001	92	2152	7.76	12.51	4.04	3.04	9	3	2	1
WV	Wood	541071002	2002	365	8648	9.9	11.29	6.21	2.63	42	7	1	0
WV	Wood	541071002	2003	365	8641	9.48	12.26	5.8	2.61	53	9	2	0
WV	Wood	541071002	2004	366	8581	10.88	13.25	7	2.55	57	13	3	1
WV	Wood	541071002	2005	266	6219	8.34	12.71	4.07	3.23	42	12	1	1

Appendix B: Supplement to the SO_2 Exposure Assessment

B.1 OVERVIEW

This appendix contains supplemental descriptions of the methods and data used in the SO_2 exposure assessment, as well as detailed results from the exposure analyses performed. First, a broad description of the exposure modeling approach is described (section B.2), applicable to the two exposure modeling domains conducted: Greene County, Mo. and St. Louis, MO. Supplementary input data used in AERMOD are provided in section B.3, as well as the model predictions and ambient monitor measurements in each modeling domain. Section B.4 has additional input and output data for APEX.

A series of Attachments also follow, further documenting some of the data sources and modeling approaches used, as well as previously conducted uncertainty analyses on selected input parameters in APEX:

Attachment 1. Technical Memorandum on Meteorological Data Preparation for AERMOD for SO_2 REA for Greene County And St. Louis Modeling Domains, Year 2002.

Attachment 2. Technical Memorandum on the Analysis of NHIS Asthma Prevalence Data.

Attachment 3. Technical Memorandum on Estimating Physiological Parameters for the Exposure Model

Attachment 4. Technical Memorandum on Longitudinal Diary Construction Approach

Attachment 5. Technical Memorandum on the Evaluation Cluster-Markov Algorithm

Attachment 6. Technical Memorandum on Analysis of Air Exchange Rate Data

Attachment 7. Technical Memorandum on the Uncertainty Analysis of Residential Air Exchange Rate Distributions

Attachment 8. Technical Memorandum on the Distributions of Air Exchange Rate Averages Over Multiple Days

B.2 HUMAN EXPOSURE MODELING USING APEX

The Air Pollutants Exposure model (APEX) is a personal computer (PC)-based program designed to estimate human exposure to criteria and air toxic pollutants at the local, urban, and consolidated metropolitan levels. APEX, also known as TRIM.Expo, is the human inhalation exposure module of EPA's Total Risk Integrated Methodology (TRIM) model framework (US EPA, 1999), a modeling system with multimedia capabilities for assessing human health and ecological risks from hazardous and criteria air pollutants. It is developed to support evaluations with a scientifically sound, flexible, and user-friendly methodology. Additional information on the TRIM modeling system, as well as downloads of the APEX Model, user's guide, and other supporting documentation, are on EPA's Technology Transfer Network (TTN) at http://www.epa.gov/ttn/fera.

B.2.1 History

APEX was derived from the National Ambient Air Quality Standards (NAAQS) Exposure Model (NEM) series of models, developed to estimate exposure to the criteria pollutants (e.g., carbon monoxide (CO), ozone O_3). In 1979, EPA began by assembling a database of human activity patterns that could be used to estimate exposures to indoor and outdoor pollutants (Roddin et al., 1979). These data were then combined with measured outdoor concentrations in NEM to estimate exposures to CO (Biller et al., 1981; Johnson and Paul, 1983). In 1988, OAQPS began to incorporate probabilistic elements into the NEM methodology and use activity pattern data based on various human activity diary studies to create an early version of probabilistic NEM for O_3 (i.e., pNEM/O_3). In 1991, a probabilistic version of NEM was extended to CO (pNEM/CO) that included a one-compartment mass-balance model to estimate CO concentrations in indoor microenvironments. The application of this model to Denver, Colorado has been documented in Johnson et al. (1992). Additional enhancements to pNEM/O_3 in the early- to mid-1990's allowed for probabilistic exposure assessments in nine urban areas for the general population, outdoor children, and outdoor workers (Johnson et al., 1996a; 1996b; 1996c). Between 1999 and 2001, updated versions of pNEM/CO (versions 2.0 and 2.1) were developed that relied on activity diary data from EPA's Consolidated Human Activities Database (CHAD) and enhanced algorithms for simulating gas stove usage, estimating alveolar ventilation rate (a measure of human respiration), and modeling home-to-work commuting patterns.

The first version of APEX was essentially identical to pNEM/CO (version 2.0) except that it was capable of running on a PC instead of a mainframe. The next version, APEX2, was substantially different, particularly in the use of a personal profile approach (i.e., simulation of individuals) rather than a cohort simulation (i.e., groups of similar persons). APEX3 introduced a number of new features including automatic site selection from national databases, a series of new output tables providing summary exposure and dose statistics, and a thoroughly reorganized method of describing microenvironments and their parameters. Most of the spatial and temporal constraints of pNEM and APEX1 were removed or relaxed by version 3.

The version of APEX used in this exposure assessment is APEX4.3, described in the APEX User's Guide and the APEX Technical Support Document (US EPA, 2009a; 2009b) and referred to here as the APEX User's Guide and TSD. This latest version has the added flexibility of addressing user defined exposure timesteps within an hour.

B.2.2 APEX Model Overview

> A **microenvironment** is a three-dimensional space in which human contact with an environmental pollutant takes place and which can be treated as a well-characterized, relatively homogeneous location with respect to pollutant concentrations for a specified time period.

APEX estimates human exposure to criteria and toxic air pollutants at the local, urban, or consolidated metropolitan area levels using a stochastic, microenvironmental approach. The model randomly selects data for a sample of hypothetical individuals from an actual population database and simulates each hypothetical individual's movements through time and space (e.g., at home, in vehicles) to estimate their exposure to a pollutant. APEX simulates commuting, and thus exposures that occur at home and work locations, for individuals who work in different areas than they live.

APEX can be conceptualized as a simulated field study that would involve selecting an actual sample of specific individuals who live in (or work and live in) a geographic area and then continuously monitoring their activities and subsequent inhalation exposure to a specific air pollutant during a specific period of time.

The main differences between APEX and an actual field study are that in APEX:

- The sample of individuals is a virtual sample, not actual persons. However, the population of individuals appropriately balanced according to various demographic variables and census data using their relative frequencies, in order to obtain a representative sample (to the extent possible) of the actual people in the study area

- The activity patterns of the sampled individuals (e.g., the specification of indoor and other microenvironments visited and the time spent in each) are assumed by the model to be comparable to individuals with similar demographic characteristics, according to activity data such as diaries compiled in EPA's Consolidated Human Activity Database (or CHAD; US EPA, 2002; McCurdy et al., 2000)
- The pollutant exposure concentrations are estimated by the model using a set of user-input ambient outdoor concentrations (either modeled or measured) and information on the behavior of the pollutant in various microenvironments;
- Variation in ambient air quality levels can be simulated by either adjusting air quality concentrations to just meet alternative ambient standards, or by reducing source emissions and obtaining resulting air quality modeling outputs that reflect these potential emission reductions, and
- The model accounts for the most significant factors contributing to inhalation exposure – the temporal and spatial distribution of people and pollutant concentrations throughout the study area and among microenvironments – while also allowing the flexibility to adjust some of these factors for alternative scenarios and sensitivity analyses.

APEX is designed to simulate human population exposure to criteria and air toxic pollutants at local, urban, and regional scales. The user specifies the geographic area to be modeled and the number of individuals to be simulated to represent this population. APEX then generates a personal profile for each simulated person that specifies various parameter values required by the model. The model next uses diary-derived time/activity data matched to each personal profile to generate an exposure event sequence (also referred to as *activity pattern* or *diary*) for the modeled individual that spans a specified time period, such as one year. Each event in the sequence specifies a start time, exposure duration, geographic location, microenvironment, and activity performed. Probabilistic algorithms are used to estimate the pollutant concentration associated with each exposure event. The estimated pollutant concentrations account for the effects of ambient (outdoor) pollutant concentration, penetration factors, air exchange rates, decay/deposition rates, and proximity to emission sources, depending on the microenvironment, available data, and estimation method selected by the user. Because the modeled individuals represent a random sample of the population of interest, the distribution of modeled individual exposures can be extrapolated to the larger population. Additional discussion regarding the five basic exposure modeling steps noted in the SO_2 REA are described in sections that follow.

B.2.2.1 Study Area Characterization

The APEX study area has traditionally been on the scale of a city or slightly larger metropolitan area, although it is now possible to model larger areas such as combined statistical areas (CSAs). In the exposure analyses performed as part of this NAAQS review, the study area is defined by either a single or a few counties. The demographic data used by the model to create personal profiles is provided at the census block level. For each block the model requires demographic information representing the distribution of age, gender, race, and work status within the study population. Each block has a location specified by latitude and longitude for some representative point (e.g., geographic center). The current release of APEX includes input files that already contain this demographic and location data for all census tracts, block groups, and blocks in the 50 United States, based on the 2000 Census. In this assessment, exposures were evaluated at the block level.

Air Quality Data

Air quality data can be input to the model as measured data from an ambient monitor or that generated by air quality modeling. This exposure analysis used modeled air quality data, whereas the principal emission sources included both mobile and stationary sources as well as fugitive emissions. Air quality data used for input to APEX were generated using AERMOD, a steady-state, Gaussian plume model (US EPA, 2004). The following steps were performed using AERMOD.

In APEX, the ambient air quality data are assigned to geographic areas called districts. The districts are used to assign pollutant concentrations to the blocks/tracts and microenvironments being modeled. The ambient air quality data are provided by the user as hourly time series for each district. As with blocks/tracts, each district has a representative location (latitude and longitude). APEX calculates the distance from each block/tract to each district center, and assigns the block/tract to the nearest district, provided the block/tract representative location point (e.g., geographic center) is in the district. Each block/tract can be assigned to only one district. In this assessment the district was synonymous with the receptor modeled in the dispersion modeling.

Meteorological Data

Ambient temperatures are input to APEX for different sites (locations). As with districts, APEX calculates the distance from each block to each temperature site and assigns each block to the nearest site. Hourly temperature data are from the National Climatic Data Center Surface Airways Hourly TD-3280 dataset (NCDC Surface Weather Observations). Daily average and 1-hour maxima are computed from these hourly data.

There are two files that are used to provide meteorological data to APEX. One file, the meteorological station location file, contains the locations of meteorological data recordings expressed in latitude and longitude coordinates. This file also contains start and end dates for the data recording periods. The temperature data file contains the data from the locations in the temperature zone location file. This file contains hourly temperature readings for the period being modeled for the meteorological stations in and around the study area.

B.2.2.2 Generate Simulated Individuals

APEX stochastically generates a user-specified number of simulated persons to represent the population in the study area. Each simulated person is represented by a personal profile, a summary of personal attributes that define the individual. APEX generates the simulated person or profile by probabilistically selecting values for a set of profile variables (Table B.2-1). The profile variables could include:

- Demographic variables, generated based on the census data;
- Physical variables, generated based on sets of distribution data;
- Other daily varying variables, generated based on literature-derived distribution data that change daily during the simulation period.

APEX first selects demographic and physical attributes for each specified individual, and then follows the individual over time and calculates his or her time series of exposure.

Table B.2-1. Examples of profile variables in APEX.

Variable Type	Profile Variables	Description
Demographic	Age	Age (years)
	Gender	Male or Female
	Home block	Block in which a simulated person lives
	Work tract	Tract in which a simulated person works
	Employment status	Indicates employment outside home
Physical	Air conditioner	Indicates presence of air conditioning at home
	Gas Stove	Indicates presence of gas stove at home

Population Demographics

APEX takes population characteristics into account to develop accurate representations of study area demographics. Specifically, population counts by area and employment probability estimates are used to develop representative profiles of hypothetical individuals for the simulation.

APEX is flexible in the resolution of population data provided. As long as the data are available, any resolution can be used (e.g., county, census tract, census block). For this application of the model, census block level data were used. Block-level population counts come from the 2000 Census of Population and Housing Summary File 1 (SF-1). This file contains the 100-percent data, which is the information compiled from the questions asked of all people and about every housing unit.

As part of the population demographics inputs, it is important to integrate working patterns into the assessment. In the 2000 U.S. Census, estimates of employment were developed by census information (US Census Bureau, 2007). The employment statistics are broken down by gender and age group, so that each gender/age group combination is given an employment probability fraction (ranging from 0 to 1) within each census tract. The age groupings used are: 16-19, 20-21, 22-24, 25-29, 30-34, 35-44, 45-54, 55-59, 60-61, 62-64, 65-69, 70-74, and >75. Children under 16 years of age were assumed to be not employed.

Since this analysis was conducted at the census block level, block level employment probabilities were required. It was assumed that the employment probabilities for a census tract apply uniformly to the constituent census blocks.

Commuting

In addition to using estimates of employment by tract, APEX also incorporates home-to-work commuting data. Commuting data were originally derived from the 2000 Census and were collected as part of the Census Transportation Planning Package (CTPP) (US DOT, 2007). The data used contain counts of individuals commuting from home to work locations at a number of geographic scales. These data were processed to calculate fractions for each tract-to-tract flow to create the national commuting data distributed with APEX. This database contains commuting data for each of the 50 states and Washington, D.C.

Commuting within the Home Tract

The APEX data set does not differentiate people that work at home from those that commute within their home tract.

Commuting Distance Cutoff

A preliminary data analysis of the home-work counts showed that a graph of log(flows) versus log(distance) had a near-constant slope out to a distance of around 120 kilometers. Beyond that distance, the relationship also had a fairly constant slope but it was flatter, meaning that flows were not as sensitive to distance. A simple interpretation of this result is that up to 120 km, the majority of the flow was due to persons traveling back and forth daily, and the numbers of such persons decrease rapidly with increasing distance. Beyond 120 km, the majority of the flow is comprised of persons who stay at the workplace for extended times, in which case the separation distance is not as crucial in determining the flow.

To apply the home-work data to commuting patterns in APEX, a simple rule was chosen. It was assumed that all persons in home-work flows up to 120 km are daily commuters, and no persons in more widely separated flows commute daily. This meant that the list of destinations for each home tract was restricted to only those work tracts that are within 120 km of the home tract. When the same cutoff was performed on the 1990 census data, it resulted in 4.75% of the home-work pairs in the nationwide database being eliminated, representing 1.3% of the workers. The assumption is that this 1.3% of workers do not commute from home to work on a daily basis. It is expected that the cutoff reduced the 2000 data by similar amounts.

Eliminated Records

A number of tract-to-tract pairs were eliminated from the database for various reasons. A fair number of tract-to-tract pairs represented workers who either worked outside of the U.S.

(9,631 tract pairs with 107,595 workers) or worked in an unknown location (120,830 tract pairs with 8,940,163 workers). An additional 515 workers in the commuting database whose data were missing from the original files, possibly due to privacy concerns or errors, were also deleted.

Commuting outside the study area

APEX allows for some flexibility in the treatment of persons in the modeled population who commute to destinations outside the study area. By specifying "KeepLeavers = No" in the simulation control parameters file, people who work inside the study area but live outside of it are not modeled, nor are people who live in the study area but work outside of it. By specifying "KeepLeavers = Yes," these commuters are modeled. This triggers the use of two additional parameters, called LeaverMult and LeaverAdd. While a commuter is at work, if the workplace is outside the study area, then the ambient concentration is assumed to be related to the average concentration over all air districts at the same point in time, and is calculated as:

$$Ambient\ Concentration = LeaverMult \times avg(t) + LeaverAdd \qquad \text{equation (B-1)}$$

where:

Ambient Concentration	=	Calculated ambient air concentrations for locations outside of the study area (ppm or ppm)
LeaverMult	=	Multiplicative factor for city-wide average concentration, applied when working outside study area
avg(t)	=	Average ambient air concentration over all air districts in study area, for time *t* (ppm or ppm)
LeaverAdd	=	Additive term applied when working outside study area

All microenvironmental concentrations for locations outside of the study area are determined from this ambient concentration by the same function as applies inside the study area.

Block-level commuting

For census block simulations, APEX requires block-level commuting file. A special software preprocesser was created to generate these files for APEX on the basis of the tract-level commuting data and finely-resolved land use data. The software calculates commuting flows between census blocks for the employed population according equation (B-2).

$$Flow_{block} = Flow_{tract} \times F_{pop} \times F_{land} \qquad \text{equation (B-2)}$$

where:

$Flow_{block}$	= flow of working population between a home block and a work block.
$Flow_{tract}$	= flow of working population between a home tract and a work tract.
F_{pop}	= fraction of home tract's working population residing in the home block.
F_{land}	= fraction of work tract's commercial/industrial land area in the work block

Thus, it is assumed that the frequency of commuting to a workplace block within a tract is proportional to the amount of commercial and industrial land in the block.

Profile Functions

A *Profile Functions* file contains settings used to generate results for variables related to simulated individuals. While certain settings for individuals are generated automatically by APEX based on other input files, including demographic characteristics, others can be specified using this file. For example, the file may contain settings for determining whether the profiled individual's residence has an air conditioner, a gas stove, etc. As an example, the *Profile Functions* file contains fractions indicating the prevalence of air conditioning in the cities modeled in this assessment (Figure B.2-1). APEX uses these fractions to stochastically generate air conditioning status for each individual. The derivation of particular data used in specific microenvironments is provided below.

```
AC_Home
! Has air conditioning at home
TABLE
INPUT1 PROBABILITY 2     "A/C probabilities"
0.85 0.15
RESULT INTEGER 2        "Yes/No"
1 2
#
```

Figure B.2-1. Example of a profile function file for A/C prevalence.

B.2.2.3 Longitudinal Activity Pattern Sequences

Exposure models use human activity pattern data to predict and estimate exposure to pollutants. Different human activities, such as spending time outdoors, indoors, or driving, will have varying pollutant exposure concentrations. To accurately model individuals and their exposure to pollutants, it is critical to understand their daily activities.

The Consolidated Human Activity Database (CHAD) provides data for where people spend time and the activities performed. CHAD was designed to provide a basis for conducting multi-route, multi-media exposure assessments (McCurdy et al., 2000). The data contained within CHAD come from multiple activity pattern surveys with varied structures (Table B.2-2), however the surveys have commonality in containing daily diaries of human activities and personal attributes (e.g., age and gender).

There are four CHAD-related input files used in APEX. Two of these files can be downloaded directly from the CHADNet (http://www.epa.gov/chadnet1), and adjusted to fit into the APEX framework. These are the human activity diaries file and the personal data file, and are discussed below. A third input file contains metabolic information for different activities listed in the diary file, these are not used in this exposure analysis. The fourth input file maps five-digit location codes used in the diary file to APEX microenvironments; this file is discussed in the section describing microenvironmental calculations (Section B.2.2.4.4).

Personal Information file

Personal attribute data are contained in the CHAD questionnaire file that is distributed with APEX. This file also has information for each day individuals have diaries. The different variables in this file are:

- The study, person, and diary day identifiers
- Day of week
- Gender
- Employment status
- Age in years
- Maximum temperature in degrees Celsius for this diary day
- Mean temperature in degrees Celsius for this diary day
- Occupation code

- Time, in minutes, during this diary day for which no data are included in the database

Diary Events file

The human activity diary data are contained in the events file that is distributed with APEX. This file contains the activities for the nearly 23,000 people with intervals ranging from one minute to one hour. An individuals' diary varies in length from one to 15 days. This file contains the following variables:

- The study, person, and diary day identifiers
- Start time of this activity
- Number of minutes for this activity
- Activity code (a record of what the individual was doing)
- Location code (a record of where the individual was)

Table B.2-2. Summary of activity pattern studies used in CHAD.

Study Name	Location	Study time period	Ages	Persons	Person -days	Diary type /study design	Reference
Baltimore	A single building in Baltimore	01/1997-02/1997, 07/1998-08/1998	72-93	26	292	Diary	Williams et al. (2000)
California Adolescents and Adults (CARB)	California	10/1987-09/1988	12-17 18-94	181 1,552	181 1,552	Recall /Random	Robinson et al. (1989); Wiley et al. (1991a)
California Children (CARB)	California	04/1989-02/1990	0-11	1,200	1,200	Recall /Random	Wiley et al. (1991b)
Cincinnati (EPRI)	Cincinnati MSA	03/1985-04/1985, 08/1985	0-86	888	2,587	Diary /Random	Johnson (1989)
Denver (EPA)	Denver MSA	11/1982-02/1983	18-70	432	791	Diary /Random	Johnson (1984); Akland et al. (1985)
Los Angeles: Elementary School Children	Los Angeles	10/1989	10-12	17	51	Diary	Spier et al. (1992)
Los Angeles: High School Adolescents	Los Angeles	09/1990-10/1990	13-17	19	42	Diary	Spier et al. (1992)
National: NHAPS-Air	National	09/1992-10/1994	0-93	4,326	4,326	Recall /Random	Klepeis et al. (1996); Tsang and Klepeis (1996)
National: NHAPS-Water	National	09/1992-10/1994	0-93	4,332	4,332	Recall /Random	Klepeis et al. (1996); Tsang and Klepeis (1996)
Washington, D.C. (EPA)	Wash. DC MSA	11/1982-02/1983	18-98	639	639	Diary /Random	Hartwell et al. (1984); Akland et al. (1985)

Construction of Longitudinal Activity Sequences

Typical time-activity pattern data available for inhalation exposure modeling consist of a sequence of location/activity combinations spanning a 24-hour duration, with 1 to 3 diary-days for any single individual. Exposure modeling requires information on activity patterns over longer periods of time, e.g., a full year. For example, even for pollutant health effects with short averaging times (e.g., SO_2 5-minute average concentration) it may be desirable to know the frequency of exceedances of a concentration over a long period of time (e.g., the annual number of exceedances of a 24-hour average SO_2 concentration of 100 ppb for each simulated individual).

Long-term multi-day activity patterns can be estimated from single days by combining the daily records in various ways, and the method used for combining them will influence the variability of the long-term activity patterns across the simulated population. This in turn will influence the ability of the model to accurately represent either long-term average high-end exposures, or the number of individuals exposed multiple times to short-term high-end concentrations.

A common approach for constructing long-term activity patterns from short-term records is to re-select a daily activity pattern from the pool of data for each day, with the implicit assumption that there is no correlation between activities from day to day for the simulated individual. This approach tends to result in long-term activity patterns that are very similar across the simulated population. Thus, the resulting exposure estimates are likely to underestimate the variability across the population, and therefore, underestimate the high-end exposure concentrations or the frequency of exceedances.

A contrasting approach is to select a single activity pattern (or a single pattern for each season and/or weekday-weekend) to represent a simulated individual's activities over the duration of the exposure assessment. This approach has the implicit assumption that an individual's day-to-day activities are perfectly correlated. This approach tends to result in long-term activity patterns that are very different across the simulated population, and therefore may over-estimate the variability across the population.

Cluster-Markov Algorithm

A new algorithm has been developed and incorporated into APEX to represent the day-to-day correlation of activities for individuals. The algorithms first use cluster analysis to divide the daily activity pattern records into groups that are similar, and then select a single daily record from each group. This limited number of daily patterns is then used to construct a long-term sequence for a simulated individual, based on empirically-derived transition probabilities. This approach is intermediate between the assumption of no day-to-day correlation (i.e., re-selection for each time period) and perfect correlation (i.e., selection of a single daily record to represent all days).

The steps in the algorithm are as follows.

1. For each demographic group (age, gender, employment status), temperature range, and day-of-week combination, the associated time-activity records are partitioned into 3

groups using cluster analysis. The clustering criterion is a vector of 5 values: the time spent in each of 5 microenvironment categories (indoors – residence; indoors – other building; outdoors – near road; outdoors – away from road; in vehicle).

2. For each simulated individual, a single time-activity record is randomly selected from each cluster.
3. A Markov process determines the probability of a given time-activity pattern occurring on a given day based on the time-activity pattern of the previous day and cluster-to-cluster transition probabilities. The cluster-to-cluster transition probabilities are estimated from the available multi-day time-activity records. If insufficient multi-day time-activity records are available for a demographic group, season, day-of-week combination, then the cluster-to-cluster transition probabilities are estimated from the frequency of time-activity records in each cluster in the CHAD data base.

Details regarding the Cluster-Markov algorithm and supporting evaluations are provided in Attachments 4 and 5.

B.2.2.4 Calculating Microenvironmental Concentrations

Probabilistic algorithms estimate the pollutant concentration associated with each exposure event. The estimated pollutant concentrations account for the effects of ambient (outdoor) pollutant concentration, penetration factor, air exchange rate, decay/deposition rate, and proximity to microenvironments can use the transfer factors method while the others use the mass balance emission sources, depending on the microenvironment, available data, and the estimation method selected by the user.

APEX calculates air concentrations in the various microenvironments visited by the simulated person by using the ambient air data for the relevant blocks, the user-specified estimation method, and input parameters specific to each microenvironment. APEX calculates hourly concentrations in all the microenvironments at each hour of the simulation for each of the simulated individuals using one of two methods: by mass balance or a transfer factors method.

Mass Balance Model

The mass balance method simulates an enclosed microenvironment as a well-mixed volume in which the air concentration is spatially uniform at any specific time. The following processes are used estimate the concentration of an air pollutant in such a microenvironment:

- Inflow of air into the microenvironment

- Outflow of air from the microenvironment
- Removal of a pollutant from the microenvironment due to deposition, filtration, and chemical degradation
- Pollutant emissions inside the microenvironment.

Table B.2-3 lists the parameters required by the mass balance method to calculate concentrations in a microenvironment. A proximity factor ($f_{proximity}$) is used to account for differences in ambient concentrations between the geographic location represented by the ambient air quality data (e.g., a regional fixed-site monitor or modeled concentration) and the geographic location of the microenvironment (e.g., near a roadway). This factor could take a value either greater than or less than 1. Emission source (ES) represents the emission rate for the emission source and concentration source (CS) is the mean air concentration resulting from the source. $R_{removal}$ is defined as the removal rate of a pollutant from a microenvironment due to deposition, filtration, and chemical reaction. The air exchange rate ($R_{air\ exchange}$) is expressed in air changes per hour.

Table B.2-3. Mass balance model parameters.

Variable	Definition	Units	Value Range
$f_{proximity}$	Proximity factor	unitless	$f_{proximity} \geq 0$
CS	Concentration source	ppb	$CS \geq 0$
$R_{removal}$	Removal rate due to deposition, filtration, and chemical reaction	1/hr	$R_{removal} \geq 0$
$R_{air\ exchange}$	Air exchange rate	1/hr	$R_{air\ exchange} \geq 0$
V	Volume of microenvironment	m^3	$V > 0$

The mass balance equation for a pollutant in a microenvironment is described by:

$$\frac{dC_{ME}(t)}{dt} = \Delta C_{in} - \Delta C_{out} - \Delta C_{removal} + \Delta C_{source} \qquad \text{equation (B-3)}$$

where:

$dC_{ME}(t)$ = Change in concentration in a microenvironment at time t (ppb),

ΔC_{in} = Rate of change in microenvironmental concentration due to influx of air (ppb/hour),

ΔC_{out} = Rate of change in microenvironmental concentration due to outflux of air (ppb/hour),

$\Delta C_{removal}$	=	Rate of change in microenvironmental concentration due to removal processes (ppb/hour), and
ΔC_{source}	=	Rate of change in microenvironmental concentration due to an emission source inside the microenvironment (ppb/hour).

Within the timestep selected, each of the rates of change, ΔC_{in}, ΔC_{out}, $\Delta C_{removal}$, and ΔC_{source}, is assumed to be constant. At each timestep of the simulation period, APEX estimates the equilibrium, ending, and mean concentrations using a series of equations that account for concentration changes expected to occur due to these physical processes. Details regarding these equations are provided in the APEX TSD (US EPA, 2009b). The calculation continues to the next timestep by using the end concentration for the previous timestep as the initial microenvironmental concentration. A brief description of the input parameters estimates used for microenvironments using the mass balance approach is provided below.

Factors Model

The factors method is simpler than the mass balance method. It does not calculate concentration in a microenvironment from the concentration in the previous hour and it has fewer parameters. Table B.2-4 lists the parameters required by the factors method to calculate concentrations in a microenvironment without emissions sources.

Table B.2-4. Factors model parameters.

Variable	Definition	Units	Value Range
$f_{proximity}$	Proximity factor	unitless	$f_{proximity} \geq 0$
$f_{penetration}$	Penetration factor	unitless	$0 \leq f_{penetration} \leq 1$

The factors method uses the following equation to calculate the timestep concentration in a microenvironment from the user-provided hourly air quality data:

$$C_{ME}^{timestep} = C_{ambient} \ x \ f_{proximity} \ x \ f_{penetration} \qquad \text{equation (B-4)}$$

where:

$C_{ME}^{timestep}$	=	Timestep concentration in a microenvironment (ppb)
$C_{ambient}$	=	Timestep concentration in ambient environment (ppb)
$f_{proximity}$	=	Proximity factor (unitless)
$f_{penetration}$	=	Penetration factor (unitless)

The ambient NO_2 concentrations are from the air quality data input file. The proximity factor is a unitless parameter that represents the proximity of the microenvironment to a monitoring station. The penetration factor is a unitless parameter that represents the fraction of pollutant entering a microenvironment from outside the microenvironment via air exchange. The development of the specific proximity and penetration factors used in this analysis are discussed below for each microenvironment using this approach.

Microenvironments Modeled

In APEX, microenvironments represent the exposure locations for simulated individuals. For exposures to be estimated accurately, it is important to have realistic microenvironments that match closely to the locations where actual people spend time on a daily basis. As discussed above, the two methods available in APEX for calculating pollutant levels within microenvironments are: 1) factors and 2) mass balance. A list of microenvironments used in this study, the calculation method used, and the parameters used to calculate the microenvironment concentrations can be found in Table B.2-5.

Each of the microenvironments is designed to simulate an environment in which people spend time during the day. CHAD locations are linked to the different microenvironments in the *Microenvironment Mapping* File (see below). There are many more CHAD locations than microenvironment locations (there are 113 CHAD codes versus 12 microenvironments in this assessment), therefore most of the microenvironments have multiple CHAD locations mapped to them.

Table B.2-5. List of microenvironments and calculation methods used.

Microenvironment		Calculation Method	Parameter Types used [1]
No.	Name		
1	Indoors – Residence	Mass balance	AER and DE
2	Indoors – Bars and restaurants	Mass balance	AER and DE
3	Indoors – Schools	Mass balance	AER and DE
4	Indoors – Day-care centers	Mass balance	AER and DE
5	Indoors – Office	Mass balance	AER and DE
6	Indoors – Shopping	Mass balance	AER and DE
7	Indoors – Other	Mass balance	AER and DE
8	Outdoors – Near road	Factors	PR
9	Outdoors – Public garage - parking lot	Factors	PR
10	Outdoors – Other	Factors	None
11	In-vehicle – Cars and Trucks	Factors	PE and PR
12	In-vehicle - Mass Transit (bus, subway, train)	Factors	PE and PR
0	Not modeled		

[1] AER=air exchange rate, DE=decay-deposition rate, PR=proximity factor, PE=penetration factor

Mapping of APEX Microenvironments to CHAD Diaries

The *Microenvironment Mapping* file matches the APEX Microenvironments to CHAD Location codes. Table B.2-6 gives the mapping used for the APEX simulations.

Table B.2-6. Mapping of CHAD activity locations to APEX microenvironments.

```
CHAD Loc.  Description                              APEX micro
---------  ---------------------------------------------------
U          Uncertain of correct code            =   -1  Unknown
X          No data                              =   -1  Unknown
30000      Residence, general                   =    1  Indoors-Residence
30010      Your residence                       =    1  Indoors-Residence
30020      Other residence                      =    1  Indoors-Residence
30100      Residence, indoor                    =    1  Indoors-Residence
30120      Your residence, indoor               =    1  Indoors-Residence
30121      ..., kitchen                         =    1  Indoors-Residence
30122      ..., living room or family room      =    1  Indoors-Residence
30123      ..., dining room                     =    1  Indoors-Residence
30124      ..., bathroom                        =    1  Indoors-Residence
30125      ..., bedroom                         =    1  Indoors-Residence
30126      ..., study or office                 =    1  Indoors-Residence
30127      ..., basement                        =    1  Indoors-Residence
30128      ..., utility or laundry room         =    1  Indoors-Residence
30129      ..., other indoor                    =    1  Indoors-Residence
30130      Other residence, indoor              =    1  Indoors-Residence
30131      ..., kitchen                         =    1  Indoors-Residence
30132      ..., living room or family room      =    1  Indoors-Residence
30133      ..., dining room                     =    1  Indoors-Residence
30134      ..., bathroom                        =    1  Indoors-Residence
30135      ..., bedroom                         =    1  Indoors-Residence
```

30136	..., study or office	=	1	Indoors-Residence
30137	..., basement	=	1	Indoors-Residence
30138	..., utility or laundry room	=	1	Indoors-Residence
30139	..., other indoor	=	1	Indoors-Residence
30200	Residence, outdoor	=	10	Outdoors-Other
30210	Your residence, outdoor	=	10	Outdoors-Other
30211	..., pool or spa	=	10	Outdoors-Other
30219	..., other outdoor	=	10	Outdoors-Other
30220	Other residence, outdoor	=	10	Outdoors-Other
30221	..., pool or spa	=	10	Outdoors-Other
30229	..., other outdoor	=	10	Outdoors-Other
30300	Residential garage or carport	=	7	Indoors-Other
30310	..., indoor	=	7	Indoors-Other
30320	..., outdoor	=	10	Outdoors-Other
30330	Your garage or carport	=	1	Indoors-Residence
30331	..., indoor	=	1	Indoors-Residence
30332	..., outdoor	=	10	Outdoors-Other
30340	Other residential garage or carport	=	1	Indoors-Residence
30341	..., indoor	=	1	Indoors-Residence
30342	..., outdoor	=	10	Outdoors-Other
30400	Residence, none of the above	=	1	Indoors-Residence
31000	Travel, general	=	11	In Vehicle-Cars_and_Trucks
31100	Motorized travel	=	11	In Vehicle-Cars_and_Trucks
31110	Car	=	11	In Vehicle-Cars_and_Trucks
31120	Truck	=	11	In Vehicle-Cars_and_Trucks
31121	Truck (pickup or van)	=	11	In Vehicle-Cars_and_Trucks
31122	Truck (not pickup or van)	=	11	In Vehicle-Cars_and_Trucks
31130	Motorcycle or moped	=	8	Outdoors-Near_Road
31140	Bus	=	12	In Vehicle-Mass_Transit
31150	Train or subway	=	12	In Vehicle-Mass_Transit
31160	Airplane	=	0	Zero_concentration
31170	Boat	=	10	Outdoors-Other
31171	Boat, motorized	=	10	Outdoors-Other
31172	Boat, other	=	10	Outdoors-Other
31200	Non-motorized travel	=	10	Outdoors-Other
31210	Walk	=	10	Outdoors-Other
31220	Bicycle or inline skates/skateboard	=	10	Outdoors-Other
31230	In stroller or carried by adult	=	10	Outdoors-Other
31300	Waiting for travel	=	10	Outdoors-Other
31310	..., bus or train stop	=	8	Outdoors-Near_Road
31320	..., indoors	=	7	Indoors-Other
31900	Travel, other	=	11	In Vehicle-Cars_and_Trucks
31910	..., other vehicle	=	11	In Vehicle-Cars_and_Trucks
32000	Non-residence indoor, general	=	7	Indoors-Other
32100	Office building/ bank/ post office	=	5	Indoors-Office
32200	Industrial/ factory/ warehouse	=	5	Indoors-Office
32300	Grocery store/ convenience store	=	6	Indoors-Shopping
32400	Shopping mall/ non-grocery store	=	6	Indoors-Shopping
32500	Bar/ night club/ bowling alley	=	2	Indoors-Bars_and_Restaurants
32510	Bar or night club	=	2	Indoors-Bars_and_Restaurants
32520	Bowling alley	=	2	Indoors-Bars_and_Restaurants
32600	Repair shop	=	7	Indoors-Other
32610	Auto repair shop/ gas station	=	7	Indoors-Other
32620	Other repair shop	=	7	Indoors-Other
32700	Indoor gym /health club	=	7	Indoors-Other
32800	Childcare facility	=	4	Indoors-Day_Care_Centers
32810	..., house	=	1	Indoors-Residence
32820	..., commercial	=	4	Indoors-Day_Care_Centers
32900	Large public building	=	7	Indoors-Other
32910	Auditorium/ arena/ concert hall	=	7	Indoors-Other
32920	Library/ courtroom/ museum/ theater	=	7	Indoors-Other
33100	Laundromat	=	7	Indoors-Other
33200	Hospital/ medical care facility	=	7	Indoors-Other
33300	Barber/ hair dresser/ beauty parlor	=	7	Indoors-Other
33400	Indoors, moving among locations	=	7	Indoors-Other

33500	School	=	3	Indoors-Schools
33600	Restaurant	=	2	Indoors-Bars_and_Restaurants
33700	Church	=	7	Indoors-Other
33800	Hotel/ motel	=	7	Indoors-Other
33900	Dry cleaners	=	7	Indoors-Other
34100	Indoor parking garage	=	7	Indoors-Other
34200	Laboratory	=	7	Indoors-Other
34300	Indoor, none of the above	=	7	Indoors-Other
35000	Non-residence outdoor, general	=	10	Outdoors-Other
35100	Sidewalk, street	=	8	Outdoors-Near_Road
35110	Within 10 yards of street	=	8	Outdoors-Near_Road
35200	Outdoor public parking lot /garage	=	9	Outdoors-Public_Garage-Parking
35210	..., public garage	=	9	Outdoors-Public_Garage-Parking
35220	..., parking lot	=	9	Outdoors-Public_Garage-Parking
35300	Service station/ gas station	=	10	Outdoors-Other
35400	Construction site	=	10	Outdoors-Other
35500	Amusement park	=	10	Outdoors-Other
35600	Playground	=	10	Outdoors-Other
35610	..., school grounds	=	10	Outdoors-Other
35620	..., public or park	=	10	Outdoors-Other
35700	Stadium or amphitheater	=	10	Outdoors-Other
35800	Park/ golf course	=	10	Outdoors-Other
35810	Park	=	10	Outdoors-Other
35820	Golf course	=	10	Outdoors-Other
35900	Pool/ river/ lake	=	10	Outdoors-Other
36100	Outdoor restaurant/ picnic	=	10	Outdoors-Other
36200	Farm	=	10	Outdoors-Other
36300	Outdoor, none of the above	=	10	Outdoors-Other

B.2.2.5 Exposure Calculations

APEX calculates exposure as a time series of exposure concentrations that a simulated individual experiences during the simulation period. APEX determines the exposure using hourly ambient air concentrations, calculated concentrations in each microenvironment based on these ambient air concentrations (and indoor sources if present), and the minutes spent in a sequence of microenvironments visited according to the composite diary. The hourly exposure concentration at any clock hour during the simulation period is determined using the following equation:

$$C_i = \frac{\sum_{j=1}^{N} C_{ME(j)}^{timestep} \; t_{(j)}}{T} \qquad \text{equation (B-5)}$$

where:

C_i = Hourly exposure concentration at clock hour *i* of the simulation period (ppb)

N = Number of events (i.e., microenvironments visited) in clock hour *i* of the simulation period.

$C_{ME(j)}^{timestep}$ = Timestep concentration in microenvironment *j* (ppm)

$t_{(j)}$ = Time spent in microenvironment *j* (minutes)

T = Length of timestep (minutes)

From the timestep exposures, APEX calculates time series of 1-hour, 8-hour and daily average exposures that a simulated individual would experience during the simulation period. APEX then statistically summarizes and tabulates the timestep, hourly, 8-hour, and daily exposures. Note that if the APEX timestep is greater than an hour, the 1-hour and 8-hour exposures are not calculated and the corresponding tables are not produced. Exposures are calculated independently for all pollutants in the simulation.

From the timestep exposures, APEX can calculate the time-series of 1-hour, 8-hour, and daily average exposures that a simulated individual would experience during the simulation period. APEX then statistically summarizes and tabulates the timestep (or hourly, daily, annual average) exposures. In this analysis, the exposure indicator is 5-minute exposures above potential health effect benchmark levels. From this, APEX can calculate two general types of exposure estimates: counts of the estimated number of people exposed to a specified SO_2 concentration level and the number of times per year that they are so exposed; the latter metric is typically expressed in terms of person-occurrences or person-days. The former highlights the number of individuals exposed at least *one or more* times per modeling period to the health effect benchmark level of interest. APEX can also report counts of individuals with multiple exposures. This person-occurrences measure estimates the number of times per season that individuals are exposed to the exposure indicator of interest and then accumulates these estimates for the entire population residing in an area.

APEX tabulates and displays the two measures for exposures above levels ranging from any number of benchmark levels, by any increment (e.g., 0 to 800 ppb by 50 ppb increments for 5-minute exposures). These exposure results are tabulated for the population and subpopulations of interest.

Exposure Model Output

All of the output files written by APEX are ASCII text files. Table B.2-7 lists each of the output data files written for these simulations and provides descriptions of their content. Additional output files that can produced by APEX are given in Table 5-1 of the APEX User’s Guide, and include hourly exposure, ventilation, and energy expenditures, and even detailed event-level information, if desired. The names and locations, as well as the output table levels (e.g., output percentiles, cut-points), for these output files are specified by the user in the simulation control parameters file.

Table B.2-7. Example of APEX output files.

Output File Type	Description
Log	The *Log* file contains the record of the APEX model simulation as it progresses. If the simulation completes successfully, the log file indicates the input files and parameter settings used for the simulation and reports on a number of different factors. If the simulation ends prematurely, the log file contains error messages describing the critical errors that caused the simulation to end.
Profile Summary	The *Profile Summary* file provides a summary of each individual modeled in the simulation.
Microenvironment Summary	The *Microenvironment Summary* file provides a summary of the time and exposure by microenvironment for each individual modeled in the simulation.
Sites	The *Sites* file lists the tracts, districts, and zones in the study area, and identifies the mapping between them.
Output Tables	The *Output Tables* file contains a series of tables summarizing the results of the simulation. The percentiles and cut-off points used in these tables are defined in the simulation control parameters file.

B.3 Supplemental AERMOD Dispersion Modeling Data

B.3-1 AERMOD Input data

Table B.3-1. Emission parameters by stack for all major facility stacks in Missouri.

Stack ID	City	Facility Name	NEI Site ID	UTM X (m)[1]	UTM Y (m)[1]	SO_2 Emissions (tpy)	Stack Height (m)	Exit Temp. (K)	Stack Diam. (m)	Exit Velocity (m/s)	Profile Method[2]
5049	LABADIE	AMERENUE-LABADIE PLANT	NEI 7514	688,392	4,270,394	10,970	213	444	6.2	28	Tier 1
5050	LABADIE	AMERENUE-LABADIE PLANT	NEI 7514	688,357	4,270,439	14,753	213	444	6.2	28	Tier 1
5051	LABADIE	AMERENUE-LABADIE PLANT	NEI 7514	688,461	4,270,338	14,285	213	444	8.8	28	Tier 1
5054	LABADIE	AMERENUE-LABADIE PLANT	NEI 7514	688,442	4,270,322	7,602	213	444	8.8	28	Tier 1
5063	SPRING-FIELD	CITY UTILITIES OF SPRINGFIELD MISSOURI-JAMES RIVER POWER PLANT	NEI 7525	476,842	4,106,944	1,137	107	422	2.5	15	Tier 2
5064	SPRING-FIELD	CITY UTILITIES OF SPRINGFIELD MISSOURI-JAMES RIVER POWER PLANT	NEI 7525	476,853	4,106,922	1,433	107	422	2.5	15	Tier 1
5066	SPRING-FIELD	CITY UTILITIES OF SPRINGFIELD MISSOURI-JAMES RIVER POWER PLANT	NEI 7525	476,913	4,106,929	757	61	422	3.7	6	Tier 1
5068	SPRING-FIELD	CITY UTILITIES OF SPRINGFIELD MISSOURI-JAMES RIVER POWER PLANT	NEI 7525	476,884	4,106,932	159	61	422	3.7	6	Tier 1
5069	SPRING-FIELD	CITY UTILITIES OF SPRINGFIELD MISSOURI-JAMES RIVER POWER PLANT	NEI 7525	476,890	4,106,922	660	61	422	3.7	5	Tier 1
5070	SPRING-FIELD	CITY UTILITIES OF SPRINGFIELD MISSOURI-JAMES RIVER POWER PLANT	NEI 7525	476,918	4,106,919	567	61	422	3.7	5	Tier 1
5073	SPRING-FIELD	CITY UTILITIES OF SPRINGFIELD MISSOURI-JAMES RIVER POWER PLANT	NEI 7525	476,919	4,106,930	218	60	422	3.7	6	Tier 1
5074	SPRING-	CITY UTILITIES OF SPRINGFIELD	NEI 7525			255	60	422	3.7	6	Tier 1

Stack ID	City	Facility Name	NEI Site ID	UTM X (m)[1]	UTM Y (m)[1]	SO_2 Emissions (tpy)	Stack Height (m)	Exit Temp. (K)	Stack Diam. (m)	Exit Velocity (m/s)	Profile Method[2]
	FIELD	MISSOURI-JAMES RIVER POWER PLANT		476,952	4,106,940						
5076	SPRING-FIELD	CITY UTILITIES OF SPRINGFIELD MISSOURI-JAMES RIVER POWER PLANT	NEI 7525	477,050	4,106,880	219	60	422	3.7	6	Tier 1
5077	SPRING-FIELD	CITY UTILITIES OF SPRINGFIELD MISSOURI-JAMES RIVER POWER PLANT	NEI 7525	476,992	4,106,881	252	60	422	3.7	6	Tier 1
5084	SPRING-FIELD	CITY UTILITIES OF SPRINGFIELD MISSOURI-SOUTHWEST POWER PLANT	NEI 12640	465,416	4,111,816	3,390	117	397	3.4	21	Tier 2
5113	WEST ALTON	AMERENUE-SIOUX PLANT	NEI 7516	735,034	4,310,876	24,932	183	427	5.8	29	Tier 1
5114	WEST ALTON	AMERENUE-SIOUX PLANT	NEI 7516	735,027	4,310,819	21,025	183	427	5.8	29	Tier 1
5115	WEST ALTON	AMERENUE-SIOUX PLANT	NEI 7516	734,948	4,310,864	2	65	436	1.4	15	Tier 1
5131	HERCU-LANEUM	DOE RUN COMPANY-HERCULANEUM SMELTER	NEI 34412	729,589	4,238,084	2	3	295	0.0	0	Tier 2
5141	HERCU-LANEUM	DOE RUN COMPANY-HERCULANEUM SMELTER	NEI 34412	729,543	4,237,936	2	9	287	0.3	6	Tier 3
5145	HERCU-LANEUM	DOE RUN COMPANY-HERCULANEUM SMELTER	NEI 34412	729,537	4,237,973	15,219	168	350	6.1	18	Tier 2
5147	FESTUS	AMERENUE-RUSH ISLAND PLANT	NEI 12618	739,910	4,223,934	2	76	577	1.5	9	Tier 1
5148	FESTUS	AMERENUE-RUSH ISLAND PLANT	NEI 12618	739,893	4,223,827	10,511	213	405	8.8	25	Tier 1
5149	FESTUS	AMERENUE-RUSH ISLAND PLANT	NEI 12618	739,931	4,223,869	12,744	213	405	8.8	25	Tier 1
5244	STE. GENE-VIEVE	MISSISSIPPI LIME COMPANY-MISSISSIPPI LIME CO	NEI MO1860001	757,358	4,207,065	62	23	519	3.2	4	Tier 3
5245	STE. GENE-VIEVE	MISSISSIPPI LIME COMPANY-MISSISSIPPI LIME CO	NEI MO1860001	757,384	4,207,015	89	23	469	3.4	6	Tier 3

Stack ID	City	Facility Name	NEI Site ID	UTM X (m)[1]	UTM Y (m)[1]	SO_2 Emissions (tpy)	Stack Height (m)	Exit Temp. (K)	Stack Diam. (m)	Exit Velocity (m/s)	Profile Method[2]
5246	STE. GENE-VIEVE	MISSISSIPPI LIME COMPANY-MISSISSIPPI LIME CO	NEI MO1860001	757,697	4,206,939	103	23	469	3.4	6	Tier 3
5247	STE. GENE-VIEVE	MISSISSIPPI LIME COMPANY-MISSISSIPPI LIME CO	NEI MO1860001	757,666	4,206,950	106	23	469	3.4	6	Tier 3
5248	STE. GENE-VIEVE	MISSISSIPPI LIME COMPANY-MISSISSIPPI LIME CO	NEI MO1860001	757,697	4,206,981	105	23	469	3.4	6	Tier 3
5261	STE. GENE-VIEVE	MISSISSIPPI LIME COMPANY-MISSISSIPPI LIME CO	NEI MO1860001	757,561	4,206,988	1,290	35	343	1.7	11	Tier 3
5262	STE. GENE-VIEVE	MISSISSIPPI LIME COMPANY-MISSISSIPPI LIME CO	NEI MO1860001	757,735	4,206,971	1,394	35	343	1.7	11	Tier 3
5263	STE. GENE-VIEVE	MISSISSIPPI LIME COMPANY-MISSISSIPPI LIME CO	NEI MO1860001	757,727	4,206,997	1,505	35	344	1.7	13	Tier 3
5264	STE. GENE-VIEVE	MISSISSIPPI LIME COMPANY-MISSISSIPPI LIME CO	NEI MO1860001	757,550	4,206,964	67	35	346	2.1	9	Tier 3
5265	STE. GENE-VIEVE	MISSISSIPPI LIME COMPANY-MISSISSIPPI LIME CO	NEI MO1860001	757,524	4,206,924	77	35	346	2.1	9	Tier 3
5267	STE. GENE-VIEVE	MISSISSIPPI LIME COMPANY-MISSISSIPPI LIME CO	NEI MO1860001	757,633	4,206,999	2	20	367	1.1	15	Tier 2
5270	STE. GENE-VIEVE	MISSISSIPPI LIME COMPANY-MISSISSIPPI LIME CO	NEI MO1860001	757,627	4,206,989	1	20	362	1.2	11	Tier 3
5271	STE. GENE-VIEVE	MISSISSIPPI LIME COMPANY-MISSISSIPPI LIME CO	NEI MO1860001	757,540	4,206,931	1,199	35	343	1.7	11	Tier 3
5276	ST. LOUIS	AMERENUE-MERAMEC PLANT	NEI 7515	732,584	4,253,799	5,195	107	463	4.9	33	Tier 1
5277	ST. LOUIS	AMERENUE-MERAMEC PLANT	NEI 7515	732,631	4,253,790	6,463	107	447	4.3	31	Tier 1
5278	ST. LOUIS	AMERENUE-MERAMEC PLANT	NEI 7515	732,677	4,253,784	2,359	76	436	3.4	27	Tier 1
5279	ST. LOUIS	AMERENUE-MERAMEC PLANT	NEI 7515	732,714	4,253,779	2,430	76	436	3.2	27	Tier 1
5293	ST. LOUIS	ANHEUSER-BUSCH INC-ST LOUIS	NEI 34732	742,736	4,275,786	2	30	371	1.2	3	Tier 2

Stack ID	City	Facility Name	NEI Site ID	UTM X (m)[1]	UTM Y (m)[1]	SO_2 Emissions (tpy)	Stack Height (m)	Exit Temp. (K)	Stack Diam. (m)	Exit Velocity (m/s)	Profile Method[2]
5295	ST. LOUIS	ANHEUSER-BUSCH INC-ST LOUIS	NEI 34732	742,775	4,275,743	176	69	450	3.0	6	Tier 2
5296	ST. LOUIS	ANHEUSER-BUSCH INC-ST LOUIS	NEI 34732	742,750	4,275,704	256	69	450	3.0	6	Tier 2
5297	ST. LOUIS	ANHEUSER-BUSCH INC-ST LOUIS	NEI 34732	742,781	4,275,753	249	69	450	3.0	6	Tier 2
5298	ST. LOUIS	ANHEUSER-BUSCH INC-ST LOUIS	NEI 34732	742,800	4,275,764	158	69	450	3.0	6	Tier 2
5299	ST. LOUIS	ANHEUSER-BUSCH INC-ST LOUIS	NEI 34732	742,759	4,275,714	3,066	69	461	3.0	6	Tier 2
5302	ST. LOUIS	ANHEUSER-BUSCH INC-ST LOUIS	NEI 34732	742,739	4,275,677	2,339	69	439	3.0	6	Tier 2
5304	ST. LOUIS	ANHEUSER-BUSCH INC-ST LOUIS	NEI 34732	742,711	4,275,740	4	22	486	1.2	9	Tier 2

Notes:

[1] UTM Zone 15 values in all cases.

[2] Three methods were possible to convert annual total emissions data from the NEI into hourly temporal profiles required for AERMOD, based on availability of data:

Tier 1: CAMD hourly concentrations to create relative temporal profiles.
Tier 2: EMS-HAP seasonal and diurnal temporal profiles for source categorization codes (SCCs).
Tier 3: Flat profiles

Table B.3-2. Emission parameters by stack for all major cross-border facility stacks in the St. Louis scenario.

Stack ID	City	Facility Name	NEI Site ID	UTM X (m)[1]	UTM Y (m)[1]	SO_2 Emissions (tpy)	Stack Height (m)	Exit Temp. (K)	Stack Diam. (m)	Exit Velocity (m/s)	Profile Method[2]
1	East Alton	DYNEGY MIDWEST GENERATION INC	NEI52119	748,654	4,305,518	1536.2	76.2	427.6	5.2	8.5	Tier 1
2	East Alton	DYNEGY MIDWEST GENERATION INC	NEI52119	748,654	4,305,518	5725.8	106.7	416.5	4.6	34.6	Tier 1
3	Baldwin	DYNEGY MIDWEST GENERATION INC	NEI52781	775,316	4,233,202	9931.4	184.4	425.4	5.9	39.7	Tier 1
4	Baldwin	DYNEGY MIDWEST GENERATION INC	NEI52781	775,316	4,233,202	9053	184.4	428.7	5.9	38.3	Tier 1
5	Baldwin	DYNEGY MIDWEST GENERATION INC	NEI52781	775,316	4,233,202	7283	184.4	424.8	5.9	38.4	Tier 1
9	Hartford	Premcor Refining Group (prev. Clark Oil and Refining Corp.)	NEI52159	753,003	4,302,381	131.95786	33.5	533.2	1.5	3.1	Tier 2
10	Hartford	Premcor Refining Group (prev. Clark Oil and Refining Corp.)	NEI52159	752,783	4,302,408	907.24	19.9	502.0	1.1	6.5	Tier 2
11	Hartford	Premcor Refining Group (prev. Clark Oil and Refining Corp.)	NEI52159	752,886	4,302,285	132.9	24.1	519.3	2.1	7.0	Tier 2

Stack ID	City	Facility Name	NEI Site ID	UTM X (m)[1]	UTM Y (m)[1]	SO_2 Emissions (tpy)	Stack Height (m)	Exit Temp. (K)	Stack Diam. (m)	Exit Velocity (m/s)	Profile Method[2]
12	Hartford	Premcor Refining Group (prev. Clark Oil and Refining Corp.)	NEI52159	752,883	4,302,377	106.67	24.4	533.2	1.8	2.6	Tier 2
13	Hartford	Premcor Refining Group (prev. Clark Oil and Refining Corp.)	NEI52159	753,003	4,302,381	79	36.0	533.2	1.2	3.1	Tier 2
14	Hartford	Premcor Refining Group (prev. Clark Oil and Refining Corp.)	NEI52159	752,886	4,302,285	66.43	16.8	677.6	1.8	6.2	Tier 2
15	Hartford	Premcor Refining Group (prev. Clark Oil and Refining Corp.)	NEI52159	752,783	4,302,408	4.90219	35.4	570.4	1.5	7.8	Tier 2
16	Hartford	Premcor Refining Group (prev. Clark Oil and Refining Corp.)	NEI52159	753,003	4,302,381	171.36006	30.5	533.2	1.5	4.1	Tier 2
17	Hartford	Premcor Refining Group (prev. Clark Oil and Refining Corp.)	NEI52159	752,783	4,302,408	7.42	30.7	513.2	1.7	11.4	Tier 2
18	Sauget	BIG RIVER ZINC CORP	NEI53013	746,429	4,276,339	1.34	21.3	317.6	0.7	10.6	Tier 2
19	Sauget	BIG RIVER ZINC CORP	NEI53013	746,429	4,276,339	1377.28	25.9	422.0	0.9	41.3	Tier 2
20	Roxana	ConocoPhillips Co. (prev. Phillips 66 Co.)	NEI55835	755,000	4,302,599	15.38	106.7	472.0	4.6	11.4	Tier 2

Stack ID	City	Facility Name	NEI Site ID	UTM X (m)[1]	UTM Y (m)[1]	SO_2 Emissions (tpy)	Stack Height (m)	Exit Temp. (K)	Stack Diam. (m)	Exit Velocity (m/s)	Profile Method[2]
21	Roxana	ConocoPhillips Co. (prev. Phillips 66 Co.)	NEI55835	755,000	4,302,599	7.27	106.7	463.7	4.6	0.3	Tier 2
22	Roxana	ConocoPhillips Co. (prev. Phillips 66 Co.)	NEI55835	755,188	4,302,550	1.2	45.7	628.2	2.3	7.9	Tier 1
23	Roxana	ConocoPhillips Co. (prev. Phillips 66 Co.)	NEI55835	754,405	4,303,105	1.25	56.4	432.6	2.4	6.7	Tier 2
24	Roxana	ConocoPhillips Co. (prev. Phillips 66 Co.)	NEI55835	754,997	4,302,691	1.45	61.0	672.0	3.7	6.7	Tier 2
25	Roxana	ConocoPhillips Co. (prev. Phillips 66 Co.)	NEI55835	754,505	4,302,984	1.53	95.1	483.7	4.3	0.3	Tier 2
26	Roxana	ConocoPhillips Co. (prev. Phillips 66 Co.)	NEI55835	754,994	4,302,783	3.39	40.2	491.5	2.1	13.2	Tier 2
27	Roxana	ConocoPhillips Co. (prev. Phillips 66 Co.)	NEI55835	755,084	4,303,003	1.15	45.7	699.8	2.3	7.0	Tier 1
28	Roxana	ConocoPhillips Co. (prev. Phillips 66 Co.)	NEI55835	754,658	4,302,515	385.25	36.9	754.8	3.4	5.9	Tier 2
29	Roxana	ConocoPhillips Co. (prev. Phillips 66 Co.)	NEI55835	754,994	4,302,783	3.24	45.7	431.5	3.0	15.9	Tier 2
30	Roxana	ConocoPhillips Co. (prev. Phillips 66 Co.)	NEI55835	755,000	4,302,599	16.73	106.7	483.7	4.6	0.3	Tier 2
31	Roxana	ConocoPhillips Co. (prev. Phillips 66 Co.)	NEI55835	754,658	4,302,515	11677.82	10.1	293.7	0.1	0.1	Tier 2
32	Roxana	ConocoPhillips Co. (prev. Phillips 66 Co.)	NEI55835	755,231	4,302,561	212.41	45.7	699.8	2.4	8.8	Tier 2

Stack ID	City	Facility Name	NEI Site ID	UTM X (m)[1]	UTM Y (m)[1]	SO_2 Emissions (tpy)	Stack Height (m)	Exit Temp. (K)	Stack Diam. (m)	Exit Velocity (m/s)	Profile Method[2]
33	Roxana	ConocoPhillips Co. (prev. Phillips 66 Co.)	NEI55835	755,231	4,302,561	206.96	45.7	672.0	2.4	8.2	Tier 2
34	Roxana	ConocoPhillips Co. (prev. Phillips 66 Co.)	NEI55835	753,801	4,303,085	110.6	38.1	792.0	2.2	5.4	Tier 2
35	Roxana	ConocoPhillips Co. (prev. Phillips 66 Co.)	NEI55835	755,231	4,302,561	108.6	45.7	672.0	2.4	4.3	Tier 2
36	Granite City	NATIONAL STEEL CORP - GRANITE CITY DIV	NEI55848	747,795	4,286,723	61.88	30.5	616.5	2.1	17.9	Tier 2
37	Granite City	NATIONAL STEEL CORP - GRANITE CITY DIV	NEI55848	750,041	4,286,824	506.7	46.3	441.5	2.1	10.6	Tier 2
38	Granite City	NATIONAL STEEL CORP - GRANITE CITY DIV	NEI55848	749,778	4,286,692	228.47	24.5	372.0	1.5	6.2	Tier 2
39	Granite City	NATIONAL STEEL CORP - GRANITE CITY DIV	NEI55848	749,897	4,286,788	421.58883	68.6	460.9	4.3	4.5	Tier 2
40	Granite City	NATIONAL STEEL CORP - GRANITE CITY DIV	NEI55848	749,970	4,286,761	375.19	15.4	453.7	0.9	9.9	Tier 2
41	Granite City	NATIONAL STEEL CORP - GRANITE CITY DIV	NEI55848	750,041	4,286,824	351.93	46.3	441.5	2.1	1.2	Tier 2
42	Granite City	NATIONAL STEEL CORP - GRANITE CITY DIV	NEI55848	749,847	4,286,849	264.95442	61.0	460.9	3.4	3.1	Tier 2

Stack ID	City	Facility Name	NEI Site ID	UTM X (m)[1]	UTM Y (m)[1]	SO_2 Emissions (tpy)	Stack Height (m)	Exit Temp. (K)	Stack Diam. (m)	Exit Velocity (m/s)	Profile Method[2]
43	Granite City	NATIONAL STEEL CORP - GRANITE CITY DIV	NEI55848	750,280	4,286,925	923.52	43.5	538.7	2.0	9.2	Tier 2
44	Granite City	NATIONAL STEEL CORP - GRANITE CITY DIV	NEI55848	749,828	4,286,663	501.19	43.5	538.7	2.0	9.2	Tier 2
46	Granite City	NATIONAL STEEL CORP - GRANITE CITY DIV	NEI55848	747,842	4,286,755	85.86	30.5	616.5	2.1	17.9	Tier 2
47	Granite City	NATIONAL STEEL CORP - GRANITE CITY DIV	NEI55848	750,180	4,286,983	20.99	24.9	335.9	1.5	8.9	Tier 2
50	Granite City	NATIONAL STEEL CORP - GRANITE CITY DIV	NEI55848	748,053	4,287,055	8	19.2	323.7	2.1	13.1	Tier 2
51	Granite City	NATIONAL STEEL CORP - GRANITE CITY DIV	NEI55848	750,255	4,286,924	959.82	43.5	538.7	2.0	9.2	Tier 2

Notes:
[1] UTM Zone 15 values in all cases.
[2] Three methods were possible to convert annual total emissions data from the NEI into hourly temporal profiles required for AERMOD, based on availability of data:
Tier 1: CAMD hourly concentrations to create relative temporal profiles.
Tier 2: EMS-HAP seasonal and diurnal temporal profiles for source categorization codes (SCCs).
Tier 3: Flat profiles

B.3.2 AERMOD Air Quality Evaluation Data

Table B.3-2. Measured ambient monitor SO_2 concentration distributions and the modeled monitor receptor and receptors within 4 km of the ambient monitors in Greene County for year 2002.

Ambient Monitor ID	Receptor(s)[1]	Percentile Concentration (ppb)									
		100	99	95	90	80	70	60	50	25	0
290770026	AERMOD P2.5	29	6	2	1	0	0	0	0	0	0
	AERMOD P50	48	12	4	2	1	1	0	0	0	0
	AERMOD P97.5	101	46	18	8	2	1	1	1	0	0
	Ambient Monitor	114	46	16	7	3	2	1	1	1	0
	AERMOD Monitor	48	22	11	6	2	1	1	1	0	0
290770032	AERMOD P2.5	30	10	5	3	2	1	1	1	0	0
	AERMOD P50	41	12	6	4	3	2	2	2	1	0
	AERMOD P97.5	62	14	8	6	5	4	3	3	2	0
	Ambient Monitor	28	8	6	5	4	4	3	3	2	0
	AERMOD Monitor	42	14	8	6	5	4	3	3	1	0
290770037	AERMOD P2.5	35	5	2	1	0	0	0	0	0	0
	AERMOD P50	53	13	3	2	1	0	0	0	0	0
	AERMOD P97.5	106	55	21	8	2	1	1	0	0	0
	Ambient Monitor	144	49	8	4	2	2	2	2	0	0
	AERMOD Monitor	115	42	5	3	1	1	1	0	0	0
290770040	AERMOD P2.5	34	5	2	1	0	0	0	0	0	0
	AERMOD P50	53	13	3	2	1	0	0	0	0	0
	AERMOD P97.5	106	55	21	8	2	1	1	0	0	0
	Ambient Monitor	203	18	6	3	2	1	1	0	0	0
	AERMOD Monitor	116	45	6	3	1	1	1	0	0	0
290770041	AERMOD P2.5	31	5	2	1	0	0	0	0	0	0
	AERMOD P50	52	14	3	2	1	0	0	0	0	0
	AERMOD P97.5	108	56	22	8	2	1	1	0	0	0
	Ambient Monitor	33	9	3	2	1	1	1	0	0	0
	AERMOD Monitor	73	23	4	2	1	1	1	0	0	0

Notes:
[1] AERMOD concentrations are for the given percentile (p2.5 = 2.5th; p50 = 50th; p97.5 = 97.5th) of the modeled distribution of all modeled air quality receptors within 4 km of ambient monitor. *AERMOD monitor* is the concentration prediction at the ambient monitor location using AERMOD.

Table B.3-3. Measured ambient monitor SO_2 concentration diurnal profile and the modeled monitor receptor and receptors within 4 km of the ambient monitors in Greene County for year 2002.

Monitor ID	Hour of Day	Annual Average SO_2 Concentration (ppb) at Given Receptor				
		AERMOD P2.5	AERMOD P50	AERMOD P97.5	Ambient Monitor	AERMOD Monitor
290770026	1	0.2	0.4	1.6	2.7	1.2
	2	0.2	0.4	1.8	2.4	1.0
	3	0.2	0.4	2.0	2.5	0.9
	4	0.1	0.3	1.6	2.5	0.9
	5	0.1	0.3	1.5	2.9	0.8
	6	0.1	0.3	1.7	2.9	0.9
	7	0.2	0.7	2.3	3.6	1.4
	8	0.5	1.5	4.2	4.2	2.8
	9	0.7	1.5	5.6	4.6	3.6
	10	0.8	1.6	5.6	5.3	3.4
	11	0.7	1.4	6.0	5.0	3.7
	12	0.5	1.2	6.3	4.7	3.2
	13	0.6	1.1	6.1	4.5	2.8
	14	0.6	1.0	6.0	4.1	2.6
	15	0.5	1.0	5.8	3.7	2.6
	16	0.6	1.0	5.1	3.8	2.5
	17	0.6	1.3	4.6	3.7	2.9
	18	0.5	1.2	3.7	2.9	2.9
	19	0.3	0.9	2.3	2.6	2.4
	20	0.2	0.5	1.7	3.0	1.4
	21	0.2	0.5	1.7	2.8	1.4
	22	0.2	0.5	1.9	3.0	1.4
	23	0.2	0.4	1.9	2.9	1.1
	24	0.2	0.4	1.9	2.9	1.1
290770032	1	1.5	2.3	3.2	2.8	3.0
	2	1.4	2.1	3.0	2.6	2.9
	3	1.4	2.2	3.4	2.5	2.8
	4	1.3	2.0	2.8	2.5	2.7
	5	1.1	1.7	2.4	2.3	2.5
	6	1.1	1.8	2.5	2.2	2.4
	7	1.4	2.0	2.5	2.3	2.5
	8	1.9	2.2	2.7	2.7	2.9
	9	1.7	2.3	3.4	3.0	3.2
	10	1.5	2.3	3.9	3.3	3.6
	11	1.3	2.2	4.0	3.2	3.5
	12	1.2	2.2	4.1	3.2	3.6
	13	1.1	2.1	4.3	3.3	3.6
	14	1.1	2.0	4.1	3.2	3.6
	15	1.0	2.0	4.0	3.2	3.5
	16	1.1	2.1	4.1	3.1	3.4
	17	1.4	2.4	3.6	3.2	3.5
	18	1.6	2.4	3.3	3.1	3.5
	19	1.8	2.4	3.2	3.1	3.4

Monitor ID	Hour of Day	Annual Average SO_2 Concentration (ppb) at Given Receptor				
		AERMOD P2.5	AERMOD P50	AERMOD P97.5	Ambient Monitor	AERMOD Monitor
	20	1.7	2.5	3.2	3.1	3.4
	21	1.8	2.4	3.3	3.1	3.3
	22	1.7	2.6	3.6	3.1	3.4
	23	1.6	2.5	3.4	3.1	3.4
	24	1.4	2.4	3.2	2.9	3.1
290770037	1	0.2	0.2	1.4	1.6	0.5
	2	0.2	0.2	1.5	1.5	0.5
	3	0.2	0.2	1.7	1.5	0.5
	4	0.1	0.2	1.5	1.9	0.4
	5	0.1	0.2	1.4	1.9	0.3
	6	0.1	0.2	1.6	1.8	0.3
	7	0.1	0.4	2.4	1.9	0.3
	8	0.4	1.0	4.5	2.3	1.0
	9	0.6	1.2	6.2	3.1	1.9
	10	0.8	1.5	6.4	3.8	3.7
	11	0.7	1.4	7.0	4.1	4.6
	12	0.6	1.3	6.9	4.8	5.4
	13	0.6	1.3	7.0	5.0	5.0
	14	0.6	1.2	7.2	5.2	4.6
	15	0.5	1.2	6.5	5.3	4.3
	16	0.5	1.2	5.7	4.9	3.1
	17	0.5	1.2	5.2	4.2	2.4
	18	0.4	1.0	4.2	3.0	1.9
	19	0.3	0.5	2.5	2.2	0.7
	20	0.2	0.3	1.4	2.2	0.5
	21	0.2	0.3	1.5	1.9	0.5
	22	0.2	0.3	1.7	1.8	0.6
	23	0.2	0.2	1.8	1.9	0.5
	24	0.2	0.2	1.6	2.1	0.5
290770040	1	0.2	0.2	1.4	1.0	0.5
	2	0.2	0.2	1.5	0.8	0.5
	3	0.2	0.2	1.7	1.0	0.5
	4	0.1	0.2	1.5	1.0	0.4
	5	0.1	0.2	1.4	1.0	0.3
	6	0.1	0.2	1.6	1.0	0.3
	7	0.1	0.4	2.4	1.0	0.3
	8	0.4	1.0	4.5	1.2	0.8
	9	0.6	1.2	6.2	1.6	1.8
	10	0.8	1.5	6.4	2.2	3.7
	11	0.7	1.4	7.0	2.4	4.8
	12	0.5	1.3	6.9	2.9	6.2
	13	0.6	1.3	7.0	2.4	5.9
	14	0.6	1.2	7.2	3.0	4.8
	15	0.5	1.2	6.5	2.8	4.6
	16	0.5	1.2	5.7	2.2	3.2
	17	0.5	1.1	5.2	1.8	2.6
	18	0.4	1.0	4.2	1.8	1.8

Monitor ID	Hour of Day	Annual Average SO_2 Concentration (ppb) at Given Receptor				
		AERMOD P2.5	AERMOD P50	AERMOD P97.5	Ambient Monitor	AERMOD Monitor
	19	0.3	0.5	2.5	1.2	0.8
	20	0.2	0.3	1.4	1.0	0.5
	21	0.2	0.3	1.5	1.0	0.5
	22	0.2	0.3	1.7	0.9	0.6
	23	0.2	0.2	1.8	0.9	0.5
	24	0.2	0.2	1.6	1.0	0.5
290770041	1	0.2	0.3	1.5	0.6	0.6
	2	0.2	0.3	1.7	0.6	0.5
	3	0.2	0.3	1.9	0.6	0.6
	4	0.1	0.2	1.5	0.5	0.5
	5	0.1	0.2	1.4	0.4	0.4
	6	0.1	0.2	1.7	0.6	0.4
	7	0.1	0.6	2.4	0.6	0.6
	8	0.5	1.2	4.9	0.8	1.5
	9	0.6	1.4	6.2	1.1	1.7
	10	0.7	1.7	6.5	1.4	1.8
	11	0.6	1.5	7.2	1.5	2.4
	12	0.4	1.4	7.0	1.5	2.1
	13	0.5	1.4	7.4	1.6	2.4
	14	0.4	1.3	7.9	1.3	2.0
	15	0.4	1.2	6.6	1.1	2.1
	16	0.4	1.3	6.2	1.0	2.3
	17	0.4	1.2	5.4	0.9	2.1
	18	0.4	1.1	4.2	0.7	1.8
	19	0.3	0.5	2.6	0.6	0.8
	20	0.2	0.3	1.5	0.6	0.6
	21	0.2	0.3	1.6	0.7	0.6
	22	0.2	0.4	1.8	0.7	0.7
	23	0.2	0.3	1.9	0.6	0.6
	24	0.2	0.3	1.8	0.7	0.6

Table B.3-4. Measured ambient monitor SO_2 concentration distributions and the modeled monitor receptor and receptors within 4 km of the ambient monitors in St. Louis for year 2002.

Ambient Monitor ID	Receptor(s)[1]	Percentile Concentration (ppb)									
		100	99	95	90	80	70	60	50	25	0
291890004	AERMOD P2.5	60	20	11	7	4	3	2	2	1	0
	AERMOD P50	69	22	12	8	5	3	2	2	1	0
	AERMOD P97.5	103	25	14	9	5	4	3	2	1	0
	Ambient Monitor	99	24	13	8	5	3	2	1	0	0
	AERMOD Monitor	67	22	11	7	4	3	2	2	1	0
291890006	AERMOD P2.5	48	19	10	7	4	3	2	2	1	0
	AERMOD P50	55	20	11	7	5	3	2	2	1	0
	AERMOD P97.5	94	20	12	8	5	4	3	2	1	0
	Ambient Monitor	85	18	9	6	3	2	1	1	0	0
	AERMOD Monitor	73	20	11	8	5	3	3	2	1	0
291893001	AERMOD P2.5	58	24	13	9	5	4	3	2	1	0
	AERMOD P50	75	26	14	10	6	4	3	2	1	0
	AERMOD P97.5	91	30	17	12	8	6	5	3	2	0
	Ambient Monitor	80	24	12	8	5	4	3	2	1	0
	AERMOD Monitor	71	25	14	10	6	4	3	2	1	0
291895001	AERMOD P2.5	97	32	13	8	5	4	3	2	1	0
	AERMOD P50	168	38	14	9	6	4	3	2	1	0
	AERMOD P97.5	545	51	15	10	6	4	3	2	1	0
	Ambient Monitor	158	23	12	8	5	4	3	2	1	0
	AERMOD Monitor	191	40	14	9	6	4	3	2	1	0
291897003	AERMOD P2.5	67	25	11	7	4	3	2	2	1	0
	AERMOD P50	89	28	12	8	5	3	3	2	1	0
	AERMOD P97.5	138	32	13	9	5	4	3	2	1	0
	Ambient Monitor	91	24	12	8	5	4	3	2	1	0
	AERMOD Monitor	99	27	12	8	5	4	3	2	1	0
295100007	AERMOD P2.5	71	26	13	8	4	3	2	2	1	0
	AERMOD P50	93	31	18	11	7	5	4	3	1	0
	AERMOD P97.5	137	43	23	16	10	8	6	5	2	0
	Ambient Monitor	64	25	14	10	6	5	3	2	1	0
	AERMOD Monitor	100	32	17	11	7	6	5	4	2	0
295100086	AERMOD P2.5	71	29	15	11	7	5	4	3	1	0
	AERMOD P50	91	32	18	13	9	6	5	4	2	0
	AERMOD P97.5	124	36	22	16	11	8	6	5	3	0
	Ambient Monitor	86	30	16	11	7	5	4	3	1	0
	AERMOD Monitor	111	31	17	13	8	6	5	4	2	0

Notes:
[1] AERMOD concentrations are for the given percentile (p2.5 = 2.5th; p50 = 50th; p97.5 = 97.5th) of the modeled distribution of all modeled air quality receptors within 4 km of ambient monitor. *AERMOD monitor* is the concentration prediction at the ambient monitor location using AERMOD.

Table B.3-5. Measured ambient monitor SO_2 concentration diurnal profile and the modeled monitor receptor and receptors within 4 km of the ambient monitors in St. Louis for year 2002.

Ambient Monitor ID	Hour of Day	Annual Average SO_2 Concentration (ppb) at Given Receptor				
		AERMOD P2.5	AERMOD P50	AERMOD P97.5	Ambient Monitor	AERMOD Monitor
291890004	1	2.0	2.6	3.2	2.4	2.2
	2	1.7	2.2	2.7	2.1	1.8
	3	1.5	1.9	2.3	1.8	1.7
	4	1.5	1.9	2.3	1.8	1.6
	5	1.4	1.8	2.1	1.8	1.7
	6	1.4	1.8	2.6	2.0	1.8
	7	1.8	2.2	2.6	2.4	2.0
	8	2.7	3.2	4.0	3.3	3.0
	9	4.0	4.5	4.8	4.1	4.2
	10	4.6	5.0	5.4	4.6	4.7
	11	4.8	5.0	5.3	4.6	4.8
	12	4.6	5.2	5.6	4.5	4.8
	13	4.4	4.9	5.2	4.1	4.5
	14	4.1	4.7	5.0	4.3	4.2
	15	3.9	4.3	4.6	4.0	4.0
	16	3.7	4.2	4.4	3.6	3.7
	17	3.8	4.4	4.7	3.8	3.9
	18	3.5	4.2	4.6	3.8	3.5
	19	3.1	3.6	4.0	3.4	3.1
	20	3.0	3.5	3.7	2.9	3.1
	21	2.7	3.4	3.7	2.8	2.9
	22	2.4	2.9	3.3	2.9	2.6
	23	2.1	2.7	3.3	2.9	2.4
	24	2.1	2.6	3.0	2.5	2.2
291890006	1	2.4	2.6	2.9	1.6	2.6
	2	2.1	2.3	2.6	1.6	2.5
	3	1.7	1.9	2.1	1.5	2.0
	4	1.8	2.0	2.3	1.2	2.1
	5	1.6	1.8	1.9	1.2	1.8
	6	1.5	1.6	1.7	1.2	1.5
	7	2.0	2.0	2.1	1.4	2.0
	8	2.5	2.7	2.7	1.9	2.5
	9	4.2	4.3	4.4	2.7	4.3
	10	4.4	4.6	4.8	3.4	4.7
	11	4.8	4.9	5.3	3.5	5.1
	12	4.3	4.5	4.8	3.8	4.6
	13	4.2	4.3	4.7	3.5	4.6
	14	4.1	4.2	4.6	2.9	4.6
	15	3.9	4.0	4.4	2.6	4.3
	16	3.7	3.8	4.2	2.9	4.2
	17	3.8	4.0	4.6	2.7	4.3
	18	3.4	3.7	4.5	2.6	4.1
	19	3.0	3.3	3.8	2.4	3.4

	20	2.9	3.1	3.4	2.4	3.0
	21	2.8	3.0	3.4	2.0	3.1
	22	2.5	2.7	3.0	2.0	2.8
	23	2.3	2.8	3.2	1.9	2.8
	24	2.2	2.4	2.8	1.8	2.7
291893001	1	3.0	3.6	4.2	2.2	3.5
	2	2.8	3.2	3.9	2.2	3.2
	3	2.3	2.7	3.3	2.0	2.7
	4	2.5	2.8	3.4	1.7	2.8
	5	2.1	2.5	2.8	1.8	2.5
	6	2.2	2.6	3.1	2.3	2.7
	7	2.6	3.0	3.7	2.8	3.1
	8	3.2	3.7	4.6	3.7	3.6
	9	4.5	5.1	6.5	4.5	5.0
	10	5.2	5.6	7.8	4.9	5.7
	11	5.3	5.8	8.1	4.8	5.8
	12	5.3	5.8	8.2	4.7	5.8
	13	5.0	5.4	7.7	4.4	5.3
	14	4.6	5.1	7.8	4.5	5.0
	15	4.5	4.8	7.3	4.1	4.8
	16	4.3	4.7	7.1	3.8	4.7
	17	4.5	4.8	6.4	3.8	4.7
	18	4.3	4.8	6.0	4.1	4.8
	19	3.9	4.3	5.3	3.7	4.2
	20	3.6	3.9	4.7	3.5	3.9
	21	3.6	4.0	4.6	3.4	4.0
	22	3.3	3.8	4.7	3.2	3.7
	23	3.2	3.8	4.5	3.0	3.9
	24	3.0	3.7	4.4	2.7	3.6
291895001	1	3.2	3.7	4.9	3.1	3.8
	2	3.1	3.7	5.1	2.9	3.5
	3	2.8	3.2	3.8	2.7	3.2
	4	2.8	3.3	4.3	2.7	3.2
	5	2.4	3.0	3.9	2.7	3.3
	6	2.5	3.6	4.9	2.8	3.8
	7	2.6	3.2	3.9	3.2	3.0
	8	3.2	4.3	5.3	4.0	4.7
	9	4.5	5.5	6.1	4.6	5.4
	10	5.3	6.0	6.6	4.7	6.0
	11	5.5	5.9	6.1	5.2	6.0
	12	5.6	5.7	6.0	5.1	6.0
	13	4.6	5.3	5.7	4.6	5.3
	14	4.6	5.1	5.3	4.1	5.2
	15	4.4	4.8	5.0	4.1	4.9
	16	4.1	4.6	4.9	3.9	4.6
	17	4.1	4.5	4.8	4.1	4.7
	18	4.5	4.8	5.3	3.9	4.9
	19	3.2	4.2	5.3	3.7	3.7
	20	3.3	4.1	5.5	3.2	4.0
	21	3.1	4.3	5.6	3.5	3.9

	22	3.5	4.4	5.6	3.3	4.7
	23	3.7	4.4	6.3	3.2	5.6
	24	3.8	4.3	5.1	2.9	4.3
291897003	1	2.3	2.8	3.3	2.6	2.7
	2	2.6	3.0	3.2	2.4	3.2
	3	2.1	2.6	2.9	2.5	2.7
	4	2.2	2.5	3.0	2.4	2.4
	5	1.7	2.2	2.7	2.3	2.2
	6	2.1	2.5	3.2	2.5	2.5
	7	1.8	2.1	2.6	3.2	2.1
	8	2.9	3.4	3.9	4.1	3.2
	9	4.1	4.4	5.0	4.7	4.5
	10	4.9	5.3	5.8	4.8	5.4
	11	4.8	5.2	5.6	5.1	5.4
	12	4.5	5.0	5.6	4.7	5.1
	13	4.3	4.7	5.1	4.5	4.9
	14	4.0	4.4	4.8	4.4	4.6
	15	3.9	4.4	4.7	4.2	4.6
	16	3.6	4.1	4.4	3.8	4.3
	17	3.7	4.3	4.6	3.7	4.5
	18	3.2	4.2	4.7	3.9	4.4
	19	3.1	3.8	4.5	3.6	3.8
	20	2.8	3.2	4.0	3.5	3.2
	21	2.8	3.4	3.9	3.3	3.2
	22	3.4	3.7	4.0	3.1	3.9
	23	2.7	3.3	4.2	3.1	3.6
	24	3.0	3.4	3.8	2.9	3.6
295100007	1	2.2	3.7	5.8	3.4	4.0
	2	2.1	3.4	5.6	3.2	3.5
	3	1.6	3.0	5.3	3.2	3.3
	4	1.7	3.1	5.2	3.0	3.3
	5	1.4	3.0	5.1	2.9	3.1
	6	1.6	3.1	5.2	3.1	3.2
	7	2.9	4.5	7.6	3.7	4.6
	8	3.6	5.2	7.8	4.1	5.2
	9	5.0	6.6	8.4	5.2	6.6
	10	5.1	6.8	8.2	5.7	7.0
	11	5.1	7.1	8.5	5.5	7.5
	12	4.9	7.0	8.2	4.9	7.2
	13	4.6	6.9	8.1	4.7	7.1
	14	4.5	6.8	8.1	4.6	7.1
	15	4.0	6.3	7.6	4.4	6.6
	16	4.0	6.2	7.8	4.2	6.6
	17	4.4	6.2	8.2	4.2	6.6
	18	4.2	6.0	8.7	3.9	6.3
	19	3.6	5.7	10.0	3.8	6.5
	20	3.5	5.1	7.4	4.2	5.2
	21	3.2	4.8	7.1	4.1	4.9
	22	2.7	4.4	6.6	4.0	4.5
	23	2.6	4.0	5.9	4.1	4.0

	24	2.3	3.9	5.8	3.7	3.9
295100086	1	3.8	4.9	6.5	4.3	4.8
	2	3.3	4.7	6.7	4.2	4.4
	3	3.1	4.3	5.5	3.7	4.1
	4	3.0	4.0	5.6	3.9	4.0
	5	3.0	3.8	5.8	3.9	3.6
	6	2.3	3.9	5.9	4.3	4.0
	7	3.7	4.4	7.0	4.4	4.3
	8	4.2	5.5	7.0	5.4	5.3
	9	5.8	7.0	8.0	6.3	6.9
	10	6.7	8.1	8.4	6.0	8.1
	11	6.6	8.0	8.4	6.0	8.0
	12	6.5	7.8	8.3	5.4	7.8
	13	6.2	7.7	8.1	5.1	7.6
	14	6.1	7.5	7.9	4.9	7.4
	15	5.7	7.1	7.4	4.6	7.1
	16	5.6	7.2	7.5	4.7	7.2
	17	5.3	7.2	7.9	4.9	6.9
	18	5.2	7.2	8.5	4.4	7.0
	19	5.0	6.5	9.2	4.6	6.2
	20	4.7	6.2	8.0	4.7	6.0
	21	4.6	6.3	7.7	4.9	6.1
	22	4.3	5.6	7.9	4.8	5.1
	23	4.1	5.4	7.3	4.3	5.1
	24	3.8	5.1	6.9	4.2	4.8

B.4 SUPPLEMENTAL APEX EXPOSURE MODELING DATA

B.4.1 APEX Input Data Distributions for SO_2 deposition

In recognizing the relationship between SO_2 deposition rate and various surface types within indoor microenvironments and that the presence of these surfaces would vary in proportions dependent on the microenvironment, staff estimated the APEX input SO_2 deposition rate distributions using a Monte Carlo sampling approach. First, 1,000 different hypothetical indoor microenvironments were simulated, each with a different ratio of wall area to floor area and furniture area to floor area. Based on these ratios, surface area to volume ratios were estimated in each sample indoor microenvironment. Then, surface area to volume ratios were used to convert the deposition velocities to deposition rates in hr^{-1} by dividing the velocities by the surface area to volume ratio and then making an appropriate unit conversion. And finally, the deposition rate for each surface type was combined using a weighted average to estimate an effective deposition rate, as follows:

$$D_{eff} = \frac{D_{floor} + D_{ceiling} * \frac{A_{ceiling}}{A_{floor}} + D_{furniture} * \frac{A_{furntiture}}{A_{floor}}}{1 + \frac{A_{ceiling}}{A_{floor}} + \frac{A_{furniture}}{A_{floor}}} \qquad \text{equation (B-6)}$$

where D denotes deposition rate, A denotes area of the indoor microenvironment, and D_{eff} is the effective deposition rate. If more than one surface type is present in the sample indoor microenvironment (e.g. both carpet and non-carpeted floors), these values were first averaged using the fraction of the room that contains each. Details regarding the data used for estimating the SO_2 deposition rate within simulated indoor microenvironments are provided in the following sections.

B.4.1.1 Surface deposition data and surface type mapping

Staff obtained SO_2 deposition velocities from a literature review conducted by Grøntoft and Raychaudhuri (2004). These authors categorized the data by several relative humidities and considering several different surface types. Staff mapped the surface classes reported in Grøntoft and Raychaudhuri (2004) to surface types typically found within indoor microenvironments (Table B.4-1).

Table B.4-1. Classification of SO_2 deposition data for several microenvironmental surfaces.

Surface Category	Surface Type	Surface Class[1]	Deposition in cm/s[1]		
			50% Relative Humidity	70% Relative Humidity	90% Relative Humidity
Floor	Carpet	Average of the wool and synthetic carpet values	0.0625	0.075	0.117
	Floor	Synthetic Floor Covering – medium worn	0.007	0.015	0.032
Ceiling	Ceiling Tile	Coarse composite panels	0.14	0.15	0.18
	Ceiling Wallboard	Treated gypsum wallboard	0.048	0.16	0.27
Wall	Wallpaper	Wall paper	0.036	0.043	0.068
	Wall Wallboard	Treated gypsum wallboard	0.048	0.16	0.27
	Wood paneling	Surface treated wood work and wall boards	0.014	0.047	0.078
Furniture	Furniture	Cloth	0.019	0.023	0.036

Notes:
[1] Obtained from Table 6 of Grøntoft and Raychaudhuri (2004).

B.4.1.2 Indoor Microenvironment Configurations

Because the configuration of rooms within a building will affect the wall area to floor area ratio, staff first estimated the areas of several indoor microenvironments. Staff had to make several assumptions due to the limited availability of data. The first broad assumption was that a single room within the indoor microenvironment could represent all potential rooms within the particular building type. Secondly, staff assumed all rooms were square to calculate the area distributions. Additional assumptions specific to the type of indoor microenvironment are provided below, along with the estimated indoor microenvironment area distributions.

Residential area distributions

In residences, the American Housing Survey (AHS, 2008) provides a matrix that gives the number of survey homes within a given total square footage and a given number of rooms category. Staff converted the data to probabilities using the total number of homes in each category (Table B.4-2). In calculating the room area using these distributions, a series of two independent random numbers were used to select a square footage category and then to find the number of rooms within that square footage category, accounting for the inherent correlation of the number of rooms in a given building with the total square footage. Staff derived a representative room area by dividing the square footage by the number of rooms.

Table B.4-2. Distributions used to calculate a representative room size in an indoor residential microenvironment.

		Square Footage					
		250	**750**	**1250**	**1750**	**2250**	**2750**
	Cumulative probability for each square footage class →	**0.01**	**0.10**	**0.35**	**0.60**	**0.77**	**1.00**
Cumulative probability for number of rooms within each square footage class ↓	**Rooms**						
	1	0.07	0.00	0.00	0.00	0.00	0.00
	2	0.13	0.00	0.00	0.00	0.00	0.00
	3	0.40	0.07	0.01	0.00	0.00	0.00
	4	0.64	0.47	0.13	0.04	0.02	0.01
	5	0.81	0.80	0.54	0.28	0.15	0.08
	6	0.90	0.94	0.86	0.65	0.41	0.23
	7	0.97	0.98	0.96	0.90	0.71	0.46
	8	0.99	0.99	0.99	0.98	0.92	0.71
	9	0.99	1.00	1.00	0.99	0.98	0.87
	10	1.00			1.00	1.00	1.00

Non-residential area distributions

An office can contain many different rooms, each with either one or two occupants (usually a smaller office) or a collection of cubicles (usually a larger office).

Staff used the Building Assessment Survey and Evaluation study (BASE; US EPA, 2008a) to generate representative office areas for simulated buildings. The BASE data provided the mean, standard deviation, minimum, and maximum of the total square footage and the number of people per square meter of occupied space (Table B.4-3).[1] Based on this, staff represented the data as a normal distribution and set the lower and upper limits using the minimum and maximum observations. BASE (US EPA, 2008a) also provides the average number of occupants in private or semi-private work areas (40%) compared to shared space (60%).[2] Staff assumed that the private and semi-private offices have an average of two people in each and the shared spaces have an average of six people in each. In calculating the area, two independent random numbers were used to select the total floor area and the number of occupants in that floor area. The total square footage of the office was then divided by the number of rooms to obtain the representative office area.

For schools, the distribution of the total building square footage is available from the Commercial Building Energy Consumption Survey (CBECS; US DOE, 2003); however, information on the number of rooms in each square footage class is not available. As an alternate data source, information was available on the range of the square footage of a typical school classroom (600 to 1,400 square feet) to generate a uniform distribution bounded by these extremes (NCBG, 2008; US Army Corps of Engineers, 2002). For restaurants and other buildings, staff assumed that the entire building was one room; therefore, the CBECS (US DOE, 2003) provided data for this building category to estimate square footage distributions (Table B.4-3).

Table B.4-3. Distributions used to calculate representative room size for non-residential microenvironments.

Microenvironment	Parameter 1[a]	Parameter 2[b]	Parameter 3[c]	Parameter 4[d]	Distribution Type
Office, Building size (ft^2)	16,632	8,035	4,612	69,530	Normal
Office, number of people per m^2.	4.0	1.5	1.5	8.5	Normal

[1] http://www.epa.gov/iaq/base/pdfs/test_space_characteristics/tc-0.pdf
[2] http://www.epa.gov/iaq/base/pdfs/test_space_characteristics/tc-1.pdf

School (ft^2)	600	1,400	N/A	N/A	Uniform
Restaurant (ft^2)	5,340	31	668	42,699	Lognormal
Other Buildings (ft^2)	3,750	24	750	18,796	Lognormal

Notes:
[a] Mean for normal, geometric mean for lognormal, lower limit for uniform distribution.
[b] Standard deviation for normal, geometric standard deviation for lognormal, upper limit for uniform.
[c] Minimum value for normal and lognormal.
[d] Maximum value for normal and lognormal.

Additional specifications

Two additional specifications were required to calculate the room volumes and surface areas: the ceiling heights and surface area of furniture within the rooms. Table B.4-4 provides the data values and sources used to estimate each of these variables.

Table B.4-4. Ceiling heights and furniture surface area to floor ratios for simulated indoor microenvironments.

Indoor Microenvironment	Ceiling Height[a]	Furniture Surface Area to Floor Ratio
Residence	8 ft	2[b]
Office	10 ft	4[c]
School	10 ft	4[c]
Restaurant	10 ft	4[c]
Other Buildings	10 ft	4[c]

Notes:
[a] Assumed by staff.
[b] Thatcher et al. (2002) and Singer et al. (2002).
[c] The surface area to volume ratio was assumed higher in the commercial microenvironments than in residences. A value of 4 was selected since it kept the range of total surface area to volume ratio within a typical range of 2 to 4 (Lawrence Berkeley National Laboratory., 2003).

B.4.1.3 Surface type probabilities

Following the calculation of the basic dimensions of the simulated room, staff performed additional probabilistic sampling to specify the surface types present. In some microenvironments, it is possible that only a single surface type be present (e.g., a public access building likely contains only hard floors and no carpet). However, in other cases, a typical building may have multiple surface types (e.g., a residence may have a mixture of both hard floor and carpet). Thus, in each microenvironment, staff estimated a probability of occurrence for each surface type. If more than one surface type is possible at the same time, then staff also approximated the fraction of each. Table B.4-5 summarizes both the probabilities and fractions assumed by staff for each microenvironment.

B.4.1.4 Final SO_2 deposition distributions

Following the estimation of the room dimensions and surface types within each simulated indoor microenvironment, an effective deposition rate was estimated for all 1,000 sample buildings. The geometric mean and geometric standard deviation were calculated across all 1,000 samples and used to parameterize a lognormal distribution (Table B.4-6). In applying these to the relative humidity conditions in the study areas, staff assumed that the relative humidity is below 50% when the air conditioning or heating unit is on. If the building has no air conditioner, the ambient summer humidity was used (90 % in the morning, 50% in the afternoon). Staff also assumed that all non-residential buildings had air-conditioning.

As far as mapping to the APEX microenvironments, residences, offices, and restaurants are explicitely modeled microenvironments. The daycare microenvironment used the school deposition distribution, while other indoor microenvironments (i.e., shopping or other) used the other building deposition distribution.

Table B.4-5. Probability of occurrence and fractional quantity for surface types in indoor micronenvironments.

Indoor Microenvironment	Floor		Ceiling		Wall		
	Carpet	Hard floor	Wallboard	Ceiling Tile	Wallboard	Wallpaper	Wood Paneling
Residence	P = 1 F = N{0.52, 0.23}[a]	P = 1 F = 1 - fraction carpeted[a]	P = 1[c]	P = 0[c]	P = 1 F= 5/6 if wallpaper is present[c]	P = 0.225 F= 1/6 if wallpaper is present[d]	P = 0[c]
Office	P = 1 F = 5/6 if hard floor present[c]	P = 0.34 F= 1/6 if hard floor is present[b]	P = 0[c]	P = 1[c]	P = 1 F is adjusted if wallpaper and/or wood paneling is present[c]	P = 0.11 F= 1/6 if wallpaper is present[b]	P = 0.13 F = 1/6 if wood paneling is present[b]
School	P = 0[c]	P = 1[c]	P = 0[c]	P = 1[c]	P = 1[c]	P = 0[c]	P = 0[c]
Restaurant	P = 0.1[d]	P = 0.9[d]	P = 0.55[d]	P = 0.45[d]	P = 1 F is adjusted if wallpaper and/or wood paneling is present[c]	P = 0.09 F = 1/2 if wallpaper is present[d]	P = 0.25 F = 1/10 If wood paneling is present[d]
Other Buildings	P = 0.1[d]	P = 0.9[d]	P = 0.19[d]	P = 0.81[d]	P = 1 F is adjusted if wallpaper and/or wood paneling is present[c]	P = 0.09 F = 1/2 if wallpaper is present[d]	P = 0.045 F=1/10 if wood paneling is present[d]

Notes:
[a] US EPA, 2008b.
[b] BASE study, Table 4 (US EPA, 2008a); the fraction of 1/6 is based on professional judgment.
[c] Assumed by staff.
[d] Source Ranking Database (SRD, US EPA, 2004b). The fraction of buildings value in the database was used to specify a probability each surface type occurs in the microenvironment. SRD names were matched to the APEX environments. Most categories in the SRD have the same fraction of building values. To map to the necessary surface types: Carpet – Networx represented carpet; Ceiling tile represented ceiling tile; vinyl coated wallpaper represented wallpaper; and Hardwood plywood paneling represented wood paneling. Fractions were assumed by staff. Then, probabilities in the remaining surface types were calculated assuming either only one type could be present or multiple types could be present.

Table B.4-6. Final parameter estimates of SO_2 deposition distributions in several indoor microenvironments modeled in APEX.

Microenv-ironment	Heating or Air Conditioning in Use				Air Conditioning Not in Use (Summertime Ambient Morning Relative Humidity of 90%)			
	Geom. Mean (hr^{-1})	Geom. Stand. Dev. (hr^{-1})	Lower Limit (hr^{-1})	Upper Limit (hr^{-1})	Geom. Mean (hr^{-1})	Geom. Stand. Dev. (hr^{-1})	Lower Limit (hr^{-1})	Upper Limit (hr^{-1})
Residence	3.14	1.11	2.20	5.34	13.41	1.11	10.31	26.96
Office	3.99	1.04	3.63	4.37	N/A	N/A	N/A	N/A
School	4.02	1.02	3.90	4.21	N/A	N/A	N/A	N/A
Restaurant	2.36	1.28	1.64	4.17	N/A	N/A	N/A	N/A
Other Buildings	2.82	1.21	1.71	4.12	N/A	N/A	N/A	N/A

Notes:
N/A not applicable, assumed by staff to always have A/C in operation.

B.4.2 APEX Exposure Output

Table B.4-7. APEX estimated SO_2 exposures in Greene County (*as is* air quality scenario) while at moderate or greater exertion level.

5-minute Exposure Level (ppb)	Number of Person Days	Number of Persons	Subpopulation	Fraction of Total Population
0	3218000	21262	DMTS,ASTHMA,MOD	0.97
50	309	193	DMTS,ASTHMA,MOD	0.01
100	18	13	DMTS,ASTHMA,MOD	0.00
150	0	0	DMTS,ASTHMA,MOD	0.00
200	0	0	DMTS,ASTHMA,MOD	0.00
250	0	0	DMTS,ASTHMA,MOD	0.00
300	0	0	DMTS,ASTHMA,MOD	0.00
350	0	0	DMTS,ASTHMA,MOD	0.00
400	0	0	DMTS,ASTHMA,MOD	0.00
450	0	0	DMTS,ASTHMA,MOD	0.00
500	0	0	DMTS,ASTHMA,MOD	0.00
550	0	0	DMTS,ASTHMA,MOD	0.00
600	0	0	DMTS,ASTHMA,MOD	0.00
650	0	0	DMTS,ASTHMA,MOD	0.00
700	0	0	DMTS,ASTHMA,MOD	0.00
750	0	0	DMTS,ASTHMA,MOD	0.00
800	0	0	DMTS,ASTHMA,MOD	0.00
0	1821000	7280	DMTS,ASTHMACHILD,MOD	1.00
50	193	108	DMTS,ASTHMACHILD,MOD	0.01
100	9	4	DMTS,ASTHMACHILD,MOD	0.00
150	0	0	DMTS,ASTHMACHILD,MOD	0.00
200	0	0	DMTS,ASTHMACHILD,MOD	0.00
250	0	0	DMTS,ASTHMACHILD,MOD	0.00
300	0	0	DMTS,ASTHMACHILD,MOD	0.00
350	0	0	DMTS,ASTHMACHILD,MOD	0.00
400	0	0	DMTS,ASTHMACHILD,MOD	0.00
450	0	0	DMTS,ASTHMACHILD,MOD	0.00
500	0	0	DMTS,ASTHMACHILD,MOD	0.00
550	0	0	DMTS,ASTHMACHILD,MOD	0.00
600	0	0	DMTS,ASTHMACHILD,MOD	0.00
650	0	0	DMTS,ASTHMACHILD,MOD	0.00
700	0	0	DMTS,ASTHMACHILD,MOD	0.00
750	0	0	DMTS,ASTHMACHILD,MOD	0.00
800	0	0	DMTS,ASTHMACHILD,MOD	0.00

Table B.4-8. APEX estimated SO_2 exposures in Greene County (current standard air quality scenario) while at moderate or greater exertion level.

5-minute Exposure Level (ppb)	Number of Person Days	Number of Persons	Subpopulation	Fraction of Total Population
0	3218000	21262	DMTS,ASTHMA,MOD	0.97
50	9598	4322	DMTS,ASTHMA,MOD	0.20
100	1659	982	DMTS,ASTHMA,MOD	0.04
150	511	323	DMTS,ASTHMA,MOD	0.01
200	197	139	DMTS,ASTHMA,MOD	0.01
250	90	67	DMTS,ASTHMA,MOD	0.00
300	22	18	DMTS,ASTHMA,MOD	0.00
350	18	13	DMTS,ASTHMA,MOD	0.00
400	13	13	DMTS,ASTHMA,MOD	0.00
450	4	4	DMTS,ASTHMA,MOD	0.00
500	0	0	DMTS,ASTHMA,MOD	0.00
550	0	0	DMTS,ASTHMA,MOD	0.00
600	0	0	DMTS,ASTHMA,MOD	0.00
650	0	0	DMTS,ASTHMA,MOD	0.00
700	0	0	DMTS,ASTHMA,MOD	0.00
750	0	0	DMTS,ASTHMA,MOD	0.00
800	0	0	DMTS,ASTHMA,MOD	0.00
0	1821000	7280	DMTS,ASTHMACHILD,MOD	1.00
50	6393	2609	DMTS,ASTHMACHILD,MOD	0.36
100	1036	569	DMTS,ASTHMACHILD,MOD	0.08
150	323	188	DMTS,ASTHMACHILD,MOD	0.03
200	112	72	DMTS,ASTHMACHILD,MOD	0.01
250	49	40	DMTS,ASTHMACHILD,MOD	0.01
300	13	9	DMTS,ASTHMACHILD,MOD	0.00
350	9	4	DMTS,ASTHMACHILD,MOD	0.00
400	4	4	DMTS,ASTHMACHILD,MOD	0.00
450	4	4	DMTS,ASTHMACHILD,MOD	0.00
500	0	0	DMTS,ASTHMACHILD,MOD	0.00
550	0	0	DMTS,ASTHMACHILD,MOD	0.00
600	0	0	DMTS,ASTHMACHILD,MOD	0.00
650	0	0	DMTS,ASTHMACHILD,MOD	0.00
700	0	0	DMTS,ASTHMACHILD,MOD	0.00
750	0	0	DMTS,ASTHMACHILD,MOD	0.00
800	0	0	DMTS,ASTHMACHILD,MOD	0.00

Table B.4-9. APEX estimated SO_2 exposures in Greene County (99th %ile, 50 ppb alternative standard scenario) while at moderate or greater exertion level.

5-minute Exposure Level (ppb)	Number of Person Days	Number of Persons	Subpopulation	Fraction of Total Population
0	3218000	21262	DMTS,ASTHMA,MOD	0.97
50	18	13	DMTS,ASTHMA,MOD	0.00
100	0	0	DMTS,ASTHMA,MOD	0.00
150	0	0	DMTS,ASTHMA,MOD	0.00
200	0	0	DMTS,ASTHMA,MOD	0.00
250	0	0	DMTS,ASTHMA,MOD	0.00
300	0	0	DMTS,ASTHMA,MOD	0.00
350	0	0	DMTS,ASTHMA,MOD	0.00
400	0	0	DMTS,ASTHMA,MOD	0.00
450	0	0	DMTS,ASTHMA,MOD	0.00
500	0	0	DMTS,ASTHMA,MOD	0.00
550	0	0	DMTS,ASTHMA,MOD	0.00
600	0	0	DMTS,ASTHMA,MOD	0.00
650	0	0	DMTS,ASTHMA,MOD	0.00
700	0	0	DMTS,ASTHMA,MOD	0.00
750	0	0	DMTS,ASTHMA,MOD	0.00
800	0	0	DMTS,ASTHMA,MOD	0.00
0	1821000	7280	DMTS,ASTHMACHILD,MOD	1.00
50	9	4	DMTS,ASTHMACHILD,MOD	0.00
100	0	0	DMTS,ASTHMACHILD,MOD	0.00
150	0	0	DMTS,ASTHMACHILD,MOD	0.00
200	0	0	DMTS,ASTHMACHILD,MOD	0.00
250	0	0	DMTS,ASTHMACHILD,MOD	0.00
300	0	0	DMTS,ASTHMACHILD,MOD	0.00
350	0	0	DMTS,ASTHMACHILD,MOD	0.00
400	0	0	DMTS,ASTHMACHILD,MOD	0.00
450	0	0	DMTS,ASTHMACHILD,MOD	0.00
500	0	0	DMTS,ASTHMACHILD,MOD	0.00
550	0	0	DMTS,ASTHMACHILD,MOD	0.00
600	0	0	DMTS,ASTHMACHILD,MOD	0.00
650	0	0	DMTS,ASTHMACHILD,MOD	0.00
700	0	0	DMTS,ASTHMACHILD,MOD	0.00
750	0	0	DMTS,ASTHMACHILD,MOD	0.00
800	0	0	DMTS,ASTHMACHILD,MOD	0.00

Table B.4-10. APEX estimated SO_2 exposures in Greene County (99th %ile, 100 ppb alternative standard scenario) while at moderate or greater exertion level.

5-minute Exposure Level (ppb)	Number of Person Days	Number of Persons	Subpopulation	Fraction of Total Population
0	3218000	21262	DMTS,ASTHMA,MOD	0.97
50	359	229	DMTS,ASTHMA,MOD	0.01
100	18	13	DMTS,ASTHMA,MOD	0.00
150	0	0	DMTS,ASTHMA,MOD	0.00
200	0	0	DMTS,ASTHMA,MOD	0.00
250	0	0	DMTS,ASTHMA,MOD	0.00
300	0	0	DMTS,ASTHMA,MOD	0.00
350	0	0	DMTS,ASTHMA,MOD	0.00
400	0	0	DMTS,ASTHMA,MOD	0.00
450	0	0	DMTS,ASTHMA,MOD	0.00
500	0	0	DMTS,ASTHMA,MOD	0.00
550	0	0	DMTS,ASTHMA,MOD	0.00
600	0	0	DMTS,ASTHMA,MOD	0.00
650	0	0	DMTS,ASTHMA,MOD	0.00
700	0	0	DMTS,ASTHMA,MOD	0.00
750	0	0	DMTS,ASTHMA,MOD	0.00
800	0	0	DMTS,ASTHMA,MOD	0.00
0	1821000	7280	DMTS,ASTHMACHILD,MOD	1.00
50	229	139	DMTS,ASTHMACHILD,MOD	0.02
100	9	4	DMTS,ASTHMACHILD,MOD	0.00
150	0	0	DMTS,ASTHMACHILD,MOD	0.00
200	0	0	DMTS,ASTHMACHILD,MOD	0.00
250	0	0	DMTS,ASTHMACHILD,MOD	0.00
300	0	0	DMTS,ASTHMACHILD,MOD	0.00
350	0	0	DMTS,ASTHMACHILD,MOD	0.00
400	0	0	DMTS,ASTHMACHILD,MOD	0.00
450	0	0	DMTS,ASTHMACHILD,MOD	0.00
500	0	0	DMTS,ASTHMACHILD,MOD	0.00
550	0	0	DMTS,ASTHMACHILD,MOD	0.00
600	0	0	DMTS,ASTHMACHILD,MOD	0.00
650	0	0	DMTS,ASTHMACHILD,MOD	0.00
700	0	0	DMTS,ASTHMACHILD,MOD	0.00
750	0	0	DMTS,ASTHMACHILD,MOD	0.00
800	0	0	DMTS,ASTHMACHILD,MOD	0.00

Table B.4-11. APEX estimated SO_2 exposures in Greene County (99th %ile, 150 ppb alternative standard scenario) while at moderate or greater exertion level.

5-minute Exposure Level (ppb)	Number of Person Days	Number of Persons	Subpopulation	Fraction of Total Population
0	3218000	21262	DMTS,ASTHMA,MOD	0.97
50	1327	811	DMTS,ASTHMA,MOD	0.04
100	139	103	DMTS,ASTHMA,MOD	0.00
150	18	13	DMTS,ASTHMA,MOD	0.00
200	9	9	DMTS,ASTHMA,MOD	0.00
250	0	0	DMTS,ASTHMA,MOD	0.00
300	0	0	DMTS,ASTHMA,MOD	0.00
350	0	0	DMTS,ASTHMA,MOD	0.00
400	0	0	DMTS,ASTHMA,MOD	0.00
450	0	0	DMTS,ASTHMA,MOD	0.00
500	0	0	DMTS,ASTHMA,MOD	0.00
550	0	0	DMTS,ASTHMA,MOD	0.00
600	0	0	DMTS,ASTHMA,MOD	0.00
650	0	0	DMTS,ASTHMA,MOD	0.00
700	0	0	DMTS,ASTHMA,MOD	0.00
750	0	0	DMTS,ASTHMA,MOD	0.00
800	0	0	DMTS,ASTHMA,MOD	0.00
0	1821000	7280	DMTS,ASTHMACHILD,MOD	1.00
50	798	466	DMTS,ASTHMACHILD,MOD	0.06
100	67	49	DMTS,ASTHMACHILD,MOD	0.01
150	9	4	DMTS,ASTHMACHILD,MOD	0.00
200	4	4	DMTS,ASTHMACHILD,MOD	0.00
250	0	0	DMTS,ASTHMACHILD,MOD	0.00
300	0	0	DMTS,ASTHMACHILD,MOD	0.00
350	0	0	DMTS,ASTHMACHILD,MOD	0.00
400	0	0	DMTS,ASTHMACHILD,MOD	0.00
450	0	0	DMTS,ASTHMACHILD,MOD	0.00
500	0	0	DMTS,ASTHMACHILD,MOD	0.00
550	0	0	DMTS,ASTHMACHILD,MOD	0.00
600	0	0	DMTS,ASTHMACHILD,MOD	0.00
650	0	0	DMTS,ASTHMACHILD,MOD	0.00
700	0	0	DMTS,ASTHMACHILD,MOD	0.00
750	0	0	DMTS,ASTHMACHILD,MOD	0.00
800	0	0	DMTS,ASTHMACHILD,MOD	0.00

Table B.4-12. APEX estimated SO_2 exposures in Greene County (99th %ile, 200 ppb alternative standard scenario) while at moderate or greater exertion level.

5-minute Exposure Level (ppb)	Number of Person Days	Number of Persons	Subpopulation	Fraction of Total Population
0	3218000	21262	DMTS,ASTHMA,MOD	0.97
50	2779	1600	DMTS,ASTHMA,MOD	0.07
100	359	229	DMTS,ASTHMA,MOD	0.01
150	94	72	DMTS,ASTHMA,MOD	0.00
200	18	13	DMTS,ASTHMA,MOD	0.00
250	13	13	DMTS,ASTHMA,MOD	0.00
300	0	0	DMTS,ASTHMA,MOD	0.00
350	0	0	DMTS,ASTHMA,MOD	0.00
400	0	0	DMTS,ASTHMA,MOD	0.00
450	0	0	DMTS,ASTHMA,MOD	0.00
500	0	0	DMTS,ASTHMA,MOD	0.00
550	0	0	DMTS,ASTHMA,MOD	0.00
600	0	0	DMTS,ASTHMA,MOD	0.00
650	0	0	DMTS,ASTHMA,MOD	0.00
700	0	0	DMTS,ASTHMA,MOD	0.00
750	0	0	DMTS,ASTHMA,MOD	0.00
800	0	0	DMTS,ASTHMA,MOD	0.00
0	1821000	7280	DMTS,ASTHMACHILD,MOD	1.00
50	1757	955	DMTS,ASTHMACHILD,MOD	0.13
100	229	139	DMTS,ASTHMACHILD,MOD	0.02
150	54	45	DMTS,ASTHMACHILD,MOD	0.01
200	9	4	DMTS,ASTHMACHILD,MOD	0.00
250	4	4	DMTS,ASTHMACHILD,MOD	0.00
300	0	0	DMTS,ASTHMACHILD,MOD	0.00
350	0	0	DMTS,ASTHMACHILD,MOD	0.00
400	0	0	DMTS,ASTHMACHILD,MOD	0.00
450	0	0	DMTS,ASTHMACHILD,MOD	0.00
500	0	0	DMTS,ASTHMACHILD,MOD	0.00
550	0	0	DMTS,ASTHMACHILD,MOD	0.00
600	0	0	DMTS,ASTHMACHILD,MOD	0.00
650	0	0	DMTS,ASTHMACHILD,MOD	0.00
700	0	0	DMTS,ASTHMACHILD,MOD	0.00
750	0	0	DMTS,ASTHMACHILD,MOD	0.00
800	0	0	DMTS,ASTHMACHILD,MOD	0.00

Table B.4-13. APEX estimated SO_2 exposures in Greene County (99th %ile, 250 ppb alternative standard scenario) while at moderate or greater exertion level.

5-minute Exposure Level (ppb)	Number of Person Days	Number of Persons	Subpopulation	Fraction of Total Population
0	3218000	21262	DMTS,ASTHMA,MOD	0.97
50	4918	2726	DMTS,ASTHMA,MOD	0.12
100	780	484	DMTS,ASTHMA,MOD	0.02
150	202	143	DMTS,ASTHMA,MOD	0.01
200	63	54	DMTS,ASTHMA,MOD	0.00
250	18	13	DMTS,ASTHMA,MOD	0.00
300	13	13	DMTS,ASTHMA,MOD	0.00
350	4	4	DMTS,ASTHMA,MOD	0.00
400	0	0	DMTS,ASTHMA,MOD	0.00
450	0	0	DMTS,ASTHMA,MOD	0.00
500	0	0	DMTS,ASTHMA,MOD	0.00
550	0	0	DMTS,ASTHMA,MOD	0.00
600	0	0	DMTS,ASTHMA,MOD	0.00
650	0	0	DMTS,ASTHMA,MOD	0.00
700	0	0	DMTS,ASTHMA,MOD	0.00
750	0	0	DMTS,ASTHMA,MOD	0.00
800	0	0	DMTS,ASTHMA,MOD	0.00
0	1821000	7280	DMTS,ASTHMACHILD,MOD	1.00
50	3201	1659	DMTS,ASTHMACHILD,MOD	0.23
100	457	256	DMTS,ASTHMACHILD,MOD	0.04
150	117	76	DMTS,ASTHMACHILD,MOD	0.01
200	40	31	DMTS,ASTHMACHILD,MOD	0.00
250	9	4	DMTS,ASTHMACHILD,MOD	0.00
300	4	4	DMTS,ASTHMACHILD,MOD	0.00
350	4	4	DMTS,ASTHMACHILD,MOD	0.00
400	0	0	DMTS,ASTHMACHILD,MOD	0.00
450	0	0	DMTS,ASTHMACHILD,MOD	0.00
500	0	0	DMTS,ASTHMACHILD,MOD	0.00
550	0	0	DMTS,ASTHMACHILD,MOD	0.00
600	0	0	DMTS,ASTHMACHILD,MOD	0.00
650	0	0	DMTS,ASTHMACHILD,MOD	0.00
700	0	0	DMTS,ASTHMACHILD,MOD	0.00
750	0	0	DMTS,ASTHMACHILD,MOD	0.00
800	0	0	DMTS,ASTHMACHILD,MOD	0.00

Table B.4-14. APEX estimated SO_2 exposures in Greene County (98th %ile, 200 ppb alternative standard scenario) while at moderate or greater exertion level.

5-minute Exposure Level (ppb)	Number of Person Days	Number of Persons	Subpopulation	Fraction of Total Population
0	3218000	21262	DMTS,ASTHMA,MOD	0.97
50	4138	2304	DMTS,ASTHMA,MOD	0.10
100	632	386	DMTS,ASTHMA,MOD	0.02
150	161	117	DMTS,ASTHMA,MOD	0.01
200	45	40	DMTS,ASTHMA,MOD	0.00
250	18	13	DMTS,ASTHMA,MOD	0.00
300	13	13	DMTS,ASTHMA,MOD	0.00
350	0	0	DMTS,ASTHMA,MOD	0.00
400	0	0	DMTS,ASTHMA,MOD	0.00
450	0	0	DMTS,ASTHMA,MOD	0.00
500	0	0	DMTS,ASTHMA,MOD	0.00
550	0	0	DMTS,ASTHMA,MOD	0.00
600	0	0	DMTS,ASTHMA,MOD	0.00
650	0	0	DMTS,ASTHMA,MOD	0.00
700	0	0	DMTS,ASTHMA,MOD	0.00
750	0	0	DMTS,ASTHMA,MOD	0.00
800	0	0	DMTS,ASTHMA,MOD	0.00
0	1821000	7280	DMTS,ASTHMACHILD,MOD	1.00
50	2654	1390	DMTS,ASTHMACHILD,MOD	0.19
100	390	220	DMTS,ASTHMACHILD,MOD	0.03
150	85	58	DMTS,ASTHMACHILD,MOD	0.01
200	27	22	DMTS,ASTHMACHILD,MOD	0.00
250	9	4	DMTS,ASTHMACHILD,MOD	0.00
300	4	4	DMTS,ASTHMACHILD,MOD	0.00
350	0	0	DMTS,ASTHMACHILD,MOD	0.00
400	0	0	DMTS,ASTHMACHILD,MOD	0.00
450	0	0	DMTS,ASTHMACHILD,MOD	0.00
500	0	0	DMTS,ASTHMACHILD,MOD	0.00
550	0	0	DMTS,ASTHMACHILD,MOD	0.00
600	0	0	DMTS,ASTHMACHILD,MOD	0.00
650	0	0	DMTS,ASTHMACHILD,MOD	0.00
700	0	0	DMTS,ASTHMACHILD,MOD	0.00
750	0	0	DMTS,ASTHMACHILD,MOD	0.00
800	0	0	DMTS,ASTHMACHILD,MOD	0.00

Table B.4-15. APEX estimated SO_2 exposures in St. Louis (*as is* air quality scenario) while at moderate or greater exertion level.

5-minute Exposure Level (ppb)	Subpopulation	Number of Persons	Number of Person Days	Fraction of Total Population
0	DMTS,ASTHMA,MOD	102436	16677000	0.97
50	DMTS,ASTHMA,MOD	24405	44100	0.23
100	DMTS,ASTHMA,MOD	3866	4631	0.04
150	DMTS,ASTHMA,MOD	789	896	0.01
200	DMTS,ASTHMA,MOD	229	244	0.00
250	DMTS,ASTHMA,MOD	69	69	0.00
300	DMTS,ASTHMA,MOD	23	23	0.00
350	DMTS,ASTHMA,MOD	8	8	0.00
400	DMTS,ASTHMA,MOD	8	8	0.00
450	DMTS,ASTHMA,MOD	0	0	0.00
500	DMTS,ASTHMA,MOD	0	0	0.00
550	DMTS,ASTHMA,MOD	0	0	0.00
600	DMTS,ASTHMA,MOD	0	0	0.00
650	DMTS,ASTHMA,MOD	0	0	0.00
700	DMTS,ASTHMA,MOD	0	0	0.00
750	DMTS,ASTHMA,MOD	0	0	0.00
800	DMTS,ASTHMA,MOD	0	0	0.00
0	DMTS,ASTHMACHILD,MOD	41714	10560000	1.00
50	DMTS,ASTHMACHILD,MOD	16938	32800	0.41
100	DMTS,ASTHMACHILD,MOD	2776	3357	0.07
150	DMTS,ASTHMACHILD,MOD	575	651	0.01
200	DMTS,ASTHMACHILD,MOD	160	176	0.00
250	DMTS,ASTHMACHILD,MOD	39	38	0.00
300	DMTS,ASTHMACHILD,MOD	16	15	0.00
350	DMTS,ASTHMACHILD,MOD	0	0	0.00
400	DMTS,ASTHMACHILD,MOD	0	0	0.00
450	DMTS,ASTHMACHILD,MOD	0	0	0.00
500	DMTS,ASTHMACHILD,MOD	0	0	0.00
550	DMTS,ASTHMACHILD,MOD	0	0	0.00
600	DMTS,ASTHMACHILD,MOD	0	0	0.00
650	DMTS,ASTHMACHILD,MOD	0	0	0.00
700	DMTS,ASTHMACHILD,MOD	0	0	0.00
750	DMTS,ASTHMACHILD,MOD	0	0	0.00
800	DMTS,ASTHMACHILD,MOD	0	0	0.00

Table B.4-16. APEX estimated SO_2 exposures in St. Louis (current standard air quality scenario) while at moderate or greater exertion level.

5-minute Exposure Level (ppb)	Subpopulation	Number of Persons	Number of Person Days	Fraction of Total Population
0	DMTS,ASTHMA,MOD	102436	16677000	0.97
50	DMTS,ASTHMA,MOD	93692	2889400	0.89
100	DMTS,ASTHMA,MOD	79422	793000	0.75
150	DMTS,ASTHMA,MOD	63016	316400	0.60
200	DMTS,ASTHMA,MOD	48211	153990	0.46
250	DMTS,ASTHMA,MOD	36315	84540	0.34
300	DMTS,ASTHMA,MOD	26363	49440	0.25
350	DMTS,ASTHMA,MOD	19278	31700	0.18
400	DMTS,ASTHMA,MOD	14181	20719	0.13
450	DMTS,ASTHMA,MOD	10448	14242	0.10
500	DMTS,ASTHMA,MOD	7853	10060	0.07
550	DMTS,ASTHMA,MOD	5880	7229	0.06
600	DMTS,ASTHMA,MOD	4431	5343	0.04
650	DMTS,ASTHMA,MOD	3336	3972	0.03
700	DMTS,ASTHMA,MOD	2631	3099	0.02
750	DMTS,ASTHMA,MOD	1985	2253	0.02
800	DMTS,ASTHMA,MOD	1556	1747	0.01
0	DMTS,ASTHMACHILD,MOD	41714	10560000	1.00
50	DMTS,ASTHMACHILD,MOD	41607	2158300	1.00
100	DMTS,ASTHMACHILD,MOD	40319	602800	0.97
150	DMTS,ASTHMACHILD,MOD	36287	239310	0.87
200	DMTS,ASTHMACHILD,MOD	30504	116260	0.73
250	DMTS,ASTHMACHILD,MOD	24386	63570	0.58
300	DMTS,ASTHMACHILD,MOD	18254	36830	0.44
350	DMTS,ASTHMACHILD,MOD	13539	23507	0.32
400	DMTS,ASTHMACHILD,MOD	9991	15304	0.24
450	DMTS,ASTHMACHILD,MOD	7547	10636	0.18
500	DMTS,ASTHMACHILD,MOD	5658	7420	0.14
550	DMTS,ASTHMACHILD,MOD	4237	5295	0.10
600	DMTS,ASTHMACHILD,MOD	3204	3901	0.08
650	DMTS,ASTHMACHILD,MOD	2376	2851	0.06
700	DMTS,ASTHMACHILD,MOD	1909	2231	0.05
750	DMTS,ASTHMACHILD,MOD	1426	1609	0.03
800	DMTS,ASTHMACHILD,MOD	1111	1240	0.03

Table B.4-17. APEX estimated SO_2 exposures in St. Louis (99th %ile, 50 ppb air quality scenario) while at moderate or greater exertion level.

5-minute Exposure Level (ppb)	Subpopulation	Number of Persons	Number of Person Days	Fraction of Total Population
0	DMTS,ASTHMA,MOD	102436	16677000	0.97
50	DMTS,ASTHMA,MOD	14488	21379	0.14
100	DMTS,ASTHMA,MOD	1595	1794	0.02
150	DMTS,ASTHMA,MOD	298	328	0.00
200	DMTS,ASTHMA,MOD	69	69	0.00
250	DMTS,ASTHMA,MOD	16	15	0.00
300	DMTS,ASTHMA,MOD	8	8	0.00
350	DMTS,ASTHMA,MOD	0	0	0.00
400	DMTS,ASTHMA,MOD	0	0	0.00
450	DMTS,ASTHMA,MOD	0	0	0.00
500	DMTS,ASTHMA,MOD	0	0	0.00
550	DMTS,ASTHMA,MOD	0	0	0.00
600	DMTS,ASTHMA,MOD	0	0	0.00
650	DMTS,ASTHMA,MOD	0	0	0.00
700	DMTS,ASTHMA,MOD	0	0	0.00
750	DMTS,ASTHMA,MOD	0	0	0.00
800	DMTS,ASTHMA,MOD	0	0	0.00
0	DMTS,ASTHMACHILD,MOD	41714	10560000	1.00
50	DMTS,ASTHMACHILD,MOD	10229	15835	0.25
100	DMTS,ASTHMACHILD,MOD	1135	1272	0.03
150	DMTS,ASTHMACHILD,MOD	214	237	0.01
200	DMTS,ASTHMACHILD,MOD	39	38	0.00
250	DMTS,ASTHMACHILD,MOD	8	8	0.00
300	DMTS,ASTHMACHILD,MOD	0	0	0.00
350	DMTS,ASTHMACHILD,MOD	0	0	0.00
400	DMTS,ASTHMACHILD,MOD	0	0	0.00
450	DMTS,ASTHMACHILD,MOD	0	0	0.00
500	DMTS,ASTHMACHILD,MOD	0	0	0.00
550	DMTS,ASTHMACHILD,MOD	0	0	0.00
600	DMTS,ASTHMACHILD,MOD	0	0	0.00
650	DMTS,ASTHMACHILD,MOD	0	0	0.00
700	DMTS,ASTHMACHILD,MOD	0	0	0.00
750	DMTS,ASTHMACHILD,MOD	0	0	0.00
800	DMTS,ASTHMACHILD,MOD	0	0	0.00

Table B.4-18. APEX estimated SO_2 exposures in St. Louis (99th %ile, 100 ppb air quality scenario) while at moderate or greater exertion level.

5-minute Exposure Level (ppb)	Subpopulation	Number of Persons	Number of Person Days	Fraction of Total Population
0	DMTS,ASTHMA,MOD	102436	16677000	0.97
50	DMTS,ASTHMA,MOD	48725	158000	0.46
100	DMTS,ASTHMA,MOD	14488	21379	0.14
150	DMTS,ASTHMA,MOD	4654	5619	0.04
200	DMTS,ASTHMA,MOD	1595	1794	0.02
250	DMTS,ASTHMA,MOD	666	742	0.01
300	DMTS,ASTHMA,MOD	298	328	0.00
350	DMTS,ASTHMA,MOD	153	152	0.00
400	DMTS,ASTHMA,MOD	69	69	0.00
450	DMTS,ASTHMA,MOD	38	38	0.00
500	DMTS,ASTHMA,MOD	16	15	0.00
550	DMTS,ASTHMA,MOD	8	8	0.00
600	DMTS,ASTHMA,MOD	8	8	0.00
650	DMTS,ASTHMA,MOD	8	8	0.00
700	DMTS,ASTHMA,MOD	0	0	0.00
750	DMTS,ASTHMA,MOD	0	0	0.00
800	DMTS,ASTHMA,MOD	0	0	0.00
0	DMTS,ASTHMACHILD,MOD	41714	10560000	1.00
50	DMTS,ASTHMACHILD,MOD	30703	119350	0.74
100	DMTS,ASTHMACHILD,MOD	10229	15835	0.25
150	DMTS,ASTHMACHILD,MOD	3349	4100	0.08
200	DMTS,ASTHMACHILD,MOD	1135	1272	0.03
250	DMTS,ASTHMACHILD,MOD	491	551	0.01
300	DMTS,ASTHMACHILD,MOD	214	237	0.01
350	DMTS,ASTHMACHILD,MOD	99	99	0.00
400	DMTS,ASTHMACHILD,MOD	39	38	0.00
450	DMTS,ASTHMACHILD,MOD	31	31	0.00
500	DMTS,ASTHMACHILD,MOD	8	8	0.00
550	DMTS,ASTHMACHILD,MOD	0	0	0.00
600	DMTS,ASTHMACHILD,MOD	0	0	0.00
650	DMTS,ASTHMACHILD,MOD	0	0	0.00
700	DMTS,ASTHMACHILD,MOD	0	0	0.00
750	DMTS,ASTHMACHILD,MOD	0	0	0.00
800	DMTS,ASTHMACHILD,MOD	0	0	0.00

Table B.4-19. APEX estimated SO_2 exposures in St. Louis (99th %ile 150 ppb air quality scenario) while at moderate or greater exertion level.

5-minute Exposure Level (ppb)	Subpopulation	Number of Persons	Number of Person Days	Fraction of Total Population
0	DMTS,ASTHMA,MOD	102436	16677000	0.97
50	DMTS,ASTHMA,MOD	68830	429400	0.65
100	DMTS,ASTHMA,MOD	33447	73000	0.32
150	DMTS,ASTHMA,MOD	14488	21379	0.14
200	DMTS,ASTHMA,MOD	6702	8403	0.06
250	DMTS,ASTHMA,MOD	3212	3817	0.03
300	DMTS,ASTHMA,MOD	1595	1794	0.02
350	DMTS,ASTHMA,MOD	844	958	0.01
400	DMTS,ASTHMA,MOD	521	582	0.00
450	DMTS,ASTHMA,MOD	298	328	0.00
500	DMTS,ASTHMA,MOD	198	198	0.00
550	DMTS,ASTHMA,MOD	130	130	0.00
600	DMTS,ASTHMA,MOD	69	69	0.00
650	DMTS,ASTHMA,MOD	38	38	0.00
700	DMTS,ASTHMA,MOD	23	23	0.00
750	DMTS,ASTHMA,MOD	16	15	0.00
800	DMTS,ASTHMA,MOD	8	8	0.00
0	DMTS,ASTHMACHILD,MOD	41714	10560000	1.00
50	DMTS,ASTHMACHILD,MOD	38024	325900	0.91
100	DMTS,ASTHMACHILD,MOD	22721	54890	0.54
150	DMTS,ASTHMACHILD,MOD	10229	15835	0.25
200	DMTS,ASTHMACHILD,MOD	4843	6177	0.12
250	DMTS,ASTHMACHILD,MOD	2323	2767	0.06
300	DMTS,ASTHMACHILD,MOD	1135	1272	0.03
350	DMTS,ASTHMACHILD,MOD	621	705	0.01
400	DMTS,ASTHMACHILD,MOD	376	422	0.01
450	DMTS,ASTHMACHILD,MOD	214	237	0.01
500	DMTS,ASTHMACHILD,MOD	138	137	0.00
550	DMTS,ASTHMACHILD,MOD	76	76	0.00
600	DMTS,ASTHMACHILD,MOD	39	38	0.00
650	DMTS,ASTHMACHILD,MOD	31	31	0.00
700	DMTS,ASTHMACHILD,MOD	16	15	0.00
750	DMTS,ASTHMACHILD,MOD	8	8	0.00
800	DMTS,ASTHMACHILD,MOD	0	0	0.00

Table B.4-20. APEX estimated SO_2 exposures in St. Louis (99th %ile, 200 ppb air quality scenario) while at moderate or greater exertion level.

5-minute Exposure Level (ppb)	Subpopulation	Number of Persons	Number of Person Days	Fraction of Total Population
0	DMTS,ASTHMA,MOD	102436	16677000	0.97
50	DMTS,ASTHMA,MOD	79775	813700	0.76
100	DMTS,ASTHMA,MOD	48725	158000	0.46
150	DMTS,ASTHMA,MOD	27030	51270	0.26
200	DMTS,ASTHMA,MOD	14488	21379	0.14
250	DMTS,ASTHMA,MOD	8097	10427	0.08
300	DMTS,ASTHMA,MOD	4654	5619	0.04
350	DMTS,ASTHMA,MOD	2707	3198	0.03
400	DMTS,ASTHMA,MOD	1595	1794	0.02
450	DMTS,ASTHMA,MOD	1050	1180	0.01
500	DMTS,ASTHMA,MOD	666	742	0.01
550	DMTS,ASTHMA,MOD	428	458	0.00
600	DMTS,ASTHMA,MOD	298	328	0.00
650	DMTS,ASTHMA,MOD	214	229	0.00
700	DMTS,ASTHMA,MOD	153	152	0.00
750	DMTS,ASTHMA,MOD	107	107	0.00
800	DMTS,ASTHMA,MOD	69	69	0.00
0	DMTS,ASTHMACHILD,MOD	41714	10560000	1.00
50	DMTS,ASTHMACHILD,MOD	40388	618700	0.97
100	DMTS,ASTHMACHILD,MOD	30703	119350	0.74
150	DMTS,ASTHMACHILD,MOD	18690	38210	0.45
200	DMTS,ASTHMACHILD,MOD	10229	15835	0.25
250	DMTS,ASTHMACHILD,MOD	5856	7718	0.14
300	DMTS,ASTHMACHILD,MOD	3349	4100	0.08
350	DMTS,ASTHMACHILD,MOD	1947	2292	0.05
400	DMTS,ASTHMACHILD,MOD	1135	1272	0.03
450	DMTS,ASTHMACHILD,MOD	773	857	0.02
500	DMTS,ASTHMACHILD,MOD	491	551	0.01
550	DMTS,ASTHMACHILD,MOD	314	336	0.01
600	DMTS,ASTHMACHILD,MOD	214	237	0.01
650	DMTS,ASTHMACHILD,MOD	145	160	0.00
700	DMTS,ASTHMACHILD,MOD	99	99	0.00
750	DMTS,ASTHMACHILD,MOD	61	61	0.00
800	DMTS,ASTHMACHILD,MOD	39	38	0.00

Table B.4-21. APEX estimated SO_2 exposures in St. Louis (99^{th} %ile, 250 ppb air quality scenario) while at moderate or greater exertion level.

5-minute Exposure Level (ppb)	Subpopulation	Number of Persons	Number of Person Days	Fraction of Total Population
0	DMTS,ASTHMA,MOD	102436	16677000	0.97
50	DMTS,ASTHMA,MOD	85784	1276000	0.81
100	DMTS,ASTHMA,MOD	60235	278550	0.57
150	DMTS,ASTHMA,MOD	39121	97390	0.37
200	DMTS,ASTHMA,MOD	23681	42330	0.22
250	DMTS,ASTHMA,MOD	14488	21379	0.14
300	DMTS,ASTHMA,MOD	9180	12037	0.09
350	DMTS,ASTHMA,MOD	5750	7061	0.05
400	DMTS,ASTHMA,MOD	3696	4416	0.04
450	DMTS,ASTHMA,MOD	2452	2843	0.02
500	DMTS,ASTHMA,MOD	1595	1794	0.02
550	DMTS,ASTHMA,MOD	1150	1287	0.01
600	DMTS,ASTHMA,MOD	751	858	0.01
650	DMTS,ASTHMA,MOD	574	643	0.01
700	DMTS,ASTHMA,MOD	405	435	0.00
750	DMTS,ASTHMA,MOD	298	328	0.00
800	DMTS,ASTHMA,MOD	229	244	0.00
0	DMTS,ASTHMACHILD,MOD	41714	10560000	1.00
50	DMTS,ASTHMACHILD,MOD	41147	967000	0.99
100	DMTS,ASTHMACHILD,MOD	35351	210680	0.85
150	DMTS,ASTHMACHILD,MOD	25834	73310	0.62
200	DMTS,ASTHMACHILD,MOD	16477	31530	0.39
250	DMTS,ASTHMACHILD,MOD	10229	15835	0.25
300	DMTS,ASTHMACHILD,MOD	6686	8975	0.16
350	DMTS,ASTHMACHILD,MOD	4138	5166	0.10
400	DMTS,ASTHMACHILD,MOD	2637	3173	0.06
450	DMTS,ASTHMACHILD,MOD	1786	2070	0.04
500	DMTS,ASTHMACHILD,MOD	1135	1272	0.03
550	DMTS,ASTHMACHILD,MOD	849	941	0.02
600	DMTS,ASTHMACHILD,MOD	536	613	0.01
650	DMTS,ASTHMACHILD,MOD	422	475	0.01
700	DMTS,ASTHMACHILD,MOD	298	321	0.01
750	DMTS,ASTHMACHILD,MOD	214	237	0.01
800	DMTS,ASTHMACHILD,MOD	160	176	0.00

Table B.4-21. APEX estimated SO_2 exposures in St. Louis (98^{th} %ile 200 ppb air quality scenario) while at moderate or greater exertion level.

5-minute Exposure Level (ppb)	Subpopulation	Number of Persons	Number of Person Days	Fraction of Total Population
0	DMTS,ASTHMA,MOD	102436	16677000	0.97
50	DMTS,ASTHMA,MOD	84633	1159900	0.80
100	DMTS,ASTHMA,MOD	57867	249490	0.55
150	DMTS,ASTHMA,MOD	36682	85910	0.35
200	DMTS,ASTHMA,MOD	21576	37060	0.20
250	DMTS,ASTHMA,MOD	12925	18498	0.12
300	DMTS,ASTHMA,MOD	8014	10304	0.08
350	DMTS,ASTHMA,MOD	5022	6041	0.05
400	DMTS,ASTHMA,MOD	3174	3772	0.03
450	DMTS,ASTHMA,MOD	2023	2299	0.02
500	DMTS,ASTHMA,MOD	1387	1539	0.01
550	DMTS,ASTHMA,MOD	913	1035	0.01
600	DMTS,ASTHMA,MOD	666	742	0.01
650	DMTS,ASTHMA,MOD	474	512	0.00
700	DMTS,ASTHMA,MOD	314	344	0.00
750	DMTS,ASTHMA,MOD	229	252	0.00
800	DMTS,ASTHMA,MOD	198	198	0.00
0	DMTS,ASTHMACHILD,MOD	41714	10560000	1.00
50	DMTS,ASTHMACHILD,MOD	41070	880000	0.98
100	DMTS,ASTHMACHILD,MOD	34529	188770	0.83
150	DMTS,ASTHMACHILD,MOD	24576	64600	0.59
200	DMTS,ASTHMACHILD,MOD	15085	27517	0.36
250	DMTS,ASTHMACHILD,MOD	9168	13677	0.22
300	DMTS,ASTHMACHILD,MOD	5774	7596	0.14
350	DMTS,ASTHMACHILD,MOD	3648	4446	0.09
400	DMTS,ASTHMACHILD,MOD	2285	2721	0.05
450	DMTS,ASTHMACHILD,MOD	1464	1655	0.04
500	DMTS,ASTHMACHILD,MOD	1011	1110	0.02
550	DMTS,ASTHMACHILD,MOD	675	759	0.02
600	DMTS,ASTHMACHILD,MOD	491	551	0.01
650	DMTS,ASTHMACHILD,MOD	352	375	0.01
700	DMTS,ASTHMACHILD,MOD	222	245	0.01
750	DMTS,ASTHMACHILD,MOD	160	183	0.00
800	DMTS,ASTHMACHILD,MOD	138	137	0.00

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ATTACHMENT 1. TECHNICAL MEMORANDUM ON METEOROLOGICAL DATA PREPARATION FOR AERMOD FOR SO_2 REA FOR GREENE COUNTY AND ST. LOUIS MODELING DOMAINS, YEAR 2002

Meteorological data preparation for AERMOD for SO_2 REA for Greene County, MO and St. Louis, MO

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1. Introduction

National Weather Service (NWS) meteorological data are often used as the source of input meteorological data for AERMOD (U. S. EPA, 2004a). For the SO_2 Risk and Exposure Assessment, two study areas were chosen: Greene County, Missouri, which includes the city of Springfield, and St. Louis, Missouri. Tables 1 and 2 list the surface and upper air NWS stations chosen for the two areas. Figure 1 shows the relationship between each surface station and its paired upper air station.

For the St. Louis domain, two other stations were also considered: Spirit of St. Louis Airport (SUS) and St. Louis Downtown Airport (CPS). SUS and CPS were used in the 1st draft REA (U.S. EPA 2008a). The spatial relationship between the St. Louis area stations is shown in Figure 2. Preliminary analysis of the three stations for the St. Louis domain revealed that CPS and SUS contained significantly more calms and missing hours than STL. It was therefore determined that STL would be more representative for the majority of emission sources for the St. Louis modeling domain, and would be used for all of the St. Louis modeling. Given the distances shown in Figures 2 and 3 between the stations, the choice was not unreasonable.

Table 1. Surface stations for the SO_2 study areas. Latitude and longitude are the best approximation coordinates of the meteorological towers.

Area	Station	Identifier	WMO (WBAN)	Latitude	Longitude	Elevation (m)	GMT offset
Greene County	Springfield-Branson Regional AP	SGF	724400 (13995)	37.23528	-93.40028	387	6
St. Louis	Lambert-St. Louis International AP	STL	724340 (13994)	38.7525	-90.37361	161	6

Table 2. Upper air stations for the SO_2 study areas.

Area	Station	Identifier	WMO (WBAN)	Latitude	Longitude	Elevation (m)	GMT offset
Greene County	Springfield-Branson Regional AP	SGF	724400 (13995)	37.23	-93.40	394	6
St. Louis	Lincoln-Logan County AP, IL	ILX	724340 (4833)	40.15	-89.33	178	6

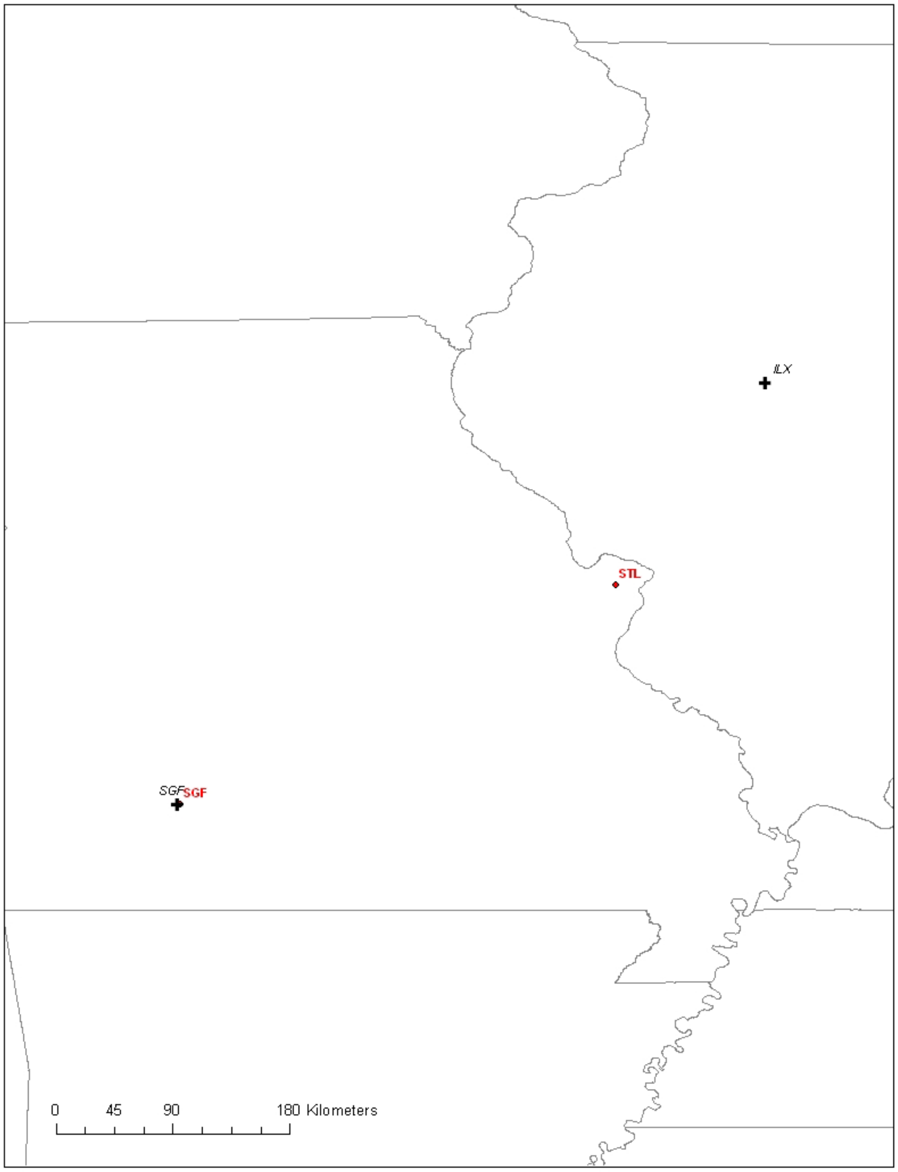

Figure 1. Location of surface stations (red dots) relative to upper air stations (crosses) for Greene County and St. Louis, MO.

A potential concern related to the use of NWS meteorological data for dispersion modeling is the often high incidence of calms and variable wind conditions reported for the Automated Surface Observing Stations (ASOS) in use at most NWS stations since the mid-1990's. A variable wind observation may include wind speeds up to 6 knots, but the wind direction is reported as missing. The AERMOD model currently cannot simulate dispersion under these conditions. To reduce the number of calms and missing winds in the surface data for each of the four stations, archived one-minute winds for the ASOS stations were used to calculate hourly average wind speed and directions, which were used to supplement the standard archive of winds reported for each station in the Integrated Surface Hourly (ISH) database. Details regarding this procedure are described below.

Section 2 describes preparation of the surface and upper data from the ISH database and FSL website including the preparation of data and calculation of hourly winds from one-minute ASOS data, Section 3 describes AERSURFACE processing for surface characteristics, and Section 4 describes the AERMET processing. Section 5 provides a brief analysis of the AERMET output for the stations. References are listed in Section 6.

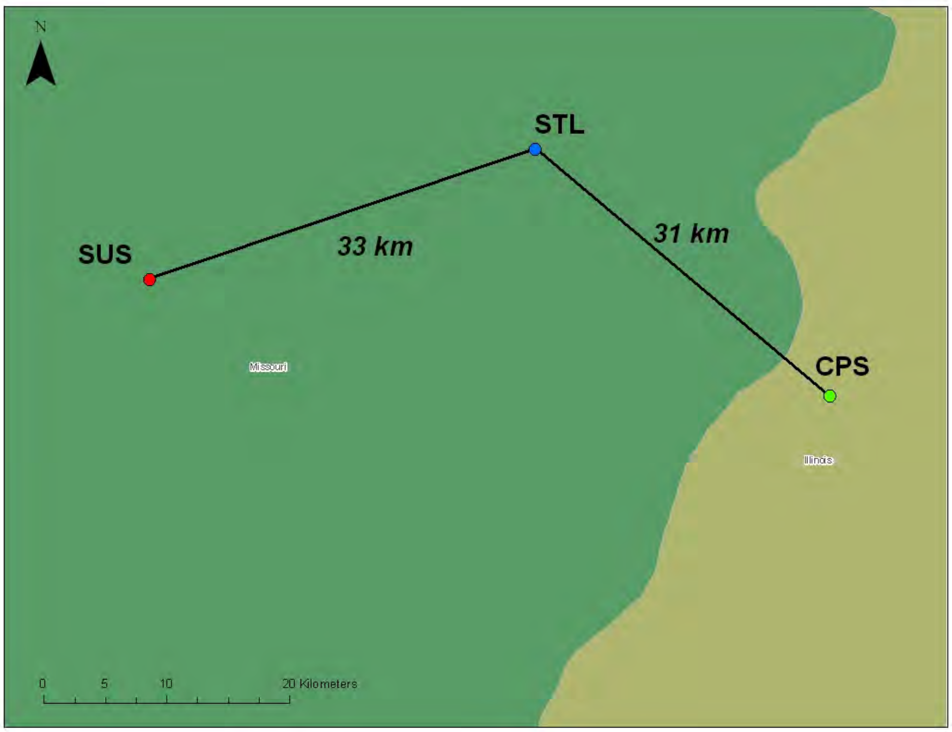

Figure 2. Distance between STL and SUS and CPS.

2. Surface and upper air data preparation

2.1 Surface data and hourly averaged wind calculations

One year of surface data for 2002 for each of the stations listed in Table 1 were downloaded from the ISH archive at NCDC. Surface data from NWS locations often contain a large number of calms and variable winds. This is due to the implementation of the ASOS program to replace observer-based data beginning in the mid-1990's, and the adoption of the METAR standard for reporting NWS observations in July 1996. Currently, the wind speed and direction used to represent the hour in AERMOD is based on a single two-minute average, usually reported about 10 minutes before the hour. The METAR system reports winds of less than three knots as calm (coded as 0 knots), and winds up to six knots will be reported as variable when the variation in the 2-minute wind direction is more than 60 degrees. This variable wind is reported as a non-zero wind speed with a missing wind direction. The number of calms and variable winds can influence concentration calculations in AERMOD because concentrations are not calculated for calms or variable wind hours. Significant numbers of calm and variable hours may compromise the representativeness of NWS surface data for AERMOD applications. This is especially of concern for applications involving low-level releases since the worst-case dispersion conditions for such sources are associated with low wind speeds, and the hours being discarded as calm or variable are biased toward this condition.

Recently, NCDC began archiving the two-minute average wind speeds for each minute of the hour for most ASOS stations for public access. These values have not been subjected to the METAR coding for calm and variable winds. Recent work in AQMG has focused on utilizing these 1 minute winds to calculate hourly average winds to reduce the number of calms and variable winds for a given station and year. For data input into AERMOD, one minute winds for SGF and STL were used to calculate hourly average winds for 2002 (the 1-minute ASOS wind data were not available for SUS or CPS for 2002). These hourly average winds are input to AERMET and replace the winds reported for the hour from the ISH dataset. Following is the methodology used to calculate the hourly average winds for this application:

One minute data files are monthly, so each month for 2002 was downloaded.

1. Each line of the data file was read and QA performed on the format of the line to check if the line is valid data line. Currently, the one minute data files loosely follow a fixed format, but there are numerous exceptions. The program performed several checks on the line to ensure that wind direction and wind speed were in the correct general location. If a minute was listed twice, the second line for that minute was assumed to be the correct line. In the files, wind directions were recorded at the nearest whole degree and wind speed to the nearest whole knot.

2. If the reported wind speed was less than 2 knots, the wind speed was reset to 1 knot. This was done because anything less than 2 knots was considered below the instrument threshold (if the anemometer is not a sonic anemometer, which was the case for SGF and STL for 2002). This generally conforms to the meteorological monitoring guidance recommendation of applying a wind speed of one half the threshold value to each wind

sample below threshold when processing samples to obtain hourly averages. At the same time, the x- and y-components of the wind direction were calculated using equations 1 and 2 below, which are the functions inside the summation of equations 6.2.17 and 6.2.18 of the meteorological guidance document (U.S. EPA, 2000). The components were only calculated for minutes that did not require resetting.

$$v_x = -\sin\theta \quad (1)$$

$$v_y = -\cos\theta \quad (2)$$

where v_x and v_y are the x- and y-components of the one minute wind direction θ.

3. For all minutes that passed the QA check in step 1, the wind speeds were converted from knots to m/s.
4. Before calculating hourly averages, the number of valid minutes (those with wind directions) was checked for each hour. An hourly average would be calculated if the there were at least two valid 2-minute averages reported for the hour. This could be even minutes, odd minutes, or a mixture of non-overlapping even and odd minutes. Even minutes were given priority over odd. If at least two valid minutes were found, then all available (non-overlapping) minutes would be used to calculate hourly averages. The most observations that could be used were 30 2-minute values (30 even or 30 odd).
5. For wind speed averages, all available non-overlapping minutes' speeds were used, even those subject to resets as described in step 2. The hourly wind speed was an arithmetic average of the wind speeds used.
6. For wind directions, the x- and y-components were summed according to equations 6.2.17 and 6.2.18 of the meteorological monitoring guidance (U.S. EPA, 2000), summarized in equations 3 and 4 below with v_{xi} and v_{yi} calculated in equations 1 and 2. The hourly wind direction was calculated based on a unit-vector approach, using equation 6.2.19 of the meteorological monitoring guidance (U.S.EPA, 2000), summarized in equation 5. The one minute average wind directions do not use the flow correction as shown in equation 6.2.19, since the calculated direction is the direction from which the wind was blowing, not the direction in which it is blowing, as shown by the flow correction in 6.2.19. Instead, the one minute program corrected for the direction from which the wind was blowing.

$$V_X = \frac{1}{N}\sum_{i=1}^{N} v_{xi} \quad (3)$$

$$V_Y = \frac{1}{N}\sum_{i=1}^{N} v_{yi} \quad (4)$$

$$\theta = Arc\tan\left(V_X / V_Y \right) + CORR \quad (5)$$

Where Vx and Vy are the hourly averaged x- and y-components of the wind, θ is the hourly averaged wind direction, N is the number of observations used for the hour, and

$$\text{CORR} = \begin{cases} 180 \text{ for } V_x > 0 \text{ and } V_y > 0 \text{ or } V_x < 0 \text{ and } V_y > 0 \\ 0 \text{ for } V_x < 0 \text{ and } V_y < 0 \\ 360 \text{ for } V_x \geq 0 \text{ and } V_y < 0 \end{cases}$$

2.2 Upper air data

For AERMET processing, an upper air station must be paired with the surface station, as shown in Table 2. Upper air data in the Forecast System Laboratory (FSL) format was downloaded from the FSL, (currently named Global Systems Division) website, http://www.fsl.noaa.gov/. The data period chosen was January 1, 2002 through December 31, 2002 for all times and all levels. The selected wind speed units were chosen as tenths of a meter per second. Each station was downloaded as a separate file.

3. AERSURFACE

The AERSURFACE tool (U.S. EPA, 2008b) was used to determine surface characteristics (albedo, Bowen ratio, and surface roughness) for input to AERMET. Surface characteristics were calculated for the location of the ASOS meteorological towers. As noted in the AERSURFACE User's Guide (U.S. EPA, 2008), AERSURFACE should be run for the location of the actual meteorological tower to ensure accurate representation of the conditions around the site. The approximate locations of the meteorological towers were determined using aerial photos and the station history from NCDC. The coordinates used are listed in Table 1.

A draft version of AERSURFACE (08256) that utilizes 2001 NLCD was used to determine the surface characteristics for this application since the 2001 land cover data will be more representative of the meteorological data period than the 1992 NLCD data supported by the current version of AERSURFACE available on EPA's SCRAM website. All stations were considered "at an airport" for the low, medium, and high intensity developed categories. SGF and STL did not have continuous snow cover as outlined in the 1st draft SO_2 REA (U.S. EPA, 2008a). Monthly seasonal assignments did not follow the defaults as outlined in the AERSURFACE User's Guide (U.S. EPA, 2008a) and the monthly seasonal assignments were defined as shown in Table 3. Since the default seasonal assignments were not used, the surface characteristics were output by month.

Table 3. Seasonal monthly assignments.

Station	Winter (no snow)	Spring	Summer	Autumn
SGF	December, January, February, March	April, May	June, July, August	September, October, November
STL	December, January, February	March, April, May	June, July, August	September, October, November

Seasonal definitions	
Winter (no snow)	Late autumn after frost and harvest, or winter with no snow
Spring	Transitional spring with partial green coverage or short annuals
Summer	Midsummer with lush vegetation
Autumn	Autumn with unharvested cropland

Moisture conditions (average, dry or wet) for Bowen ratio were based on annual precipitation using the methodology outlined in the AERSURFACE User's Guide (U.S. EPA, 2008b): Years in the top 30% of the 30-year precipitation distribution are considered wet. Those in the bottom 30% of the distribution are dry. Otherwise, a given year is considered average. For the two surface stations, the 2007 local climatological database was used to look at 30 years (1978-2007) annual precipitation. For SGF, 2002 was considered dry while STL was considered average. The ranked 30 year distributions are shown in Table 4 with time series of the annual precipitation in Figure 3.

Table 4. Annual precipitation (inches) for Springfield and St. Louis. Years in green are top 30% of distribution (wettest), years in brown are the bottom 30% of the distribution (driest) and years in white are the middle 40%. 2002 is denoted in bold. 30 year averages are denoted by yellow rows.

Springfield St.		Louis	
Year	**Precipitation (inches)**	**Year**	**Precipitation (inches)**
1990	63.19	1982	54.97
1985	56.50	1993	54.76
1993	55.78	1984	51.65
1987	55.49	1985	50.73
1994	49.02	2003	46.06
1979	48.94	1981	45.52
1998	48.47	1990	45.09
1988	48.46	1983	44.80
1992	48.04	1996	43.67
1982	47.67	1998	43.62
1984	45.78	2004	42.27
2001	45.29	1995	41.68
1983	45.05	**2002 40**	**.95**
1996	44.86	1987	38.38
2007	44.27	2005	37.85
1978	43.95	1978	37.71
1981	43.72	2000	37.37
2004	43.23	2001	35.29
2003	42.61	1986	34.88
1995	41.86	1994	34.70
1999	41.53	1999	34.06
1986	40.19	1988	33.93
2006	38.87	1992	33.49
1997	38.48	1991	33.48
2002	**37.82**	1997	31.23
1991	37.59	2007	30.57
2000	35.36	2006	29.93
2005	35.32	1979	29.48
1989	31.50	1989	28.60
1980	27.36	1980	27.48
30-year average	40.21	30-year average	39.14

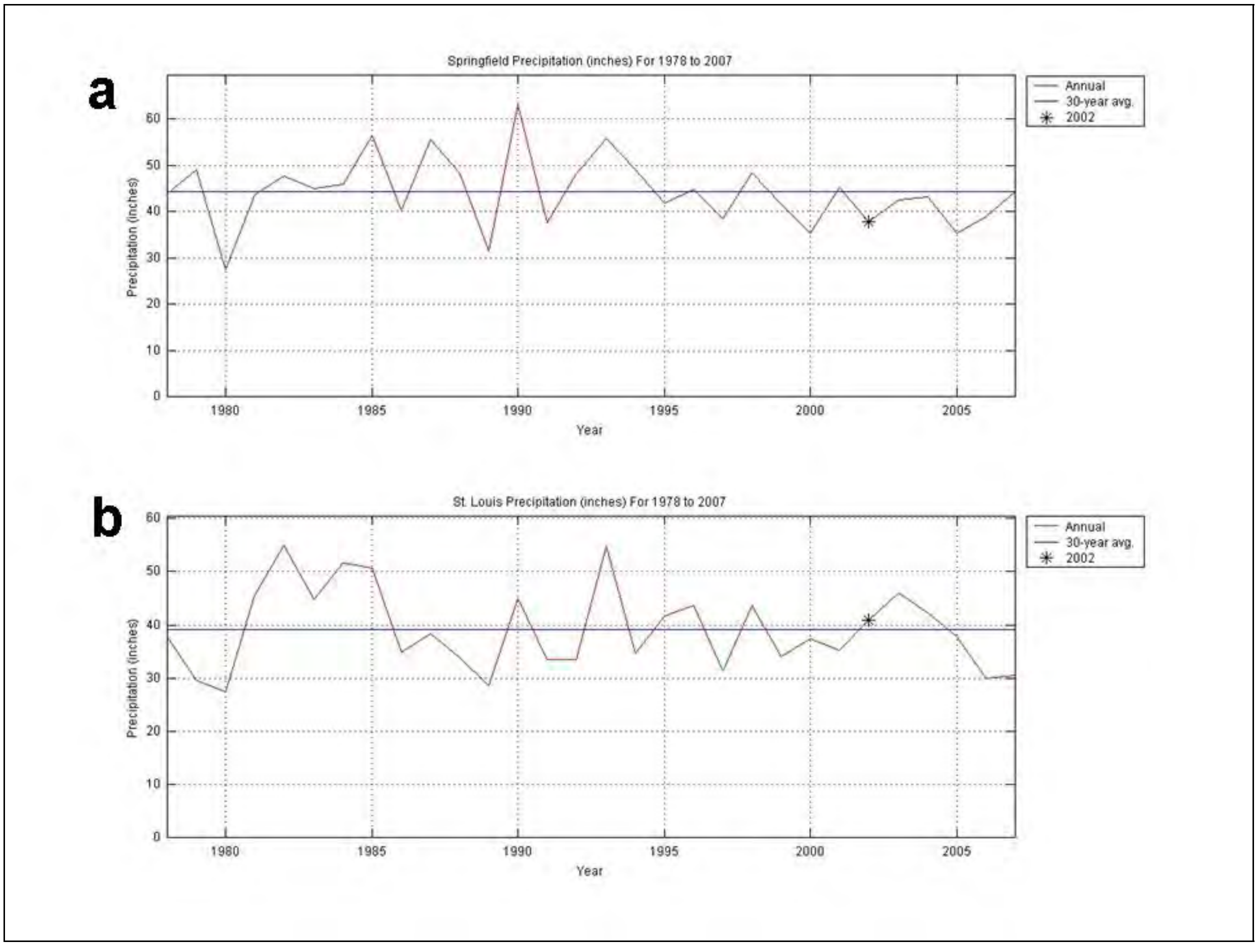

Figure 3. 30 year time series of annual precipitation (inches) for a) Springfield, and b) St. Louis. Annual averages are in red, 30-year averages in blue, and 2002 denoted by asterisk.

AERSURFACE also allows for the surface roughness to be defined by up to 12 sectors. The landuse around SGF and STL were analyzed using the NLCD data and aerial photographs. The resulting sectors are shown in Figures 4 and 5.

After determining the moisture conditions and surface roughness sectors, AERSURFACE was run for each station with output by month and sector. The resulting surface characteristics were input into AERMET stage 3. The surface characteristics are shown in Appendix A.

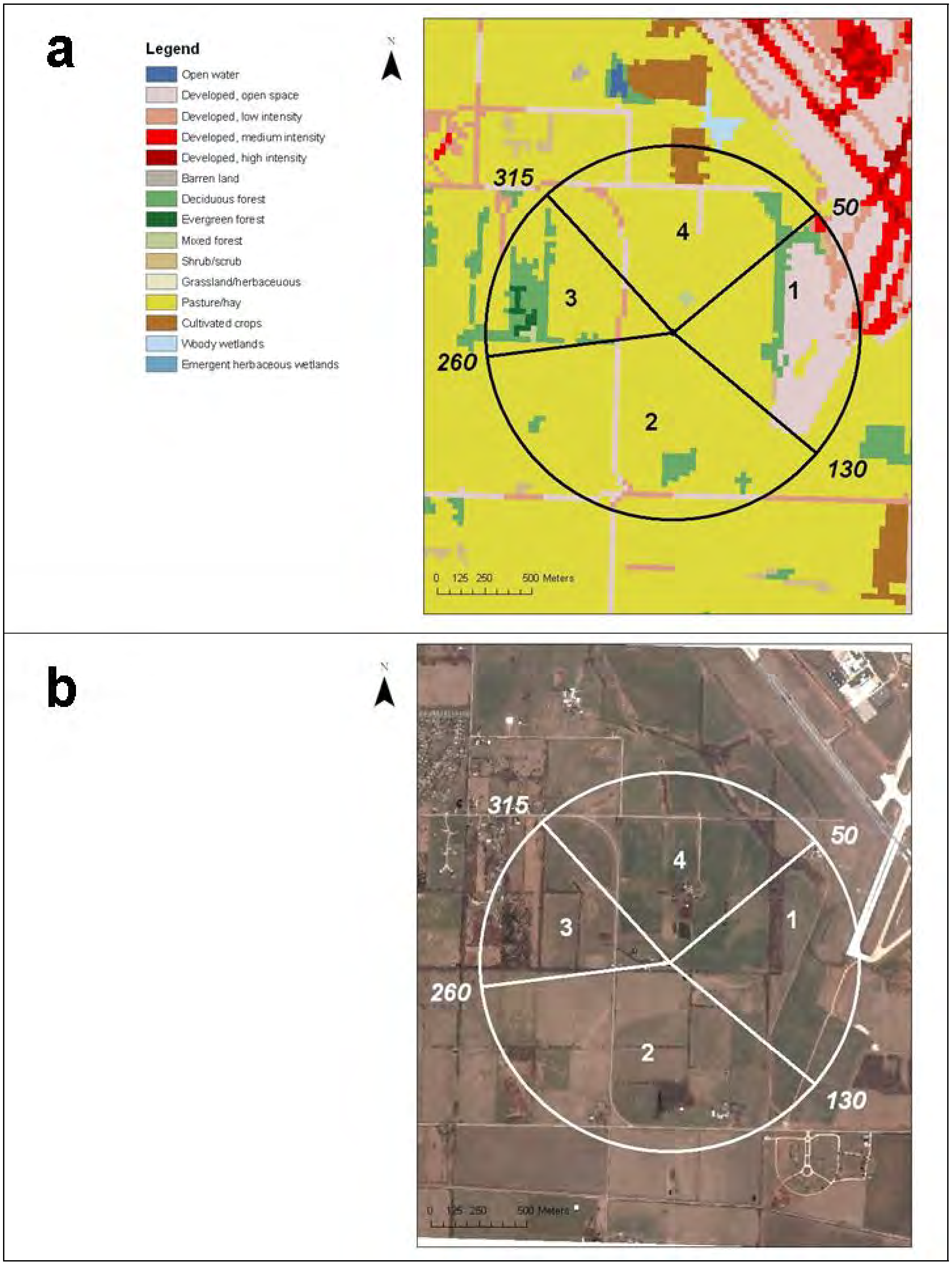

Figure 4. Surface roughness sectors for SGF with a) 2001 NLCD landuse and b) 2003 aerial photograph.

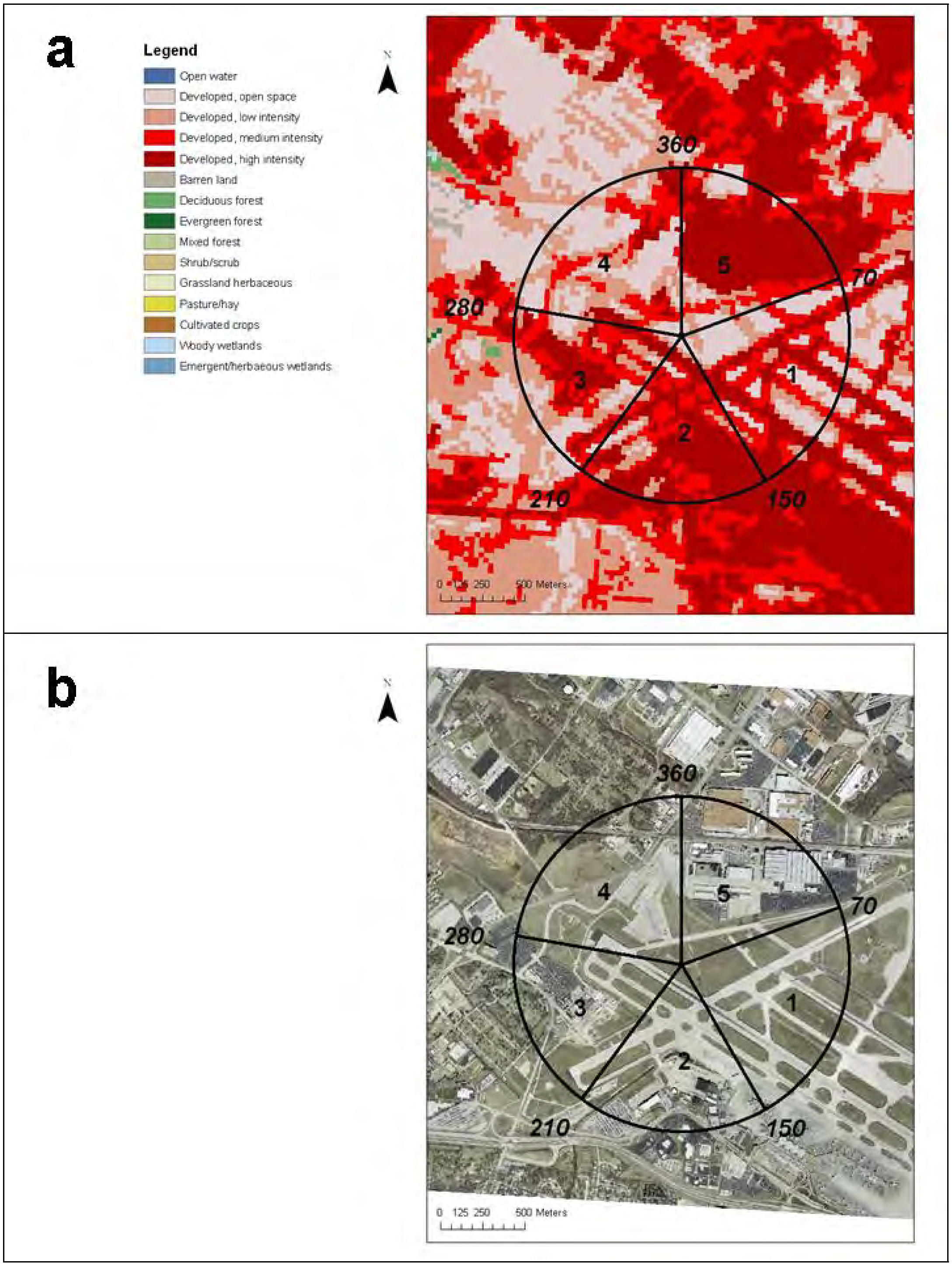

Figure 5. Surface roughness sectors for STL with a) 2001 NLCD landuse and b) 2002 aerial photograph.

4. AERMET

The meteorological data files for each station (upper air, ISH data, one minute data) were processed in AERMET (U.S. EPA, 2004), which includes three "Stages" for processing of meteorological data. Stage 1 was used to read in all the data files and perform initial QA. The upper air data was processed via the UPPERAIR pathway. The ISH data was processed via the SURFACE pathway, and the one minute hourly average winds were processed via the ONSITE pathway. Hourly averaged winds were read into AERMET for the one minute hourly average winds. For the hourly averaged one minute winds, the threshold was set to 0.01 m/s. The lowest wind speeds for SGF and STL, including one minute data, was around 0.54 m/s.

In Stage 2, the upper air, ISH surface data, and hourly averaged winds were merged together for each station. After Stage 2, Stage 3 was run to create the input files for AERMOD. When hourly averaged winds were available, those winds would be used for the hour and all other data would come from the ISH data (temperature, cloud cover, precipitation, etc.) If no hourly averaged winds were available for the hour, all surface data came from the ISH data via the SUBNWS keyword in the Stage 3 input file. As noted in Section 3, surface characteristics from AERSURFACE are input into Stage 3. The resulting output from Stage 3 were the .SFC and .PFL files input into AERMOD.

An AERMOD run, using a single source and receptor, was used to determine the number of calms and missing hours for each station. Missing hours can be due to missing winds, temperatures or soundings. Missing hours can also result from variable winds. The number of calms and missing hours for each station are shown in Table 5. Also shown in Table 5 are the number of calms and missing when using only the ISH winds for surface winds, no hourly averaged one minute winds included. Note that including the hourly averaged winds dramatically reduces the number of calms and missing hours.

Table 5. Number of calms and missing hours for each station. Totals reflect the use of hourly averaged one minute winds.

	With hourly averaged winds		Without hourly averaged winds	
Station	**Calms**	**Missing**	**Calms**	**Missing**
SGF	116	135	830	448
STL	67	98	648	401

5. Analysis

Wind roses for 2002 for the two stations are shown in Figure 6. For SGF, the wind was predominantly from the south and south-southeast. For STL, winds were predominantly from the south but strong components of the wind were from the westerly direction (northwest, west, and southwest).

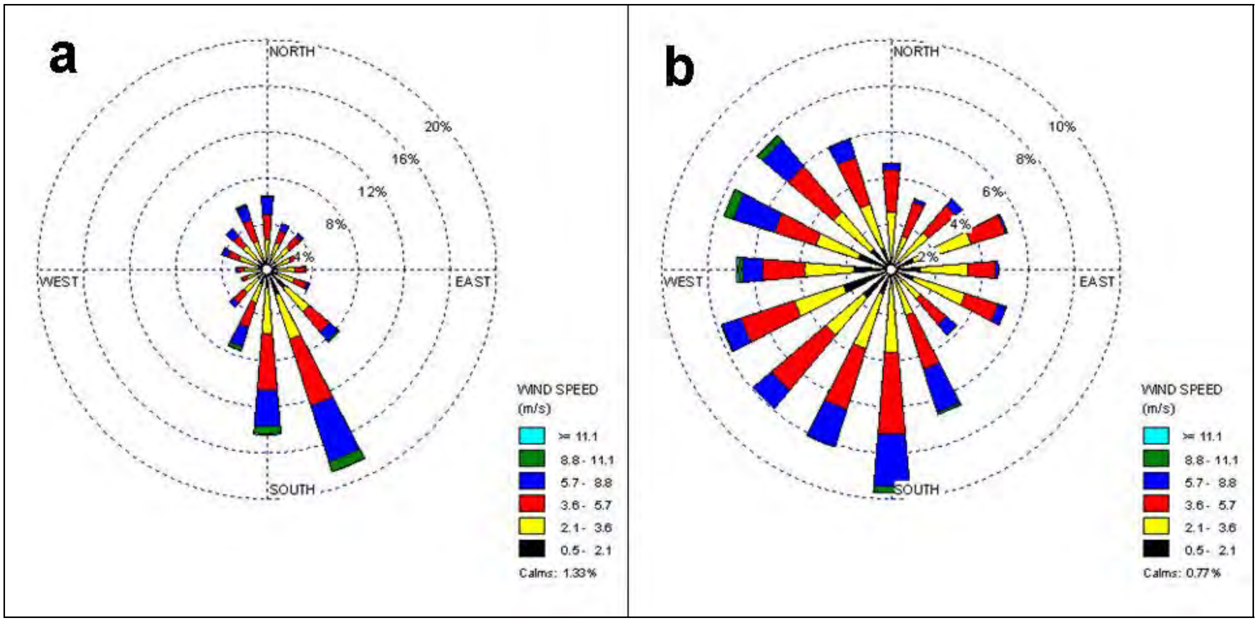

Figure 6. 2002 wind roses after AERMET processing for a) SGF and b) STL.

For SGF and STL, 2002 was compared against 30-year climatology for precipitation and temperature. Precipitation has been discussed in Section 3 (Table 4 and Figure 3). A distribution of the annual mean temperatures from 1978 to 2007 is shown in Table 6 with time series of mean temperatures shown in Figure 7. For Springfield, 2002 was drier than the 30-year average (Table 4 and Figure 3) and about average for the mean temperature (Table 6 and Figure 7). For St. Louis, the precipitation was slightly above the 30-year average (Table 4 and Figure 3) with the mean temperature about one degree above the 30-year average (Table 6 and Figure 7).

Table 6. 30-year distribution of mean annual temperatures (Fahrenheit) for Springfield and St. Louis. 2002 is denoted in bold.

Springfield St.		**Louis**	
Year	**Temperature**	**Year**	**Temperature**
2006	58.9	1991	59.2
2007	58.1	1990	59.0
1998	57.9	1998	58.7
2005	57.9	2006	58.5
1990	57.8	2007	58.3
1999	57.6	1987	58.2
1991	57.5	1999	58.0
1987	57.3	2005	58.0
1986	57.2	**2002 5**	**7.9**
1980	57.1	1994	57.7
1981	57.1	2001	57.7
1994	57.1	1986	57.6
1984	56.7	2004	57.6
2004	56.7	1992	57.2
2001	56.6	1988	57.0
1982	56.3	1995	57.0
1992	56.3	2003	56.5
1995	56.2	1980	56.4
2002 5	**6.2**	1984	56.4
1983	56.0	2000	56.2
2000	55.9	1981	56.1
2003	55.8	1983	55.9
1988	55.3	1989	55.7
1985	55.1	1993	55.6
1993	54.9	1985	55.2
1997	54.5	1997	55.1
1996	54.4	1996	54.9
1989	54.0	1982	54.8
1978	53.9	1979	54.1
1979	53.5	1978	53.2
30-year average	**56.3**	**30-year average**	**56.8**

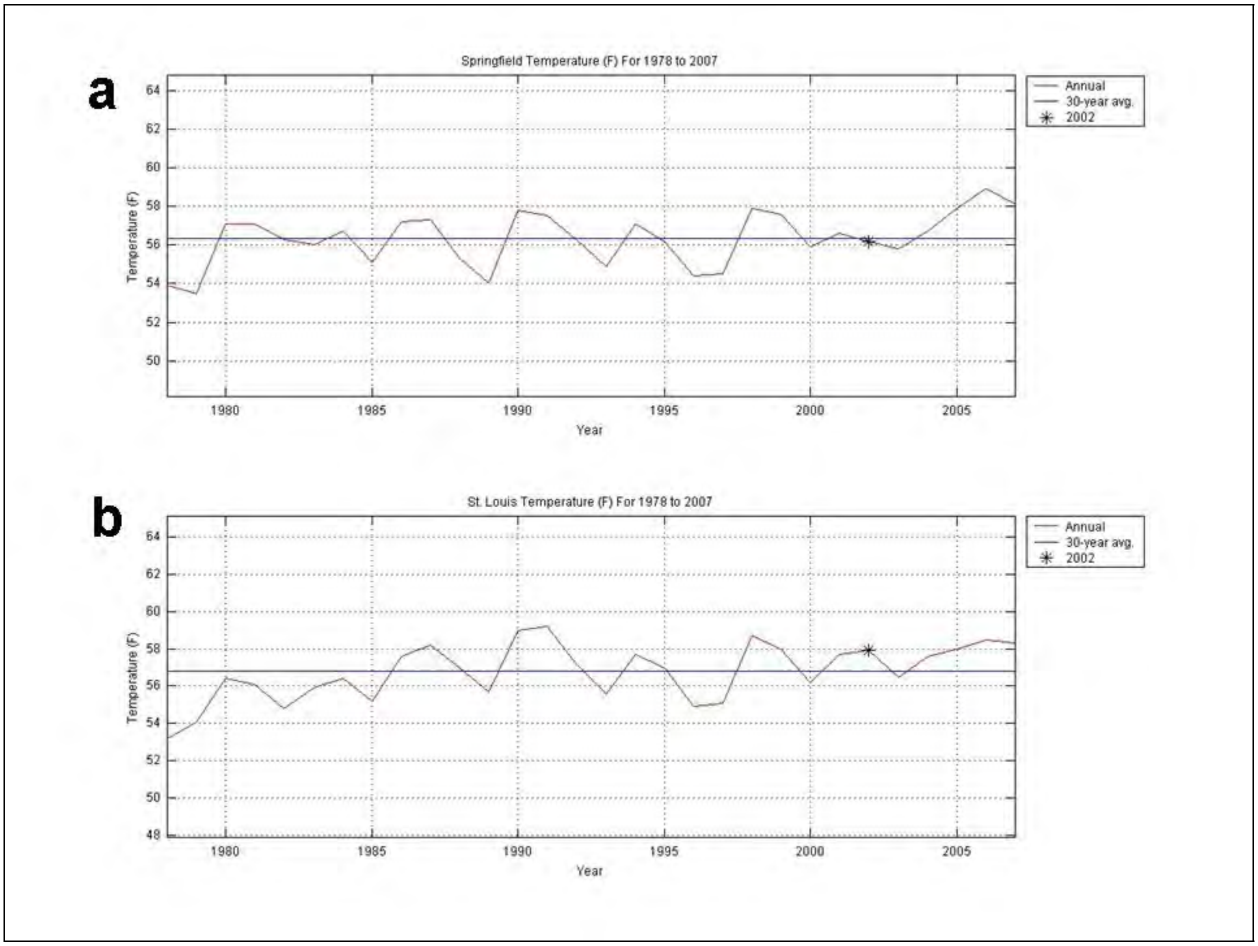

Figure 7. 30 year time series of mean annual temperatures (Fahrenheit) for a) Springfield, and b) St. Louis. Annual averages are in red, 30-year averages in blue, and 2002 denoted by asterisk.

6. References

U.S. EPA, 2000: Meteorological Monitoring Guidance for Regulatory Modeling Applications. EPA-454/R-99-005. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711.

U.S. EPA, 2004: User's Guide for the AERMOD Meteorological Preprocessor (AERMET). EPA-454/B-03-002. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711.

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U.S. EPA, 2008b. AERSURFACE User's Guide. EPA-454/B-08-001. U.S. Environmental Protection Agency, Research Triangle Park, NC. http://www.epa.gov/scram001/7thconf/aermod/aersurface_userguide.pdf

Appendix A. Surface characteristics.

Tables A1 and A2 show the surface characteristics for Springfield and St. Louis for 2002 based on 2001 landuse.

Table A1. Springfield monthly surface characteristics by sector.

Month	Sector	Albedo	Bowen ratio	Surface roughness	Month	Sector	Albedo	Bowen ratio	Surface roughness
January	1	0.18	2.06	0.022	July	1	0.18	1.36	0.102
	2	0.18	2.06	0.021		2	0.18	1.36	0.146
	3	0.18	2.06	0.037		3	0.18	1.36	0.206
	4	0.18	2.06	0.022		4	0.18	1.36	0.147
February	1	0.18	2.06	0.022	August	1	0.18	1.36	0.102
	2	0.18	2.06	0.021		2	0.18	1.36	0.146
	3	0.18	2.06	0.037		3	0.18	1.36	0.206
	4	0.18	2.06	0.022		4	0.18	1.36	0.147
March	1	0.18	2.06	0.022	September	1	0.18	2.06	0.095
	2	0.18	2.06	0.021		2	0.18	2.06	0.145
	3	0.18	2.06	0.037		3	0.18	2.06	0.205
	4	0.18	2.06	0.022		4	0.18	2.06	0.145
April	1	0.15	1.2	0.033	October	1	0.18	2.06	0.095
	2	0.15	1.2	0.032		2	0.18	2.06	0.145
	3	0.15	1.2	0.055		3	0.18	2.06	0.205
	4	0.15	1.2	0.034		4	0.18	2.06	0.145
May	1	0.15	1.2	0.033	November	1	0.18	2.06	0.095
	2	0.15	1.2	0.032		2	0.18	2.06	0.145
	3	0.15	1.2	0.055		3	0.18	2.06	0.205
	4	0.15	1.2	0.034		4	0.18	2.06	0.145
June	1	0.18	1.36	0.102	December	1	0.18	2.06	0.022
	2	0.18	1.36	0.146		2	0.18	2.06	0.021
	3	0.18	1.36	0.206		3	0.18	2.06	0.037
	4	0.18	1.36	0.147		4	0.18	2.06	0.022

Table A2. St. Louis monthly surface characteristics by sector.

Month	Sector	Albedo	Bowen ratio	Surface roughness	Month	Sector	Albedo	Bowen ratio	Surface roughness
January	1	0.18	1.02	0.036	July	1	0.17	0.81	0.048
	2	0.18	1.02	0.077		2	0.17	0.81	0.081
	3	0.18	1.02	0.059		3	0.17	0.81	0.065
	4	0.18	1.02	0.036		4	0.17	0.81	0.046
	5	0.18	1.02	0.041		5	0.17	0.81	0.051
February	1	0.18	1.02	0.036	August	1	0.17	0.81	0.048
	2	0.18	1.02	0.077		2	0.17	0.81	0.081
	3	0.18	1.02	0.059		3	0.17	0.81	0.065
	4	0.18	1.02	0.036		4	0.17	0.81	0.046
	5	0.18	1.02	0.041		5	0.17	0.81	0.051
March	1	0.16	0.76	0.043	September	1	0.17	1.02	0.043
	2	0.16	0.76	0.079		2	0.17	1.02	0.079
	3	0.16	0.76	0.063		3	0.17	1.02	0.063
	4	0.16	0.76	0.041		4	0.17	1.02	0.041
	5	0.16	0.76	0.047		5	0.17	1.02	0.047
April	1	0.16	0.76	0.043	October	1	0.17	1.02	0.043
	2	0.16	0.76	0.079		2	0.17	1.02	0.079
	3	0.16	0.76	0.063		3	0.17	1.02	0.063
	4	0.16	0.76	0.041		4	0.17	1.02	0.041
	5	0.16	0.76	0.047		5	0.17	1.02	0.047
May	1	0.16	0.76	0.043	November	1	0.17	1.02	0.043
	2	0.16	0.76	0.079		2	0.17	1.02	0.079
	3	0.16	0.76	0.063		3	0.17	1.02	0.063
	4	0.16	0.76	0.041		4	0.17	1.02	0.041
	5	0.16	0.76	0.047		5	0.17	1.02	0.047
June	1	0.17	0.81	0.048	December	1	0.18	1.02	0.036
	2	0.17	0.81	0.081		2	0.18	1.02	0.077
	3	0.17	0.81	0.065		3	0.18	1.02	0.059
	4	0.17	0.81	0.046		4	0.18	1.02	0.036
	5	0.17	0.81	0.051		5	0.18	1.02	0.041

ATTACHMENT 2. TECHNICAL MEMORANDUM ON THE ANALYSIS OF NHIS ASTHMA PREVALENCE DATA

INTERNATIONAL

DRAFT MEMORANDUM

To: John Langstaff

From: Jonathan Cohen, Arlene Rosenbaum

Date: September 30, 2005

Re: EPA 68D01052, Work Assignment 3-08. Analysis of NHIS Asthma Prevalence Data

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This memorandum describes our analysis of children's asthma prevalence data from the National Health Interview Survey (NHIS) for 2003. Asthma prevalence rates for children aged 0 to 17 years were calculated for each age, gender, and region. The regions defined by NHIS are "Midwest," "Northeast," "South," and "West." For this project, asthma prevalence was defined as the probability of a Yes response to the question CASHMEV: "Ever been told that … had asthma?" among those that responded Yes or No to this question. The responses were weighted to take into account the complex survey design of the NHIS survey. Standard errors and confidence intervals for the prevalence were calculated using a logistic model, taking into account the survey design. Prevalence curves showing the variation of asthma prevalence against age for a given gender and region were plotted. A scatterplot smoothing technique using the LOESS smoother was applied to smooth the prevalence curves and compute the standard errors and confidence intervals for the smoothed prevalence estimates. Logistic analysis of the prevalence curves shows statistically significant differences in prevalence by gender and by region. Therefore we did not combine the prevalence rates for different genders or regions.

Logistic Models

NHIS survey data for 2003 were provided by EPA. One obvious approach to calculate prevalence rates and their uncertainties for a given gender, region, and age is to calculate the proportion of Yes responses among the Yes and No responses for that demographic group, weighting each response by the survey weight. Although that approach was initially used, two problems are that the distributions of the estimated prevalence rates are not well approximated by normal distributions, and that the estimated confidence intervals based on the normal approximation often extend outside the [0, 1] interval. A better approach is to use a logistic transformation and fit a model of the form:

$$\text{Prob (asthma)} = \exp(\text{beta}) / (1 + \exp(\text{beta})),$$

where beta may depend on the explanatory variables for age, gender, or region. This is equivalent to the model:

Beta = logit {prob (asthma) } = log { prob (asthma) / [1 – prob (asthma)] }.

The distribution of the estimated values of beta is more closely approximated by a normal distribution than the distribution of the corresponding estimates of prob (asthma). By applying a logit transformation to the confidence intervals for beta, the corresponding confidence intervals for prob (asthma) will always be inside [0, 1]. Another advantage of the logistic modeling is that it can be used to compare alternative statistical models, such as models where the prevalence probability depends upon age, region, and gender, or on age and region but not gender.

A variety of logistic models for asthma prevalence were fit and compared, where the transformed probability variable beta is a given function of age, gender, and region. SAS's SURVEYLOGISTIC procedure was used to fit the logistic models, taking into account the NHIS survey weights and survey design (stratification and clustering).

The following Table G-1 lists the models fitted and their log-likelihood goodness-of-fit measures. 16 models were fitted. The Strata column lists the four possible stratifications: no stratification, by gender, by region, by region and gender. For example, "4. region, gender" means that separate prevalence estimates were made for each combination of region and gender. As another example, "2. gender" means that separate prevalence estimates were made for each gender, so that for each gender, the prevalence is assumed to be the same for each region. The prevalence estimates are independently calculated for each stratum.

Table G-1. Alternative logistic models for asthma prevalence.

Model	Description	Strata	- 2 Log Likelihood	DF
1	1. logit(prob) = linear in age	1. none	54168194.62	2
2	1. logit(prob) = linear in age	2. gender	53974657.17	4
3	1. logit(prob) = linear in age	3. region	54048602.57	8
4	1. logit(prob) = linear in age	4. region, gender	53837594.97	16
5	2. logit(prob) = quadratic in age	1. none	53958021.20	3
6	2. logit(prob) = quadratic in age	2. gender	53758240.99	6
7	2. logit(prob) = quadratic in age	3. region	53818198.13	12
8	2. logit(prob) = quadratic in age	4. region, gender	53593569.84	24
9	3. logit(prob) = cubic in age	1. none	53849072.76	4
10	3. logit(prob) = cubic in age	2. gender	53639181.24	8
11	3. logit(prob) = cubic in age	3. region	53694710.66	16
12	3. logit(prob) = cubic in age	4. region, gender	53441122.98	32
13	4. logit(prob) = f(age)	1. none	53610093.48	18

Model	Description	Strata	- 2 Log Likelihood	DF
14	4. logit(prob) = f(age)	2. gender	53226610.02	36
15	4. logit(prob) = f(age)	3. region	53099749.33	72
16	4. logit(prob) = f(age)	4. region, gender	52380000.19	144

The Description column describes how beta depends upon the age:

Linear in age: Beta = $\alpha + \beta \times$ age, where α and β vary with the strata.
Quadratic in age: Beta = $\alpha + \beta \times \text{age} + \gamma \times \text{age}^2$ where α β and γ vary with the strata.
Cubic in age: Beta = $\alpha + \beta \times \text{age} + \gamma \times \text{age}^2 + \delta \times \text{age}^3$ where α β, γ, and δ vary with the strata.
f(age) Beta = arbitrary function of age, with different functions for different strata

The category f(age) is equivalent to making age one of the stratification variables, and is also equivalent to making beta a polynomial of degree 16 in age (since the maximum age for children is 17), with coefficients that may vary with the strata.

The fitted models are listed in order of complexity, where the simplest model (1) is an unstratified linear model in age and the most complex model (16) has a prevalence that is an arbitrary function of age, gender, and region. Model 16 is equivalent to calculating independent prevalence estimates for each of the 144 combinations of age, gender, and region.

Table G-1 also includes the -2 Log Likelihood, a goodness-of-fit measure, and the degrees of freedom, DF, which is the total number of estimated parameters. Two models can be compared using their -2 Log Likelihood values; lower values are preferred. If the first model is a special case of the second model, then the approximate statistical significance of the first model is estimated by comparing the difference in the -2 Log Likelihood values with a chi-squared random variable with r degrees of freedom, where r is the difference in the DF. This is a likelihood ratio test. For all pairs of models from Table G-1, all the differences are at least 70,000 and the likelihood ratios are all extremely statistically significant at levels well below 5 percent. Therefore the model 16 is clearly preferred and was used to model the prevalences.

The SURVEYLOGISTIC model predictions are tabulated in Table G-2 below and plotted in Figures 1 and 3 below. Also shown in Table G-2 and in Figures 2 and 4 are results for smoothed curves calculated using a LOESS scatterplot smoother, as discussed below.

The SURVEYLOGISTIC procedure produces estimates of the beta values and their 95 % confidence intervals for each combination of age, region, and gender. Applying the inverse logit transformation,

Prob (asthma) = exp(beta) / (1 + exp(beta)),

converted the beta values and 95 % confidence intervals into predictions and 95 % confidence intervals for the prevalence, as shown in Table G-2 and Figures 1 and 3. The standard error for the prevalence was estimated as

$$\text{Std Error \{Prob (asthma)\}} = \text{Std Error (beta)} \times \exp(-\text{beta}) / (1 + \exp(\text{beta}))^2,$$

which follows from the delta method (a first order Taylor series approximation).

Loess Smoother

The estimated prevalence curves shows that the prevalence is not a smooth function of age. The linear, quadratic, and cubic functions of age modeled by SURVEYLOGISTIC were one strategy for smoothing the curves, but they did not provide a good fit to the data. One reason for this might be due to the attempt to fit a global regression curve to all the age groups, which means that the predictions for age A are affected by data for very different ages. We instead chose to use a local regression approach that separately fits a regression curve to each age A and its neighboring ages, giving a regression weight of 1 to the age A, and lower weights to the neighboring ages using a tri-weight function:

$$\text{Weight} = \{1 - [\ |\text{age} - A| / q\ ]^3\},\ \text{ where } |\ \text{age} - A| <= q.$$

The parameter q defines the number of points in the neighborhood of the age a. Instead of calling q the smoothing parameter, SAS defines the smoothing parameter as the proportion of points in each neighborhood. We fitted a quadratic function of age to each age neighborhood, separately for each gender and region combination. We fitted these local regression curves to the beta values, the logits of the asthma prevalence estimates, and then converted them back to estimated prevalence rates by applying the inverse logit function exp(beta) / (1 + exp(beta)). In addition to the tri-weight variable, each beta value was assigned a weight of $1 / [\text{std error (beta)}]^2$, to account for their uncertainties.

The SAS LOESS procedure was applied to estimate smoothed curves for beta, the logit of the prevalence, as a function of age, separately for each region and gender. We fitted curves using the choices 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, and 1.0 for the smoothing parameter in an effort to determine the optimum choice based on various regression diagnostics.3,4

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3 Two outlier cases were adjusted to avoid wild variations in the "smoothed" curves: For the West region, males, age 0, there were 97 children surveyed that all gave No answers to the asthma question, leading to an estimated value of -15.2029 for beta with a standard error of 0.14. For the Northeast region, females, age 0, there were 29 children surveyed that all gave No answers to the asthma question, leading to an estimated value of -15.2029 for beta with a standard error of 0.19. In both cases the raw probability of asthma equals zero, so the corresponding estimated beta would be negative infinity, but SAS's software gives -15.2029 instead. To reduce the impact of these outlier cases, we replaced their estimated standard errors by 4, which is approximately four times the maximum standard error for all other region, gender, and age combinations.

4 With only 18 points, a smoothing parameter of 0.2 cannot be used because the weight function assigns zero weights to all ages except age A, and a quadratic model cannot be uniquely fitted to a single value. A smoothing parameter of 0.3 also cannot be used because that choice assigns a neighborhood of 5 points only (0.3 × 18 = 5, rounded down), of which the two outside ages have assigned weight zero, making the local quadratic model fit exactly at every point except for the end points (ages 0, 1, 16 and 17). Usually one uses a smoothing parameter below one so that not all the data are used for the local regression at a given x value.

Quantities predicted in these smoothing parameter tests were the predicted value, standard error, confidence interval lower bound and confidence interval upper bound for the betas, and the corresponding values for the prevalence rates.

The polygonal curves joining values for different ages show the predicted values with vertical lines indicating the confidence intervals in Figures 3 and 4 for smoothing parameters 0 (i.e., no smoothing) and 0.5, respectively. Note that the confidence intervals are not symmetric about the predicted values because of the inverse logit transformation.

Note that in our application of LOESS, we used weights of 1 / [std error (beta)] ^{2}, so that $\sigma^2 = 1$ for this application. The LOESS procedure estimates σ^2 from the weighted sum of squares. Since in our application we assume $\sigma^2 = 1$, we multiplied the estimated standard errors by 1 / estimated σ, and adjusted the widths of the confidence intervals by the same factor.

Additionally, because the true value of σ equals 1, the best choices of smoothing parameter should give residual standard errors close to one. Using this criterion the best choice varies with gender and region between smoothing parameters 0.4 (3 cases), 0.5 (2 cases), 0.6 (1 case), and 0.7 (1 case).

As a further regression diagnostic the residual errors from the LOESS model were divided by std error (beta) to make their variances approximately constant. These approximately studentized residuals, 'student,' should be approximately normally distributed with a mean of zero and a variance of $\sigma^2 = 1$. To test this assumption, normal probability plots of the residuals were created for each smoothing parameter, combining all the studentized residuals across genders, regions, and ages. The plots for smoothing parameters seem to be equally straight for each smoothing parameter.

The final regression diagnostic is a plot of the studentized residuals against the smoothed beta values. Ideally there should be no obvious pattern and an average studentized residual close to zero. The plots indeed showed no unusual patterns, and the results for smoothing parameters 0.5 and 0.6 seem to showed a fitted LOESS close to the studentized residual equals zero line.

The regression diagnostics suggested the choice of smoothing parameter as 0.4 or 0.5. Normal probability plots did not suggest any preferred choices. The plots of residuals against smoothed predictions suggest the choices of 0.5 or 0.6. We therefore chose the final value of 0.5. These predictions, standard errors, and confidence intervals are presented in tabular form below as Table G-2.

Figure 1. Raw asthma prevalence rates by age and gender for each region
region=Midwest

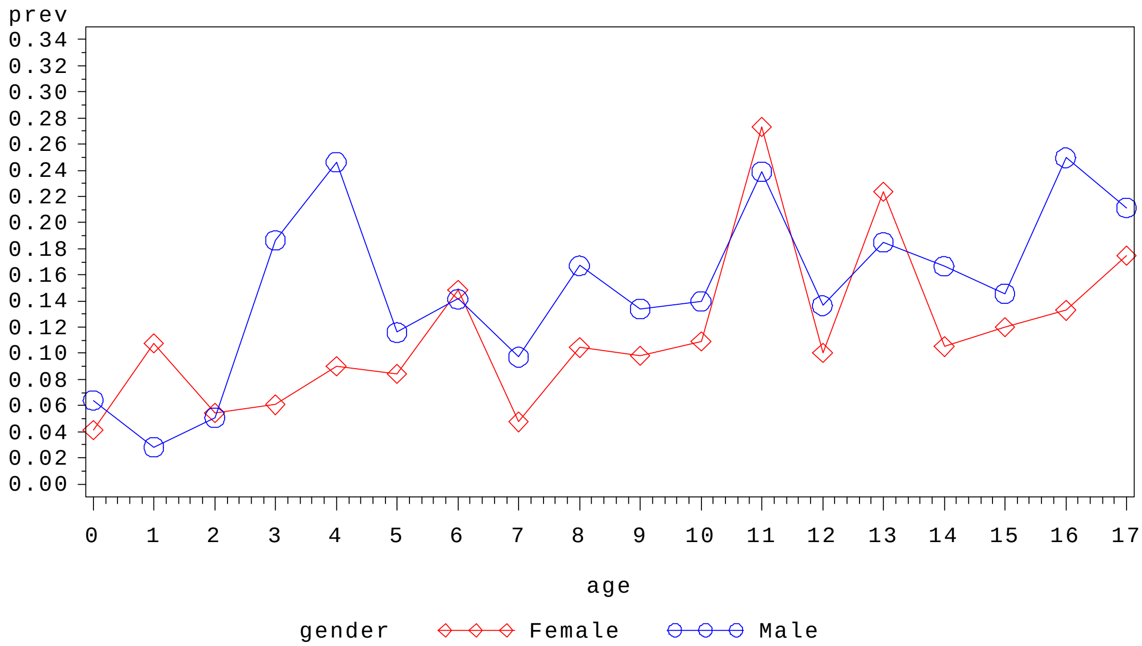


Figure 1. Raw asthma prevalence rates by age and gender for each region
region=Northeast

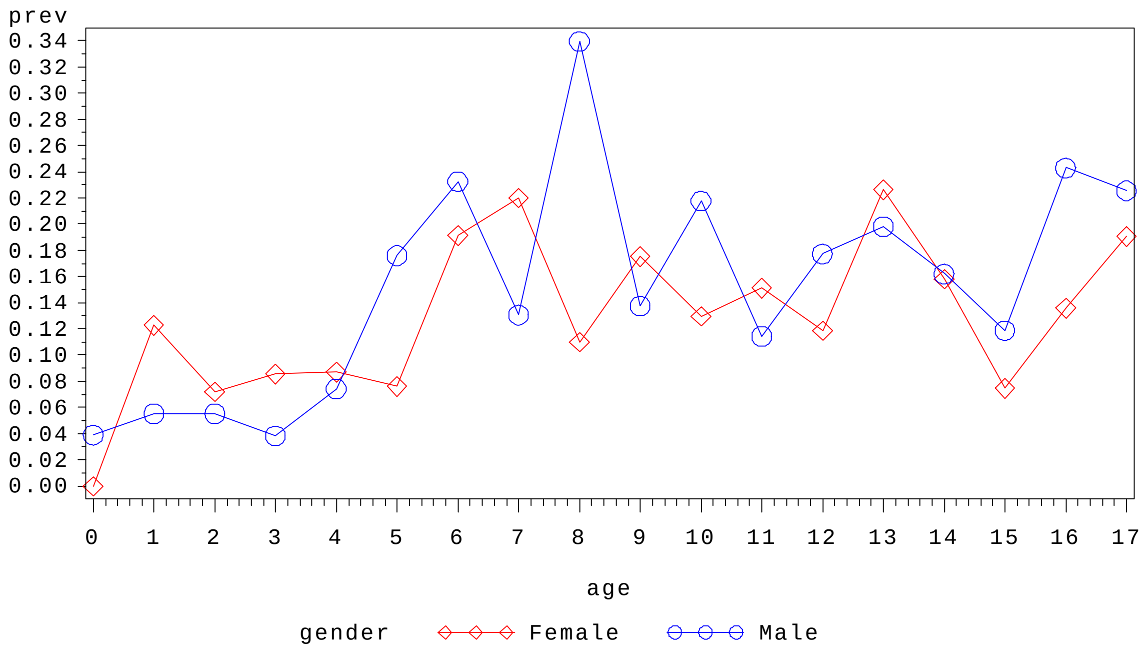


Figure 1. Raw asthma prevalence rates by age and gender for each region
region=South

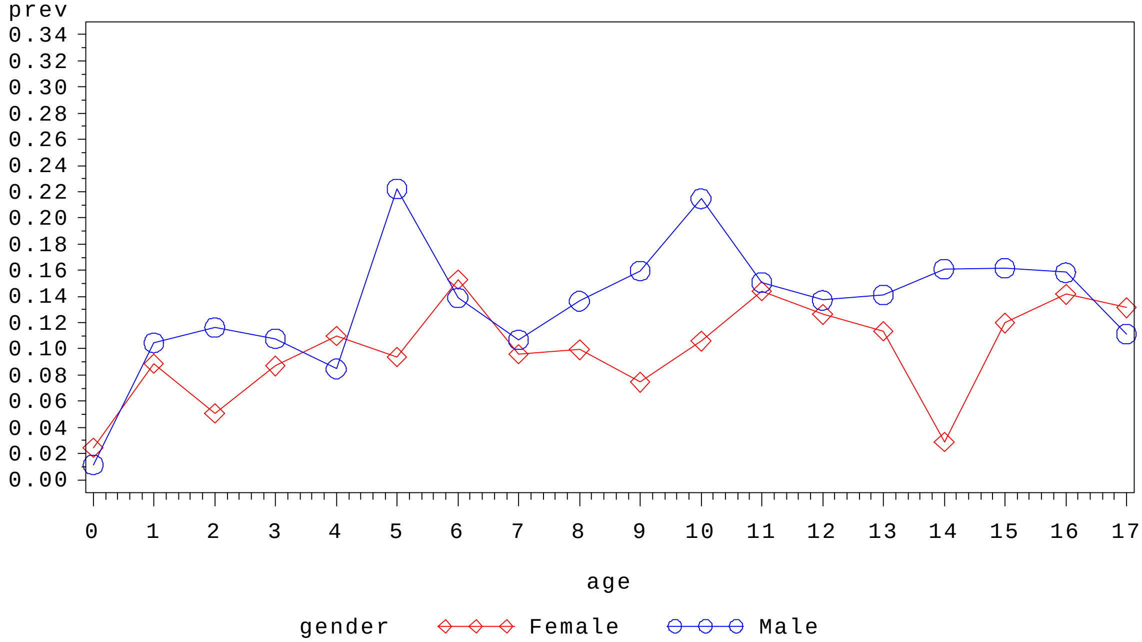


Figure 1. Raw asthma prevalence rates by age and gender for each region
region=West

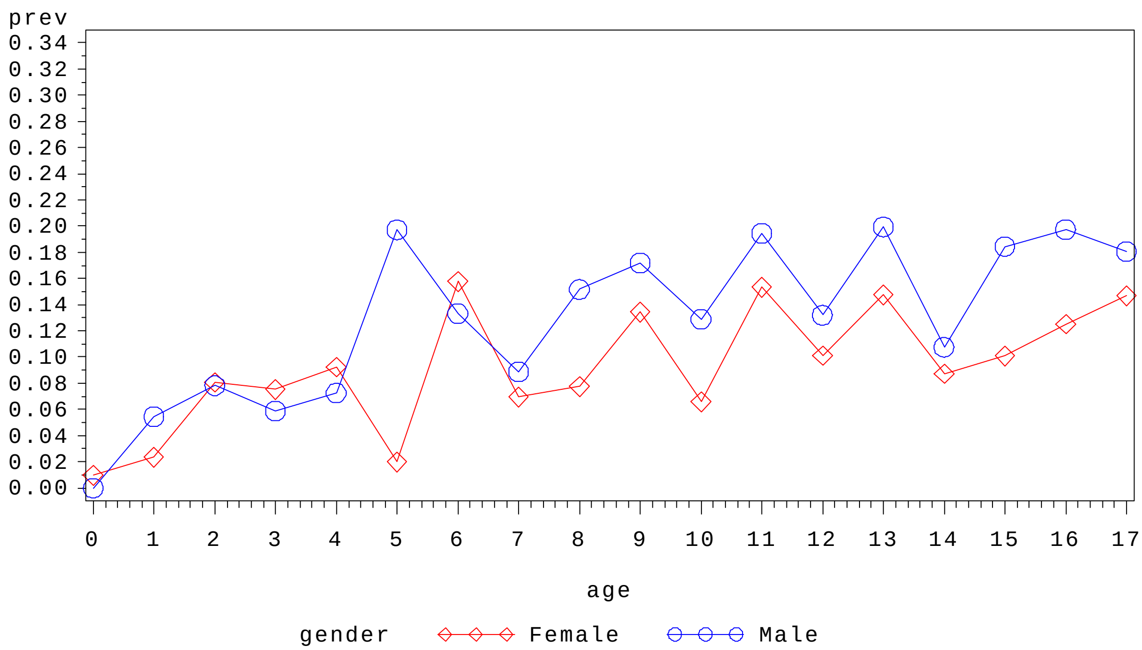


Figure 2. Smoothed asthma prevalence rates by age for each region and gender
region=Midwest

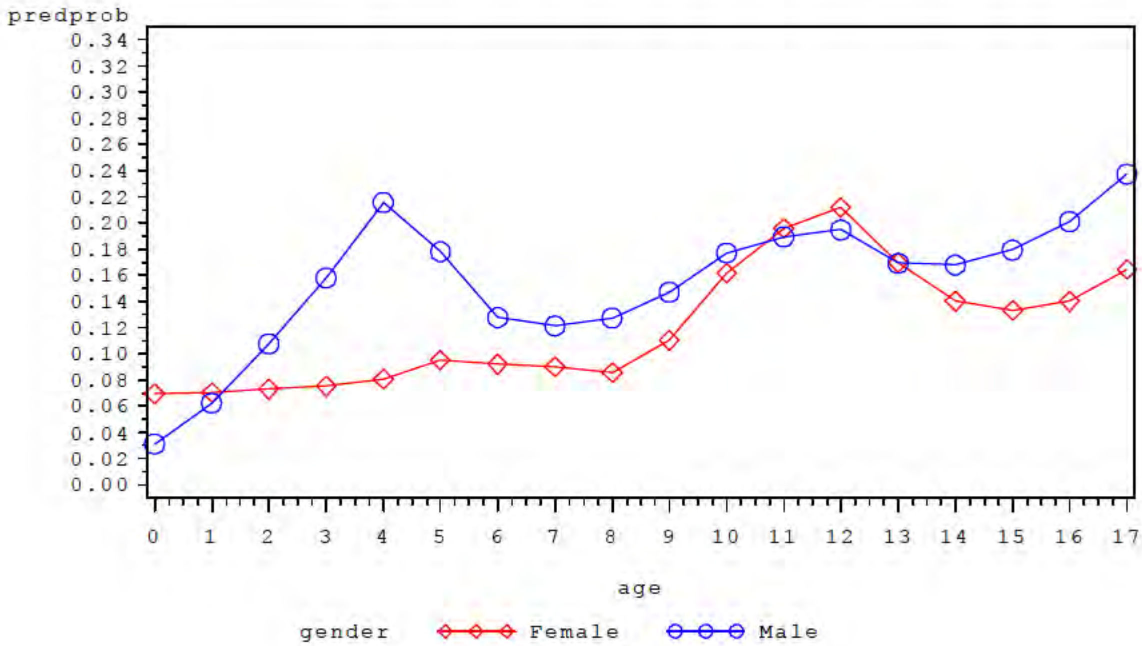


Figure 2. Smoothed asthma prevalence rates by age for each region and gender
region=Northeast

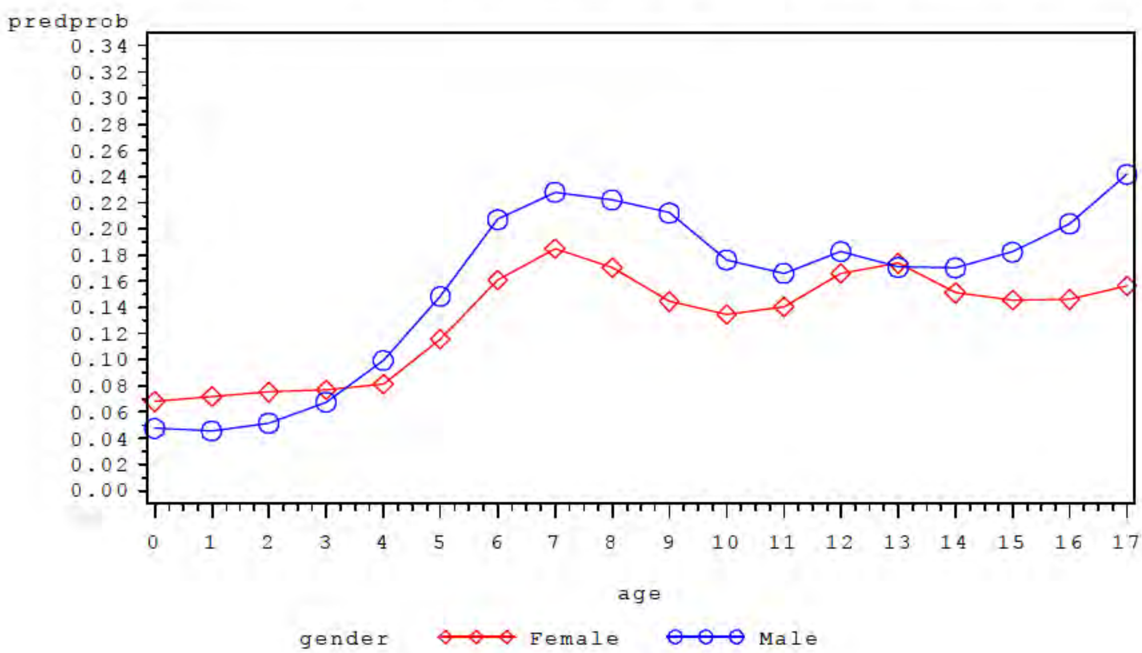


Figure 2. Smoothed asthma prevalence rates by age for each region and gender
region=South

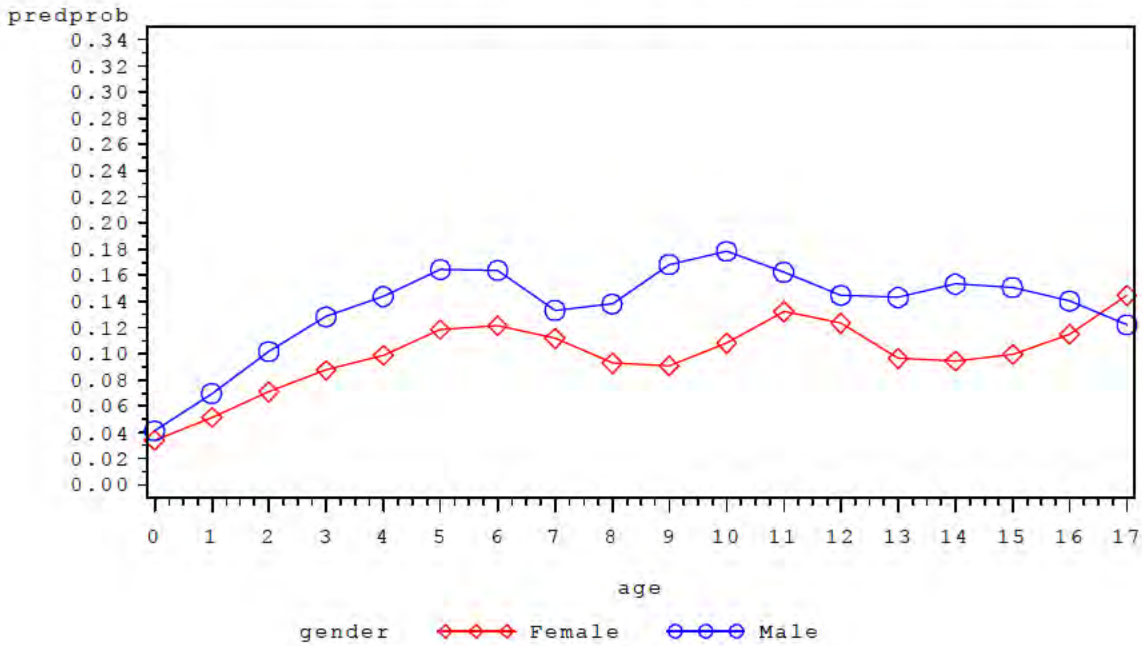


Figure 2. Smoothed asthma prevalence rates by age for each region and gender
region=West

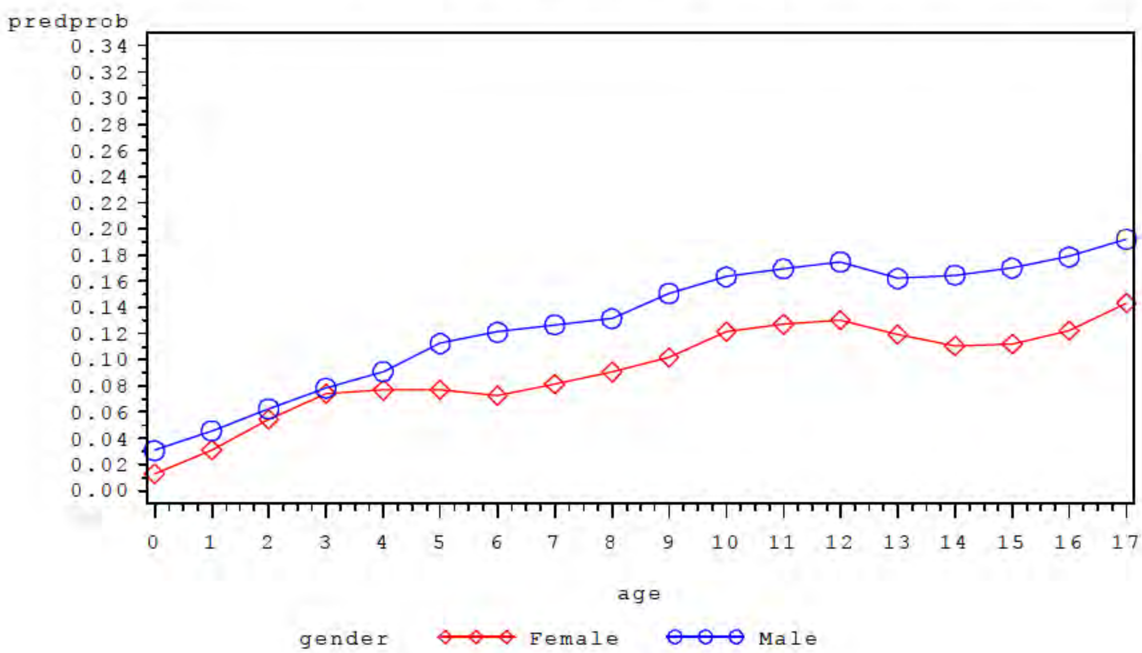


Figure 3. Raw asthma prevalence rates and confidence intervals
region=Midwest

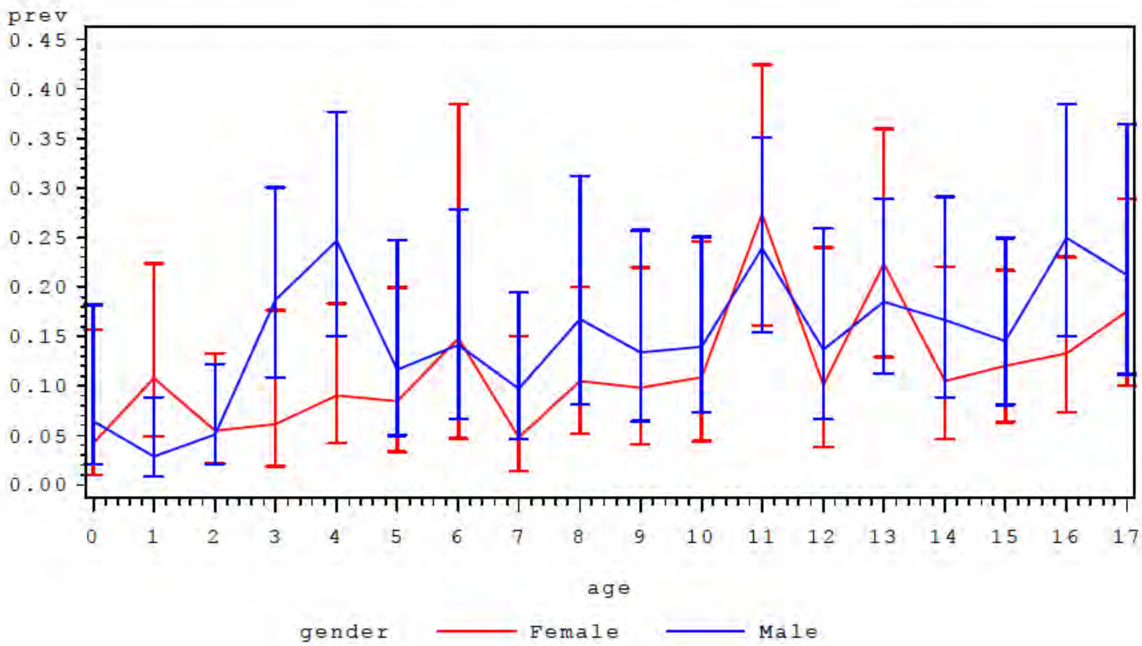


Figure 3. Raw asthma prevalence rates and confidence intervals
region=Northeast

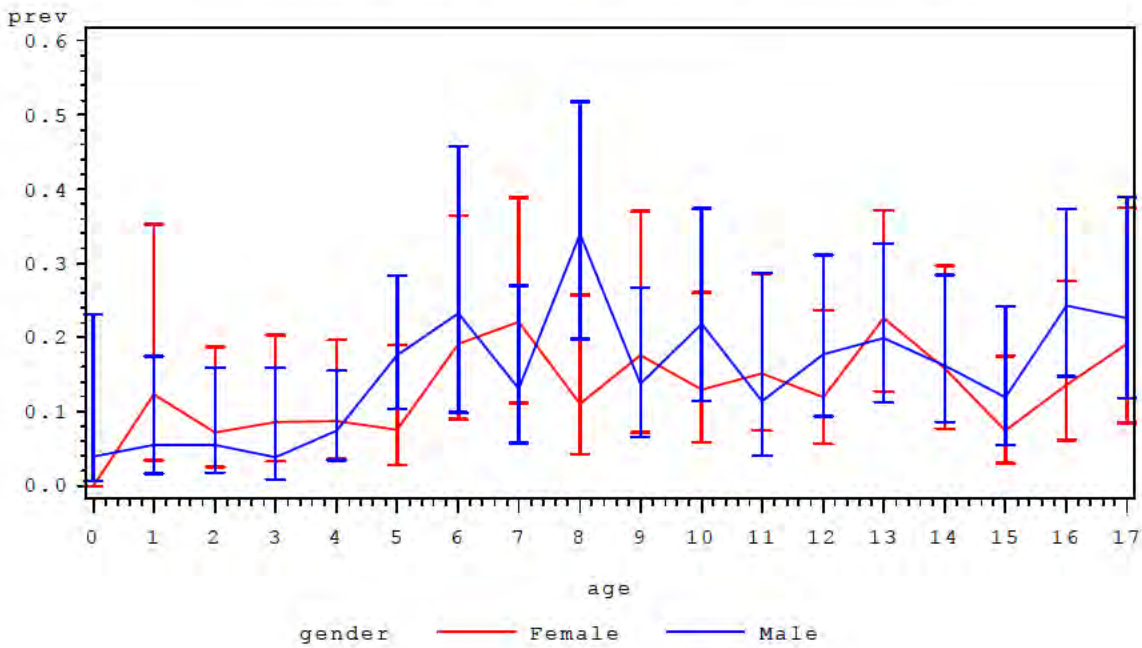


Figure 3. Raw asthma prevalence rates and confidence intervals
region=South

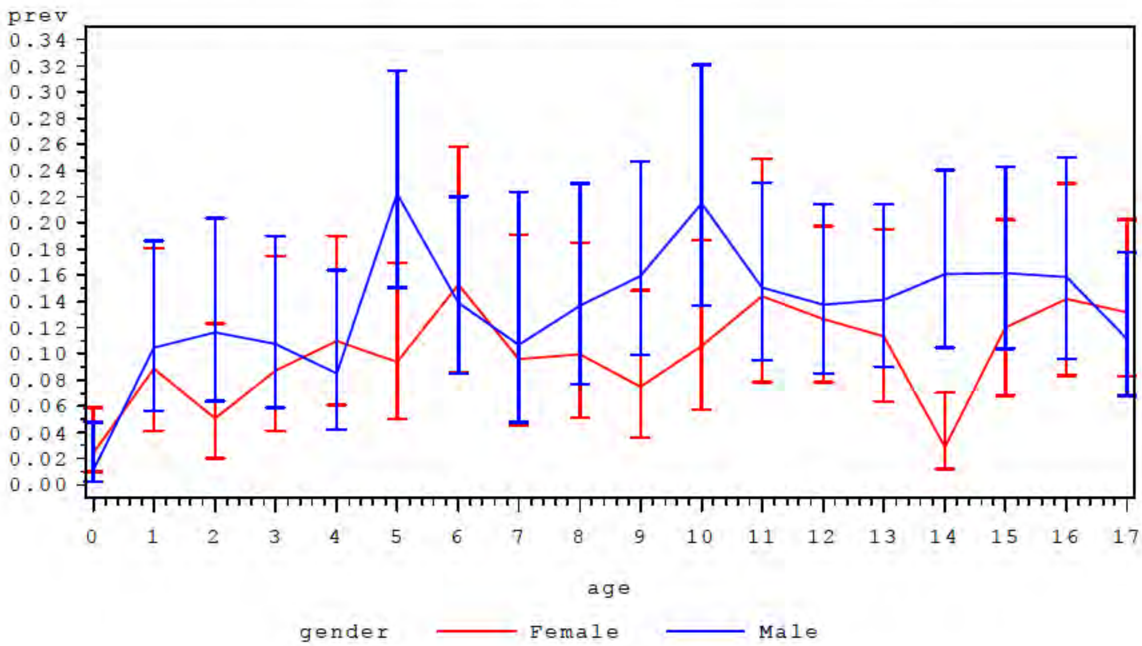


Figure 3. Raw asthma prevalence rates and confidence intervals
region=West

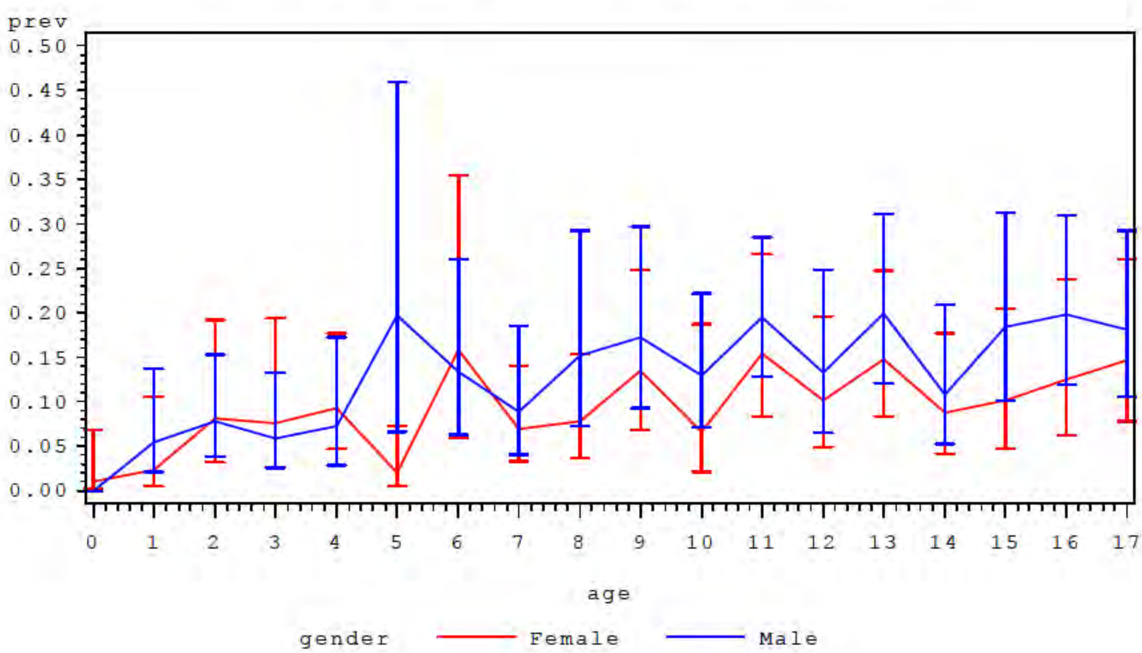


Figure 4. Smoothed asthma prevalence rates and confidence intervals
region=Midwest

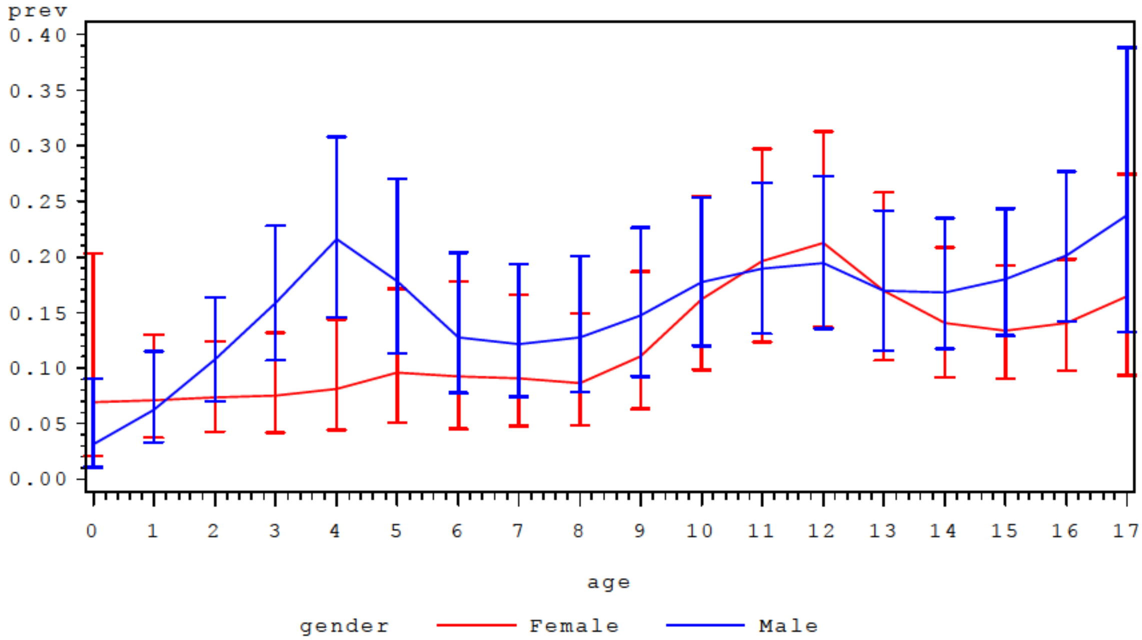


Figure 4. Smoothed asthma prevalence rates and confidence intervals
region=Northeast

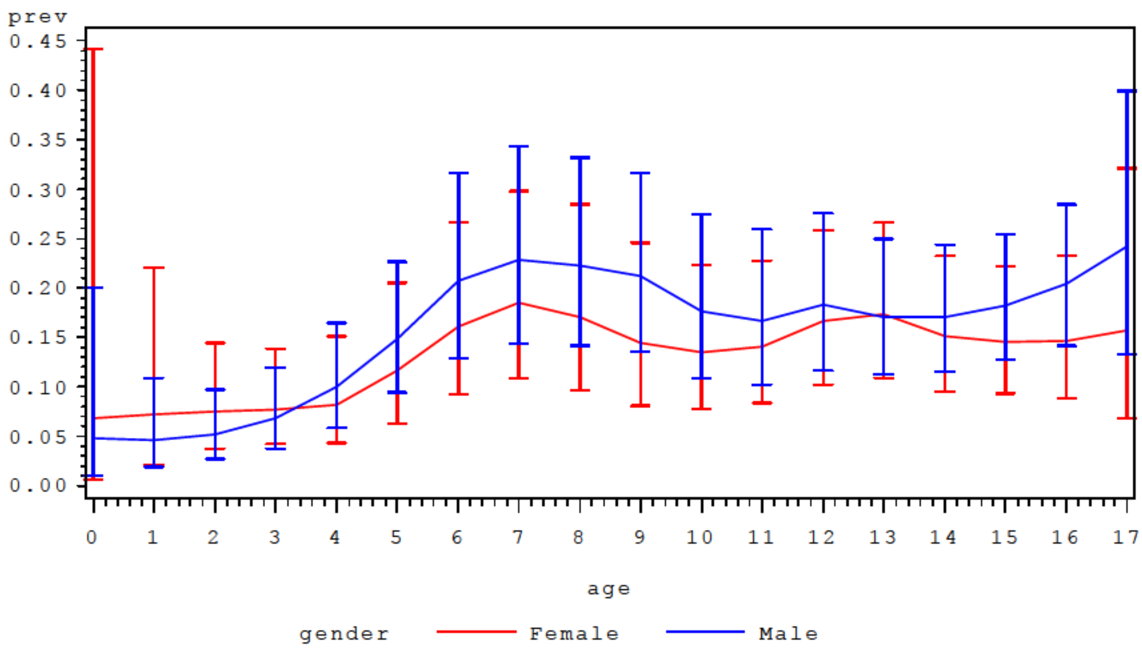


Figure 4. Smoothed asthma prevalence rates and confidence intervals
region=South

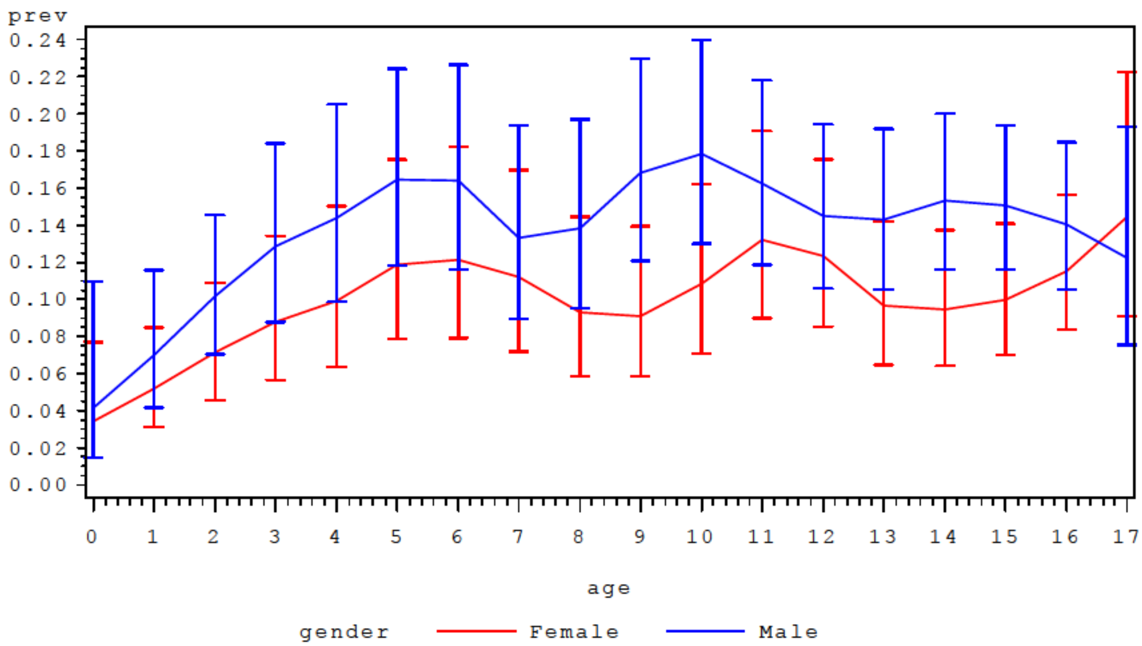


Figure 4. Smoothed asthma prevalence rates and confidence intervals
region=West

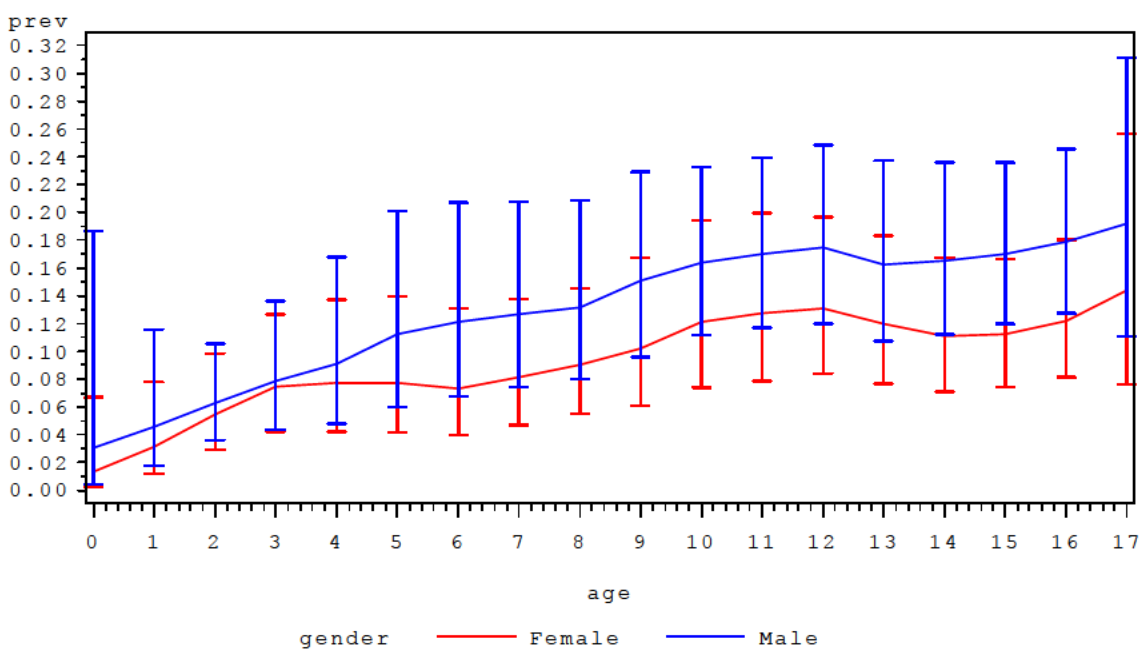


Table G-2. Raw and smoothed prevalence rates, with confidence intervals, by region, gender, and age.

Obs	Region	Gender	Age	Smoothed	Prevalence	Std Error	95 % Conf Interval – Lower Bound	95 % Conf Interval – Upper Bound
1	Midwest	Female	0	No	0.04161	0.02965	0.01001	0.15717
2	Midwest	Female	0	Yes	0.06956	0.03574	0.02143	0.20330
3	Midwest	Female	1	No	0.10790	0.04254	0.04840	0.22336
4	Midwest	Female	1	Yes	0.07078	0.01995	0.03736	0.13008
5	Midwest	Female	2	No	0.05469	0.02578	0.02131	0.13325
6	Midwest	Female	2	Yes	0.07324	0.01778	0.04228	0.12395
7	Midwest	Female	3	No	0.06094	0.03474	0.01936	0.17579
8	Midwest	Female	3	Yes	0.07542	0.01944	0.04205	0.13163
9	Midwest	Female	4	No	0.09049	0.03407	0.04233	0.18298
10	Midwest	Female	4	Yes	0.08100	0.02163	0.04417	0.14393
11	Midwest	Female	5	No	0.08463	0.03917	0.03317	0.19942
12	Midwest	Female	5	Yes	0.09540	0.02613	0.05106	0.17131
13	Midwest	Female	6	No	0.14869	0.08250	0.04643	0.38520
14	Midwest	Female	6	Yes	0.09210	0.02854	0.04534	0.17808
15	Midwest	Female	7	No	0.04757	0.02927	0.01389	0.15051
16	Midwest	Female	7	Yes	0.09032	0.02563	0.04728	0.16571
17	Midwest	Female	8	No	0.10444	0.03638	0.05160	0.19997
18	Midwest	Female	8	Yes	0.08612	0.02181	0.04842	0.14857
19	Midwest	Female	9	No	0.09836	0.04283	0.04062	0.21943
20	Midwest	Female	9	Yes	0.11040	0.02709	0.06298	0.18643
21	Midwest	Female	10	No	0.10916	0.04859	0.04400	0.24600
22	Midwest	Female	10	Yes	0.16190	0.03486	0.09838	0.25484
23	Midwest	Female	11	No	0.27341	0.06817	0.16112	0.42437
24	Midwest	Female	11	Yes	0.19597	0.03920	0.12296	0.29763
25	Midwest	Female	12	No	0.10055	0.04780	0.03816	0.23952
26	Midwest	Female	12	Yes	0.21214	0.03957	0.13724	0.31309
27	Midwest	Female	13	No	0.22388	0.05905	0.12907	0.35959

Obs	Region	Gender	Age	Smoothed	Prevalence	Std Error	95 % Conf Interval – Lower Bound	95 % Conf Interval – Upper Bound
28	Midwest	Female	13	Yes	0.16966	0.03371	0.10716	0.25807
29	Midwest	Female	14	No	0.10511	0.04233	0.04637	0.22104
30	Midwest	Female	14	Yes	0.14020	0.02603	0.09164	0.20857
31	Midwest	Female	15	No	0.12026	0.03805	0.06327	0.21670
32	Midwest	Female	15	Yes	0.13341	0.02266	0.09056	0.19226
33	Midwest	Female	16	No	0.13299	0.03933	0.07288	0.23037
34	Midwest	Female	16	Yes	0.14040	0.02235	0.09764	0.19777
35	Midwest	Female	17	No	0.17497	0.04786	0.09970	0.28884
36	Midwest	Female	17	Yes	0.16478	0.04037	0.09320	0.27468
37	Midwest	Male	0	No	0.06419	0.03612	0.02068	0.18227
38	Midwest	Male	0	Yes	0.03134	0.01537	0.01042	0.09046
39	Midwest	Male	1	No	0.02824	0.01694	0.00859	0.08879
40	Midwest	Male	1	Yes	0.06250	0.01751	0.03321	0.11457
41	Midwest	Male	2	No	0.05102	0.02343	0.02040	0.12189
42	Midwest	Male	2	Yes	0.10780	0.02078	0.06960	0.16328
43	Midwest	Male	3	No	0.18650	0.04864	0.10898	0.30057
44	Midwest	Male	3	Yes	0.15821	0.02705	0.10696	0.22775
45	Midwest	Male	4	No	0.24649	0.05823	0.15035	0.37686
46	Midwest	Male	4	Yes	0.21572	0.03661	0.14543	0.30774
47	Midwest	Male	5	No	0.11609	0.04818	0.04973	0.24793
48	Midwest	Male	5	Yes	0.17822	0.03525	0.11280	0.27003
49	Midwest	Male	6	No	0.14158	0.05280	0.06576	0.27873
50	Midwest	Male	6	Yes	0.12788	0.02799	0.07751	0.20375
51	Midwest	Male	7	No	0.09726	0.03614	0.04588	0.19448
52	Midwest	Male	7	Yes	0.12145	0.02642	0.07391	0.19317
53	Midwest	Male	8	No	0.16718	0.05814	0.08134	0.31276
54	Midwest	Male	8	Yes	0.12757	0.02700	0.07864	0.20031
55	Midwest	Male	9	No	0.13406	0.04783	0.06458	0.25769
56	Midwest	Male	9	Yes	0.14718	0.02976	0.09254	0.22603
57	Midwest	Male	10	No	0.13986	0.04422	0.07331	0.25050

Obs	Region	Gender	Age	Smoothed	Prevalence	Std Error	95 % Conf Interval – Lower Bound	95 % Conf Interval – Upper Bound
58	Midwest	Male	10	Yes	0.17728	0.02996	0.12020	0.25366
59	Midwest	Male	11	No	0.23907	0.05031	0.15449	0.35075
60	Midwest	Male	11	Yes	0.18961	0.03044	0.13100	0.26639
61	Midwest	Male	12	No	0.13660	0.04784	0.06668	0.25946
62	Midwest	Male	12	Yes	0.19487	0.03078	0.13541	0.27221
63	Midwest	Male	13	No	0.18501	0.04498	0.11230	0.28945
64	Midwest	Male	13	Yes	0.16939	0.02841	0.11528	0.24195
65	Midwest	Male	14	No	0.16673	0.05094	0.08886	0.29104
66	Midwest	Male	14	Yes	0.16795	0.02631	0.11734	0.23459
67	Midwest	Male	15	No	0.14583	0.04241	0.08054	0.24967
68	Midwest	Male	15	Yes	0.17953	0.02561	0.12951	0.24347
69	Midwest	Male	16	No	0.24965	0.06037	0.15033	0.38489
70	Midwest	Male	16	Yes	0.20116	0.03048	0.14187	0.27721
71	Midwest	Male	17	No	0.21152	0.06481	0.11131	0.36490
72	Midwest	Male	17	Yes	0.23741	0.05816	0.13243	0.38835
73	Northeast	Female	0	No	0.00000	0.00000	0.00000	0.00000
74	Northeast	Female	0	Yes	0.06807	0.06565	0.00670	0.44174
75	Northeast	Female	1	No	0.12262	0.07443	0.03476	0.35164
76	Northeast	Female	1	Yes	0.07219	0.03765	0.02088	0.22109
77	Northeast	Female	2	No	0.07217	0.03707	0.02561	0.18713
78	Northeast	Female	2	Yes	0.07522	0.02212	0.03764	0.14468
79	Northeast	Female	3	No	0.08550	0.03991	0.03324	0.20269
80	Northeast	Female	3	Yes	0.07709	0.02021	0.04162	0.13840
81	Northeast	Female	4	No	0.08704	0.03804	0.03596	0.19592
82	Northeast	Female	4	Yes	0.08171	0.02252	0.04269	0.15080
83	Northeast	Female	5	No	0.07597	0.03754	0.02801	0.18998
84	Northeast	Female	5	Yes	0.11603	0.03012	0.06258	0.20515
85	Northeast	Female	6	No	0.19149	0.06960	0.08937	0.36372
86	Northeast	Female	6	Yes	0.16106	0.03737	0.09219	0.26629
87	Northeast	Female	7	No	0.22034	0.07076	0.11195	0.38783

Obs	Region	Gender	Age	Smoothed	Prevalence	Std Error	95 % Conf Interval – Lower Bound	95 % Conf Interval – Upper Bound
88	Northeast	Female	7	Yes	0.18503	0.04087	0.10844	0.29764
89	Northeast	Female	8	No	0.11002	0.05128	0.04241	0.25654
90	Northeast	Female	8	Yes	0.17054	0.04039	0.09628	0.28407
91	Northeast	Female	9	No	0.17541	0.07488	0.07159	0.36981
92	Northeast	Female	9	Yes	0.14457	0.03538	0.08042	0.24618
93	Northeast	Female	10	No	0.12980	0.04964	0.05930	0.26087
94	Northeast	Female	10	Yes	0.13487	0.03098	0.07799	0.22319
95	Northeast	Female	11	No	0.15128	0.05287	0.07366	0.28547
96	Northeast	Female	11	Yes	0.14072	0.03068	0.08367	0.22704
97	Northeast	Female	12	No	0.11890	0.04426	0.05568	0.23597
98	Northeast	Female	12	Yes	0.16615	0.03375	0.10211	0.25877
99	Northeast	Female	13	No	0.22638	0.06285	0.12650	0.37158
100	Northeast	Female	13	Yes	0.17374	0.03402	0.10861	0.26626
101	Northeast	Female	14	No	0.15807	0.05513	0.07694	0.29719
102	Northeast	Female	14	Yes	0.15137	0.02946	0.09519	0.23220
103	Northeast	Female	15	No	0.07460	0.03409	0.02971	0.17506
104	Northeast	Female	15	Yes	0.14564	0.02761	0.09279	0.22127
105	Northeast	Female	16	No	0.13603	0.05328	0.06081	0.27686
106	Northeast	Female	16	Yes	0.14601	0.03095	0.08805	0.23241
107	Northeast	Female	17	No	0.19074	0.07382	0.08451	0.37568
108	Northeast	Female	17	Yes	0.15662	0.05374	0.06784	0.32151
109	Northeast	Male	0	No	0.03904	0.03829	0.00547	0.23095
110	Northeast	Male	0	Yes	0.04768	0.03299	0.00991	0.20023
111	Northeast	Male	1	No	0.05533	0.03425	0.01596	0.17461
112	Northeast	Male	1	Yes	0.04564	0.01831	0.01850	0.10821
113	Northeast	Male	2	No	0.05525	0.03119	0.01781	0.15872
114	Northeast	Male	2	Yes	0.05161	0.01505	0.02680	0.09709
115	Northeast	Male	3	No	0.03842	0.02923	0.00840	0.15853
116	Northeast	Male	3	Yes	0.06766	0.01784	0.03734	0.11955
117	Northeast	Male	4	No	0.07436	0.02906	0.03393	0.15522

Obs	Region	Gender	Age	Smoothed	Prevalence	Std Error	95 % Conf Interval – Lower Bound	95 % Conf Interval – Upper Bound
118	Northeast	Male	4	Yes	0.09964	0.02330	0.05859	0.16441
119	Northeast	Male	5	No	0.17601	0.04519	0.10393	0.28234
120	Northeast	Male	5	Yes	0.14854	0.02948	0.09428	0.22623
121	Northeast	Male	6	No	0.23271	0.09319	0.09832	0.45756
122	Northeast	Male	6	Yes	0.20731	0.04235	0.12875	0.31640
123	Northeast	Male	7	No	0.13074	0.05195	0.05785	0.26922
124	Northeast	Male	7	Yes	0.22820	0.04524	0.14338	0.34311
125	Northeast	Male	8	No	0.33970	0.08456	0.19726	0.51855
126	Northeast	Male	8	Yes	0.22240	0.04298	0.14157	0.33157
127	Northeast	Male	9	No	0.13761	0.05024	0.06507	0.26785
128	Northeast	Male	9	Yes	0.21238	0.04071	0.13589	0.31617
129	Northeast	Male	10	No	0.21785	0.06659	0.11464	0.37465
130	Northeast	Male	10	Yes	0.17652	0.03731	0.10824	0.27460
131	Northeast	Male	11	No	0.11448	0.05849	0.04005	0.28601
132	Northeast	Male	11	Yes	0.16617	0.03516	0.10200	0.25907
133	Northeast	Male	12	No	0.17736	0.05489	0.09349	0.31067
134	Northeast	Male	12	Yes	0.18279	0.03589	0.11611	0.27581
135	Northeast	Male	13	No	0.19837	0.05450	0.11222	0.32635
136	Northeast	Male	13	Yes	0.17078	0.03078	0.11288	0.25000
137	Northeast	Male	14	No	0.16201	0.04973	0.08618	0.28386
138	Northeast	Male	14	Yes	0.17033	0.02889	0.11547	0.24408
139	Northeast	Male	15	No	0.11894	0.04584	0.05417	0.24139
140	Northeast	Male	15	Yes	0.18246	0.02858	0.12740	0.25438
141	Northeast	Male	16	No	0.24306	0.05798	0.14759	0.37326
142	Northeast	Male	16	Yes	0.20406	0.03216	0.14187	0.28447
143	Northeast	Male	17	No	0.22559	0.06980	0.11748	0.38930
144	Northeast	Male	17	Yes	0.24185	0.06066	0.13291	0.39898
145	South	Female	0	No	0.02459	0.01116	0.01002	0.05906
146	South	Female	0	Yes	0.03407	0.01282	0.01465	0.07723
147	South	Female	1	No	0.08869	0.03373	0.04118	0.18067

Obs	Region	Gender	Age	Smoothed	Prevalence	Std Error	95 % Conf Interval – Lower Bound	95 % Conf Interval – Upper Bound
148	South	Female	1	Yes	0.05182	0.01167	0.03127	0.08472
149	South	Female	2	No	0.05097	0.02373	0.02012	0.12319
150	South	Female	2	Yes	0.07110	0.01386	0.04584	0.10869
151	South	Female	3	No	0.08717	0.03240	0.04122	0.17500
152	South	Female	3	Yes	0.08759	0.01718	0.05624	0.13394
153	South	Female	4	No	0.11010	0.03209	0.06113	0.19035
154	South	Female	4	Yes	0.09897	0.01914	0.06387	0.15025
155	South	Female	5	No	0.09409	0.02943	0.05015	0.16968
156	South	Female	5	Yes	0.11870	0.02157	0.07855	0.17548
157	South	Female	6	No	0.15318	0.04317	0.08611	0.25777
158	South	Female	6	Yes	0.12150	0.02282	0.07925	0.18182
159	South	Female	7	No	0.09608	0.03538	0.04565	0.19105
160	South	Female	7	Yes	0.11192	0.02171	0.07204	0.16985
161	South	Female	8	No	0.09955	0.03288	0.05111	0.18493
162	South	Female	8	Yes	0.09287	0.01897	0.05850	0.14436
163	South	Female	9	No	0.07477	0.02719	0.03606	0.14864
164	South	Female	9	Yes	0.09117	0.01786	0.05855	0.13929
165	South	Female	10	No	0.10602	0.03214	0.05750	0.18732
166	South	Female	10	Yes	0.10821	0.02026	0.07077	0.16201
167	South	Female	11	No	0.14411	0.04267	0.07875	0.24907
168	South	Female	11	Yes	0.13237	0.02251	0.08989	0.19071
169	South	Female	12	No	0.12646	0.02981	0.07860	0.19723
170	South	Female	12	Yes	0.12346	0.02004	0.08543	0.17519
171	South	Female	13	No	0.11376	0.03270	0.06365	0.19510
172	South	Female	13	Yes	0.09653	0.01717	0.06458	0.14190
173	South	Female	14	No	0.02915	0.01339	0.01174	0.07054
174	South	Female	14	Yes	0.09469	0.01619	0.06436	0.13721
175	South	Female	15	No	0.11985	0.03357	0.06801	0.20259
176	South	Female	15	Yes	0.09988	0.01586	0.06978	0.14099
177	South	Female	16	No	0.14183	0.03685	0.08366	0.23028

Obs	Region	Gender	Age	Smoothed	Prevalence	Std Error	95 % Conf Interval – Lower Bound	95 % Conf Interval – Upper Bound
178	South	Female	16	Yes	0.11501	0.01620	0.08365	0.15612
179	South	Female	17	No	0.13141	0.03007	0.08280	0.20226
180	South	Female	17	Yes	0.14466	0.02946	0.09067	0.22291
181	South	Male	0	No	0.01164	0.00852	0.00275	0.04790
182	South	Male	0	Yes	0.04132	0.01867	0.01487	0.10956
183	South	Male	1	No	0.10465	0.03216	0.05629	0.18635
184	South	Male	1	Yes	0.06981	0.01623	0.04125	0.11576
185	South	Male	2	No	0.11644	0.03486	0.06353	0.20382
186	South	Male	2	Yes	0.10189	0.01672	0.07024	0.14557
187	South	Male	3	No	0.10794	0.03253	0.05874	0.19005
188	South	Male	3	Yes	0.12852	0.02139	0.08793	0.18405
189	South	Male	4	No	0.08480	0.02973	0.04190	0.16410
190	South	Male	4	Yes	0.14393	0.02379	0.09861	0.20534
191	South	Male	5	No	0.22243	0.04227	0.15052	0.31592
192	South	Male	5	Yes	0.16450	0.02373	0.11821	0.22430
193	South	Male	6	No	0.13908	0.03392	0.08485	0.21964
194	South	Male	6	Yes	0.16386	0.02460	0.11613	0.22617
195	South	Male	7	No	0.10695	0.04272	0.04747	0.22347
196	South	Male	7	Yes	0.13329	0.02322	0.08951	0.19392
197	South	Male	8	No	0.13660	0.03841	0.07712	0.23049
198	South	Male	8	Yes	0.13818	0.02276	0.09484	0.19702
199	South	Male	9	No	0.15978	0.03742	0.09920	0.24720
200	South	Male	9	Yes	0.16839	0.02450	0.12062	0.23012
201	South	Male	10	No	0.21482	0.04702	0.13676	0.32086
202	South	Male	10	Yes	0.17848	0.02453	0.13021	0.23972
203	South	Male	11	No	0.15078	0.03440	0.09492	0.23112
204	South	Male	11	Yes	0.16247	0.02224	0.11881	0.21820
205	South	Male	12	No	0.13727	0.03260	0.08489	0.21438
206	South	Male	12	Yes	0.14480	0.01976	0.10610	0.19453
207	South	Male	13	No	0.14136	0.03119	0.09049	0.21409

Obs	Region	Gender	Age	Smoothed	Prevalence	Std Error	95 % Conf Interval – Lower Bound	95 % Conf Interval – Upper Bound
208	South	Male	13	Yes	0.14318	0.01928	0.10537	0.19165
209	South	Male	14	No	0.16110	0.03444	0.10438	0.24037
210	South	Male	14	Yes	0.15339	0.01875	0.11612	0.19992
211	South	Male	15	No	0.16172	0.03519	0.10394	0.24291
212	South	Male	15	Yes	0.15088	0.01746	0.11598	0.19398
213	South	Male	16	No	0.15836	0.03879	0.09614	0.24974
214	South	Male	16	Yes	0.14038	0.01773	0.10533	0.18467
215	South	Male	17	No	0.11156	0.02737	0.06810	0.17746
216	South	Male	17	Yes	0.12247	0.02596	0.07537	0.19286
217	West	Female	0	No	0.00983	0.00990	0.00135	0.06802
218	West	Female	0	Yes	0.01318	0.00987	0.00248	0.06700
219	West	Female	1	No	0.02367	0.01862	0.00497	0.10522
220	West	Female	1	Yes	0.03105	0.01312	0.01204	0.07769
221	West	Female	2	No	0.08097	0.03759	0.03170	0.19166
222	West	Female	2	Yes	0.05440	0.01482	0.02948	0.09825
223	West	Female	3	No	0.07528	0.03851	0.02679	0.19404
224	West	Female	3	Yes	0.07444	0.01842	0.04257	0.12701
225	West	Female	4	No	0.09263	0.03196	0.04621	0.17703
226	West	Female	4	Yes	0.07696	0.02064	0.04194	0.13701
227	West	Female	5	No	0.01976	0.01347	0.00513	0.07302
228	West	Female	5	Yes	0.07737	0.02123	0.04157	0.13949
229	West	Female	6	No	0.15792	0.07301	0.06009	0.35487
230	West	Female	6	Yes	0.07298	0.01985	0.03947	0.13107
231	West	Female	7	No	0.06955	0.02567	0.03321	0.13989
232	West	Female	7	Yes	0.08146	0.01987	0.04691	0.13776
233	West	Female	8	No	0.07753	0.02825	0.03731	0.15417
234	West	Female	8	Yes	0.09062	0.01994	0.05507	0.14558
235	West	Female	9	No	0.13440	0.04481	0.06802	0.24832
236	West	Female	9	Yes	0.10215	0.02347	0.06061	0.16709
237	West	Female	10	No	0.06573	0.03719	0.02102	0.18736

Obs	Region	Gender	Age	Smoothed	Prevalence	Std Error	95 % Conf Interval – Lower Bound	95 % Conf Interval – Upper Bound
238	West	Female	10	Yes	0.12152	0.02660	0.07376	0.19374
239	West	Female	11	No	0.15354	0.04584	0.08329	0.26584
240	West	Female	11	Yes	0.12719	0.02688	0.07852	0.19950
241	West	Female	12	No	0.10120	0.03594	0.04934	0.19631
242	West	Female	12	Yes	0.13054	0.02498	0.08440	0.19650
243	West	Female	13	No	0.14759	0.04125	0.08346	0.24769
244	West	Female	13	Yes	0.11968	0.02369	0.07629	0.18284
245	West	Female	14	No	0.08748	0.03284	0.04105	0.17675
246	West	Female	14	Yes	0.11063	0.02132	0.07145	0.16744
247	West	Female	15	No	0.10099	0.03841	0.04674	0.20471
248	West	Female	15	Yes	0.11236	0.02051	0.07428	0.16645
249	West	Female	16	No	0.12538	0.04343	0.06188	0.23755
250	West	Female	16	Yes	0.12224	0.02210	0.08108	0.18021
251	West	Female	17	No	0.14672	0.04582	0.07743	0.26052
252	West	Female	17	Yes	0.14371	0.03992	0.07558	0.25621
253	West	Male	0	No	0.00000	0.00000	0.00000	0.00000
254	West	Male	0	Yes	0.03075	0.02534	0.00437	0.18642
255	West	Male	1	No	0.05457	0.02662	0.02056	0.13695
256	West	Male	1	Yes	0.04584	0.01889	0.01729	0.11595
257	West	Male	2	No	0.07833	0.02789	0.03833	0.15342
258	West	Male	2	Yes	0.06254	0.01442	0.03627	0.10573
259	West	Male	3	No	0.05897	0.02530	0.02500	0.13281
260	West	Male	3	Yes	0.07844	0.01913	0.04398	0.13607
261	West	Male	4	No	0.07267	0.03354	0.02870	0.17208
262	West	Male	4	Yes	0.09122	0.02482	0.04765	0.16763
263	West	Male	5	No	0.19732	0.10033	0.06632	0.45969
264	West	Male	5	Yes	0.11262	0.02937	0.06021	0.20092
265	West	Male	6	No	0.13335	0.04859	0.06322	0.25970
266	West	Male	6	Yes	0.12119	0.02916	0.06799	0.20680
267	West	Male	7	No	0.08881	0.03493	0.04015	0.18508

Obs	Region	Gender	Age	Smoothed	Prevalence	Std Error	95 % Conf Interval – Lower Bound	95 % Conf Interval – Upper Bound
268	West	Male	7	Yes	0.12691	0.02806	0.07464	0.20758
269	West	Male	8	No	0.15183	0.05484	0.07210	0.29200
270	West	Male	8	Yes	0.13161	0.02705	0.08037	0.20811
271	West	Male	9	No	0.17199	0.05164	0.09260	0.29715
272	West	Male	9	Yes	0.15079	0.02837	0.09590	0.22915
273	West	Male	10	No	0.12897	0.03747	0.07151	0.22159
274	West	Male	10	Yes	0.16356	0.02584	0.11192	0.23279
275	West	Male	11	No	0.19469	0.04002	0.12785	0.28505
276	West	Male	11	Yes	0.16965	0.02623	0.11699	0.23956
277	West	Male	12	No	0.13214	0.04542	0.06547	0.24865
278	West	Male	12	Yes	0.17494	0.02738	0.12002	0.24792
279	West	Male	13	No	0.19947	0.04814	0.12127	0.31029
280	West	Male	13	Yes	0.16217	0.02773	0.10747	0.23732
281	West	Male	14	No	0.10759	0.03838	0.05220	0.20880
282	West	Male	14	Yes	0.16487	0.02644	0.11214	0.23582
283	West	Male	15	No	0.18459	0.05348	0.10138	0.31235
284	West	Male	15	Yes	0.17018	0.02480	0.11996	0.23578
285	West	Male	16	No	0.19757	0.04862	0.11892	0.30993
286	West	Male	16	Yes	0.17888	0.02540	0.12718	0.24569
287	West	Male	17	No	0.18078	0.04735	0.10548	0.29227
288	West	Male	17	Yes	0.19218	0.04291	0.11118	0.31153

ATTACHMENT 3. TECHNICAL MEMORANDUM ON ESTIMATING PHYSIOLOGICAL PARAMETERS FOR THE EXPOSURE MODEL

TECHNICAL MEMORANDUM

TO: Tom McCurdy, WA-COR, NERL WA 10
FROM: Kristin Isaacs and Luther Smith, Alion Science and Technology
DATE: December 20, 2005
SUBJECT: **New Values for Physiological Parameters for the Exposure Model Input File Physiology.txt.**

Table of Contents

LIST OF FIGURES

1. INTRODUCTION

The purpose of this memo is to present an updated version of the physiological parameters input file (Physiology.txt) for the APEX model. Portions of this file are also used as input for SHEDS-PM and SHEDS-AirToxics.

The physiology file contains age- and gender-based information for several physiological parameters used in human exposure modeling. This information includes distributional shapes and parameters for all age and gender cohorts from age 0 to 100 years for normalized maximal oxygen uptake (nvo2max), body mass, resting metabolic rate (RMR), and blood hemoglobin content. In addition, a parameter called blood volume factor (BVF), which is a cohort-dependent parameter in the equation for blood volume as a function of body mass, is present in the file as well.

New age- and gender-dependent distributions were developed based the best available physiological data from the literature. In this report, a summary of the current state of the physiology file is presented, followed by the derivation of new physiological data for body mass, normalized vo2max, and hemoglobin content. Portions of the SAS code used for analysis are included (Appendices A-C), as is the new Physiology.txt file (Appendix D). The final appendix (Appendix E) contains tables of all the derived physiological parameters.

2. EVALUATION OF THE CURRENT PHYSIOLOGY FILE DATA

The physiology.txt file was originally generated for the PNEM model by T. Johnson. It was last updated 6/11/1998, as documented in the report *User's Guide: Software for Estimating Ventilation (Respiration) Rates for Use in Dosimetry Models*, (T. Johnson and J. Capel). In that report, the original references for the data in the file were provided. An evaluation of the data in the file was included in a previous memo to the WA-COR under this work assignment. A summary of those findings is repeated here.

2.1 Normalized Maximal Oxygen Uptake (nvo2max).

The nvo2max data were derived from a number of sources. The data for males, especially, were pieced together from a variety of studies (a total of 6), leading to discontinuities in the distributional parameters. However, in each age and gender cohort, the distributions parameters were derived from a single published study. Additionally, much of the nvo2max data is quite old. The data for males at age 20 and at 28-69 came from a study from 1960 [1]. Data for males aged 0-8 and 16-19, and females 0-19 came from a figure in a textbook from 1977 [2], which in turn was based on limited earlier data. An additional issue with the 1977 data is (according to the report mentioned above) that values for certain ages (very young or elderly) were acquired by simple tangential extrapolation of the data in the figure.

In addition, in some cases it was not clear how the parameters were derived from the referenced studies. For example, Heil et al. [3] was referenced as the source of the values for females aged 66-100. However, an examination of that study provided no clues as to how the values were actually determined. As far as can be determined, in no place did the authors break down the means and SDs of their data into groups separated by both gender and age simultaneously.

2.2 Body Mass.

The current body mass data were derived from an in-depth analysis [4, 5] of the second CDC National Health and Nutrition Examination Survey (NHANES II) body mass data [6]. The data were relatively comprehensive, and the methods used to generate the lognormal distributions were sound. However, the NHANES II data were compiled for the years 1976-1980, so an analysis of more recent data is necessary to accurately account for changes in human activity patterns in adults and especially children.

2.3 Resting Metabolic Rate.

Not included for evaluation, per discussion with WA-COR.

2.4 Hemoglobin Content and Blood Volume Factor.

The original references for the hemoglobin content or blood volume factor values given in the current physiology.txt file could not be identified. Therefore, their validity could not be evaluated and it was desirable that new statistics be calculated.

2.5 Summary of Findings

- In some cases, especially for nvo2max, the data are unnecessarily and confusingly disjointed across ages.
- It is also unclear how some of the nvo2max values were derived from the referenced studies.
- With the exception of the Schofield equations for the BM/RMR regression, parameter distributions at each age and gender cohort were derived from data from a single study.
- Many of the studies used are very old (ex. 1960, 1977).
- Some the data is of questionable validity (for example, the extrapolation of a textbook figure is used), although it may have been the best available at the time of the compilation of the file.
- The original source of the hemoglobin content and blood volume factor data could not be identified.

- Given these conclusions, we recommended a full review and update of the current physiology.txt file data. Specifically, we recommended that where possible, new distributions or equations should be developed based on thorough, compiled data from appropriate studies.

3. DERIVATION OF NEW DISTRIBUTIONS FOR BODY MASS

3.1 The NHANES Body Mass Dataset.

New body mass distributions were generated from data from the National Health and Nutrition Examination Survey (NHANES). This survey is an ongoing study carried out by the National Center for Health Statistics of the Centers for Disease Control. EPA recognizes the utility of this dataset in characterizing the American population for risk assessment and policy support purposes [7].

Older NHANES data (for the years 1976-1980) have been used previously to develop population estimates of body mass distributions [4,5]. The current Physiology.txt file body mass distributions are based on this work. However, the analysis presented here is based on the most recent NHANES data, for the years 1999-2004 [8].

Demographic (Demo) and Body Measurement (BMX) datasets for each of the NHANES studies were downloaded from the NHANES website. The files were downloaded as SAS xpt datasets. The downloaded files were as follows:

1999-2000	**2001-2002**	**2003-2004**
BMX.xpt	BMX b r.xpt	BMX c.xpt
Demo.xpt	Demo_b.xpt	Demo_c.xpt

The Demographic datasets contained the age and gender values for each survey participant, while the Body Measurement datasets contained the body weights for each subject. The combined dataset comprised 31,126 individuals. This resulted in approximately 400-500 persons in each age 0-18 year cohort, and approximately 80-150 persons in each age 19-85 year cohort (the NHANES studies more heavily sampled children).

3.2 Calculation of the New Sampling Weights for the Combined NHANES Dataset.

In the analysis of the NHANES data, sampling weights must be used to ensure that the data are weighted to appropriately represent the national population. Sampling weights for the combined NHANES body mass dataset were derived as recommended by the documentation provided with the most recent NHANES release [9]. Specifically, the sampling weight for each subject was calculated as:

$$w_{combined} = \frac{1}{3} w_{2003-2004} \qquad (1)$$

$$w_{combined} = \frac{2}{3} w_{1999-2002} \qquad (2)$$

where $w_{combined}$ is the sampling weight for the combined dataset, $w_{2003\text{-}2004}$ is the weight for the subjects in the most recent study, and $w_{1999\text{-}2002}$ is the weight for subjects in combined 4-year (1999-2000 and 2001-2002) NHANES dataset. (Both weights are provided with the appropriate NHANES release. The combined 1999-2002 weight, which is not a simply half of that for the corresponding 2-year periods, was explicitly calculated for researcher use by CDC since the two 2-year periods use different census data.)

By using the sampling weights, once can consider any 2-year NHANES dataset or any combination of datasets as a nationally representative sample.

3.3 Fitting the Body Mass Data.

In the current physiology file, body mass is modeled as a two-parameter lognormal distribution. The NHANES body mass data were fit to several types of distributions (including normal, beta, and three-parameter lognormal distributions). It was determined that overall, the distribution that provided the best combination of good behavior over ages and good fit to the data was a two-parameter lognormal distribution.

The data were fit to the lognormal distributions using the SAS PROC UNIVARIATE procedure. The FREQ option of the procedure was used to apply the sampling weights. The SAS code used to generate the body mass distributions is provided in Appendix A.

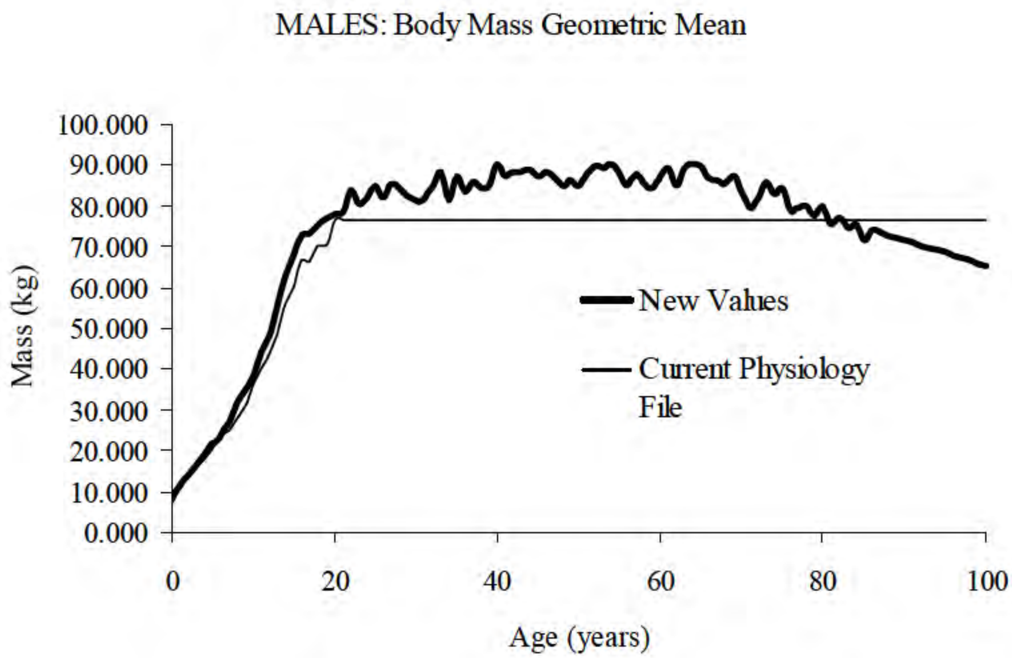
As the NHANES 1999-2003 studies only covered persons up to age 85, linear forecasts were made for ages 86-100, as based on the data for ages 60 and greater.

3.4 Body Mass Results.

Geometric means and standard deviations (SD) for the best-fit lognormal distributions for body mass are given in Figures 1 and 2. The means behaved fairly smoothly across ages. Note that for children age 0-18, the values of the new fits are similar, but slightly higher than those in the current Physiology.txt file, which were derived from earlier NHANES studies. The new means also capture the trend towards decreasing body weight in older persons that was previously neglected in the Physiology.txt file.

The maximum and minimum values for the distributions are presented in Figures 3 and 4. The minimums and maximums were calculated as the 1st and 99th percentile of the raw body mass data for the cohort. (Note that these values differ from the 1st and 99th percentiles of the fitted lognormals.) While the minimum value is consistent with the current Physiology.txt (which was based on earlier NHANES studies), the new cohort maximums are generally higher than before.

The behavior of several of the body mass parameters (especially the SD) is fairly noisy, especially for adults. This is most likely due to the smaller number of samples for adults as compared to children. Therefore, it may desirable to use age-grouped data or running averages over years in these age ranges. While the attached prepared Physiology.txt file uses the “raw” parameters, smoothed results using 5-year running averages are provided in the attached data tables (Appendix E, plots not shown). These could be used at the direction of EPA; changing the “official” release Physiology.txt file would be trivial.



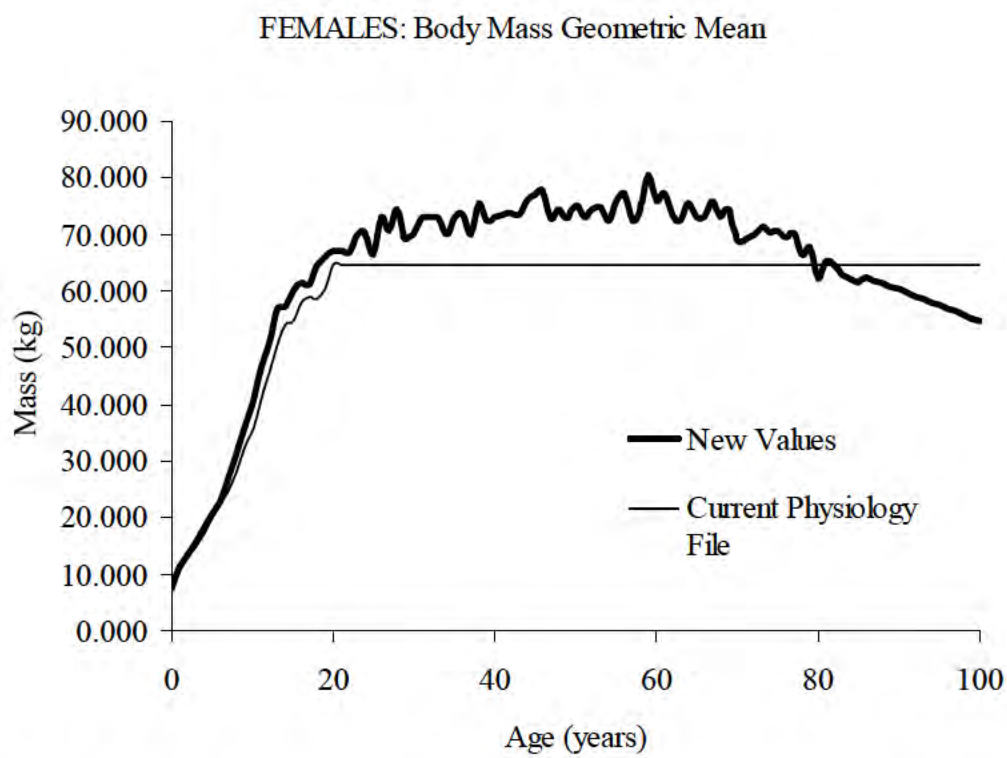
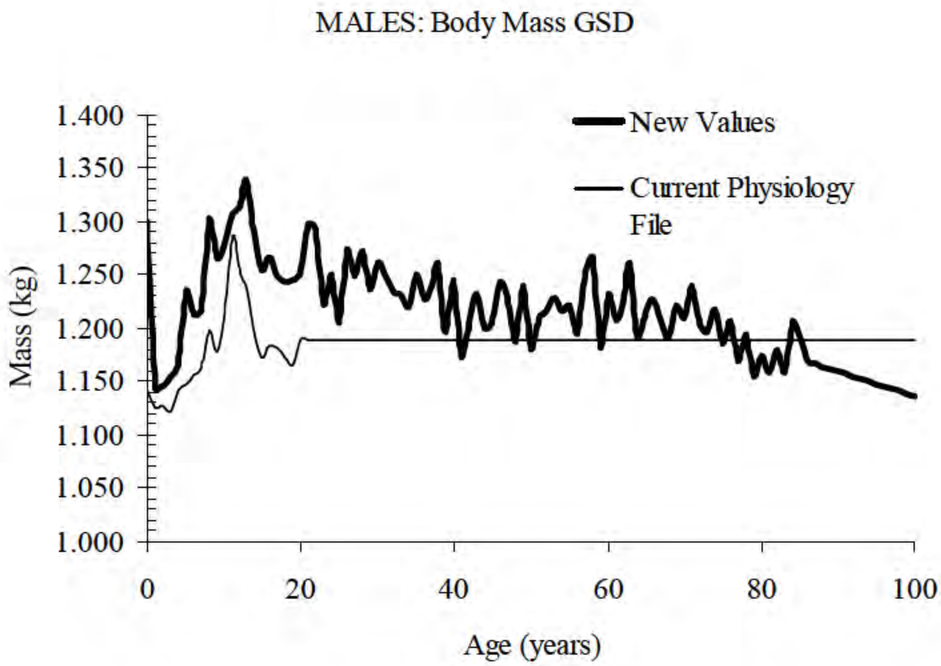


Figure 8. Geometric Means for the Best-fit Lognormal Distributions for Body Mass as a Function of Age, Derived from NHANES 1999-2004 Study Data.



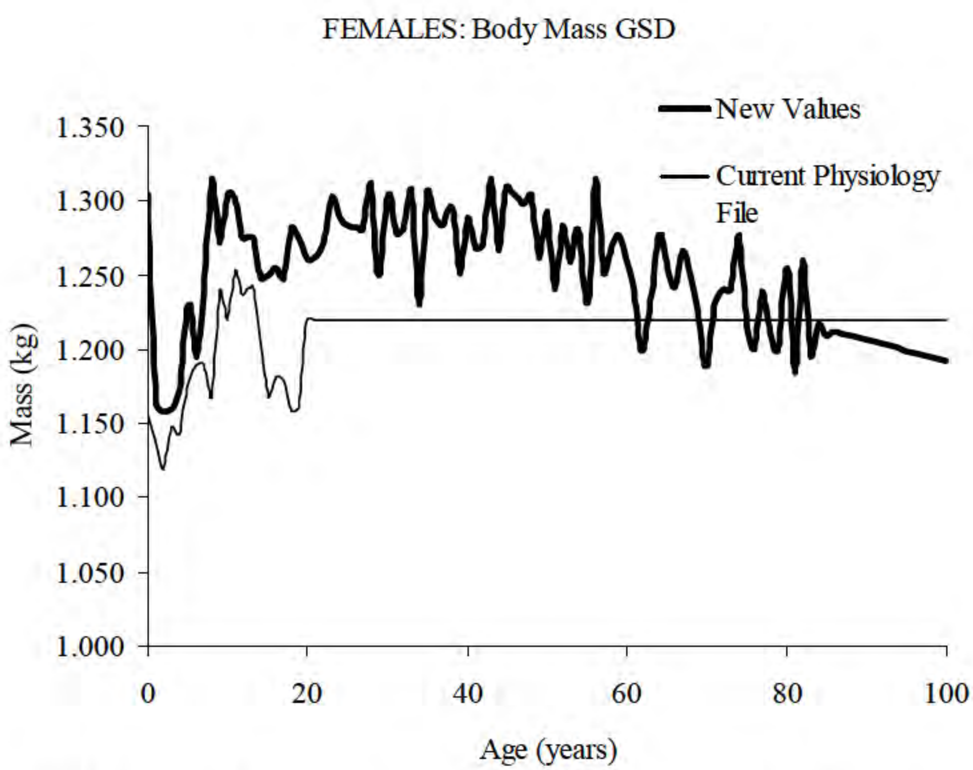
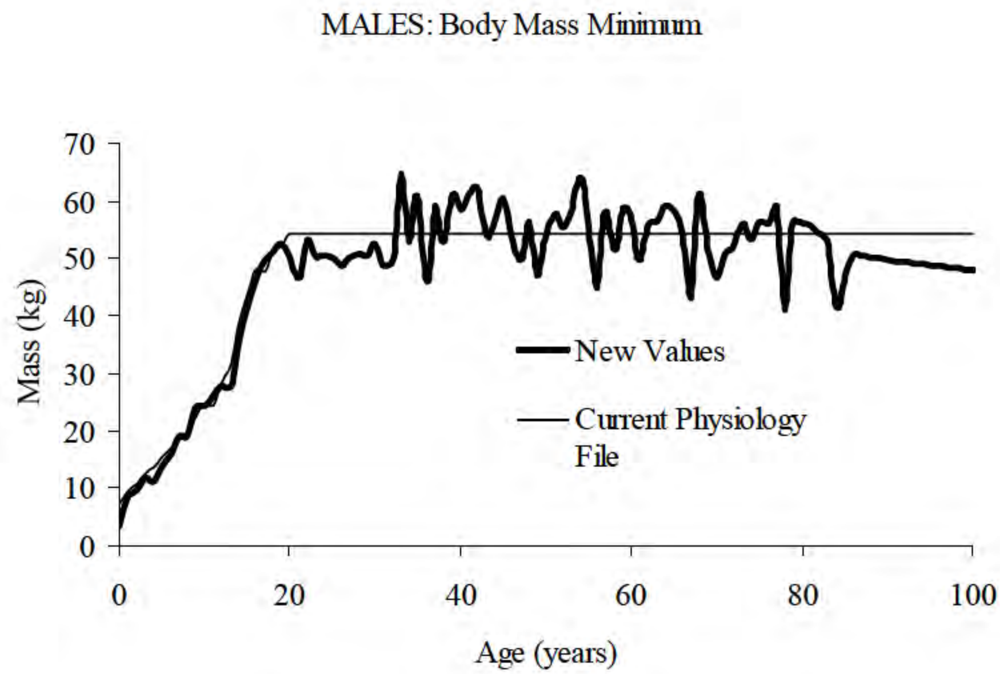


Figure 9. Geometric Standard Deviations for the Best-fit Lognormal Distributions for Body Mass as a Function of Age, Derived from NHANES 1999-2004 Study Data.



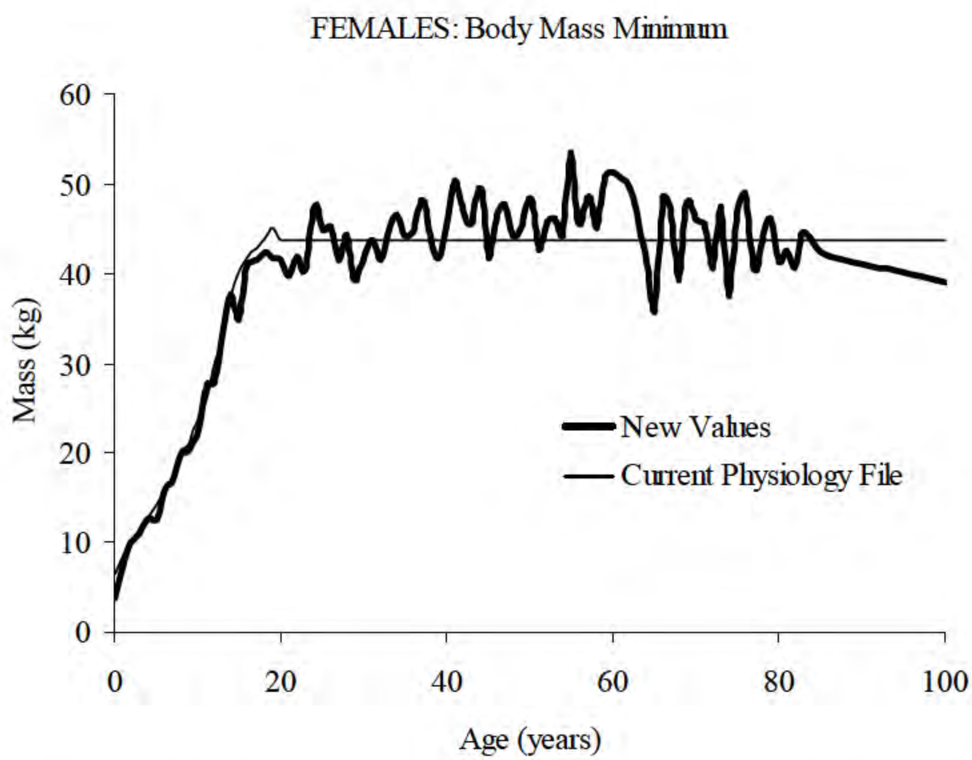
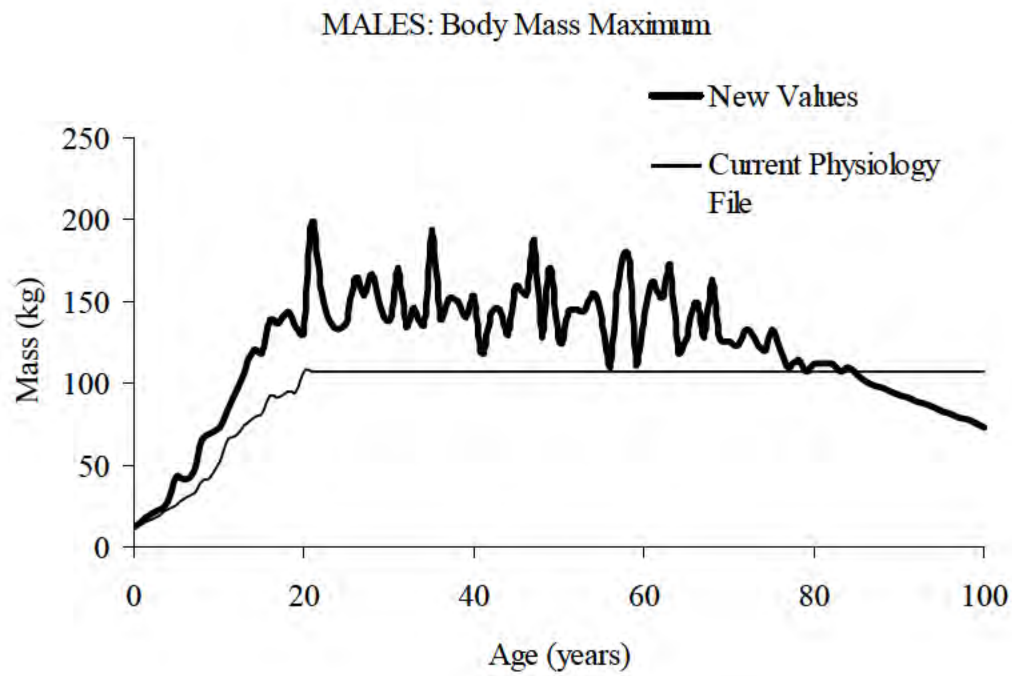


Figure 10. Minimums (1st Percentile) for Body Mass as a Function of Age, Derived from NHANES 1999-2004 Study Data.



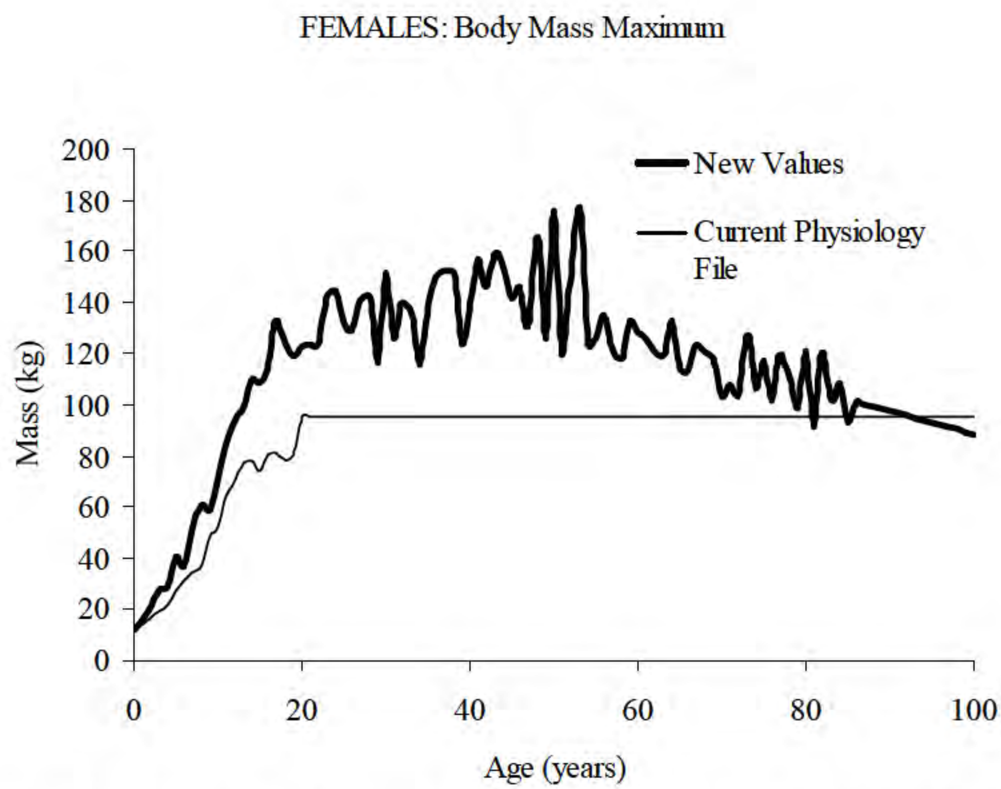


Figure 11. Maximums (99th Percentile) for Body Mass as a Function of Age, Derived from NHANES 1999-2004 Study Data.

4. DERIVATION OF NEW DISTRIBUTIONS FOR NORMALIZED VO2MAX

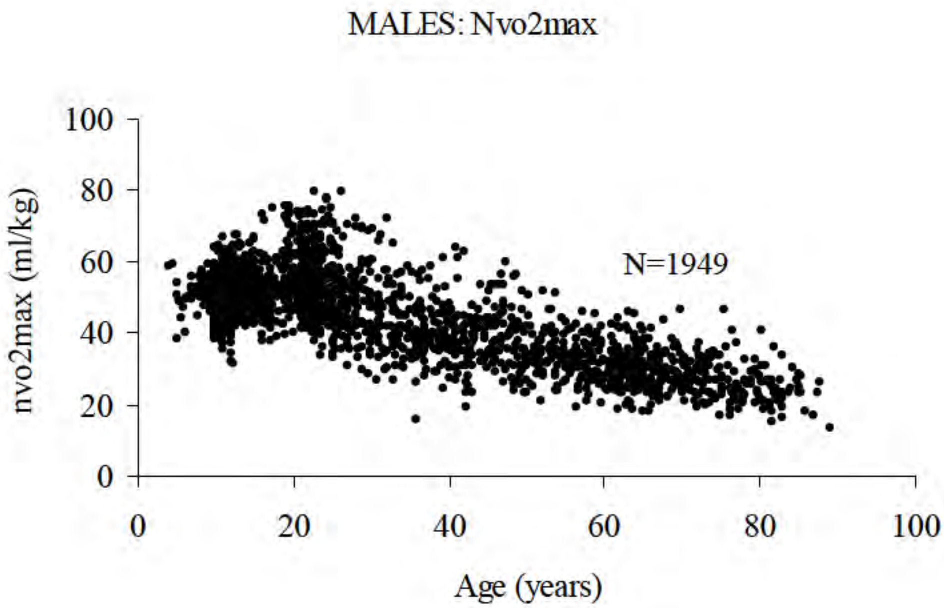
4.1 The Nvo2max Data

The NHANES studies do report data for vo2max in individuals. However, the NHANES vo2max values are estimated values, i.e. they are not measured directly. Such estimated values are not appropriate for use in this context (as per discussion with the WA-COR). Therefore, nvo2max distributional shapes were determined from a large database of experimental and literature vo2max measurements for different age/gender cohorts.

A PubMed-based literature search located a number of studies in which vo2max was directly measured. In addition, a large number of scientific papers (~350) reporting vo2max were also provided to Alion by the WA-COR. All the studies were evaluated for use by determining if: 1) any normalized vo2max data for individuals were reported or 2) any group means for narrow age-gender cohorts were reported. Studies in which the studied age group was very broad or contained both males and females were discarded. Also discarded were any studies in which vo2max was not normalized by body mass, or for which no age data were reported. Data for ill or highly-trained individuals were not used; however, studies in which subjects underwent mild or moderate exercise training were included. Two large databases, one of individual vo2max data and one of grouped means and SDs, were constructed from the valid studies.

The database of individual data comprised age versus nvo2max data for 1949 men and 1558 women. The data were pulled from either tables or graphs in 20 published studies [11-30]. Additional raw experimental data were provided by the WA-COR [31]. In the case of the graphical data, the original source was digitized and the data points were pulled from the digital figure using graphics software. (This was accomplished by calibrating the pixels of the digitized image with the range of age and nvo2max values.) The individual nvo2max data for males and females are shown in Figure 5.

The grouped mean and SD data were derived from 136 studies [32-167]. These data comprised approximately 550 means and SDs for different age/gender cohorts. Single age/gender cohort means and SD values for the Adams data [31] were also included in this dataset. Only data for subject groups having an age SD of less than approximately 2-3 years were considered. The grouped mean values for men and women are shown in Figure 6, while the group SD values are shown in Figure 7.



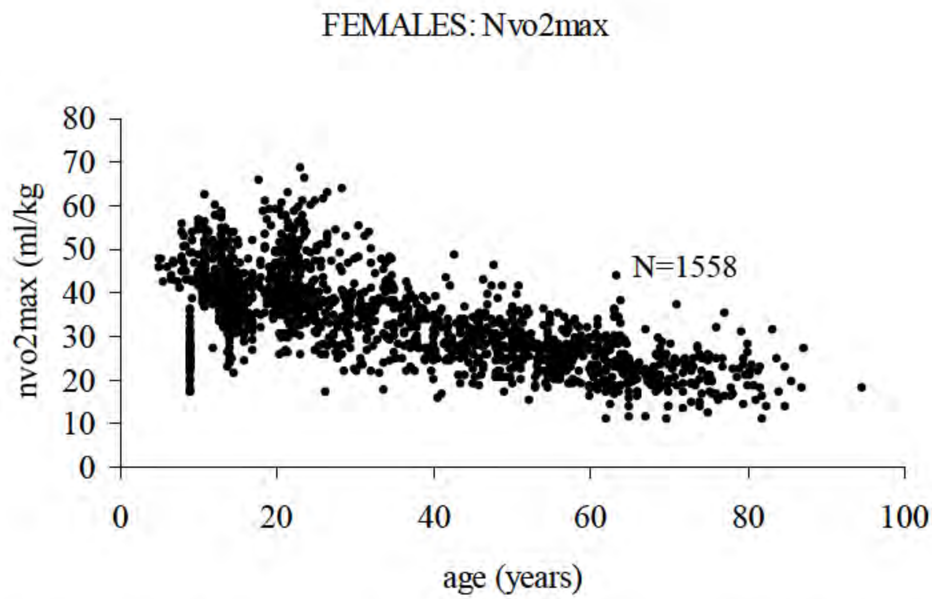
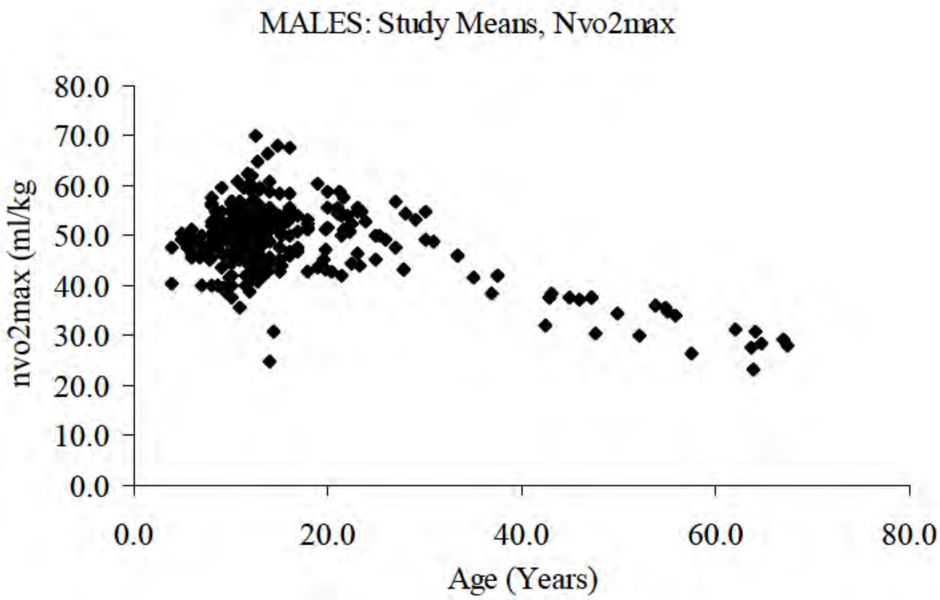


Figure 12. Individual Nvo2max Measurements for Males and Females, Derived from Literature Studies and Experimental Measurements.



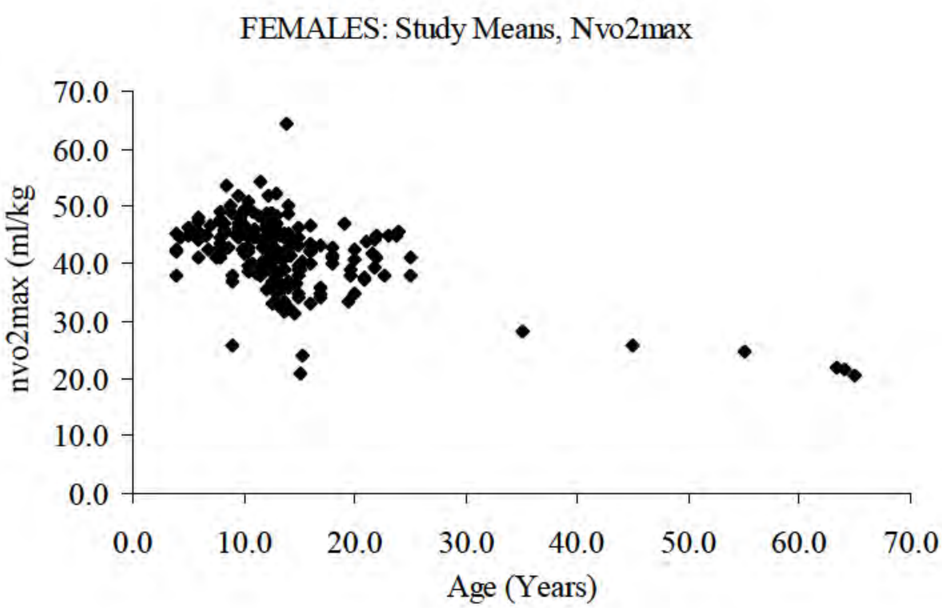
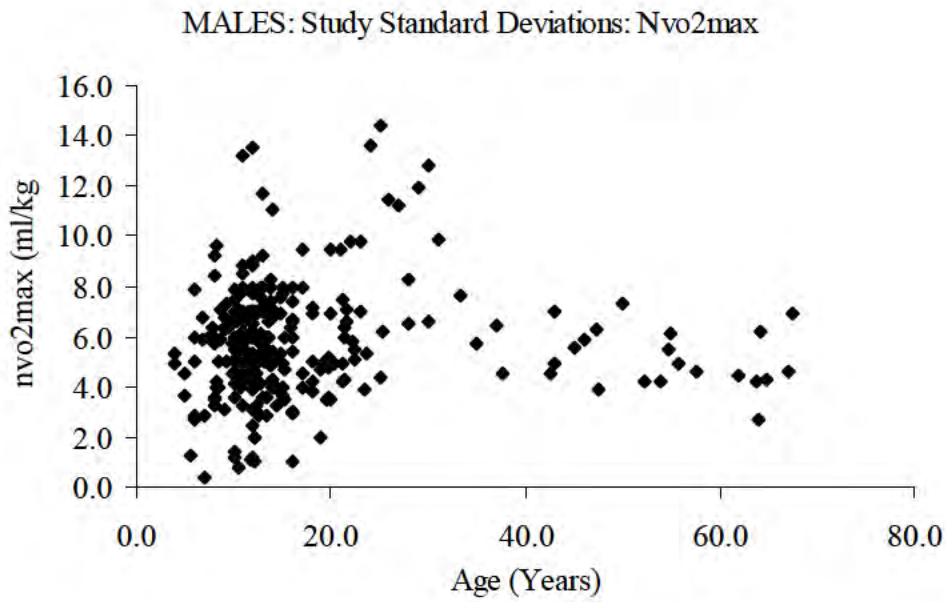


Figure 13. Grouped Mean Nvo2max Measurements for Males and Females, Derived from Literature Studies.



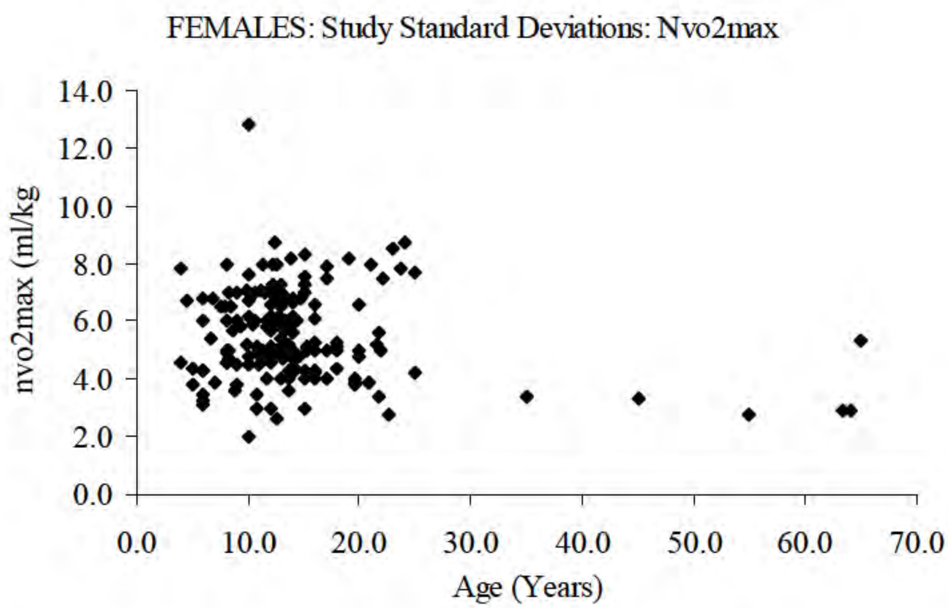


Figure 14. Nvo2max Standard Deviations for Males and Females, Derived from Literature Studies.

4.2 Determining the NVo2max Distributions

Both the grouped mean and the individual datasets were evaluated for use in deriving the nvo2max parameters.

The group means and SD were combined into single age/gender cohort values. The combined means were calculated as mean of the group means, weighted by the number of subjects. The group SD were calculated by transforming each group SD to a group variance, calculating the mean variance (weighted by the number of subjects in each study) and retransforming the variances to SDs. The combined group means and SDs are given in Figures 8 and 9.

The combined group means were fairly well-behaved across age and gender cohorts (see Figure 8), while the SD data (Figure 9) were noisier. These data may be appropriate for use in the Physiology.txt file; however, it was noted that the group mean data, while plentiful for children, were not very well represented in the adult (30+ years) age range (especially for women). This is mainly due to the fact that very few investigators use narrow age cohorts when studying adults, rather, it was far more common for broader age groups to be used. These data were not included in the grouped mean analysis, as the mean nvo2max for a broad age group cannot be assumed valid for the cohort represented by the study age mean. Therefore, we opted to use the database of individual nvo2max measurements to develop new distributions for the Physiology.txt file.

The individual nvo2max data were fit to several types of distributions (including normal, beta, and lognormal distributions). It was determined that the normal distribution fit the data best. The parameters (means and standard deviations) of the best-fit distributions were obtained using the SAS PROC UNIVARIATE procedure. The SAS code used to fit the data is given in Appendix B.

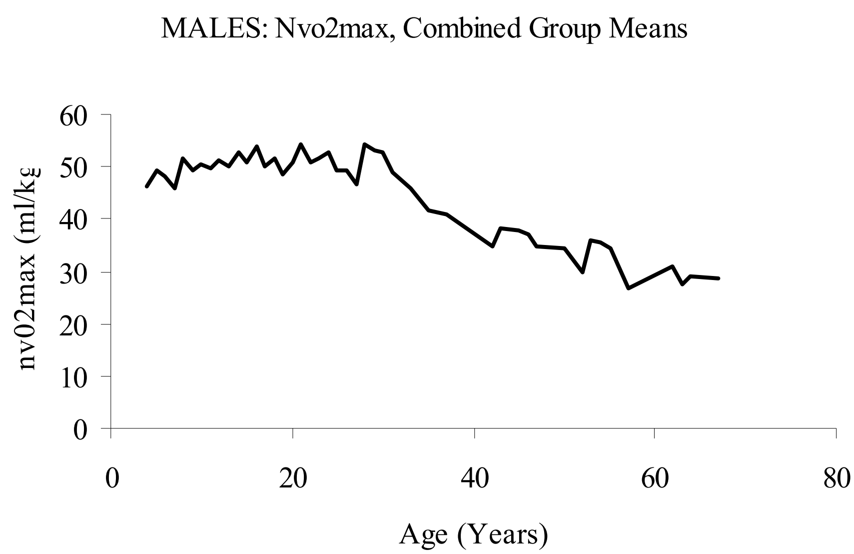
Both raw and smoothed nvo2max fits were calculated. Calculating 5-year running averages did not smooth the data considerably. Therefore, the smoothed fits were determined by choosing a best-fit functional form for the nv02max data. The data were fit to functions as follows:

Mean (Age 0-20): Linear function
Mean (Age 21-100): Parabolic function
SD (Age 0-26): Linear function
SD (Age 27-100): Parabolic function

Fitting the data in this manner also allowed for all age/gender cohorts to be represented. Since only cohorts having N>10 were fit to distributions, there were some cohorts for which no parameters were calculated. The raw and smoothed fits for means are given in Figure 10; analogous data for SD is given in Figure 11. The raw nvo2max parameters were not as clean across ages as the body mass data (probably due to the much smaller sample size), and thus the smoothed fits were selected for use in the attached Physiology.txt file. As with body mass, the raw fits may be used at the direction of EPA.

The results for the nvo2max means were in fact quite close to those in the current file. However, the values exhibited much more consistent behavior across ages, and the values for elderly persons were lower than previously. The SD values were also in the same range as the current values, yet they no longer demonstrate nonsensical discontinuities across ages.

The minimum and maximum nvo2max values were assumed to be the 1st and 99th percentile of the best-fit lognormal distribution. (**Note**: this is different from the method used for estimating the body mass limits. In that case, the samples were large enough that the percentiles of the raw data were appropriate for use as minimum and maximum. As the nvo2max data cohorts had much smaller N than the NHANES studies, the raw percentiles were less appropriate.) The maximum and minimum values are shown in Figures 12 and 13.



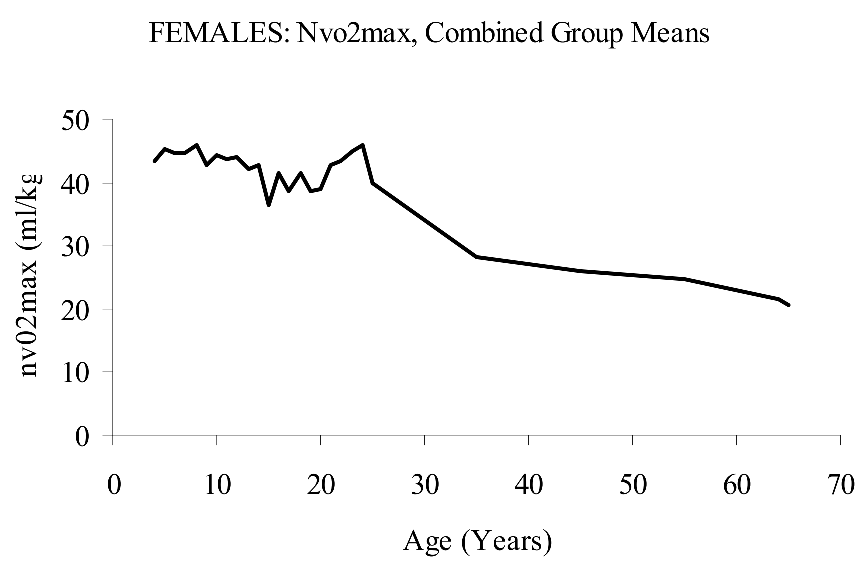
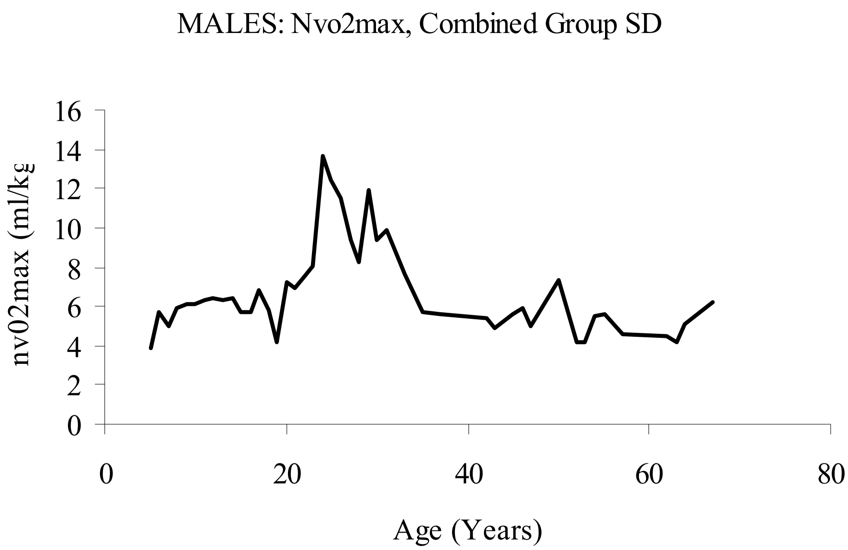


Figure 15. Combined Nvo2max Group Means for Males and Females



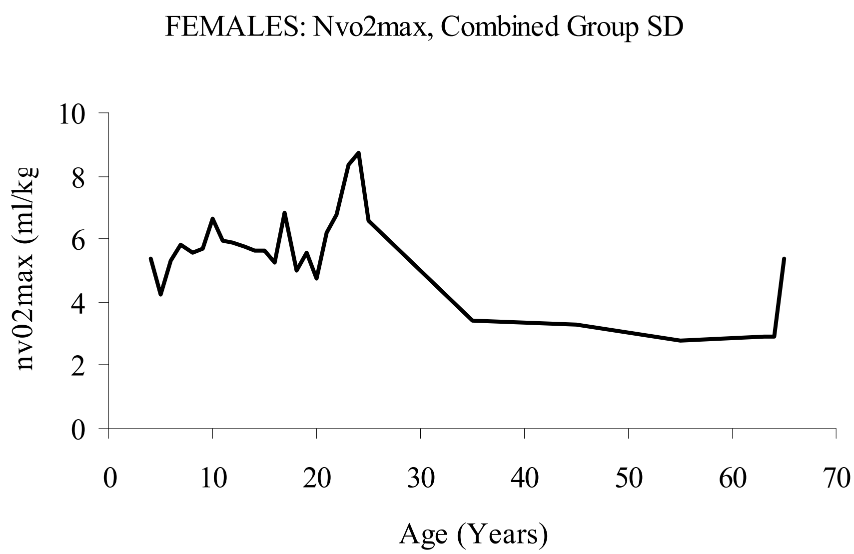


Figure 16. Combined Nvo2max Group Standard Deviations.

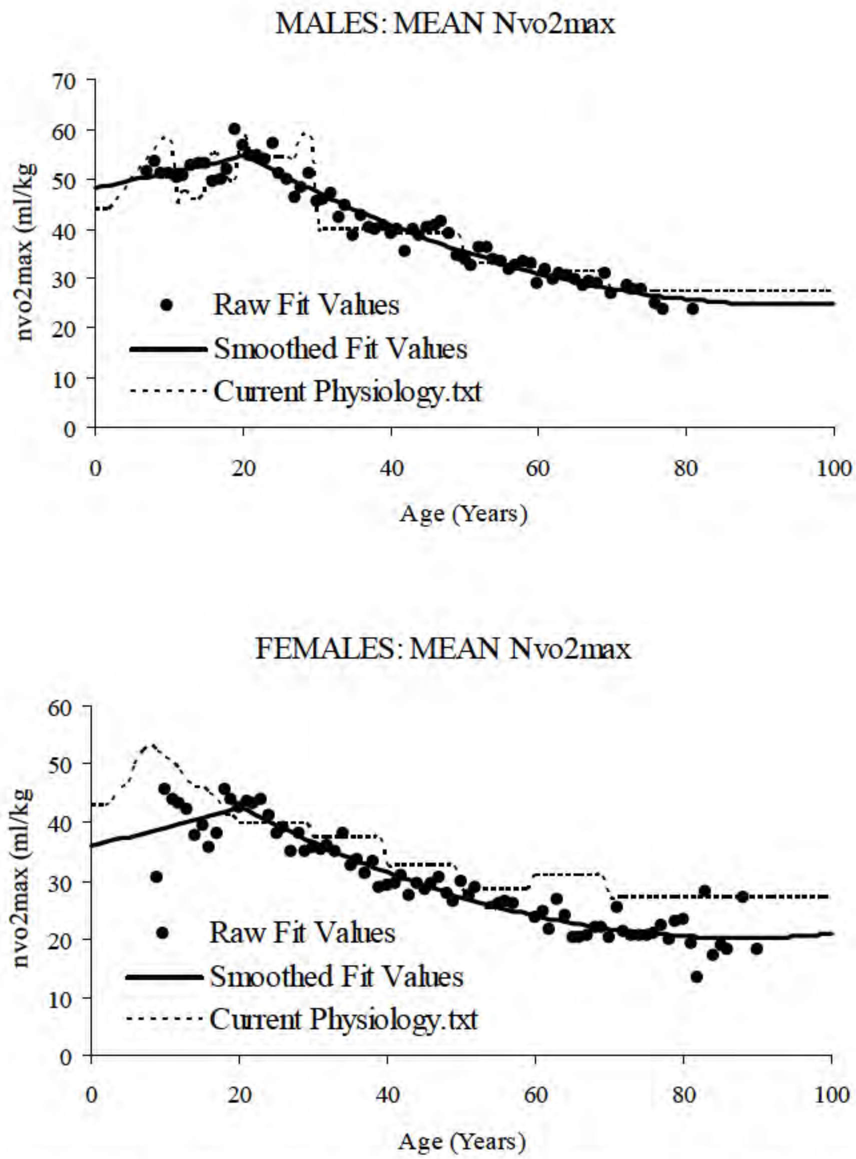
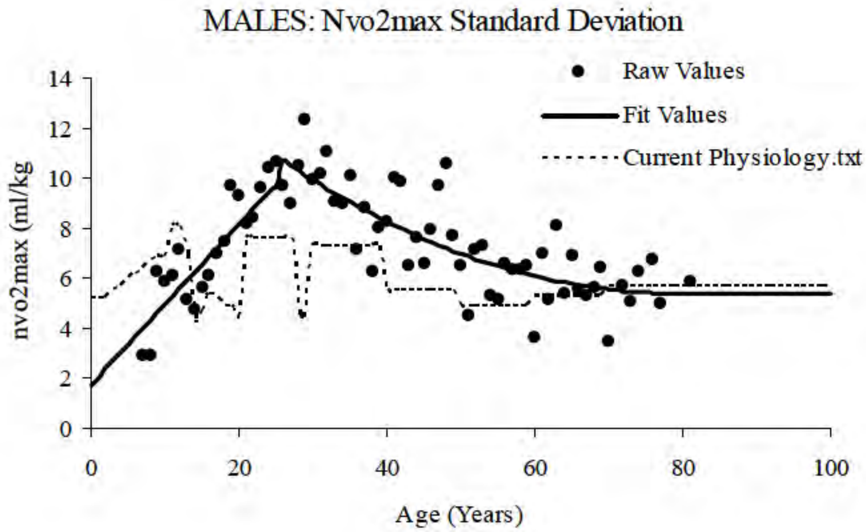


Figure 17. Nvo2max Normal Distribution Fits: Raw Fit Means and Smoothed Fits.



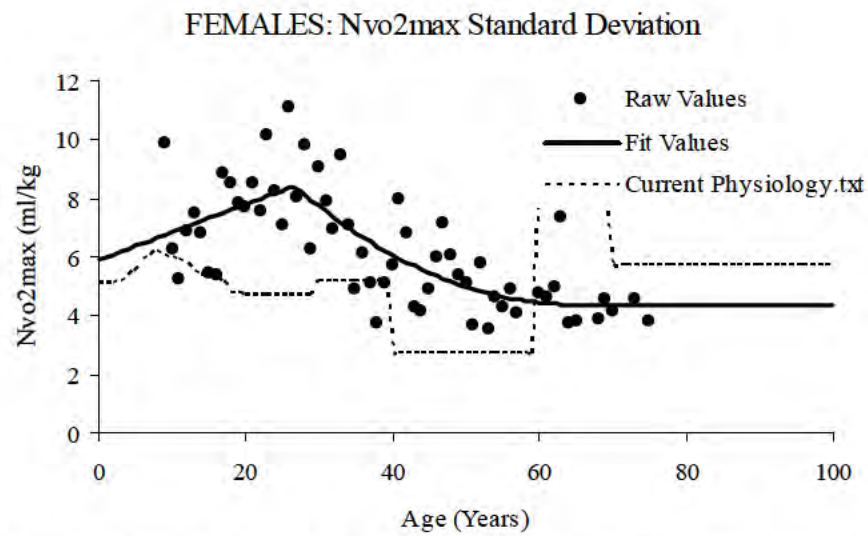
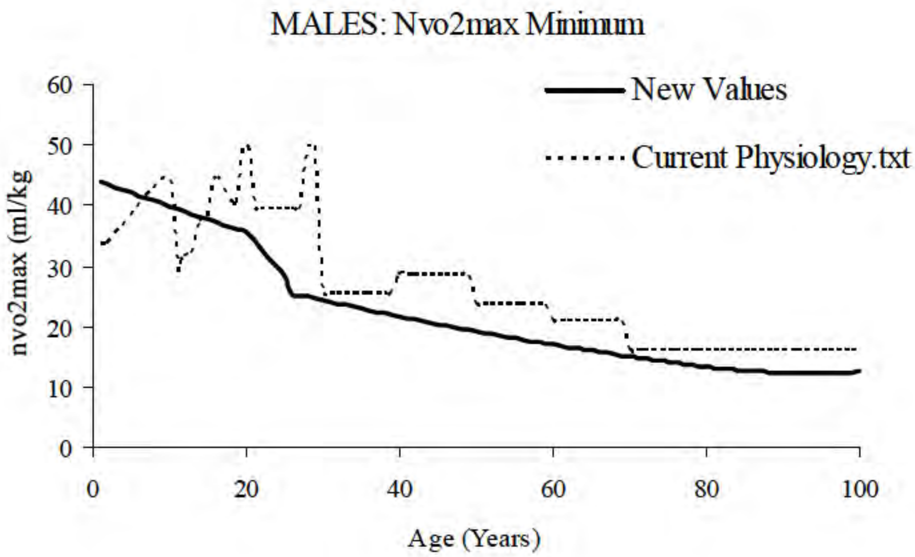


Figure 18. Nvo2max Normal Distribution Fits: Raw Fit Standard Deviations and Smoothed Fits.



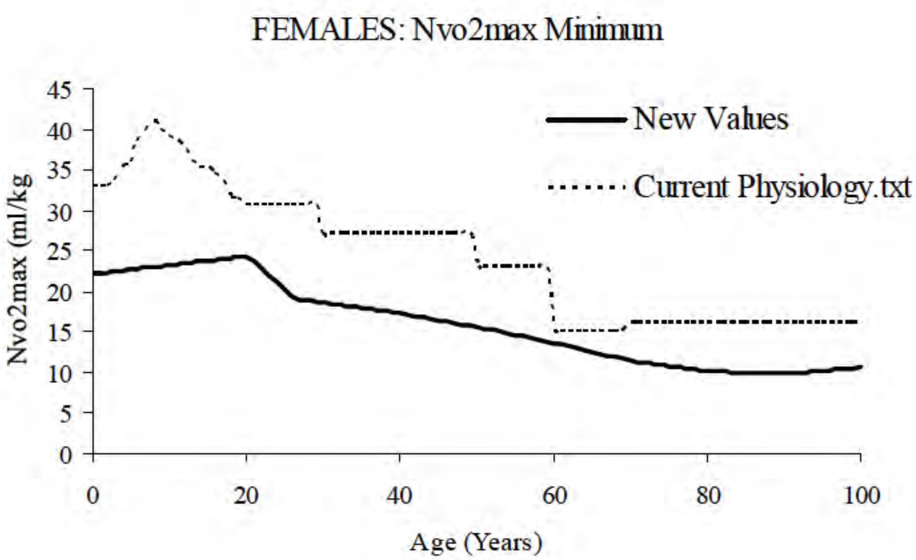
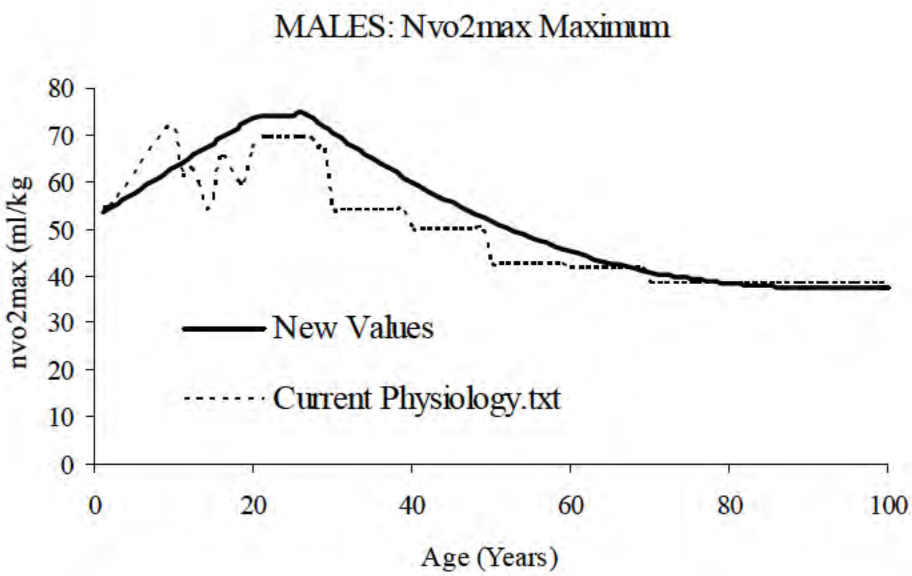


Figure 19. Nvo2max Minimums. 1st Percentile of the Best-fit Normal Distribution.



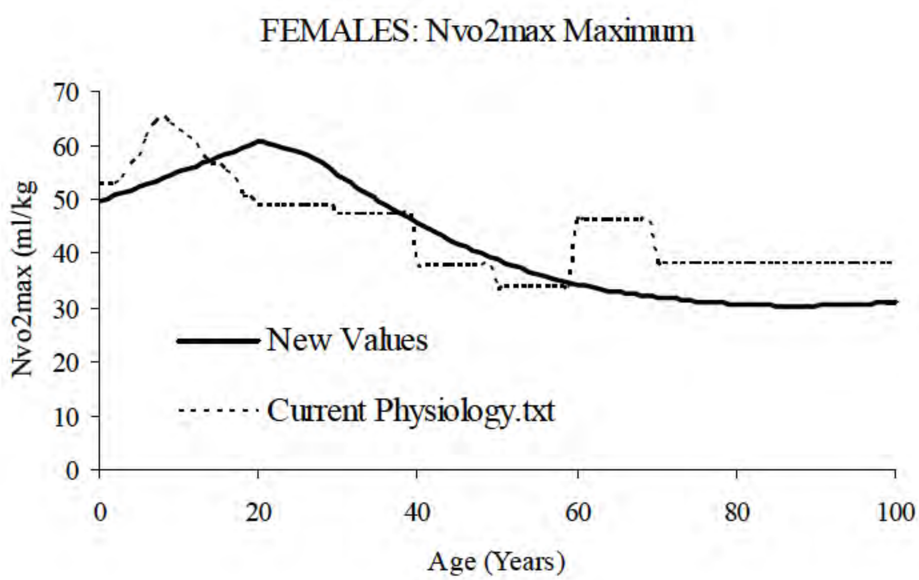


Figure 20. Nvo2max Maximums. 99th Percentile of the Best-fit Normal Distribution.

5. Derivation of New Distributions for Hemoglobin Content (Hemoglobin Density)

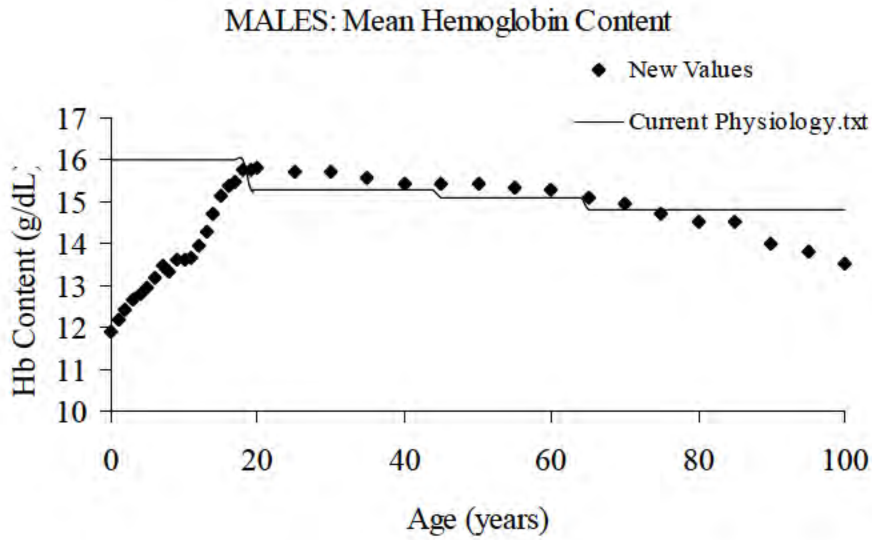
The new hemoglobin content values were derived from the combined NHANES 1999-2000 and 2001-2002 datasets. As of December 2005, hemoglobin data had not yet been released for the 2003-2004 study. The age data was provided in the Demographic datasets (Demo.xpt and Demo_b.xpt, previously downloaded for the body mass analysis) for the two survey periods, while hemoglobin content (in g/dL) was provided in the Laboratory #25 (Complete Blood Count) datasets (lab25.xpt and l25_b.xpt, which were downloaded for this analysis). The dataset comprised 20,321 individuals; appropriate sample weights were used for the combined 4-year (1999-2002) dataset as provided with the NHANES 2001-2002 data release. Similarly to the body mass data, the hemoglobin content values were analyzed in SAS. The age and hemoglobin datasets were merged and fit to normal distributions using the SAS PROC UNIVARIATE procedure. The FREQ option of the procedure was used to apply the sampling weights. The SAS code in provided in the Appendix C.

Hemoglobin content statistics were estimated for single-year age and gender cohorts for ages 1-19, as the behavior of the means were smooth in this age range. For persons 20 and over, the data were grouped in 5-year cohorts (20-24, 25-29, etc.) No blood count data were available for subjects under 1 year of age or greater than 90. The age 0 mean values were obtained by a linear regression of ages 1-20 (males) or 1 to 11 (females) back to age 0. These were the ages for which the hemoglobin content demonstrated an increase with age. The 91-95 and 96-100 mean values were obtained by a linear regression of the 61-65 and older age groups. As the standard deviations did not appear to behave as smoothly with age as did the mean values, the age 0 value was assumed equal to the age 1 value, and the age 91-95 and 96-100 value was assumed equal to the age 90-94 value.

The resulting means and standard deviations for the best-for normal distributions for hemoglobin content are given in Figures 14 and 15**.** The current hemoglobin content values are shown for comparison.

The main conclusions that can be made is that the current Physiology.txt input file overestimates mean hemoglobin content in children and in older persons. The standard deviation values in the current physiology.txt file are fairly close to those found in this analysis. The new values are not very smooth over ages; EPA may elect to continue to use the current values. It should be noted that the original reference for the current hemoglobin statistics is unknown.

Note: In the current implementation of APEX, the hemoglobin content statistics affect only the CO dose algorithm calculations.



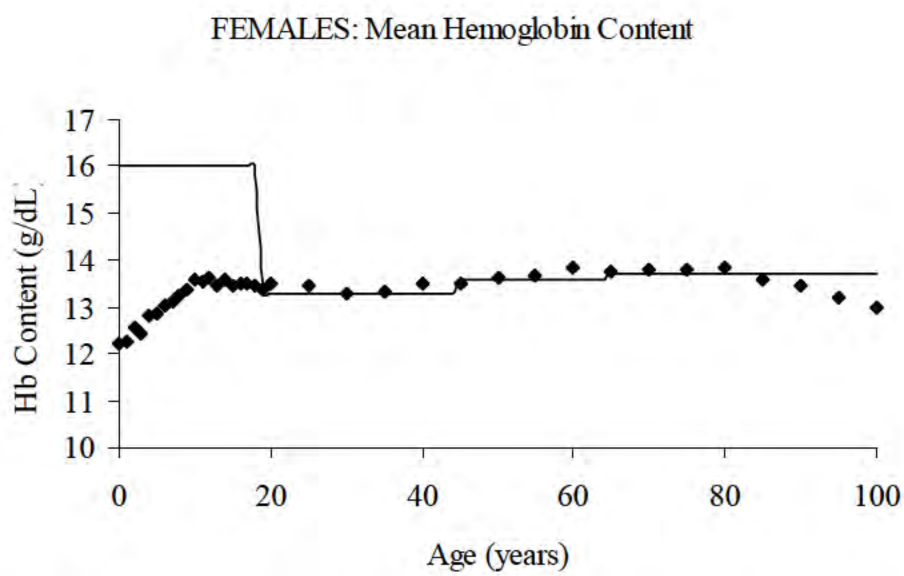


Figure 21. Mean Values of Hemoglobin Content as Derived from the 1999-2002 NHANES Dataset, with Comparison to Current Physiology.txt Values

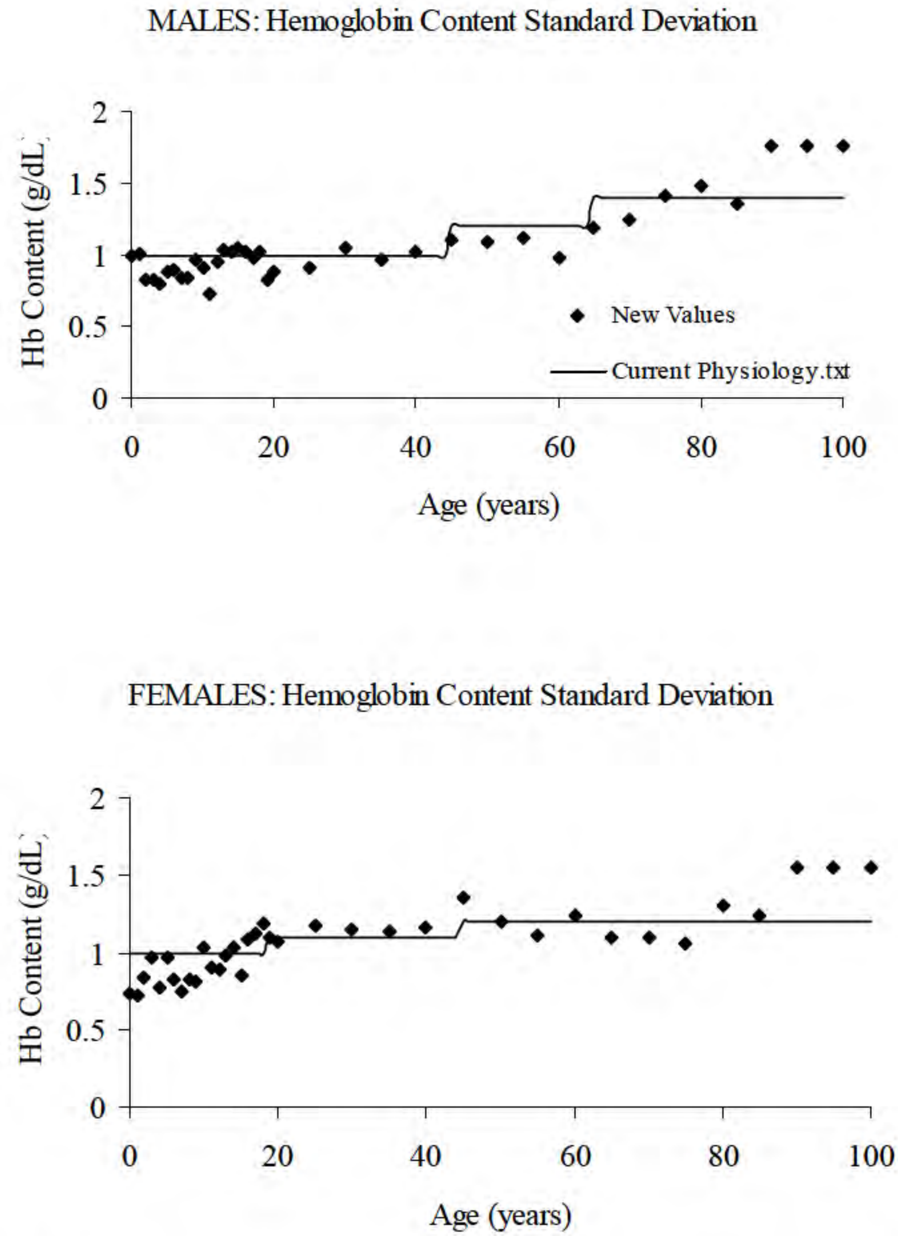


Figure 22. Values of Hemoglobin Content Standard Deviation as Derived from the 1999-2002 NHANES Dataset, with Comparison to Current Physiology.txt Values

6. BLOOD VOLUME AS A FUNCTION OF HEIGHT AND WEIGHT

In APEX, blood volume is estimated as a function of height and weight by the following equation:

$$V_{blood} = BVF*Weight + K*Height^3 - 30$$

where V_{blood} is the blood volume (ml), Weight is in pounds, and height is in inches. BVF is the blood volume factor that is read in from the physiology file, and K is a gender-dependent constant (0.00683 for males, 0.00678 for females). This is a modification of Allen's equation [168] to include the age/gender dependent BVF and adjusted for the given units.

As previously mentioned, the data upon which the BVF values in the physiology file were based could not be identified. The available documentation for pNEM documents a non-age-dependent use of these equations.

In addition, no appropriate data were found for deriving new estimates for the BVF variable as a function of age and gender for use with the Allen equations. It should be noted however, that these equations were modified by Nadler [169]. These equations seem to be used somewhat more often than the originals in the literature.

In addition, other (more recent) equations exist for estimation of blood volume from height and weight specifically in children [170,171] or body surface area [172]. In particular, Linderkamp et al. [170] derived prediction equations for blood volume as a function of a number of physiological parameters for children in three different age groups. It is recommended that further analysis of this study and others be undertaken.

However, inclusion of new blood volume equations in APEX would require changes beyond the current physiology file (i.e. other, more intensive, code changes would be needed). Thus, at the present time, no specific improvements to the current BVF values in the physiology file can be made.

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Appendix A. SAS Code for Estimating the Body Mass Distributions

```
/* This program calculates lognormal distributions for BM from the NHANES 1999-2004 Data

K K Isaacs 10/2005
Alion Science and Technology

Distributions are derived from raw body mass and age data downloaded from the CDC site at
http://www.cdc.gov/nchs/about/major/nhanes/

The data are stored in the downloaded datasets:

1999-2000 (SAS export files)
BMX.xpt (NHANES Body Measurement Data, contains body wt in kg)
Demo.xpt  (NHAMES Demographic Data, contains age in years or months)

2001-2002 (SAS export files)
BMX_b_r.xpt (NHANES Body Measurement Data, contains body wt in kg)
Demo_b.xpt  (NHAMES Demographic Data, contains age in years or months)

2003-2004 (SAS export files)
BMX_c.xpt (NHANES Body Measurement Data, contains body wt in kg)
Demo_c.xpt  (NHAMES Demographic Data, contains age in years or months)

*/

* Merge the Body Measurement and Demographics datasets;

Data weight;
   merge Demo Demo_b Demo_c Bmx Bmx_b_r Bmx_c;
   by SEQN;
   mass=BMXWT;
   gen=RIAGENDR;
   ageyrs=RIDAGEYR;
   agemonths=RIDAGEEX;
   wt = (2/3)*WTMEC4YR;
   if (SEQN>21004) THEN wt=(1/3)*WTMEC2YR;
   if agemonths<12 and agemonths>0 THEN ageyrs=0;
   keep SEQN mass gen ageyrs agemonths wt;
run;

proc sort data=weight;
   by gen ageyrs;
run;

Proc univariate data=weight;
by gen ageyrs;
var mass;
freq wt;
histogram mass / lognormal;

run;
```

APPENDIX B. SAS CODE FOR ESTIMATING THE NORMALIZED VO2MAX DISTRIBUTIONS

```
/*************************************************************************/
/*   This is a program to fit the  V02Max (Adams and others) data to different
distributional shapes.

Adams experimental data provided in Excel form by Stephen Graham and Tom McCurdy, EPA

Other data collected by Alion Science and Tech.

This work was performed for WA 10, APEX/SHEDS Physiology File Update
```

```
K. K. Isaacs October 2005

Alion Science and Technology
/************************************************************************/;

*load datasets;

Data    alldata ;
  infile  'H:\kki-05-PHYSIOLOGY_10\NVO2MAX\vo2max.csv' DLM="," END=eof;
  input    age nvo2max gender;
  output alldata;

proc sort data=alldata;
by gender age;
run;

Proc univariate data=alldata;
by gender age;
var nvo2max;
histogram nvo2max / normal;
output out=outputdata1 N=samplesize mean=Mean
        std=StdDeviation ProbN=NormalFit;
run;

Proc export data=outputdata1 outfile="H:\kki-05-PHYSIOLOGY_10\Alldata_vo2max.csv"
replace;
run;
```

APPENDIX C. SAS CODE FOR ESTIMATING THE HEMOGLOBIN CONTENT DATA

```
/* This program calculates best fit normal distributions for hemoglobin content
from the NHANES 1999-2000 and 2001-2002 datasets.

Alion Science and Technology
K K Isaacs 12/2005

Distributions are derived from hemoglobin content and age data downloaded from the CDC
site at
http://www.cdc.gov/nchs/about/major/nhanes/nhanes99-00.htm
and
http://www.cdc.gov/nchs/about/major/nhanes/nhanes01-02.htm

The data are stored in the downloaded datasets:

1999-2000
lab25.xpt (NHANES Lab dataset #25)
Demo.xpt  (NHANES Demographic Data, contains age in years or months)

2001-2002
l25_b.xpt (NHANES Lab dataset #25)
Demo_b.xpt  (NHANES Demographic Data, contains age in years or months)
*/

*Data are read into SAS by loading the xpt files.

* Merge the Laboratory and Demographics datasets;

Data Hb;
   merge Demo Lab25 Demo_b L25_b;
   by SEQN;                            * Sample number;
   Hb=LBXHGB;                          * Hb content g/dL;
   gen=RIAGENDR;                       * Gender;
   ageyrs=RIDAGEYR;                    * Age in years;
   agemonths=RIDAGEEX;                 * Age in months;
   wt = WTMEC4YR;                      * 4-year sample weights;
   if agemonths<12 and agemonths>0 THEN ageyrs=0;     * Age 0;
   if ageyrs>20 then ageyrs=(floor(ageyrs/5)+1)*5;   * Bin in 5-year incs;
```

```
   keep SEQN Hb gen ageyrs agemonths wt;
run;

proc sort data=Hb;
   by gen ageyrs;
run;

Proc univariate data=Hb;
by gen ageyrs;
var Hb;
req wt;                              * Apply sample weights;
histogram Hb / normal;               * Fit to Normal;
output out=outputs N=samplesize mean=Mean
        std=StdDeviation ProbN=NormalFit;
run;

Proc export data=outputs outfile="H:\kki-05-PHYSIOLOGY_10\Hemoglobin\HbFitswt.csv"
replace;
run;
```

APPENDIX D. THE NEW PHYSIOLOGY.TXT FILE

Note: The values contained in the file conform to the current APEX read formats. That is, the number of decimal places for each parameter is dictated by the APEX code. It is likely that this will change in the future, at which point more significant digits could be added to the Physiology.txt file.

Males age 0-100, then females age 0-100 (last revised 12-20-05)
NVO2max distribution

Age	Source	Distr	Mean	SD	Lower	Upper	Assumptions
0	NA	Normal	48.3	1.7	44.3	52.2	
1	NA	Normal	48.6	2.0	43.8	53.3	
2	NA	Normal	48.9	2.4	43.4	54.4	
3	NA	Normal	49.2	2.7	43.0	55.4	
4	NA	Normal	49.5	3.0	42.5	56.5	
5	NA	Normal	49.8	3.3	42.1	57.6	
6	NA	Normal	50.1	3.7	41.6	58.6	
7	NA	Normal	50.4	4.0	41.2	59.7	
8	NA	Normal	50.8	4.3	40.8	60.8	
9	NA	Normal	51.1	4.6	40.3	61.8	
10	NA	Normal	51.4	5.0	39.9	62.9	
11	NA	Normal	51.7	5.3	39.4	64.0	
12	NA	Normal	52.0	5.6	39.0	65.0	
13	NA	Normal	52.3	5.9	38.6	66.1	
14	NA	Normal	52.6	6.2	38.1	67.2	
15	NA	Normal	53.0	6.6	37.7	68.2	
16	NA	Normal	53.3	6.9	37.3	69.3	
17	NA	Normal	53.6	7.2	36.8	70.4	
18	NA	Normal	53.9	7.5	36.4	71.4	
19	NA	Normal	54.2	7.9	35.9	72.5	
20	NA	Normal	54.5	8.2	35.5	73.6	
21	NA	Normal	54.2	8.5	34.5	74.0	
22	NA	Normal	53.4	8.8	32.9	74.0	
23	NA	Normal	52.6	9.2	31.4	73.9	
24	NA	Normal	51.8	9.5	29.8	73.9	
25	NA	Normal	51.1	9.8	28.3	73.9	
26	NA	Normal	50.3	10.7	25.5	75.2	
27	NA	Normal	49.6	10.5	25.2	74.0	
28	NA	Normal	48.8	10.3	24.9	72.8	
29	NA	Normal	48.1	10.1	24.6	71.6	
30	NA	Normal	47.4	9.9	24.3	70.4	
31	NA	Normal	46.7	9.7	24.0	69.3	
32	NA	Normal	46.0	9.6	23.8	68.2	
33	NA	Normal	45.3	9.4	23.5	67.1	
34	NA	Normal	44.6	9.2	23.2	66.0	
35	NA	Normal	44.0	9.0	23.0	65.0	
36	NA	Normal	43.3	8.9	22.7	64.0	
37	NA	Normal	42.7	8.7	22.4	62.9	
38	NA	Normal	42.1	8.6	22.2	61.9	
39	NA	Normal	41.4	7.3	25.5	54.1	
40	NA	Normal	40.8	5.5	28.4	50.0	
41	NA	Normal	40.2	5.5	28.4	50.0	
42	NA	Normal	39.7	5.5	28.4	50.0	
43	NA	Normal	39.1	5.5	28.4	50.0	
44	NA	Normal	38.5	5.5	28.4	50.0	
45	NA	Normal	38.0	5.5	28.4	50.0	
46	NA	Normal	37.4	5.5	28.4	50.0	
47	NA	Normal	36.9	5.5	28.4	50.0	
48	NA	Normal	36.4	5.5	28.4	50.0	
49	NA	Normal	35.9	5.5	28.4	50.0	
50	NA	Normal	35.4	4.9	23.5	42.7	
51	NA	Normal	34.9	4.9	23.5	42.7	
52	NA	Normal	34.5	4.9	23.5	42.7	
53	NA	Normal	34.0	4.9	23.5	42.7	
54	NA	Normal	33.6	4.9	23.5	42.7	
55	NA	Normal	33.1	4.9	23.5	42.7	
56	NA	Normal	32.7	4.9	23.5	42.7	
57	NA	Normal	32.3	4.9	23.5	42.7	
58	NA	Normal	31.9	4.9	23.5	42.7	
59	NA	Normal	31.5	4.9	23.5	42.7	
60	NA	Normal	31.1	5.3	21.0	41.8	
61	NA	Normal	30.7	5.3	21.0	41.8	
62	NA	Normal	30.4	5.3	21.0	41.8	
63	NA	Normal	30.0	5.3	21.0	41.8	

64	NA	Normal	29.7	5.3	21.0	41.8
65	NA	Normal	29.4	5.3	21.0	41.8
66	NA	Normal	29.1	5.3	21.0	41.8
67	NA	Normal	28.8	5.3	21.0	41.8
68	NA	Normal	28.5	5.3	21.0	41.8
69	NA	Normal	28.2	5.3	21.0	41.8
70	NA	Normal	27.9	5.7	16.1	38.3
71	NA	Normal	27.7	5.7	16.1	38.3
72	NA	Normal	27.4	5.7	16.1	38.3
73	NA	Normal	27.2	5.7	16.1	38.3
74	NA	Normal	27.0	5.7	16.1	38.3
75	NA	Normal	26.7	5.7	16.1	38.3
76	NA	Normal	26.5	5.7	16.1	38.3
77	NA	Normal	26.4	5.7	16.1	38.3
78	NA	Normal	26.2	5.7	16.1	38.3
79	NA	Normal	26.0	5.7	16.1	38.3
80	NA	Normal	25.8	5.7	16.1	38.3
81	NA	Normal	25.7	5.7	16.1	38.3
82	NA	Normal	25.6	5.7	16.1	38.3
83	NA	Normal	25.4	5.7	16.1	38.3
84	NA	Normal	25.3	5.7	16.1	38.3
85	NA	Normal	25.2	5.7	16.1	38.3
86	NA	Normal	25.1	5.7	16.1	38.3
87	NA	Normal	25.1	5.7	16.1	38.3
88	NA	Normal	25.0	5.7	16.1	38.3
89	NA	Normal	24.9	5.7	16.1	38.3
90	NA	Normal	24.9	5.7	16.1	38.3
91	NA	Normal	24.9	5.7	16.1	38.3
92	NA	Normal	24.8	5.7	16.1	38.3
93	NA	Normal	24.8	5.7	16.1	38.3
94	NA	Normal	24.8	5.7	16.1	38.3
95	NA	Normal	24.8	5.7	16.1	38.3
96	NA	Normal	24.9	5.7	16.1	38.3
97	NA	Normal	24.9	5.7	16.1	38.3
98	NA	Normal	25.0	5.7	16.1	38.3
99	NA	Normal	25.0	5.7	16.1	38.3
100	NA	Normal	25.1	5.7	16.1	38.3
0	NA	Normal	35.9	5.9	22.2	49.6
1	NA	Normal	36.2	6.0	22.3	50.2
2	NA	Normal	36.5	6.1	22.4	50.7
3	NA	Normal	36.9	6.2	22.5	51.3
4	NA	Normal	37.2	6.3	22.6	51.8
5	NA	Normal	37.5	6.4	22.7	52.4
6	NA	Normal	37.9	6.5	22.8	52.9
7	NA	Normal	38.2	6.6	22.9	53.5
8	NA	Normal	38.5	6.7	23.0	54.0
9	NA	Normal	38.9	6.8	23.1	54.6
10	NA	Normal	39.2	6.9	23.3	55.1
11	NA	Normal	39.5	7.0	23.4	55.7
12	NA	Normal	39.9	7.0	23.5	56.2
13	NA	Normal	40.2	7.1	23.6	56.8
14	NA	Normal	40.5	7.2	23.7	57.3
15	NA	Normal	40.9	7.3	23.8	57.9
16	NA	Normal	41.2	7.4	23.9	58.5
17	NA	Normal	41.5	7.5	24.0	59.0
18	NA	Normal	41.8	7.6	24.1	59.6
19	NA	Normal	42.2	7.7	24.2	60.1
20	NA	Normal	42.5	7.8	24.4	60.7
21	NA	Normal	42.1	7.9	23.7	60.5
22	NA	Normal	41.5	8.0	22.9	60.1
23	NA	Normal	40.8	8.1	22.0	59.6
24	NA	Normal	40.2	8.2	21.1	59.2
25	NA	Normal	39.6	8.3	20.3	58.8
26	NA	Normal	39.0	8.4	19.5	58.4
27	NA	Normal	38.4	8.4	18.9	57.8
28	NA	Normal	37.8	8.1	18.8	56.7
29	NA	Normal	37.2	7.9	18.7	55.6
30	NA	Normal	36.6	7.7	18.6	54.6
31	NA	Normal	36.0	7.6	18.5	53.6
32	NA	Normal	35.5	7.4	18.4	52.6
33	NA	Normal	34.9	7.2	18.2	51.7
34	NA	Normal	34.4	7.0	18.1	50.7
35	NA	Normal	33.9	6.8	18.0	49.8
36	NA	Normal	33.4	6.7	17.8	48.9
37	NA	Normal	32.9	6.5	17.7	48.0
38	NA	Normal	32.4	6.4	17.6	47.2
39	NA	Normal	31.9	6.2	17.4	46.4
40	NA	Normal	31.4	6.1	17.3	45.6
41	NA	Normal	31.0	6.0	17.1	44.8
42	NA	Normal	30.5	5.8	17.0	44.0
43	NA	Normal	30.1	5.7	16.8	43.3

44	NA	Normal	29.6	5.6	16.6	42.6
45	NA	Normal	29.2	5.5	16.5	41.9
46	NA	Normal	28.8	5.4	16.3	41.2
47	NA	Normal	28.4	5.3	16.1	40.6
48	NA	Normal	28.0	5.2	16.0	40.0
49	NA	Normal	27.6	5.1	15.8	39.4
50	NA	Normal	27.2	5.0	15.6	38.8
51	NA	Normal	26.8	4.9	15.4	38.3
52	NA	Normal	26.5	4.8	15.2	37.7
53	NA	Normal	26.1	4.8	15.1	37.2
54	NA	Normal	25.8	4.7	14.9	36.7
55	NA	Normal	25.5	4.7	14.7	36.3
56	NA	Normal	25.2	4.6	14.5	35.9
57	NA	Normal	24.9	4.6	14.3	35.4
58	NA	Normal	24.6	4.5	14.1	35.1
59	NA	Normal	24.3	4.5	13.9	34.7
60	NA	Normal	24.0	4.5	13.6	34.3
61	NA	Normal	23.7	4.4	13.4	34.0
62	NA	Normal	23.5	4.4	13.2	33.7
63	NA	Normal	23.2	4.4	13.0	33.4
64	NA	Normal	23.0	4.4	12.8	33.2
65	NA	Normal	22.7	4.4	12.5	33.0
66	NA	Normal	22.5	4.4	12.3	32.7
67	NA	Normal	22.3	4.4	12.1	32.5
68	NA	Normal	22.1	4.4	11.9	32.3
69	NA	Normal	21.9	4.4	11.7	32.1
70	NA	Normal	21.7	4.4	11.5	32.0
71	NA	Normal	21.6	4.4	11.4	31.8
72	NA	Normal	21.4	4.4	11.2	31.6
73	NA	Normal	21.3	4.4	11.1	31.5
74	NA	Normal	21.1	4.4	10.9	31.3
75	NA	Normal	21.0	4.4	10.8	31.2
76	NA	Normal	20.9	4.4	10.7	31.1
77	NA	Normal	20.8	4.4	10.6	31.0
78	NA	Normal	20.7	4.4	10.4	30.9
79	NA	Normal	20.6	4.4	10.4	30.8
80	NA	Normal	20.5	4.4	10.3	30.7
81	NA	Normal	20.4	4.4	10.2	30.6
82	NA	Normal	20.3	4.4	10.1	30.6
83	NA	Normal	20.3	4.4	10.1	30.5
84	NA	Normal	20.3	4.4	10.0	30.5
85	NA	Normal	20.2	4.4	10.0	30.4
86	NA	Normal	20.2	4.4	10.0	30.4
87	NA	Normal	20.2	4.4	10.0	30.4
88	NA	Normal	20.2	4.4	10.0	30.4
89	NA	Normal	20.2	4.4	10.0	30.4
90	NA	Normal	20.2	4.4	10.0	30.4
91	NA	Normal	20.2	4.4	10.0	30.4
92	NA	Normal	20.3	4.4	10.1	30.5
93	NA	Normal	20.3	4.4	10.1	30.5
94	NA	Normal	20.4	4.4	10.2	30.6
95	NA	Normal	20.4	4.4	10.2	30.6
96	NA	Normal	20.5	4.4	10.3	30.7
97	NA	Normal	20.6	4.4	10.4	30.8
98	NA	Normal	20.7	4.4	10.5	30.9
99	NA	Normal	20.8	4.4	10.6	31.0
100	NA	Normal	20.9	4.4	10.7	31.1

Males age 0-100, then females age 0-100 (last revised 12-20-05)

Body mass distribution, kg

Age	Source	Distr	GM	GSD	Lower	Upper	Assumptions
0	CDC	LN	7.8	1.301	3.6	11.8	
1	CDC	LN	11.4	1.143	8.2	16.1	
2	CDC	LN	13.9	1.146	9.8	20.9	
3	CDC	LN	16.0	1.154	11.7	23.7	
4	CDC	LN	18.5	1.165	11.1	28.1	
5	CDC	LN	21.6	1.234	13.7	42.4	
6	CDC	LN	23.1	1.213	16.1	41.1	
7	CDC	LN	27.1	1.216	19.3	46.8	
8	CDC	LN	31.7	1.302	19.1	66.2	
9	CDC	LN	34.7	1.265	24.0	69.9	
10	CDC	LN	38.3	1.280	24.3	72.9	
11	CDC	LN	44.1	1.308	26.2	83.8	
12	CDC	LN	48.0	1.315	27.7	94.8	
13	CDC	LN	55.4	1.340	27.7	106.6	
14	CDC	LN	62.8	1.293	35.7	121.0	
15	CDC	LN	67.7	1.255	41.5	117.9	
16	CDC	LN	72.5	1.267	45.8	139.1	
17	CDC	LN	73.1	1.248	49.9	136.6	
18	CDC	LN	75.1	1.243	51.2	144.2	
19	CDC	LN	77.2	1.245	52.6	134.5	
20	CDC	LN	78.0	1.250	50.5	130.0	

21	CDC	LN	78.2	1.297	46.8	199.2
22	CDC	LN	83.8	1.292	53.3	155.4
23	CDC	LN	80.6	1.222	50.5	137.6
24	CDC	LN	81.7	1.251	50.6	132.6
25	CDC	LN	84.8	1.206	50.2	136.1
26	CDC	LN	81.8	1.273	48.9	164.5
27	CDC	LN	85.2	1.249	50.0	153.9
28	CDC	LN	84.3	1.272	51.0	167.2
29	CDC	LN	82.1	1.236	50.6	147.2
30	CDC	LN	81.6	1.262	52.5	139.0
31	CDC	LN	81.3	1.249	48.8	170.6
32	CDC	LN	84.7	1.235	49.7	135.8
33	CDC	LN	88.2	1.231	64.8	146.3
34	CDC	LN	81.2	1.221	53.1	136.9
35	CDC	LN	87.2	1.251	61.0	193.3
36	CDC	LN	83.4	1.228	45.8	140.5
37	CDC	LN	85.8	1.241	59.3	150.9
38	CDC	LN	84.1	1.260	52.8	149.7
39	CDC	LN	84.6	1.196	61.2	140.6
40	CDC	LN	90.1	1.246	58.5	154.0
41	CDC	LN	87.4	1.173	61.3	117.7
42	CDC	LN	88.3	1.205	62.2	144.0
43	CDC	LN	88.4	1.233	54.0	145.3
44	CDC	LN	88.5	1.200	56.6	128.9
45	CDC	LN	87.1	1.205	60.6	160.2
46	CDC	LN	88.2	1.243	54.2	154.3
47	CDC	LN	86.5	1.229	49.9	188.3
48	CDC	LN	84.8	1.186	56.3	128.3
49	CDC	LN	86.2	1.240	47.0	171.3
50	CDC	LN	84.7	1.179	53.4	124.4
51	CDC	LN	88.0	1.208	57.9	143.6
52	CDC	LN	89.9	1.216	55.2	144.9
53	CDC	LN	89.0	1.228	58.2	143.3
54	CDC	LN	90.1	1.216	64.1	155.2
55	CDC	LN	88.3	1.222	55.1	138.6
56	CDC	LN	84.8	1.195	45.0	110.3
57	CDC	LN	87.5	1.253	58.3	160.0
58	CDC	LN	85.1	1.266	51.6	179.0
59	CDC	LN	84.2	1.182	58.7	112.4
60	CDC	LN	87.0	1.232	57.3	141.7
61	CDC	LN	89.0	1.207	49.9	162.8
62	CDC	LN	84.8	1.228	56.0	152.1
63	CDC	LN	89.1	1.262	56.3	171.6
64	CDC	LN	90.0	1.193	59.1	119.0
65	CDC	LN	89.9	1.215	58.1	126.3
66	CDC	LN	86.8	1.228	54.0	150.1
67	CDC	LN	86.2	1.207	43.1	127.5
68	CDC	LN	85.2	1.191	61.2	163.2
69	CDC	LN	87.1	1.222	50.7	127.2
70	CDC	LN	82.8	1.210	46.5	125.5
71	CDC	LN	79.6	1.240	51.0	122.8
72	CDC	LN	82.0	1.204	51.9	132.7
73	CDC	LN	85.6	1.196	56.2	128.3
74	CDC	LN	83.0	1.217	53.3	120.0
75	CDC	LN	84.5	1.185	56.5	133.5
76	CDC	LN	78.7	1.207	55.9	121.1
77	CDC	LN	79.4	1.170	58.7	109.3
78	CDC	LN	79.9	1.195	41.1	115.1
79	CDC	LN	77.6	1.155	56.4	107.8
80	CDC	LN	79.9	1.174	56.0	111.9
81	CDC	LN	75.4	1.157	55.8	111.9
82	CDC	LN	76.8	1.180	54.4	111.8
83	CDC	LN	74.6	1.158	53.2	107.0
84	CDC	LN	75.3	1.205	41.5	109.5
85	CDC	LN	71.8	1.191	46.9	105.8
86	CDC	LN	74.0	1.170	50.6	101.1
87	CDC	LN	73.4	1.170	50.4	99.1
88	CDC	LN	72.7	1.160	50.2	97.2
89	CDC	LN	72.1	1.160	50.0	95.2
90	CDC	LN	71.5	1.160	49.8	93.2
91	CDC	LN	70.9	1.160	49.6	91.3
92	CDC	LN	70.3	1.160	49.4	89.3
93	CDC	LN	69.6	1.150	49.3	87.4
94	CDC	LN	69.0	1.150	49.1	85.4
95	CDC	LN	68.4	1.150	48.9	83.4
96	CDC	LN	67.8	1.150	48.7	81.5
97	CDC	LN	67.1	1.140	48.5	79.5
98	CDC	LN	66.5	1.140	48.3	77.6
99	CDC	LN	65.9	1.140	48.1	75.6
100	CDC	LN	65.3	1.140	47.9	73.6
0	CDC	LN	7.4	1.304	3.7	12.1

1	CDC	LN	11.1	1.163	7.4	15.3
2	CDC	LN	13.3	1.158	10.1	20.4
3	CDC	LN	15.6	1.160	11.0	27.9
4	CDC	LN	18.0	1.171	12.8	29.1
5	CDC	LN	20.4	1.229	12.6	40.4
6	CDC	LN	22.5	1.194	15.9	36.7
7	CDC	LN	26.5	1.239	16.9	51.0
8	CDC	LN	30.5	1.315	19.8	60.8
9	CDC	LN	35.2	1.271	20.3	58.6
10	CDC	LN	40.6	1.304	22.7	71.2
11	CDC	LN	46.6	1.302	27.7	84.6
12	CDC	LN	50.7	1.274	27.8	93.3
13	CDC	LN	56.6	1.275	33.4	99.5
14	CDC	LN	57.2	1.248	37.7	110.0
15	CDC	LN	60.1	1.249	34.9	108.4
16	CDC	LN	61.6	1.255	40.9	113.8
17	CDC	LN	61.2	1.248	41.5	133.1
18	CDC	LN	64.6	1.281	42.4	123.6
19	CDC	LN	66.2	1.274	41.6	118.5
20	CDC	LN	67.0	1.262	41.5	122.6
21	CDC	LN	67.2	1.262	39.7	123.7
22	CDC	LN	66.8	1.273	42.0	123.5
23	CDC	LN	69.7	1.304	40.3	143.0
24	CDC	LN	70.3	1.289	47.5	144.5
25	CDC	LN	66.3	1.283	44.8	131.8
26	CDC	LN	73.0	1.281	45.3	128.9
27	CDC	LN	70.6	1.281	41.4	140.9
28	CDC	LN	74.4	1.312	44.3	142.1
29	CDC	LN	69.1	1.250	39.3	116.3
30	CDC	LN	70.6	1.305	42.1	151.5
31	CDC	LN	73.0	1.278	43.7	125.9
32	CDC	LN	72.9	1.281	41.5	139.7
33	CDC	LN	72.7	1.307	44.9	135.2
34	CDC	LN	69.8	1.230	46.6	115.3
35	CDC	LN	73.0	1.306	44.2	138.4
36	CDC	LN	73.5	1.289	44.6	150.1
37	CDC	LN	70.0	1.284	48.1	152.1
38	CDC	LN	75.6	1.295	43.7	151.7
39	CDC	LN	72.3	1.251	41.6	123.1
40	CDC	LN	72.9	1.289	45.5	137.4
41	CDC	LN	73.4	1.268	50.5	156.9
42	CDC	LN	73.7	1.270	47.1	146.1
43	CDC	LN	73.4	1.314	45.6	159.5
44	CDC	LN	75.7	1.266	49.5	153.0
45	CDC	LN	76.8	1.308	41.6	141.5
46	CDC	LN	77.5	1.304	46.6	145.8
47	CDC	LN	72.8	1.298	47.8	130.6
48	CDC	LN	74.6	1.303	44.2	166.0
49	CDC	LN	72.8	1.261	45.1	125.5
50	CDC	LN	75.2	1.292	48.4	175.7
51	CDC	LN	72.9	1.240	42.5	120.2
52	CDC	LN	74.5	1.283	45.7	146.6
53	CDC	LN	74.7	1.259	46.2	176.6
54	CDC	LN	72.4	1.281	44.3	123.1
55	CDC	LN	76.0	1.231	53.6	125.6
56	CDC	LN	77.3	1.315	45.6	134.9
57	CDC	LN	72.4	1.252	48.6	122.6
58	CDC	LN	74.5	1.267	45.0	117.7
59	CDC	LN	80.6	1.277	50.9	133.0
60	CDC	LN	75.8	1.260	51.3	128.3
61	CDC	LN	77.1	1.240	50.7	125.6
62	CDC	LN	73.3	1.198	49.7	121.1
63	CDC	LN	72.3	1.238	46.9	119.9
64	CDC	LN	75.4	1.281	41.1	132.5
65	CDC	LN	72.9	1.254	35.9	113.7
66	CDC	LN	73.1	1.242	48.4	113.3
67	CDC	LN	75.8	1.266	47.2	123.8
68	CDC	LN	73.2	1.250	39.3	120.7
69	CDC	LN	74.4	1.225	48.0	118.0
70	CDC	LN	69.0	1.188	45.9	102.8
71	CDC	LN	69.1	1.232	45.5	108.1
72	CDC	LN	69.9	1.240	40.7	103.8
73	CDC	LN	71.4	1.240	47.4	127.6
74	CDC	LN	70.4	1.277	37.4	106.4
75	CDC	LN	70.5	1.216	46.8	117.4
76	CDC	LN	69.5	1.199	48.8	101.7
77	CDC	LN	70.1	1.240	40.3	119.8
78	CDC	LN	66.4	1.211	44.1	109.8
79	CDC	LN	67.8	1.200	46.2	98.4
80	CDC	LN	62.2	1.255	41.2	121.4
81	CDC	LN	65.4	1.184	42.7	91.4

82	CDC	LN	64.8	1.260	40.6	120.0
83	CDC	LN	62.9	1.196	44.7	101.2
84	CDC	LN	62.2	1.216	43.5	108.4
85	CDC	LN	61.5	1.209	42.3	93.2
86	CDC	LN	62.4	1.210	41.9	101.2
87	CDC	LN	61.8	1.210	41.7	100.3
88	CDC	LN	61.3	1.210	41.5	99.4
89	CDC	LN	60.7	1.210	41.3	98.4
90	CDC	LN	60.2	1.210	41.1	97.5
91	CDC	LN	59.6	1.200	40.9	96.6
92	CDC	LN	59.1	1.200	40.7	95.7
93	CDC	LN	58.5	1.200	40.5	94.8
94	CDC	LN	58.0	1.200	40.3	93.9
95	CDC	LN	57.4	1.200	40.1	93.0
96	CDC	LN	56.9	1.200	39.9	92.1
97	CDC	LN	56.3	1.200	39.7	91.2
98	CDC	LN	55.8	1.190	39.5	90.3
99	CDC	LN	55.2	1.190	39.3	89.4
100	CDC	LN	54.7	1.190	39.1	88.5

Males age 0-100 then females age 0-100 (last revised 6-11-98)

Regression equation Estimate for RMR

Age	Source	DV	IV	Slope	Interc	SE	Units	med. wgt
0	R47g	BMR	BM	0.244	-0.127	0.290	MJ/day	2.1
1	R47g	BMR	BM	0.244	-0.127	0.290	MJ/day	2.7
2	R47g	BMR	BM	0.244	-0.127	0.280	MJ/day	3.2
3	R47h	BMR	BM	0.095	2.110	0.280	MJ/day	3.6
4	R47h	BMR	BM	0.095	2.110	0.280	MJ/day	3.8
5	R47h	BMR	BM	0.095	2.110	0.280	MJ/day	4.0
6	R47h	BMR	BM	0.095	2.110	0.280	MJ/day	4.3
7	R47h	BMR	BM	0.095	2.110	0.280	MJ/day	4.5
8	R47h	BMR	BM	0.095	2.110	0.280	MJ/day	4.8
9	R47h	BMR	BM	0.095	2.110	0.280	MJ/day	5.0
10	R47i	BMR	BM	0.074	2.754	0.440	MJ/day	5.4
11	R47i	BMR	BM	0.074	2.754	0.440	MJ/day	5.7
12	R47i	BMR	BM	0.074	2.754	0.440	MJ/day	6.0
13	R47i	BMR	BM	0.074	2.754	0.440	MJ/day	6.3
14	R47i	BMR	BM	0.074	2.754	0.440	MJ/day	6.9
15	R47i	BMR	BM	0.074	2.754	0.440	MJ/day	7.2
16	R47i	BMR	BM	0.074	2.754	0.440	MJ/day	7.7
17	R47i	BMR	BM	0.074	2.754	0.440	MJ/day	7.6
18	R47j	BMR	BM	0.063	2.896	0.640	MJ/day	7.3
19	R47j	BMR	BM	0.063	2.896	0.640	MJ/day	7.4
20	R47j	BMR	BM	0.063	2.896	0.640	MJ/day	7.7
21	R47j	BMR	BM	0.063	2.896	0.640	MJ/day	7.7
22	R47j	BMR	BM	0.063	2.896	0.640	MJ/day	7.7
23	R47j	BMR	BM	0.063	2.896	0.640	MJ/day	7.7
24	R47j	BMR	BM	0.063	2.896	0.640	MJ/day	7.7
25	R47j	BMR	BM	0.063	2.896	0.640	MJ/day	7.7
26	R47j	BMR	BM	0.063	2.896	0.640	MJ/day	7.7
27	R47j	BMR	BM	0.063	2.896	0.640	MJ/day	7.7
28	R47j	BMR	BM	0.063	2.896	0.640	MJ/day	7.7
29	R47j	BMR	BM	0.063	2.896	0.640	MJ/day	7.7
30	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
31	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
32	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
33	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
34	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
35	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
36	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
37	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
38	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
39	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
40	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
41	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
42	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
43	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
44	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
45	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
46	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
47	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
48	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
49	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
50	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
51	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
52	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
53	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
54	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
55	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
56	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
57	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
58	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3

59	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
60	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
61	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
62	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
63	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
64	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
65	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
66	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
67	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
68	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
69	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
70	R47k	BMR	BM	0.048	3.653	0.700	MJ/day	7.3
71	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
72	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
73	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
74	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
75	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
76	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
77	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
78	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
79	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
80	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
81	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
82	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
83	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
84	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
85	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
86	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
87	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
88	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
89	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
90	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
91	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
92	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
93	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
94	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
95	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
96	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
97	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
98	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
99	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
100	R47l	BMR	BM	0.049	2.459	0.690	MJ/day	6.2
0	R47a	BMR	BM	0.244	-0.130	0.250	MJ/day	2.0
1	R47a	BMR	BM	0.244	-0.130	0.250	MJ/day	2.5
2	R47a	BMR	BM	0.244	-0.130	0.250	MJ/day	3.0
3	R47b	BMR	BM	0.085	2.033	0.290	MJ/day	3.3
4	R47b	BMR	BM	0.085	2.033	0.290	MJ/day	3.5
5	R47b	BMR	BM	0.085	2.033	0.290	MJ/day	3.7
6	R47b	BMR	BM	0.085	2.033	0.290	MJ/day	3.9
7	R47b	BMR	BM	0.085	2.033	0.290	MJ/day	4.1
8	R47b	BMR	BM	0.085	2.033	0.290	MJ/day	4.4
9	R47b	BMR	BM	0.085	2.033	0.290	MJ/day	4.7
10	R47c	BMR	BM	0.056	2.898	0.470	MJ/day	4.9
11	R47c	BMR	BM	0.056	2.898	0.470	MJ/day	5.2
12	R47c	BMR	BM	0.056	2.898	0.470	MJ/day	5.5
13	R47c	BMR	BM	0.056	2.898	0.470	MJ/day	5.7
14	R47c	BMR	BM	0.056	2.898	0.470	MJ/day	5.9
15	R47c	BMR	BM	0.056	2.898	0.470	MJ/day	6.0
16	R47c	BMR	BM	0.056	2.898	0.470	MJ/day	6.1
17	R47c	BMR	BM	0.056	2.898	0.470	MJ/day	6.2
18	R47d	BMR	BM	0.062	2.036	0.500	MJ/day	5.7
19	R47d	BMR	BM	0.062	2.036	0.500	MJ/day	5.8
20	R47d	BMR	BM	0.062	2.036	0.500	MJ/day	6.0
21	R47d	BMR	BM	0.062	2.036	0.500	MJ/day	6.0
22	R47d	BMR	BM	0.062	2.036	0.500	MJ/day	6.0
23	R47d	BMR	BM	0.062	2.036	0.500	MJ/day	6.0
24	R47d	BMR	BM	0.062	2.036	0.500	MJ/day	6.0
25	R47d	BMR	BM	0.062	2.036	0.500	MJ/day	6.0
26	R47d	BMR	BM	0.062	2.036	0.500	MJ/day	6.0
27	R47d	BMR	BM	0.062	2.036	0.500	MJ/day	6.0
28	R47d	BMR	BM	0.062	2.036	0.500	MJ/day	6.0
29	R47d	BMR	BM	0.062	2.036	0.500	MJ/day	6.0
30	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
31	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
32	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
33	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
34	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
35	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
36	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
37	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
38	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7

39	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
40	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
41	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
42	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
43	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
44	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
45	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
46	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
47	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
48	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
49	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
50	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
51	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
52	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
53	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
54	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
55	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
56	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
57	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
58	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
59	R47e	BMR	BM	0.034	3.538	0.470	MJ/day	5.7
60	R47e	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
61	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
62	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
63	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
64	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
65	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
66	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
67	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
68	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
69	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
70	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
71	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
72	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
73	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
74	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
75	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
76	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
77	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
78	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
79	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
80	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
81	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
82	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
83	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
84	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
85	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
86	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
87	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
88	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
89	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
90	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
91	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
92	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
93	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
94	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
95	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
96	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
97	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
98	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
99	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2
100	R47f	BMR	BM	0.038	2.755	0.450	MJ/day	5.2

Males age 0-100 then females age 0-100 (HG last revised 12-20-05)
Blood Volume factor and Hemoglobin content

Age	BLDFAC	HGMN	HGSTD
0	17.0	11.9	1.0
1	17.0	12.2	1.0
2	17.0	12.4	0.8
3	17.0	12.7	0.8
4	17.0	12.8	0.8
5	17.0	13.0	0.9
6	17.0	13.2	0.9
7	17.0	13.5	0.8
8	17.0	13.4	0.8
9	17.0	13.6	1.0
10	17.0	13.6	0.9
11	17.0	13.7	0.7
12	17.0	14.0	1.0
13	17.0	14.3	1.0
14	17.0	14.7	1.0
15	17.0	15.1	1.0

16	17.0	15.4	1.0
17	17.0	15.5	1.0
18	17.0	15.7	1.0
19	20.4	15.8	0.8
20	20.4	15.8	0.9
21	20.4	15.7	0.9
22	20.4	15.7	0.9
23	20.4	15.7	0.9
24	20.4	15.7	0.9
25	20.4	15.7	0.9
26	20.4	15.7	1.0
27	20.4	15.7	1.0
28	20.4	15.7	1.0
29	20.4	15.7	1.0
30	20.4	15.7	1.0
31	20.4	15.6	1.0
32	20.4	15.6	1.0
33	20.4	15.6	1.0
34	20.4	15.6	1.0
35	20.4	15.6	1.0
36	20.4	15.4	1.0
37	20.4	15.4	1.0
38	20.4	15.4	1.0
39	20.4	15.4	1.0
40	20.4	15.4	1.0
41	20.4	15.4	1.1
42	20.4	15.4	1.1
43	20.4	15.4	1.1
44	20.4	15.4	1.1
45	20.4	15.4	1.1
46	20.4	15.4	1.1
47	20.4	15.4	1.1
48	20.4	15.4	1.1
49	20.4	15.4	1.1
50	20.4	15.4	1.1
51	20.4	15.3	1.1
52	20.4	15.3	1.1
53	20.4	15.3	1.1
54	20.4	15.3	1.1
55	20.4	15.3	1.1
56	20.4	15.3	1.0
57	20.4	15.3	1.0
58	20.4	15.3	1.0
59	20.4	15.3	1.0
60	20.4	15.3	1.0
61	20.4	15.1	1.2
62	20.4	15.1	1.2
63	20.4	15.1	1.2
64	20.4	15.1	1.2
65	20.4	15.1	1.2
66	20.4	15.0	1.2
67	20.4	15.0	1.2
68	20.4	15.0	1.2
69	20.4	15.0	1.2
70	20.4	15.0	1.2
71	20.4	14.7	1.4
72	20.4	14.7	1.4
73	20.4	14.7	1.4
74	20.4	14.7	1.4
75	20.4	14.7	1.4
76	20.4	14.5	1.5
77	20.4	14.5	1.5
78	20.4	14.5	1.5
79	20.4	14.5	1.5
80	20.4	14.5	1.5
81	20.4	14.5	1.4
82	20.4	14.5	1.4
83	20.4	14.5	1.4
84	20.4	14.5	1.4
85	20.4	14.5	1.4
86	20.4	14.0	1.8
87	20.4	14.0	1.8
88	20.4	14.0	1.8
89	20.4	14.0	1.8
90	20.4	14.0	1.8
91	20.4	13.8	1.8
92	20.4	13.8	1.8
93	20.4	13.8	1.8
94	20.4	13.8	1.8
95	20.4	13.8	1.8
96	20.4	13.5	1.8

97	20.4	13.5	1.8
98	20.4	13.5	1.8
99	20.4	13.5	1.8
100	20.4	13.5	1.8
0	17.0	12.2	0.7
1	17.0	12.3	0.7
2	17.0	12.6	0.8
3	17.0	12.5	1.0
4	17.0	12.8	0.8
5	17.0	12.9	1.0
6	17.0	13.0	0.8
7	17.0	13.1	0.8
8	17.0	13.3	0.8
9	17.0	13.4	0.8
10	17.0	13.6	1.0
11	17.0	13.5	0.9
12	17.0	13.6	0.9
13	17.0	13.5	1.0
14	17.0	13.6	1.0
15	17.0	13.5	0.9
16	17.0	13.5	1.1
17	17.0	13.5	1.1
18	17.0	13.5	1.2
19	14.6	13.4	1.1
20	14.6	13.5	1.1
21	14.6	13.5	1.2
22	14.6	13.5	1.2
23	14.6	13.5	1.2
24	14.6	13.5	1.2
25	14.6	13.5	1.2
26	14.6	13.3	1.1
27	14.6	13.3	1.1
28	14.6	13.3	1.1
29	14.6	13.3	1.1
30	14.6	13.3	1.1
31	14.6	13.3	1.1
32	14.6	13.3	1.1
33	14.6	13.3	1.1
34	14.6	13.3	1.1
35	14.6	13.3	1.1
36	14.6	13.5	1.2
37	14.6	13.5	1.2
38	14.6	13.5	1.2
39	14.6	13.5	1.2
40	14.6	13.5	1.2
41	14.6	13.5	1.3
42	14.6	13.5	1.3
43	14.6	13.5	1.3
44	14.6	13.5	1.3
45	14.6	13.5	1.3
46	14.6	13.6	1.2
47	14.6	13.6	1.2
48	14.6	13.6	1.2
49	14.6	13.6	1.2
50	14.6	13.6	1.2
51	14.6	13.7	1.1
52	14.6	13.7	1.1
53	14.6	13.7	1.1
54	14.6	13.7	1.1
55	14.6	13.7	1.1
56	14.6	13.8	1.2
57	14.6	13.8	1.2
58	14.6	13.8	1.2
59	14.6	13.8	1.2
60	14.6	13.8	1.2
61	14.6	13.8	1.1
62	14.6	13.8	1.1
63	14.6	13.8	1.1
64	14.6	13.8	1.1
65	14.6	13.8	1.1
66	14.6	13.8	1.1
67	14.6	13.8	1.1
68	14.6	13.8	1.1
69	14.6	13.8	1.1
70	14.6	13.8	1.1
71	14.6	13.8	1.1
72	14.6	13.8	1.1
73	14.6	13.8	1.1
74	14.6	13.8	1.1
75	14.6	13.8	1.1
76	14.6	13.8	1.3

77	14.6	13.8	1.3
78	14.6	13.8	1.3
79	14.6	13.8	1.3
80	14.6	13.8	1.3
81	14.6	13.6	1.2
82	14.6	13.6	1.2
83	14.6	13.6	1.2
84	14.6	13.6	1.2
85	14.6	13.6	1.2
86	14.6	13.4	1.6
87	14.6	13.4	1.6
88	14.6	13.4	1.6
89	14.6	13.4	1.6
90	14.6	13.4	1.6
91	14.6	13.2	1.6
92	14.6	13.2	1.6
93	14.6	13.2	1.6
94	14.6	13.2	1.6
95	14.6	13.2	1.6
96	14.6	13.0	1.6
97	14.6	13.0	1.6
98	14.6	13.0	1.6
99	14.6	13.0	1.6
100	14.6	13.0	1.6

Appendix E. All Derived Physiological Parameters

Table 7. Nv02max Values for Males: Raw and Smoothed Fits.

Age	MALES MEAN Raw Fit Values	MEAN Smoothed Fit Values	SD Raw Fit Values	SD Smoothed Fit Values	MIN (1st Pctl)	MAX (99th Pctl)
0.00		48.25		1.71	44.26	52.24
1.00		48.56		2.04	43.82	53.30
2.00		48.88		2.36	43.39	54.37
3.00		49.19		2.68	42.95	55.43
4.00		49.50		3.01	42.51	56.50
5.00		49.82		3.33	42.07	57.56
6.00		50.13		3.65	41.63	58.63
7.00	51.37	50.44	2.86	3.98	41.19	59.70
8.00	53.46	50.76	2.86	4.30	40.76	60.76
9.00	51.10	51.07	6.26	4.62	40.32	61.83
10.00	51.28	51.39	5.87	4.95	39.88	62.89
11.00	50.13	51.70	6.04	5.27	39.44	63.96
12.00	50.70	52.01	7.13	5.59	39.00	65.02
13.00	52.74	52.33	5.13	5.92	38.56	66.09
14.00	52.93	52.64	4.72	6.24	38.13	67.16
15.00	53.18	52.95	5.57	6.56	37.69	68.22
16.00	49.46	53.27	6.06	6.89	37.25	69.29
17.00	49.77	53.58	6.93	7.21	36.81	70.35
18.00	51.98	53.90	7.48	7.53	36.37	71.42
19.00	59.88	54.21	9.65	7.86	35.93	72.48
20.00	56.80	54.52	9.31	8.18	35.50	73.55
21.00	54.60	54.23	8.17	8.50	34.45	74.01
22.00	54.61	53.42	8.40	8.83	32.89	73.95
23.00	53.76	52.63	9.60	9.15	31.35	73.91
24.00	57.23	51.84	10.44	9.47	29.81	73.88
25.00	50.90	51.07	10.63	9.80	28.29	73.86
26.00	50.06	50.31	9.66	10.69	25.45	75.17
27.00	46.38	49.56	8.95	10.49	25.16	73.96
28.00	48.32	48.82	10.47	10.29	24.88	72.77
29.00	51.02	48.10	12.31	10.10	24.60	71.59
30.00	45.59	47.38	9.91	9.92	24.32	70.44
31.00	45.86	46.67	10.14	9.73	24.04	69.31
32.00	46.90	45.98	11.03	9.55	23.76	68.20
33.00	42.08	45.30	9.08	9.38	23.49	67.10
34.00	44.48	44.63	8.95	9.20	23.22	66.03
35.00	38.63	43.97	10.10	9.03	22.95	64.98
36.00	42.63	43.32	7.11	8.87	22.69	63.95
37.00	40.41	42.68	8.81	8.71	22.42	62.94
38.00	39.70	42.05	6.22	8.55	22.16	61.94

39.00	40.62	41.44	8.01	8.40	21.90	60.97
40.00	39.02	40.83	8.28	8.25	21.64	60.02
41.00	39.72	40.24	9.96	8.10	21.39	59.09
42.00	35.58	39.66	9.85	7.96	21.14	58.18
43.00	39.98	39.09	6.46	7.82	20.89	57.28
44.00	38.65	38.53	7.60	7.69	20.64	56.41
45.00	40.15	37.98	6.59	7.56	20.40	55.56
46.00	40.67	37.44	7.89	7.43	20.16	54.73
47.00	41.51	36.92	9.68	7.31	19.91	53.92
48.00	38.92	36.40	10.52	7.19	19.68	53.12
49.00	34.65	35.90	7.68	7.07	19.44	52.35
50.00	33.85	35.41	6.49	6.96	19.21	51.60
51.00	32.52	34.92	4.51	6.86	18.98	50.87
52.00	36.31	34.45	7.08	6.75	18.75	50.16
53.00	36.23	34.00	7.31	6.65	18.52	49.47
54.00	33.91	33.55	5.29	6.56	18.30	48.79
55.00	33.40	33.11	5.08	6.46	18.08	48.14
56.00	31.68	32.69	6.52	6.37	17.86	47.51
57.00	32.47	32.27	6.33	6.29	17.64	46.90
58.00	33.24	31.87	6.32	6.21	17.43	46.31
59.00	33.05	31.48	6.45	6.13	17.22	45.74
60.00	29.02	31.10	3.59	6.06	17.01	45.19
61.00	31.68	30.73	6.95	5.99	16.80	44.66
62.00	29.72	30.37	5.09	5.92	16.60	44.14
63.00	30.90	30.02	8.06	5.86	16.40	43.65
64.00	30.65	29.69	5.32	5.80	16.20	43.18
65.00	29.86	29.36	6.90	5.75	16.00	42.73
66.00	28.60	29.05	5.51	5.70	15.80	42.30
67.00	29.47	28.75	5.25	5.65	15.61	41.89
68.00	28.95	28.46	5.63	5.61	15.42	41.50
69.00	31.13	28.18	6.43	5.57	15.23	41.13
70.00	27.12	27.91	3.44	5.53	15.05	40.78
71.00		27.65		5.50	14.86	40.45
72.00	28.56	27.41	5.71	5.47	14.68	40.13
73.00	27.62	27.17	5.03	5.45	14.50	39.84
74.00	27.84	26.95	6.27	5.43	14.33	39.57
75.00		26.74		5.41	14.15	39.32
76.00	25.05	26.54	6.68	5.40	13.98	39.09
77.00	23.74	26.35	4.99	5.39	13.81	38.88
78.00		26.17		5.38	13.65	38.69
79.00		26.00		5.38	13.48	38.52
80.00		25.84		5.39	13.32	38.37
81.00	23.68	25.70	5.88	5.39	13.17	38.22
82.00		25.57		5.39	13.04	38.09
83.00		25.44		5.39	12.92	37.97
84.00		25.33		5.39	12.81	37.86
85.00		25.23		5.39	12.70	37.76
86.00		25.14		5.39	12.62	37.67
87.00		25.06		5.39	12.54	37.59
88.00		25.00		5.39	12.47	37.52

89.00		24.94		5.39	12.42	37.47
90.00		24.90		5.39	12.37	37.42
91.00		24.86		5.39	12.34	37.39
92.00		24.84		5.39	12.32	37.37
93.00		24.83		5.39	12.31	37.36
94.00		24.83		5.39	12.31	37.36
95.00		24.84		5.39	12.32	37.37
96.00		24.87		5.39	12.34	37.39
97.00		24.90		5.39	12.37	37.43
98.00		24.95		5.39	12.42	37.47
99.00		25.00		5.39	12.48	37.53
100.00		25.07		5.39	12.54	37.60

Table 8. Nv02max Values for Females: Raw and Smoothed Fits

Age	FEMALES MEAN Raw Fit Values	MEAN Smoothed Fit Values	SD Raw Fit Values	SD Smoothed Fit Values	MIN (1st Pctl)	MAX (99th Pctl)
0.00		35.88		5.90	22.15	49.61
1.00		36.21		6.00	22.26	50.17
2.00		36.54		6.09	22.37	50.72
3.00		36.87		6.19	22.48	51.27
4.00		37.20		6.28	22.59	51.82
5.00		37.54		6.38	22.70	52.37
6.00		37.87		6.47	22.81	52.93
7.00		38.20		6.57	22.92	53.48
8.00		38.53		6.66	23.03	54.03
9.00	30.56	38.86	9.90	6.76	23.14	54.58
10.00	45.53	39.19	6.27	6.85	23.25	55.13
11.00	43.88	39.52	5.26	6.95	23.36	55.69
12.00	43.03	39.85	6.88	7.04	23.47	56.24
13.00	42.00	40.18	7.48	7.14	23.58	56.79
14.00	37.57	40.51	6.79	7.23	23.69	57.34
15.00	39.57	40.85	5.43	7.33	23.80	57.89
16.00	35.51	41.18	5.36	7.42	23.91	58.45
17.00	38.22	41.51	8.86	7.52	24.02	59.00
18.00	45.67	41.84	8.53	7.61	24.13	59.55
19.00	43.87	42.17	7.83	7.71	24.24	60.10
20.00	42.52	42.50	7.69	7.80	24.35	60.65
21.00	43.45	42.10	8.51	7.90	23.73	60.48
22.00	43.22	41.45	7.59	7.99	22.86	60.05
23.00	43.87	40.81	10.13	8.09	21.99	59.63
24.00	41.14	40.18	8.22	8.18	21.14	59.22
25.00	38.20	39.56	7.09	8.28	20.30	58.82
26.00	38.98	38.95	11.12	8.37	19.47	58.43
27.00	34.94	38.35	8.02	8.35	18.93	57.76

28.00	38.08	37.75	9.80	8.14	18.82	56.69
29.00	35.13	37.17	6.30	7.94	18.71	55.64
30.00	35.79	36.60	9.10	7.74	18.59	54.61
31.00	35.22	36.04	7.89	7.55	18.47	53.60
32.00	36.06	35.48	6.93	7.37	18.35	52.62
33.00	34.95	34.94	9.51	7.19	18.23	51.66
34.00	38.13	34.41	7.08	7.01	18.10	50.72
35.00	32.63	33.88	4.88	6.84	17.97	49.80
36.00	33.59	33.37	6.17	6.68	17.83	48.91
37.00	31.11	32.87	5.13	6.52	17.70	48.04
38.00	33.12	32.37	3.76	6.37	17.55	47.19
39.00	28.80	31.89	5.14	6.22	17.41	46.37
40.00	29.06	31.42	5.74	6.08	17.26	45.57
41.00	29.54	30.95	8.00	5.95	17.11	44.79
42.00	30.90	30.50	6.82	5.82	16.96	44.03
43.00	27.60	30.05	4.32	5.70	16.80	43.30
44.00	29.33	29.62	4.17	5.58	16.64	42.59
45.00	28.53	29.19	4.90	5.47	16.48	41.90
46.00	29.41	28.78	6.00	5.36	16.31	41.24
47.00	30.49	28.37	7.15	5.26	16.14	40.60
48.00	27.92	27.97	6.05	5.16	15.97	39.98
49.00	26.48	27.59	5.36	5.07	15.79	39.38
50.00	29.80	27.21	5.13	4.99	15.61	38.81
51.00	27.49	26.84	3.66	4.91	15.43	38.26
52.00	28.95	26.49	5.83	4.83	15.24	37.73
53.00	23.77	26.14	3.56	4.77	15.06	37.23
54.00	25.34	25.80	4.61	4.70	14.86	36.74
55.00	26.05	25.48	4.29	4.65	14.67	36.29
56.00	26.30	25.16	4.91	4.60	14.47	35.85
57.00	26.06	24.85	4.07	4.55	14.27	35.44
58.00		24.55		4.51	14.06	35.05
59.00		24.27		4.48	13.85	34.68
60.00	23.67	23.99	4.81	4.45	13.64	34.33
61.00	24.70	23.72	4.65	4.43	13.43	34.01
62.00	21.63	23.46	4.99	4.41	13.21	33.71
63.00	26.64	23.21	7.38	4.40	12.99	33.44
64.00	23.84	22.97	3.77	4.39	12.76	33.18
65.00	20.26	22.74	3.83	4.39	12.53	32.95
66.00	20.38	22.52		4.39	12.31	32.73
67.00	20.49	22.31		4.39	12.10	32.52
68.00	22.05	22.11	3.90	4.39	11.90	32.32
69.00	21.92	21.92	4.56	4.39	11.71	32.13
70.00	20.38	21.74	4.15	4.39	11.53	31.95
71.00	25.30	21.57		4.39	11.36	31.78
72.00	21.21	21.41		4.39	11.20	31.62
73.00	20.46	21.26	4.59	4.39	11.05	31.47
74.00	20.63	21.12		4.39	10.91	31.33
75.00	20.60	20.99	3.80	4.39	10.78	31.20
76.00	20.91	20.87		4.39	10.66	31.08
77.00	22.27	20.76		4.39	10.55	30.97

78.00	19.93	20.65	4.39	10.44	30.86
79.00	22.80	20.56	4.39	10.35	30.77
80.00	23.19	20.48	4.39	10.27	30.69
81.00	19.29	20.41	4.39	10.20	30.62
82.00	13.44	20.34	4.39	10.13	30.55
83.00	28.03	20.29	4.39	10.08	30.50
84.00	17.00	20.25	4.39	10.04	30.46
85.00	18.69	20.21	4.39	10.00	30.42
86.00	18.18	20.19	4.39	9.98	30.40
87.00		20.18	4.39	9.97	30.39
88.00	27.15	20.17	4.39	9.96	30.38
89.00		20.18	4.39	9.97	30.39
90.00	18.18	20.20	4.39	9.98	30.41
91.00		20.22	4.39	10.01	30.43
92.00		20.26	4.39	10.05	30.47
93.00		20.30	4.39	10.09	30.51
94.00		20.36	4.39	10.15	30.57
95.00		20.42	4.39	10.21	30.63
96.00		20.50	4.39	10.28	30.71
97.00		20.58	4.39	10.37	30.79
98.00		20.67	4.39	10.46	30.88
99.00		20.78	4.39	10.57	30.99
100.00		20.89	4.39	10.68	31.10

Table 3. Body Mass Raw Fits.

	MALES				FEMALES			
Age	Geometric Mean	GSD	Min	Max	Geometric Mean	GSD	Min	Max
0.00	7.767	1.301	3.6	11.8	7.429	1.304	3.7	12.1
1.00	11.440	1.143	8.2	16.1	11.119	1.163	7.4	15.3
2.00	13.932	1.146	9.8	20.9	13.258	1.158	10.1	20.4
3.00	15.967	1.154	11.7	23.7	15.587	1.160	11	27.9
4.00	18.475	1.165	11.1	28.1	18.005	1.171	12.8	29.1
5.00	21.618	1.234	13.7	42.4	20.353	1.229	12.6	40.4
6.00	23.142	1.213	16.1	41.1	22.454	1.194	15.9	36.7
7.00	27.072	1.216	19.3	46.8	26.483	1.239	16.9	51
8.00	31.651	1.302	19.1	66.2	30.534	1.315	19.8	60.8
9.00	34.656	1.265	24	69.9	35.235	1.271	20.3	58.6
10.00	38.329	1.280	24.3	72.9	40.550	1.304	22.7	71.2
11.00	44.149	1.308	26.2	83.8	46.579	1.302	27.7	84.6
12.00	47.988	1.315	27.7	94.8	50.673	1.274	27.8	93.3
13.00	55.364	1.340	27.7	106.6	56.649	1.275	33.4	99.5
14.00	62.832	1.293	35.7	121	57.214	1.248	37.7	110
15.00	67.650	1.255	41.5	117.9	60.091	1.249	34.9	108.4
16.00	72.460	1.267	45.8	139.1	61.582	1.255	40.9	113.8
17.00	73.081	1.248	49.9	136.6	61.229	1.248	41.5	133.1

18.00	75.060	1.243	51.2	144.2	64.591	1.281	42.4	123.6
19.00	77.182	1.245	52.6	134.5	66.156	1.274	41.6	118.5
20.00	77.952	1.250	50.5	130	66.981	1.262	41.5	122.6
21.00	78.239	1.297	46.8	199.2	67.218	1.262	39.7	123.7
22.00	83.845	1.292	53.3	155.4	66.823	1.273	42	123.5
23.00	80.607	1.222	50.5	137.6	69.721	1.304	40.3	143
24.00	81.706	1.251	50.6	132.6	70.284	1.289	47.5	144.5
25.00	84.818	1.206	50.2	136.1	66.300	1.283	44.8	131.8
26.00	81.812	1.273	48.9	164.5	72.973	1.281	45.3	128.9
27.00	85.166	1.249	50	153.9	70.604	1.281	41.4	140.9
28.00	84.321	1.272	51	167.2	74.363	1.312	44.3	142.1
29.00	82.144	1.236	50.6	147.2	69.110	1.250	39.3	116.3
30.00	81.581	1.262	52.5	139	70.616	1.305	42.1	151.5
31.00	81.275	1.249	48.8	170.6	73.039	1.278	43.7	125.9
32.00	84.715	1.235	49.7	135.8	72.938	1.281	41.5	139.7
33.00	88.188	1.231	64.8	146.3	72.710	1.307	44.9	135.2
34.00	81.163	1.221	53.1	136.9	69.773	1.230	46.6	115.3
35.00	87.192	1.251	61	193.3	73.044	1.306	44.2	138.4
36.00	83.404	1.228	45.8	140.5	73.547	1.289	44.6	150.1
37.00	85.759	1.241	59.3	150.9	70.019	1.284	48.1	152.1
38.00	84.132	1.260	52.8	149.7	75.587	1.295	43.7	151.7
39.00	84.611	1.196	61.2	140.6	72.295	1.251	41.6	123.1
40.00	90.071	1.246	58.5	154	72.888	1.289	45.5	137.4
41.00	87.425	1.173	61.3	117.7	73.363	1.268	50.5	156.9
42.00	88.290	1.205	62.2	144	73.697	1.270	47.1	146.1
43.00	88.423	1.233	54	145.3	73.438	1.314	45.6	159.5
44.00	88.528	1.200	56.6	128.9	75.742	1.266	49.5	153
45.00	87.102	1.205	60.6	160.2	76.795	1.308	41.6	141.5
46.00	88.157	1.243	54.2	154.3	77.544	1.304	46.6	145.8
47.00	86.547	1.229	49.9	188.3	72.849	1.298	47.8	130.6
48.00	84.793	1.186	56.3	128.3	74.646	1.303	44.2	166
49.00	86.235	1.240	47	171.3	72.844	1.261	45.1	125.54
50.00	84.659	1.179	53.4	124.4	75.217	1.292	48.4	175.7
51.00	87.975	1.208	57.9	143.6	72.941	1.240	42.5	120.2
52.00	89.886	1.216	55.2	144.9	74.472	1.283	45.7	146.6
53.00	89.012	1.228	58.2	143.3	74.733	1.259	46.2	176.6
54.00	90.098	1.216	64.1	155.2	72.413	1.281	44.3	123.1
55.00	88.268	1.222	55.1	138.6	75.951	1.231	53.6	125.6
56.00	84.796	1.195	45	110.3	77.322	1.315	45.6	134.9
57.00	87.501	1.253	58.3	160	72.378	1.252	48.6	122.6
58.00	85.116	1.266	51.6	179	74.548	1.267	45	117.7
59.00	84.190	1.182	58.7	112.4	80.638	1.277	50.9	133
60.00	87.044	1.232	57.3	141.7	75.777	1.260	51.3	128.3
61.00	89.007	1.207	49.9	162.8	77.121	1.240	50.7	125.6
62.00	84.788	1.228	56.04	152.1	73.347	1.198	49.7	121.1
63.00	89.137	1.262	56.3	171.6	72.308	1.238	46.9	119.9
64.00	89.974	1.193	59.1	119	75.440	1.281	41.1	132.5
65.00	89.891	1.215	58.1	126.3	72.910	1.254	35.9	113.7
66.00	86.814	1.228	54	150.1	73.101	1.242	48.4	113.3
67.00	86.207	1.207	43.1	127.5	75.835	1.266	47.2	123.8

68.00	85.172	1.191	61.2	163.2	73.207	1.250	39.3	120.7
69.00	87.116	1.222	50.7	127.2	74.368	1.225	48	118
70.00	82.775	1.210	46.5	125.5	68.977	1.188	45.9	102.8
71.00	79.630	1.240	51	122.8	69.083	1.232	45.5	108.1
72.00	82.011	1.204	51.9	132.7	69.898	1.240	40.7	103.8
73.00	85.590	1.196	56.2	128.3	71.360	1.240	47.4	127.6
74.00	83.001	1.217	53.3	120	70.410	1.277	37.4	106.4
75.00	84.465	1.185	56.5	133.5	70.526	1.216	46.8	117.4
76.00	78.733	1.207	55.9	121.1	69.549	1.199	48.8	101.7
77.00	79.376	1.170	58.7	109.3	70.128	1.240	40.3	119.8
78.00	79.909	1.195	41.1	115.1	66.375	1.211	44.1	109.8
79.00	77.629	1.155	56.4	107.8	67.780	1.200	46.2	98.4
80.00	79.866	1.174	56	111.9	62.214	1.255	41.2	121.4
81.00	75.405	1.157	55.8	111.9	65.397	1.184	42.7	91.4
82.00	76.798	1.180	54.4	111.8	64.755	1.260	40.6	120
83.00	74.611	1.158	53.2	107	62.886	1.196	44.7	101.2
84.00	75.325	1.205	41.5	109.5	62.215	1.216	43.5	108.4
85.00	71.776	1.191	46.9	105.8	61.453	1.209	42.3	93.2
86.00	73.986494	1.17	50.57	101.07	62.400356	1.21	41.85	101.16
87.00	73.364276	1.17	50.38	99.113	61.847614	1.21	41.66	100.26
88.00	72.742058	1.16	50.19	97.154	61.294872	1.21	41.47	99.351
89.00	72.11984	1.16	50	95.194	60.74213	1.21	41.27	98.445
90.00	71.497622	1.16	49.81	93.235	60.189388	1.21	41.08	97.538
91.00	70.875404	1.16	49.62	91.276	59.636646	1.2	40.88	96.632
92.00	70.253186	1.16	49.44	89.317	59.083904	1.2	40.69	95.726
93.00	69.630968	1.15	49.25	87.358	58.531162	1.2	40.49	94.82
94.00	69.00875	1.15	49.06	85.399	57.97842	1.2	40.3	93.914
95.00	68.386532	1.15	48.87	83.44	57.425678	1.2	40.1	93.008
96.00	67.764314	1.15	48.68	81.481	56.872936	1.2	39.91	92.102
97.00	67.142096	1.14	48.49	79.522	56.320194	1.2	39.71	91.195
98.00	66.519878	1.14	48.3	77.563	55.767452	1.19	39.52	90.289
99.00	65.89766	1.14	48.11	75.604	55.21471	1.19	39.32	89.383
100.00	65.275442	1.14	47.92	73.645	54.661968	1.19	39.13	88.477

**Dark shading (age 86+) designates linear forecast.

Table 4. Body Mass Smoothed Fits (5-Year Running Averages).

Age	MALES Geometric Mean	GSD	Min	Max	FEMALES Geometric Mean	GSD	Min	Max
0.00	7.767209794	1.300901	3.6	11.8	7.428916349	1.304229	3.7	12.1
1.00	11.44008024	1.143324	8.2	16.1	11.11947416	1.162608	7.4	15.3
2.00	13.93227373	1.145566	9.8	20.9	13.25797158	1.158434	10.1	20.4
3.00	15.96664726	1.153689	11.7	23.7	15.58684049	1.159883	11	27.9
4.00	18.47458493	1.164972	11.1	28.1	18.00506307	1.17108	12.8	29.1
5.00	21.61756114	1.233822	13.7	42.4	20.35285099	1.229237	12.6	40.4

6.00	23.14243627	1.213499	16.1	41.1	22.45431948	1.194119	15.9	36.7
7.00	27.07246068	1.215834	19.3	46.8	26.48323788	1.23892	16.9	51
8.00	31.6505017	1.301873	19.1	66.2	30.53391399	1.315137	19.8	60.8
9.00	34.65600448	1.265317	24	69.9	35.23472141	1.271364	20.3	58.6
10.00	38.32939135	1.279707	24.3	72.9	40.54996835	1.303997	22.7	71.2
11.00	44.14863459	1.30753	26.2	83.8	46.57910267	1.302182	27.7	84.6
12.00	47.98795299	1.314848	27.7	94.8	50.67329267	1.273946	27.8	93.3
13.00	55.36374737	1.33952	27.7	106.6	56.64881107	1.275455	33.4	99.5
14.00	62.83159173	1.292533	35.7	121	57.21362103	1.24795	37.7	110
15.00	67.65031426	1.254999	41.5	117.9	60.09135575	1.24897	34.9	108.4
16.00	72.45980541	1.267468	45.8	139.1	61.58214656	1.255162	40.9	113.8
17.00	73.08089659	1.248405	49.9	136.6	61.22931022	1.248057	41.5	133.1
18.00	75.06031573	1.243204	51.2	144.2	64.59054256	1.281298	42.4	123.6
19.00	77.18236513	1.244928	52.6	134.5	66.15556407	1.274083	41.6	118.5
20.00	77.95205826	1.250326	50.5	130	66.98146906	1.261822	41.5	122.6
21.00	78.45564692	1.265585	50.88	152.66	66.35375002	1.270386	41.44	122.38
22.00	79.56489519	1.261251	50.74	151.34	67.37976393	1.274844	41.02	126.26
23.00	80.46958232	1.262527	50.34	150.96	68.20537834	1.277813	42.2	131.46
24.00	81.84267254	1.253588	50.28	152.18	68.06901959	1.282127	42.86	133.3
25.00	82.55729313	1.248802	50.7	145.24	69.21992781	1.285979	43.98	134.34
26.00	82.82151847	1.240222	50.04	144.94	69.97607936	1.287735	43.86	137.82
27.00	83.56439112	1.250399	50.14	150.86	70.90453453	1.289413	44.66	137.64
28.00	83.65195203	1.247428	50.14	153.78	70.66975978	1.28161	43.02	132
29.00	83.00459482	1.258753	50.6	154.36	71.53295767	1.285847	42.48	135.94
30.00	82.89721864	1.253937	50.58	155.58	71.54621552	1.285108	42.16	135.34
31.00	82.80701235	1.251132	50.52	151.96	72.01313142	1.28495	42.18	135.1
32.00	83.58034187	1.242848	53.28	147.78	71.6826276	1.283915	42.3	133.72
33.00	83.38418057	1.239735	53.78	145.72	71.81523165	1.280002	43.76	133.52
34.00	84.50647805	1.237533	55.48	156.58	72.30094254	1.280205	44.18	130.9
35.00	84.9321819	1.233184	54.88	150.56	72.40264379	1.282492	44.36	135.74
36.00	85.14102649	1.234298	56.8	153.58	71.81884258	1.283151	45.68	138.22
37.00	84.32994666	1.240177	54.4	154.26	72.3941641	1.280709	45.44	141.52
38.00	85.01958212	1.235131	56.02	155	72.89859355	1.284821	44.44	143.08
39.00	85.59524544	1.233983	55.52	147.14	72.86733489	1.281407	44.7	142.88
40.00	86.39949423	1.223065	58.62	142.58	72.830387	1.277165	45.88	144.24
41.00	86.90564401	1.215924	59.2	141.2	73.56585153	1.274483	45.68	143.04
42.00	87.76379051	1.210495	59.44	140.32	73.13604869	1.278433	46.06	144.6
43.00	88.54719729	1.211458	58.52	137.98	73.82543503	1.281514	47.64	150.58
44.00	87.95342484	1.203416	58.94	139.22	74.60684165	1.285327	46.86	151.4
45.00	88.09985934	1.217379	57.52	146.54	75.44302619	1.292445	46.08	149.18
46.00	87.751282	1.222211	55.06	155.4	75.27348935	1.29795	46.22	146.08
47.00	87.02523405	1.212835	55.52	152	75.51517243	1.295658	45.94	147.38
48.00	86.56661258	1.220669	53.6	160.48	74.93569966	1.29459	45.06	141.888
49.00	86.07815707	1.215489	52.16	153.32	74.62001355	1.291492	46.42	148.728
50.00	86.04175058	1.208607	52.9	151.18	73.69947055	1.278764	45.6	143.608
51.00	86.70964624	1.206031	53.96	142.5	74.02400492	1.27574	45.18	146.808
52.00	87.55345712	1.2144	54.34	145.5	74.04127315	1.266893	45.58	148.928
53.00	88.32616726	1.209663	57.76	142.28	73.95491798	1.270898	45.42	148.44
54.00	89.04784314	1.218268	58.1	145.12	74.10188224	1.25873	46.46	138.42
55.00	88.4120991	1.215526	55.52	138.46	74.97813364	1.273724	47.08	141.36

56.00	87.93495739	1.222906	56.14	141.48	74.55937637	1.267547	47.66	136.56
57.00	87.15584772	1.230391	54.82	148.62	74.52242942	1.269258	47.42	124.78
58.00	85.97418819	1.223617	53.74	140.06	76.16748501	1.268509	48.74	126.76
59.00	85.72952642	1.22558	54.18	140.68	76.13252691	1.274205	48.28	127.3
60.00	86.57173577	1.228074	55.16	151.18	76.09221736	1.259138	49.3	125.44
61.00	86.0292098	1.222944	54.708	149.6	76.28599922	1.248419	49.52	125.14
62.00	86.83331368	1.22222	55.648	148.12	75.83796229	1.242552	49.9	125.58
63.00	87.99005122	1.224363	55.728	149.44	74.79845832	1.243365	47.94	125.48
64.00	88.55927286	1.220869	55.888	146.36	74.22522224	1.242246	44.86	122.56
65.00	88.12051692	1.225034	56.708	143.82	73.42130739	1.242692	44.4	120.1
66.00	88.40439667	1.220898	54.12	138.9	73.91902253	1.256261	43.9	120.64
67.00	87.61146369	1.206714	55.1	137.22	74.09892054	1.258602	42.38	120.8
68.00	87.03986775	1.212565	53.42	138.86	73.88448789	1.247351	43.76	117.9
69.00	85.61667034	1.211601	51.1	138.7	73.09783811	1.234088	45.76	115.72
70.00	84.17987726	1.213949	50.5	133.24	72.29417333	1.23216	45.18	114.68
71.00	83.34052655	1.213444	52.26	134.28	71.10679374	1.227009	43.88	110.68
72.00	83.42413149	1.214423	51.26	127.3	70.73734313	1.225132	45.5	112.06
73.00	82.60108145	1.213508	51.78	125.86	69.94568967	1.235452	43.38	109.74
74.00	82.93914453	1.208433	53.78	127.46	70.25540111	1.241	43.56	112.66
75.00	82.75981666	1.201809	54.76	127.12	70.34868617	1.23444	44.22	111.38
76.00	82.23282472	1.19492	56.12	122.44	70.39465694	1.234265	44.14	114.58
77.00	81.09670348	1.194698	53.1	119.8	69.39757689	1.228511	43.48	111.02
78.00	80.02242628	1.182282	53.72	117.36	68.87151054	1.213229	45.24	109.42
79.00	79.10265965	1.180128	53.62	113.04	67.20924709	1.221048	44.12	110.22
80.00	78.43698141	1.170309	53.6	111.2	66.37891246	1.217987	42.9	108.16
81.00	77.92142176	1.17229	52.74	111.7	65.30424541	1.222093	42.96	108.2
82.00	76.86173441	1.164819	55.16	110.08	64.60647334	1.219074	43.08	106.48
83.00	76.40090269	1.174796	52.18	110.42	63.49351577	1.22226	42.54	108.48
84.00	74.7828307	1.17822	50.36	109.2	63.34131978	1.213219	42.76	102.84
85.00	74.4992137	1.180574	49.31362	107.0343	62.74189138	1.218822	42.59095	104.7926
86.00	73.81250877	1.177977	48.50949	104.4969	62.16041309	1.208932	42.80295	100.844
87.00	73.43871959	1.179377	47.90759	102.5276	61.84223228	1.211505	42.15598	100.4742
88.00	72.79767378	1.170756	49.60794	99.66646	61.5476723	1.209819	41.71005	98.48308
89.00	72.74205786	1.164535	50.19052	97.15354	61.29487188	1.209189	41.46516	99.35077
90.00	72.11983988	1.162177	50.00172	95.19446	60.74212987	1.207753	41.27036	98.44462
91.00	71.4976219	1.159818	49.81292	93.23538	60.18938785	1.206317	41.07556	97.53846
92.00	70.87540393	1.157459	49.62412	91.27631	59.63664584	1.20488	40.88075	96.63231
93.00	70.25318595	1.1551	49.43532	89.31723	59.08390383	1.203444	40.68595	95.72615
94.00	69.63096798	1.152742	49.24652	87.35815	58.53116181	1.202008	40.49115	94.82
95.00	69.00875	1.150383	49.05772	85.39908	57.9784198	1.200571	40.29634	93.91385
96.00	68.38653203	1.148024	48.86892	83.44	57.42567778	1.199135	40.10154	93.00769
97.00	67.76431405	1.145665	48.68012	81.48092	56.87293577	1.197699	39.90674	92.10154
98.00	67.14209607	1.143307	48.49132	79.52185	56.32019375	1.196263	39.71193	91.19538
99.00	66.5198781	1.140948	48.30252	77.56277	55.76745174	1.194826	39.51713	90.28923
100.00	66.20876911	1.139769	48.20812	76.58323	55.49108073	1.194108	39.41973	89.83615

Table 5. Hemoglobin Content.

Age	MALES MEAN	STD	FEMALES	
0	11.927	0.993545	12.209	0.729499905
1	12.20959	1.013091	12.27307	0.719158646
2	12.42075	0.823171	12.55018	0.843436666
3	12.69015	0.83159	12.4519	0.965868504
4	12.8006	0.80152	12.83442	0.773409545
5	12.95822	0.878515	12.87154	0.969254536
6	13.19574	0.893008	13.01866	0.828912341
7	13.46198	0.836639	13.09899	0.754370806
8	13.35161	0.833121	13.25291	0.826349227
9	13.59742	0.971019	13.36671	0.808377267
10	13.63062	0.906785	13.58919	1.034306588
11	13.66	0.726155	13.52681	0.90041802
12	13.9727	0.955869	13.6273	0.884271668
13	14.28293	1.036749	13.46986	0.97623121
14	14.70654	1.020254	13.58878	1.034527514
15	15.13583	1.04546	13.47154	0.856131982
16	15.36442	1.021623	13.50562	1.088863466
17	15.45945	0.979296	13.49842	1.117860417
18	15.7487	1.02514	13.46091	1.18250671
19	15.76812	0.831813	13.35445	1.090493585
20	15.79371	0.880956	13.5016	1.072791517
25	15.71703	0.91072	13.47168	1.170602542
30	15.70837	1.045808	13.2967	1.145254677
35	15.55635	0.959964	13.34583	1.134192006
40	15.43525	1.021741	13.4881	1.163867696
45	15.44038	1.105939	13.48617	1.348669176
50	15.41492	1.096952	13.61113	1.193756618
55	15.31983	1.123792	13.67737	1.106237392
60	15.27653	0.97796	13.83717	1.237714453
65	15.07274	1.192645	13.76529	1.093354796
70	14.96193	1.24457	13.81911	1.093565513
75	14.72786	1.418355	13.79013	1.056812752
80	14.51	1.476879	13.84426	1.30818261
85	14.52915	1.352814	13.57546	1.238910845
90	13.97647	1.757686	13.43767	1.552685662
95	13.801	1.757686	13.2085	1.552685662
100	13.534	1.757686	13.005	1.552685662

ATTACHMENT 4. TECHNICAL MEMORANDUM ON LONGITUDINAL DIARY CONSTRUCTION APPROACH

INTERNATIONAL

TECHNICAL MEMORANDUM

TO: Stephen Graham and John Langstaff, US EPA

FROM: Arlene Rosenbaum

DATE: February 29, 2008

SUBJECT: The Cluster-Markov algorithm in APEX

Background

The goals of population exposure assessment generally include an accurate estimate of both the average exposure concentration and the high end of the exposure distribution. One of the factors influencing the number of exposures at the high end of the concentration distribution is time-activity patterns that differ from the average, e.g., a disproportionate amount of time spent near roadways. Whether a model represents these exposure scenarios well depends on whether the treatment of activity pattern data accurately characterizes differences among individuals.

Human time-activity data for population exposure models are generally derived from demographic surveys of individuals' daily activities, the amount of time spent engaged in those activities, and the ME locations where the activities occur. Typical time-activity pattern data available for inhalation exposure modeling consist of a sequence of location/activity combinations spanning a 24-hour duration, with 1 to 3 records for any single individual. But modeling assessments of exposure to air pollutants typically require information on activity patterns over long periods of time, e.g., a full year. For example, even for pollutant health effects with short averaging times (e.g., ozone 8-hour average) it may be desirable to know the frequency of exceedances of a threshold concentration over a long period of time (e.g., the annual number of exceedances of an 8-hour average ozone concentration of 0.07 ppm for each simulated individual).

Long-term activity patterns can be estimated from daily ones by combining the daily records in various ways, and the method used for combining them will influence the variability of the long-term activity patterns across the simulated population. This in turn will influence the ability of the model to accurately represent either long-term average high-end exposures, or the number of individuals exposed multiple times to short-term high-end concentrations.

A common approach for constructing long-term activity patterns from short-term records is to re-select a daily activity pattern from the pool of data for each day, with the implicit assumption that there is no correlation between activities from day to day for the simulated individual. This approach tends to result in long-term activity patterns that are very similar across the simulated population. Thus, the resulting exposure estimates are likely to underestimate the variability across the population, and therefore, underestimate the high-end concentrations.

A contrasting approach is to select a single activity pattern (or a single pattern for each season and/or weekday-weekend) to represent a simulated individual's activities over the modeling period. This approach has the implicit assumption that an individual's day to day activities are perfectly correlated. This approach tends to result in long-term activity patterns that are very different across the simulated population, and therefore may over-estimate the variability across the population.

The Cluster-Markov Algorithm

Recently, a new algorithm has been developed and incorporated into APEX that attempts to more realistically represent the day-to-day correlation of activities for individuals. The algorithms first use cluster analysis to divide the daily activity pattern records into groups that are similar, and then select a single daily record from each group. This limited number of daily patterns is then used to construct a long-term sequence for a simulated individual, based on empirically-derived transition probabilities. This approach is intermediate between the assumption of no day-to-day correlation (i.e., re-selection for each time period) and perfect correlation (i.e., selection of a single daily record to represent all days).

The steps in the algorithm are as follows.

- For each demographic group (age, gender, employment status), temperature range, and day-of-week combination, the associated time-activity records are partitioned into 3 groups using cluster analysis. The clustering criterion is a vector of 5 values: the time spent in each of 5 microenvironment categories (indoors – residence; indoors – other building; outdoors – near road; outdoors – away from road; in vehicle).
- For each simulated individual, a single time-activity record is randomly selected from each cluster.
- Next the Markov process determines the probability of a given time-activity pattern occurring on a given day based on the time-activity pattern of the previous day and cluster-to-cluster transition probabilities. The cluster-to-cluster transition probabilities are estimated from the available multi-day time-activity records. (If insufficient multi-day time-activity records are available for a demographic group, season, day-of-week combination, then the cluster-to-cluster transition probabilities are estimated from the frequency of time-activity records in each cluster in the CHAD data base.).

Figure 1 illustrates the Cluster-Markov algorithm in flow chart format.

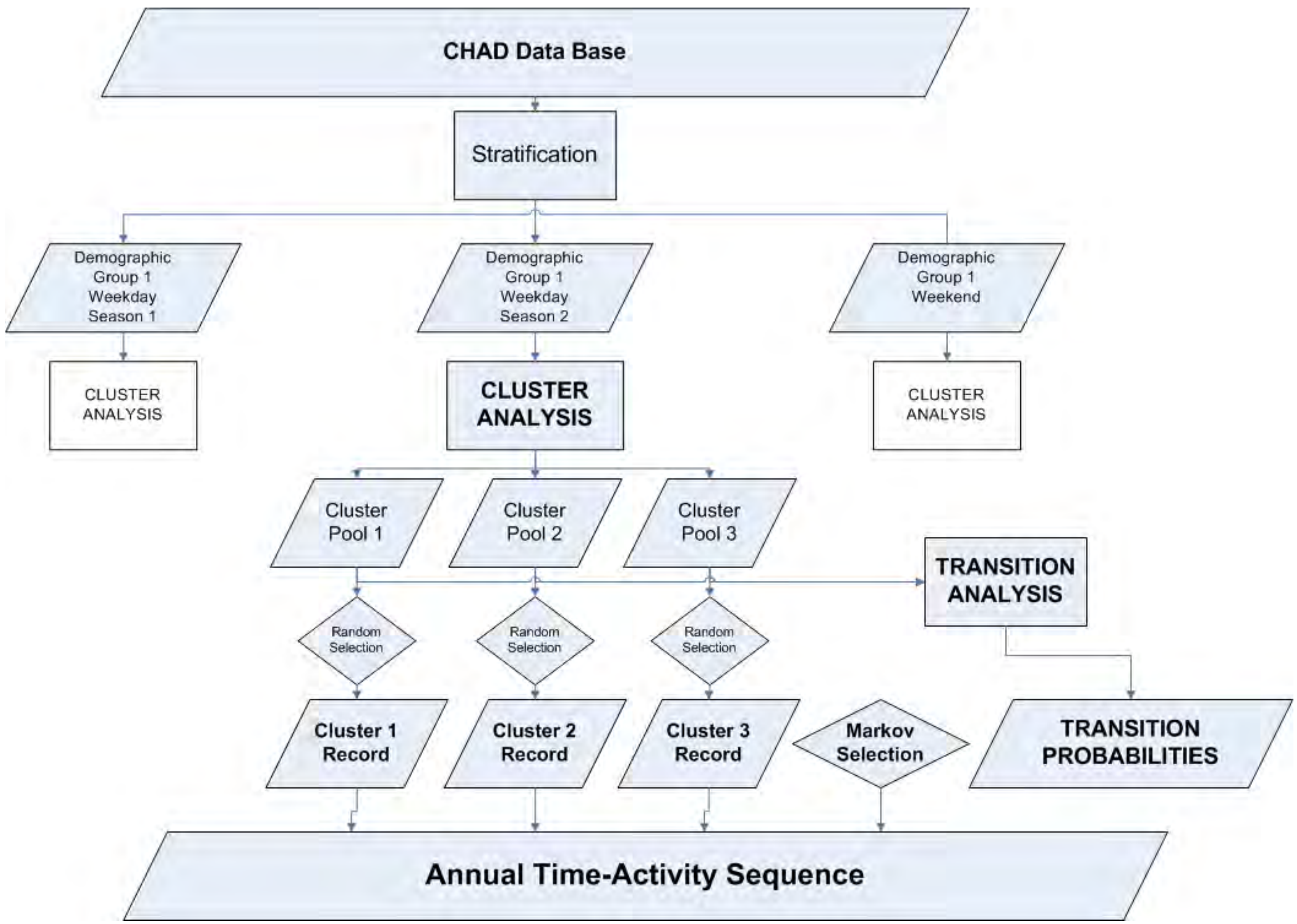

Figure 1. Flow chart of Cluster-Markov algorithm used for constructing longitudinal time-activity diaries.

Evaluation of modeled diary profiles versus observed diary profiles

The Cluster-Markov algorithm is also incorporated into the Hazardous Air Pollutant Exposure Model (HAPEM). Rosebaum and Cohen (2004) incorporated the algorithm in HAPEM and tested modeled longitudinal profiles with multi-day diary data sets collected as part of the Harvard Southern California Chronic Ozone Exposure Study (Xue et al. 2005, Geyh et al. 2000). In this study, 224 children in ages between 7 and 12 yr were followed for 1 year from June 1995 to May 1996, for 6 consecutive days each month. The subjects resided in two separate areas of San Bernardino County: urban Upland CA, and the small mountain towns of Lake Arrowhead, Crestline, and Running Springs, CA.

For purposes of clustering the activity pattern records were characterized according to time spent in each of 5 aggregate microenvironments: indoors-home, indoors-school, indoors-other, outdoors, and in-transit. For purposes of defining diary pools and for clustering and calculating transition probabilities the activity pattern records were divided by day type (i.e., weekday, weekend), season (i.e., summer or ozone season, non-summer or non-ozone season), age (7-10 and 11-12), and gender.

Week-long sequences (Wednesday through Tuesday) for each of 100 people in each age/gender group for each season were simulated. To evaluate the algorithm the following statistics were calculated for the predicted multi-day activity patterns and compared them with the actual multi-day diary data.

- For each age/gender group for each season, the average time in each microenvironment
- For each simulated person-week and microenvironment, the average of the within-person variance across all simulated persons. (The within-person variance was defined as the variance of the total time per day spent in the microenvironment across the week.)
- For each simulated person-week the variance across persons of the mean time spent in each microenvironment.

In each case the predicted statistic for the stratum was compared to the statistic for the corresponding stratum in the actual diary data. The mean normalized bias for the statistic, which is a common performance measure used in dispersion model performance and was also calculated as follows.

$$NBIAS = \frac{100}{N}\sum_{1}^{N}\frac{(predicted - observed)}{observed}$$

The predicted time-in-microenvironment averages matched well with the observed values. For combinations of microenvironment/age/gender/season the normalized bias ranges from –35% to +41%. Sixty percent of the predicted averages have bias between –9% and +9%, and the mean bias across any microenvironment ranges from -9% to +4%. Fourteen predictions have positive bias and 23 have negative bias.

For the variance across persons for the average time spent in each microenvironment, the bias ranged from –40% to +120% for any microenvironment/age/gender/season. Sixty-five percent of the predicted variances had bias between –22% and +24%. The mean normalized bias across any microenvironment ranged from –10% to +28%. Eighteen predictions had positive bias and 20 had negative bias.

For the within-person variance for time spent in each microenvironment, the bias ranged from –47% to +150% for any microenvironment/age/gender/season. Seventy percent of the predicted variances had bias between –25% and +30%. The mean normalized bias across any microenvironment ranged from –11% to +47%. Twenty-eight predictions had positive bias and 12 had negative bias, suggesting some tendency for overprediction of this variance measure.

The overall conclusion was that the proposed algorithm appeared to be able to replicate the observed data reasonably well. Although some discrepancies were rather large for some of the “variance across persons” and “within-person variance” subsets, about two-thirds of the predictions for each case were within 30% of the observed value. A detailed description of the evaluation using HAPEM is presented in Attachment 5.

Comparison of Cluster-Markov approach with other algorithms

As part of the application of APEX in support of US EPA’s recent review of the ozone NAAQS several sensitivity analyses were conducted (US EPA, 2007). One of these was to make parallel simulations using each of the three algorithms for constructing multi-day time-activity sequences that are incorporated into APEX.

Table 1 presents the results for the number of persons in Atlanta population groups with moderate exertion exposed to 8-hour average concentrations exceeding 0.07 ppm. The results show that the predictions made with alternative algorithm Cluster-Markov algorithm are substantially different from those made with simple re-sampling or with the Diversity-Autocorrelation algorithm (“base case”). Note that for the cluster algorithm approximately 30% of the individuals with 1 or more exposure have 3 or more exposures. The corresponding values for the other algorithms range from about 13% to 21%.

Table 2 presents the results for the mean and standard deviation of number of days/person with 8-hour average exposures exceeding 0.07 ppm with moderate or greater exertion. The results show that although the mean for the Cluster-Markov algorithm is similar to the other approaches, the standard deviation is substantially higher, i.e., the Cluster-Markov algorithm results in substantially higher inter-individual variability.

Table 1. Sensitivity to longitudinal diary algorithm: 2002 simulated counts of Atlanta general population and children (ages 5-18) with any or three or more 8-hour ozone exposures above 0.07 ppm concomitant with moderate or greater exertion (after US EPA 2007).

Population Group	One or more exposures			Three or more exposures		
	Simple re-sampling	**Diversity-Autocorrelation**	**Cluster-Markov**	**Simple re-sampling**	**Diversity-Autocorrelation**	**Cluster-Markov**
General Population	979,533	939,663 (-4%)	668,004 (-32%)	124,687	144,470 (+16%)	188,509 (+51%)
Children (5-18)	411,429	389,372 (-5%)	295,004 (-28%)	71,174	83,377 (+17%)	94,216 (+32%)

Table 2. Sensitivity to longitudinal diary algorithm: 2002 days per person with 8-hour ozone exposures above 0.07 ppm concomitant with moderate or greater exertion for Atlanta general population and children (ages 5-18) (after US EPA 2007).

Population Group	Mean Days/Person			Standard Deviation		
	Simple re-sampling	**Base case**	**Cluster-Markov**	**Simple re-sampling**	**Base case**	**Cluster-Markov**
General Population	0.332	0.335 (+1%)	0.342 (+3%)	0.757	0.802 (+6%)	1.197 (+58%)
Children (5-18)	0.746	0.755 (+1%)	0.758 (+2%)	1.077	1.171 (+9%)	1.652 (+53%)

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ATTACHMENT 5. TECHNICAL MEMORANDUM ON THE EVALUATION CLUSTER-MARKOV ALGORITHM

TECHNICAL MEMORANDUM

TO: Ted Palma, US EPA

FROM: Arlene Rosenbaum and Jonathan Cohen, ICF Consulting

DATE: November 4, 2004

SUBJECT: Evaluation of a multi-day activity pattern algorithm for creating longitudinal activity patterns.

BACKGROUND

In previous work ICF reviewed the HAPEM4 modeling approach for developing annual average activity patterns from the CHAD database and recommended an approach to improve the model's pattern selection process to better represent the variability among individuals. This section summarizes the recommended approach. (For details see Attachment 4)

Using cluster analysis, first the CHAD daily activity patterns are grouped into either two or three categories of similar patterns for each of the 30 combinations of day type (summer weekday, non-summer weekday, and weekend) and demographic group (males or females; age groups: 0-4, 5-11, 12-17, 18-64, 65+). Next, for each combination of day type and demographic group, category-to-category transition probabilities are defined by the relative frequencies of each second-day category associated with each given first-day category, where the same individual was observed for two consecutive days. (Consecutive day activity pattern records for a single individual constitute a small subset of the CHAD data.)

To implement the proposed algorithm, for each day type and demographic group, one daily activity pattern per category is randomly selected from the corresponding CHAD data to represent that category. That is, if there are 3 cluster categories for each of 3 day types, 9 unique activity patterns are selected to be averaged together to create an annual average activity pattern to represent an individual in a given demographic group and census tract.

The weighting for each of the 9 activity patterns used in the averaging process is determined by the product of two factors. The first is the relative frequency of its day type, i.e., 0.18 for summer weekdays, 0.54 for non-summer weekdays, and 0.28 for weekends.

The second factor in the weighting for the selected activity pattern is determined by simulating a sequence of category-types as a one-stage Markov chain process using the transition probabilities. The category for the first day is selected according to the relative frequencies of each category. The category for the second day is selected according to the category-to-category transition probabilities for the category selected for the first day. The category for the third day is selected according to the transition probabilities for the category selected for the second day. This is repeated for all days in the day type (65 for summer weekdays, 195 for non-summer weekdays, 104 for weekends), producing a sequence of daily categories. The relative frequency of the category-type in the sequence associated with the selected activity pattern is the second factor in the weighting.

PROPOSED ALGORITHM STEPS

The proposed algorithm is summarized in Figure 1. Each step is explained in this section.

Data Preparation

Step 1: Each daily activity pattern in the CHAD data base is summarized by the total minutes in each of five micro-environments: indoors – residence; indoors – other building; outdoors – near road; outdoors – away from road; in vehicle. These five numbers are assumed to represent the most important features of the activity pattern for their exposure impact.

Step 2: All CHAD activity patterns for a given day-type and demographic group are subjected to cluster analysis, resulting in 2 or 3 cluster categories. Each daily activity pattern is tagged with a cluster category.

Step 3: For each day-type and demographic group, the relative frequency of each day-type in the CHAD data base is determined.

Step 4: All CHAD activity patterns for a given day-type and demographic group that are consecutive days for a single individual, are analyzed to determine the category-to-category transition frequencies in the CHAD data base. These transition frequencies are used to calculate category-to-category transition probabilities.

For example, if there are 2 categories, A and B, then

P_{AA} = the probability that a type A pattern is followed by a type A pattern,

P_{AB} = the probability that a type A pattern is followed by a type B pattern ($P_{AB} = 1 - P_{AA}$),

P_{BB} = the probability that a type B pattern is followed by a type B pattern, and

P_{BA} = the probability that a type B pattern is followed by a type A pattern ($P_{BA} = 1 - P_{BB}$).

Activity Pattern Selection

For each day-type and demographic group in each census tract:

Step 5: One activity pattern is randomly selected from each cluster category group (i.e., 2 to 3 activity patterns)

Creating Weights for Day-type Averaging

For each day-type and demographic group in each census tract:

Step 6: A cluster category is selected for the first day of the day-type sequence, according to the relative frequency of the cluster category days in the CHAD data set.

Step 7: A cluster category is selected for each subsequent day in the day-type sequence day by day using the category-to-category transition probabilities.

Step 8: The relative frequency of each cluster category in the day-type sequence is determined.

Step 9: The activity patterns selected for each cluster category (Step 5) are averaged together using the cluster category frequencies (Step 8) as weights, to create a day-type average activity pattern.

Creating Annual Average Activity Patterns

For each demographic group in each census tract:

Step 10: The day-type average activity patterns are averaged together using the relative frequency of day-types as weights, to create an annual average activity pattern.

Creating Replicates

For each demographic group in each census tract:

Step 11: Steps 5 through 10 are repeated 29 times to create 30 annual average activity patterns.

EVALUATING THE ALGORITHM

The purpose of this study is to evaluate how well the proposed one-stage Markov chain algorithm can reproduce observed multi-day activity patterns with respect to demographic group means and inter-individual variability, while using one-day selection.

In order to accomplish this we propose to apply the algorithm to observed multi-day activity patterns provided by the WAM, and compare the means and variances of the predicted multi-day patterns with the observed patterns.

Current APEX Algorithm

Because the algorithm is being considered for incorporation into APEX, we would like the evaluation to be consistent with the approach taken in APEX for selection of activity patterns for creating multi-day sequences. The APEX approach for creating multi-day activity sequences is as follows.

Step1: A profile for a simulated individual is generated by selection of gender, age group, and home sector from a given set of distributions consistent with the population of the study area.

Step 2: A specific age within the age group is selected from a uniform distribution.

Step 3: The employment status is simulated as a function of the age.

Step 4: For each simulated day, the user defines an initial pool of possible diary days based on a user-specified function of the day type (e.g., weekday/weekend) and temperature.

Step 5: The pool is further restricted to match the target gender and employment status exactly and the age within 2A years for some parameter A. The diary days within the pool are assigned a weight of 1 if the age is within A years of the target age and a weight of w (user-defined parameter) if the age difference is between A and 2A years. For each simulated day, the probability of selecting a given diary day is equal to the age weight divided by the total of the age weights for all diary days in the pool for that day.

Approach to Incorporation of Day-to-Day Dependence into APEX Algorithm

If we were going to incorporate day-to-day dependence of activity patterns into the APEX model, we would propose preparing the data with cluster analysis and transition probabilities as described in Steps 1-4 for the proposed HAPEM 5 algorithm, with the following modifications.

- For Step 2 the activity patterns would be divided into groups based on day-type (weekday, weekend), temperature, gender, employment status, and age, with cluster analysis applied to each group. However, because the day-to-day transitions in the APEX activity selection algorithm can cross temperature bins, we would propose to use broad temperature bins for the clustering and transition probability calculations so that the cluster definitions would be fairly uniform across temperature bins. Thus we would probably define the bins according to season (e.g., summer, non-summer).
- In contrast to HAPEM, the sequence of activity patterns may be important in APEX. Therefore, for Step 4 transition probabilities would be specified for transitions between days with the same day-type and season, as in HAPEM, and also between days with different day-types and/or seasons. For example, transition probabilities would be specified for transitions between summer weekdays of each category and summer weekends of each category.

Another issue for dividing the CHAD activity records for the purposes of clustering and calculating transition probabilities is that the diary pools specified for the APEX activity selection algorithm use varying and overlapping age ranges. One way to address this problem would be to simply not include consideration of age in the clustering process, under the assumption that cluster categories are similar across age groups, even if the frequency of each cluster category varies by age group. This assumption could be tested by examination of the cluster categories stratified by age group that were developed for HAPEM5. If the assumption is found to be valid, then the cluster categories could be pre-determined for input to APEX, while the transition probabilities could be calculated within APEX during the simulation for each age range specified for dairy pools.

If the assumption is found to be invalid, then an alternative approach could be implemented that would create overlapping age groups for purposes of clustering as follows. APEX age group ranges and age window percentages would be constrained to some maximum values. Then a set of overlapping age ranges that would be at least as large as the largest possible dairy pool age ranges would be defined for the purposes of cluster analysis and transition probability calculation. The resulting sets of cluster categories and transition probabilities would be pre-determined for input into APEX and the appropriate set used by APEX for each diary pool used during the simulation.

The actual activity pattern sequence selection would be implemented as follows. The activity pattern for first day in the year would be selected exactly as is currently done in APEX, as described above. For the selecting the second day's activity pattern, each age weight would be multiplied by the transition probability P_{AB} where A is the cluster for the first day's activity pattern and B is the cluster for a given activity pattern in the available pool of diary days for day 2. (Note that day 2 may be a different day-type and/or season than day 1). The probability of selecting a given diary day on day 2 is equal to the age weight times P_{AB} divided by the total of the products of age weight and P_{AB} for all diary days in the pool for day 2. Similarly, for the transitions from day 2 to day 3, day 3 to day 4, etc.

Testing the Approach with the Multi-day Data set

We tested this approach using the available multi-day data set. For purposes of clustering we characterized the activity pattern records according to time spent in each of 5 microenvironments: indoors-home, indoors-school, indoors-other, outdoors (aggregate of the 3 outdoor microenvironments), and in-transit.

For purposes of defining diary pools and for clustering and calculating transition probabilities we divided the activity pattern records by day type (i.e., weekday, weekend), season (i.e., summer or ozone season, non-summer or non-ozone season), age (6-10 and 11-12), and gender. Since all the subjects are 6-12 years of age and all are presumably unemployed, we need not account for differences in employment status. For each day type, season, age, and gender, we found that the activity patterns appeared to group in three clusters.

In this case, we simulated week-long sequences (Wednesday through Tuesday) for each of 100 people in each age/gender group for each season, using the transition probabilities. To evaluate the algorithm we calculated the following statistics for the predicted multi-day activity patterns for comparison with the actual multi-day diary data.

- For each age/gender group for each season, the average time in each microenvironment
- For each age/gender group, season, and microenvironment, the average of the within-person variance across all simulated persons (We defined the within-

person variance as the variance of the total time per day spent in the microenvironment across the week.)

- For each age/gender group, season, and microenvironment, the variance across persons of the mean time spent in that microenvironment

In each case we compared the predicted statistic for the stratum to the statistic for the corresponding stratum in the actual diary data.5

We also calculated the mean normalized bias for the statistic, which is a common performance measure used in dispersion model performance and which is calculated as follows.

$$NBIAS = \frac{100}{N}\sum_{1}^{N}\frac{(predicted - observed)}{observed} \quad \%$$

RESULTS

Comparisons of simulated and observed data for time in each of the 5 microenvironments are presented in Tables 1 – 3 and Figures 2-5.

Average Time in Microenvironment

Table 1 and Figure 2 show the comparisons for the average time spent in each of the 5 microenvironments for each age/gender group and season. Figure 3 shows the comparison for all the microenvironments except indoor, home in order to highlight the lower values.

Table 1 and the figures show that the predicted time-in-microenvironment averages match well with the observed values. For combinations of microenvironment/age/gender/season the normalized bias ranges from –35% to +41%. Sixty percent of the predicted averages have bias between –9% and +9%, and the mean bias across any microenvironment ranges from -9% to +4%. Fourteen predictions have positive bias and 23 have negative bias. A Wilcoxon signed rank test that the median bias across the 40 combinations = 0 % was not significant (p-value = 0.40) supporting the conclusion of no overall bias.

Variance Across Persons

Table 2 and Figure 4 show the comparisons for the variance across persons for the average time spent in each microenvironment. In this case the bias ranges from –40% to +120% for any microenvironment/age/gender/season. Sixty-five percent of the predicted variances have bias between –22% and +24%. The mean normalized bias across any microenvironment ranges from –10% to +28%. Eighteen predictions have positive bias and 20 have negative bias. Figure 4 suggests a reasonably good match of predicted to observed

5 For the diary data, because the number of days per person varies, the average of the within-person variances was calculated as a weighted average, where the weight is the degrees of freedom, i.e., one less than the number of days simulated. Similarly, the variance across persons of the mean time was appropriately adjusted for the different degrees of freedom using analysis of variance.

variance in spite of 2 or 3 outliers. A Wilcoxon signed rank test that the median bias across the 40 combinations = 0 % was not significant (p-value = 0.93) supporting the conclusion of no overall bias.

Within-Person Variance for Persons

Table 3 and Figure 5 show the comparisons for the within-person variance for time spent in each microenvironment. In this case the bias ranges from –47% to +150% for any microenvironment/age/gender/season. Seventy percent of the predicted variances have bias between –25% and +30%. The mean normalized bias across any microenvironment ranges from –11% to +47%. Twenty-eight predictions have positive bias and 12 have negative bias, suggesting some tendency for overprediction of this variance measure. And indeed a Wilcoxon signed rank test that the median bias across the 40 combinations = 0 % was very significant (p-value = 0.01) showing that the within-person variance was significantly overpredicted. Still, Figure 4 suggests a reasonably good match of predicted to observed variance in most cases, with a few overpredicting outliers at the higher end of the distribution. So although the positive bias is significant in a statistical sense (i.e., the variance is more likely to be overpredicted than underpredicted), it is not clear whether the bias is large enough to be important.

CONCLUSIONS

The proposed algorithm appears to be able to replicate the observed data reasonably well, although the within-person variance is somewhat overpredicted.

It would be informative to compare this algorithm with the earlier alternative approaches in order to gain perspective on the degree of improvement, if any, afforded by this approach.

Two earlier approaches were:

1. Select a single activity pattern for each day-type/season combination from the appropriate set, and use that pattern for every day in the multi-day sequence that corresponds to that day-type and season.
2. Re-select an activity pattern for each day in the multi-day sequence from the appropriate set for the corresponding day-type and season.

Goodness-of-fit statistics could be developed to compare the three approaches and find which model best fits the data for a given stratum.

Table 1. Average time spent in each microenvironment: comparison of predicted and observed.

Microenvironment	Demographic Group	Season	Observed (hours/day)	*Predicted* (hours/day)	Normalized Bias
Indoor, home	Girls, 6-10	Summer	15.5	16.5	6%
		Not Summer	15.8	15.5	-2%
	Boys, 6-10	Summer	15.7	15.2	-3%
		Not Summer	15.8	16.4	4%
	Girls, 11-12	Summer	16.2	15.3	-5%
		Not Summer	16.5	16.5	0%
	Boys, 11-12	Summer	16.0	15.6	-3%
		Not Summer	16.2	16.1	-1%
	MEAN				-1%
Indoor, school	Girls, 6-10	Summer	0.7	0.7	-9%
		Not Summer	2.3	2.5	7%
	Boys, 6-10	Summer	0.8	0.5	-34%
		Not Summer	2.2	2.2	0%
	Girls, 11-12	Summer	0.7	0.7	6%
		Not Summer	2.1	2.4	13%
	Boys, 11-12	Summer	0.6	0.9	38%
		Not Summer	2.4	2.7	11%
	MEAN				4%
Indoor, other	Girls, 6-10	Summer	2.9	2.4	-14%
		Not Summer	2.4	2.7	13%
	Boys, 6-10	Summer	2.2	2.7	21%
		Not Summer	1.9	1.8	-3%
	Girls, 11-	Summer	2.2	1.6	-25%

	12				
		Not Summer	2.2	2.1	-2%
	Boys, 11-12	Summer	2.3	2.2	-5%
		Not Summer	1.9	2.0	4%
	MEAN				-2%
Outdoors	Girls, 6-10	Summer	3.7	3.5	-6%
		Not Summer	2.5	2.5	0%
	Boys, 6-10	Summer	4.1	4.3	4%
		Not Summer	3.1	2.7	-12%
	Girls, 11-12	Summer	3.7	5.2	41%
		Not Summer	2.3	2.1	-5%
	Boys, 11-12	Summer	3.9	4.3	9%
		Not Summer	2.6	2.4	-7%
	MEAN				3%
In-vehicle	Girls, 6-10	Summer	1.1	0.9	-20%
		Not Summer	1.0	0.9	-13%
	Boys, 6-10	Summer	1.1	1.3	13%
		Not Summer	1.0	0.9	-16%
	Girls, 11-12	Summer	1.2	1.1	-12%
		Not Summer	0.9	0.8	-15%
	Boys, 11-12	Summer	1.1	1.0	-5%
		Not Summer	0.9	0.8	-7%
	MEAN				-9%

Table 2. Variance across persons for time spent in each microenvironment: comparison of predicted and observed.

Microenvironment	Demographic Group	Season	Observed (hours/day)^2	*Predicted* (hours/day)^2	Normalized Bias
Indoor, home	Girls, 6-10	Summer	70	42	-40%
		Not Summer	67	60	-9%
	Boys, 6-10	Summer	54	49	-9%
		Not Summer	35	30	-12%
	Girls, 11-12	Summer	56	47	-17%
		Not Summer	42	38	-10%
	Boys, 11-12	Summer	57	63	12%
		Not Summer	39	42	8%
	MEAN				-10%
Indoor, school	Girls, 6-10	Summer	6.0	5.2	-13%
		Not Summer	9.5	5.9	-38%
	Boys, 6-10	Summer	5.6	3.8	-32%
		Not Summer	5.3	8.2	53%
	Girls, 11-12	Summer	4.9	5.5	11%
		Not Summer	5.4	5.3	-1%
	Boys, 11-12	Summer	5.6	6.0	6%
		Not Summer	9.2	11	23%
	MEAN				1%
Indoor, other	Girls, 6-10	Summer	46	32	-30%
		Not Summer	44	46.	6%
	Boys, 6-10	Summer	34	33	-4%
		Not Summer	23	16	-27%
	Girls, 11-	Summer	21	18	-15%

	12				
		Not Summer	28	22	-22%
	Boys, 11-12	Summer	33	31	-6%
		Not Summer	30	30	0%
	MEAN				-12%
Outdoors	Girls, 6-10	Summer	17	23	37%
		Not Summer	9.3	6.8	-27%
	Boys, 6-10	Summer	17	18	3%
		Not Summer	8.3	7.6	-8%
	Girls, 11-12	Summer	22	22	0%
		Not Summer	9.0	9.1	1%
	Boys, 11-12	Summer	13	29	120%
		Not Summer	10	11	8%
	MEAN				17%
In-vehicle	Girls, 6-10	Summer	1.9	2.3	24%
		Not Summer	1.8	1.6	-11%
	Boys, 6-10	Summer	2.5	4.7	93%
		Not Summer	1.5	1.6	9%
	Girls, 11-12	Summer	3.5	4.7	34%
		Not Summer	2.8	2.0	-28%
	Boys, 11-12	Summer	3.2	5.4	69%
		Not Summer	1.3	1.7	35%
	MEAN				28%

Table 3. Average within person variance for time spent in each microenvironment: comparison of predicted and observed.

Microenvironment	Demographic Group	Season	Observed (hours/day)^2	*Predicted* (hours/day)^2	Normalized Bias
Indoor, home	Girls, 6-10	Summer	20	29	49%
		Not Summer	18	23	25%
	Boys, 6-10	Summer	17	30	75%
		Not Summer	15	24	64%
	Girls, 11-12	Summer	22	42	93%
		Not Summer	22	25	13%
	Boys, 11-12	Summer	21	24	16%
		Not Summer	17	24	38%
	MEAN				47%
Indoor, school	Girls, 6-10	Summer	2.3	2.4	5%
		Not Summer	7.3	6.4	-12%
	Boys, 6-10	Summer	2.0	1.5	-25%
		Not Summer	6.7	5.8	-14%
	Girls, 11-12	Summer	1.7	2.1	29%
		Not Summer	7.4	7.6	3%
	Boys, 11-12	Summer	1.4	2.9	101%
		Not Summer	7.3	7.8	6%
	MEAN				12%
Indoor, other	Girls, 6-10	Summer	14	14	-4%
		Not Summer	14	18	30%
	Boys, 6-10	Summer	12	17	42%
		Not Summer	10	13	26%
	Girls, 11-	Summer	10	10	1%

	12				
		Not Summer	14	15	7%
	Boys, 11-12	Summer	11	14	26%
		Not Summer	12	13	7%
	MEAN				17%
Outdoors	Girls, 6-10	Summer	8.4	9.5	13%
		Not Summer	3.4	3.2	-3%
	Boys, 8-10	Summer	6.7	9.5	42%
		Not Summer	3.4	4.4	28%
	Girls, 11-12	Summer	10	25	150%
		Not Summer	4.0	4.5	11%
	Boys, 11-12	Summer	9.2	7.4	-20%
		Not Summer	4.3	3.7	-15%
	MEAN				26%
In-vehicle	Girls, 6-10	Summer	1.0	0.90	-13%
		Not Summer	0.90	0.48	-47%
	Boys, 6-10	Summer	1.1	1.4	31%
		Not Summer	0.81	0.71	-12%
	Girls, 11-12	Summer	1.3	1.3	4%
		Not Summer	1.3	1.1	-16%
	Boys, 11-12	Summer	2.4	1.6	-34%
		Not Summer	0.85	0.85	1%
	MEAN				-11%

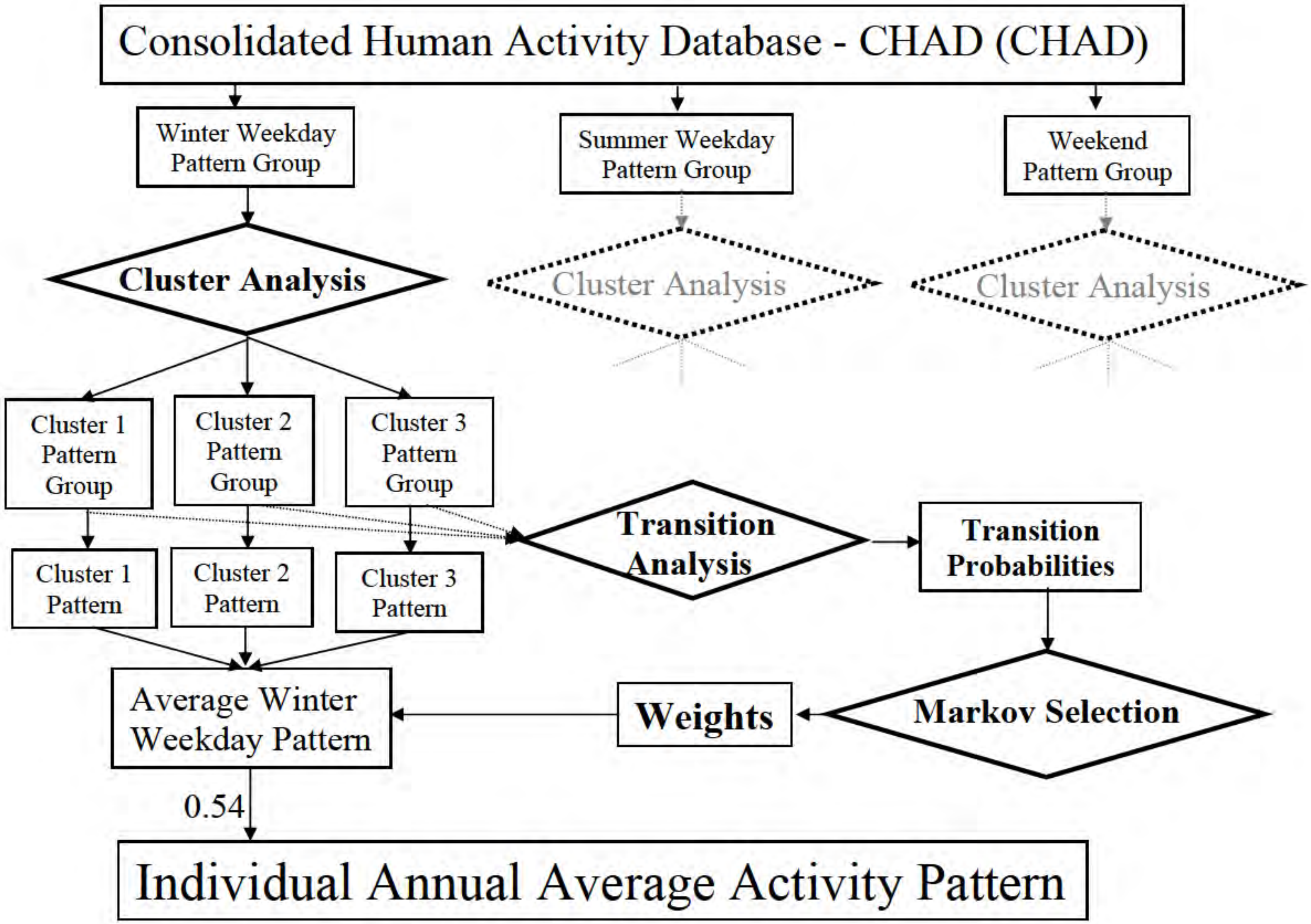

Figure 1. Flow diagram of proposed algorithm for creating annual average activity patterns for HAPEM5.

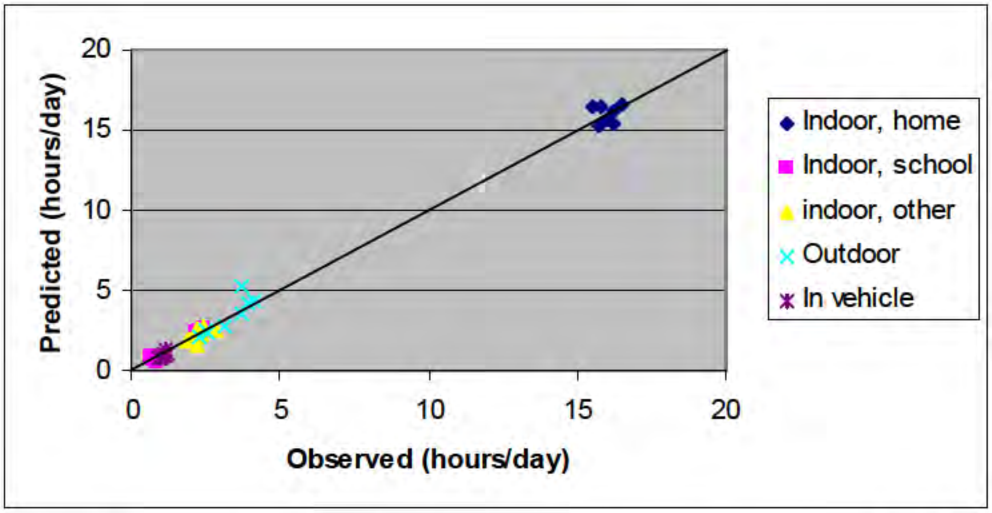

Figure 2. Comparison of predicted and observed average time in each of 5 microenvironments for age/gender groups and seasons.

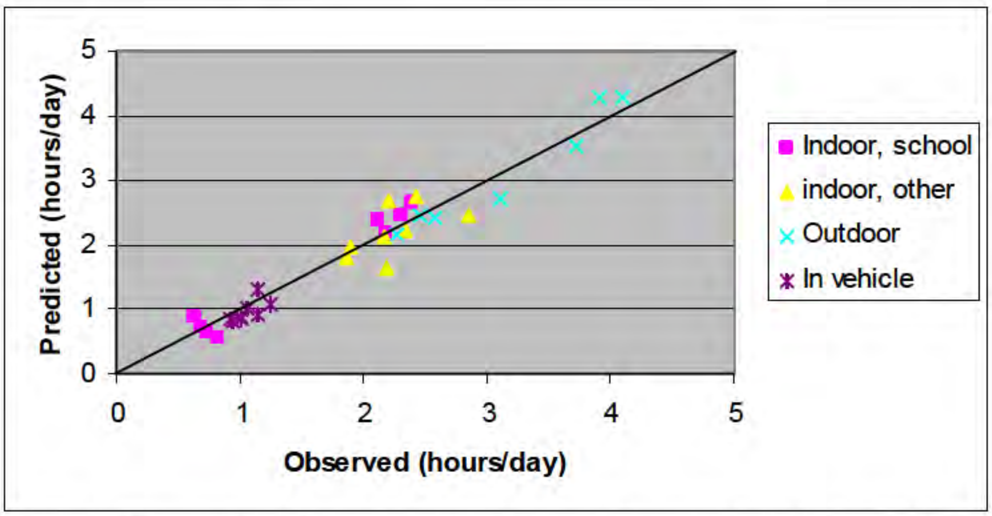

Figure 3. Comparison of predicted and observed average time in each of 4 microenvironments for age/gender groups and seasons.

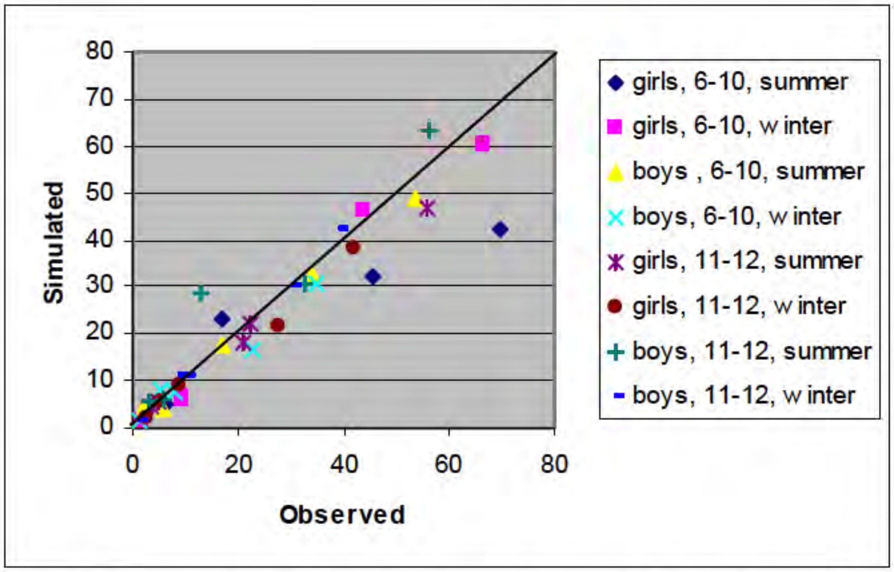

Figure 4. Comparison of predicted and observed variance across persons for time spent in each of 5 microenvironments for age/gender groups and seasons.

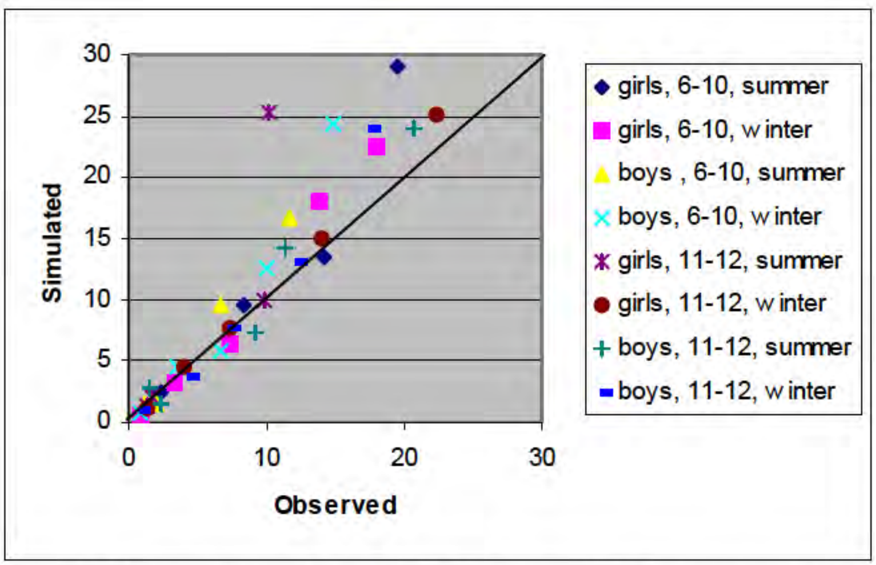

Figure 5. Comparison of predicted and observed the average within-person variance for time spent in each of 5 microenvironments by age/gender groups and seasons.

ATTACHMENT 6. TECHNICAL MEMORANDUM ON ANALYSIS OF AIR EXCHANGE RATE DATA

INTERNATIONAL

DRAFT MEMORANDUM

To: John Langstaff

From: Jonathan Cohen, Hemant Mallya, Arlene Rosenbaum

Date: September 30, 2005

Re: EPA 68D01052, Work Assignment 3-08. Analysis of Air Exchange Rate Data

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EPA is planning to use the APEX exposure model to estimate ozone exposure in 12 cities / metropolitan areas: Atlanta, GA; Boston, MA; Chicago, IL; Cleveland, OH; Detroit, MI; Houston, TX; Los Angeles, CA; New York, NY; Philadelphia, PA; Sacramento, CA; St. Louis, MO-IL; Washington, DC. As part of this effort, ICF Consulting has developed distributions of residential and non-residential air exchange rates (AER) for use as APEX inputs for the cities to be modeled. This memorandum describes the analysis of the AER data and the proposed APEX input distributions. Also included in this memorandum are proposed APEX inputs for penetration and proximity factors for selected microenvironments.

Residential Air Exchange Rates

Studies. Residential air exchange rate (AER) data were obtained from the following seven studies:

Avol: Avol et al, 1998. In this study, ozone concentrations and AERs were measured at 126 residences in the greater Los Angeles metropolitan area between February and December, 1994. Measurements were taken in four communities: Lancaster, Lake Gregory, Riverside, and San Dimas. Data included the daily average outdoor temperature, the presence or absence of an air conditioner (either central or room), and the presence or absence of a swamp (evaporative) cooler. Air exchange rates were computed based on the total house volume and based on the total house volume corrected for the furniture. These data analyses used the corrected AERs.

RTP Panel: Williams et al, 2003a, 2003b. In this study particulate matter concentrations and daily average AERs were measured at 37 residences in central North Carolina during 2000 and 2001 (averaging about 23 AER measurements per residence). The residences belong to two specific cohorts: a mostly Caucasian, non-smoking group aged at least 50 years having cardiac defibrillators living in Chapel Hill; a group of non-smoking, African Americans aged at least 50 years with controlled hypertension living in a low-to-moderate SES neighborhood in Raleigh. Data included the daily average outdoor temperature, and the number of air conditioner units (either central or room). Every residence had at least one air conditioner unit.

RIOPA: Meng et al, 2004, Weisel et al, 2004. The Relationship of Indoor, Outdoor, and Personal Air (RIOPA) study was undertaken to estimate the impact of outdoor sources of air toxics to indoor concentrations and personal exposures. Volatile organic compounds, carbonyls, fine particles and AERs were measured once or twice at 310 non-smoking residences from summer 1999 to spring 2001. Measurements were made at residences in Elizabeth, NJ, Houston TX, and Los Angeles CA. Residences in California were randomly selected. Residences in New Jersey and Texas were preferentially selected to be close (< 0.5 km) to sources of air toxics. The AER measurements (generally over 48 hours) used a PMCH tracer. Data included the daily average outdoor temperature, and the presence or absence of central air conditioning, room air conditioning, or a swamp (evaporative) cooler.

TEACH: Chillrud at al, 2004, Kinney et al, 2002, Sax et al, 2004. The Toxic Exposure Assessment, a Columbia/Harvard (TEACH) study was designed to characterize levels of and factors influencing exposures to air toxics among high school students living in inner-city neighborhoods of New York City and Los Angeles, CA. Volatile organic compounds, aldehydes, fine particles, selected trace elements, and AER were measured at 87 high school student's residences in New York City and Los Angeles in 1999 and 2000. Data included the presence or absence of an air conditioner (central or room) and hourly outdoor temperatures (which were converted to daily averages for these analyses).

Wilson 1984: Wilson et al, 1986, 1996. In this 1984 study, AER and other data were collected at about 600 southern California homes with three seven-day tests (in March and July 1984, and January, 1985) for each home. We obtained the data directly from Mr. Wilson. The available data consisted of the three seven-day averages, the month, the residence zip code, the presence or absence of a central air conditioner, and the presence or absence of a window air conditioner. We matched these data by month and zip code to the corresponding monthly average temperatures obtained from EPA's SCRAM website as well as from the archives in www.wunderground.com (personal and airport meteorological stations). Residences more than 25 miles away from the nearest available meteorological station were excluded from the analysis. For our analyses, the city/location was defined by the meteorological station, since grouping the data by zip code would not have produced sufficient data for most of the zip codes.

Wilson 1991: Wilson et al, 1996. Colome et al, 1993, 1994. In this 1991 study, AER and other data were collected at about 300 California homes with one two-day test in the winter for each home. We obtained the data directly from Mr. Wilson. The available data consisted of the two-day averages, the date, city name, the residence zip code, the presence or absence of a central air conditioner, the presence or absence of a swamp (evaporative) cooler, and the presence or absence of a window air conditioner . We matched these data by date, city, and zip code to the corresponding daily average temperatures obtained from EPA's SCRAM website as well as from the archives in www.wunderground.com (personal and airport meteorological stations). Residences more than 25 miles away from the nearest available meteorological station were excluded from the analysis. For our analyses, the city/location was defined by the meteorological station, since grouping the data by zip code would not have produced sufficient data for most of the zip codes.

Murray and Burmaster: Murray and Burmaster (1995). For this article, Murray and Burmaster corrected and compiled nationwide residential AER data from several studies conducted between 1982 and 1987. These data were originally compiled by the Lawrence Berkeley National Laboratory. We acknowledge Mr. Murray's assistance in obtaining these data for us. The available data consisted of AER measurements, dates, cities, and degree-days. Information on air conditioner presence or absence was not available.

Table A-1 summarizes these studies.

For each of the studies, air conditioner usage, window status (open or closed), and fan status (on or off) was not part of the experimental design, although some of these studies included information on whether air conditioners or fans were used (and for how long) and whether windows were closed during the AER measurements (and for how long).

As described above, in the following studies the homes were deliberately sampled from specific subsets of the population at a given location rather than the entire population: The RTP Panel study selected two specific cohorts of older subjects with specific diseases. The RIOPA study was biased towards residences near air toxics sources. The TEACH study focused on inner-city neighborhoods. Nevertheless, we included all these studies because we determined that any potential bias would be likely to be small and we preferred to keep as much data as possible.

Table A-1. Summary of Studies of Residential Air Exchange Rates

	Avol	RTP Panel	RIOPA	TEACH	Wilson 1984	Wilson 1991	Murray and Burmaster
Locations	Lancaster, Lake Gregory, Riverside, San Dimas. All in Southern CA	Research Triangle Park, NC	CA; NJ; TX	Los Angeles, CA; New York City, NY	Southern CA	Southern CA	AZ, CA, CO, CT, FL, ID, MD, MN, MT, NJ
Years	1994	2000; 2001	1999; 2000; 2001	1999; 2000	1984, 1985	1984	1982 – 1987
Months/Seasons	Feb; Mar; Apr; May; Jun; Jul; Aug; Sep; Oct; Nov	2000 (Jun; Jul; Aug; Sep; Oct; Nov), 2001 (Jan; Feb; Apr; May)	1999 (July to Dec); 2000 (all months); 2001 (Jan and Feb)	1999 (Feb; Mar; Apr; Jul; Aug); 2000 (Jan; Feb; Mar; Sep; Oct)	Mar 1984, Jul 1984, Jan 1985	Jan, Mar, Jul	Various
Number of Homes	86	37	284	85	581	288	1,884
Total AER Measurements	161	854	524	151	1,362	316	2,844
Average Number of Measurements per Home	1.87	23.08	1.85	1.78	2.34	1.10	1.51
Measurement Duration	Not Available	24 hour	24 to 96 hours	Sample time (hours) reported. Ranges from about 1 to 7 days.	7 days	7 days	Not available
Measurement Technique	Not Available	Perflourocarbon tracer.	PMCH tracer	Perflourocarbon tracer.	Perflourocarbon tracer.	Perflourocarbon tracer.	Not available
Min AER Value	0.01	0.02	0.08	0.12	0.03	0.01	0.01
Max AER Value	2.70	21.44	87.50	8.87	11.77	2.91	11.77
Mean AER Value	0.80	0.72	1.41	1.71	1.05	0.57	0.76
Min Temperature (C)	-0.04	-2.18	-6.82	-1.36	11.00	3.00	Not available

	Avol	RTP Panel	RIOPA	TEACH	Wilson 1984	Wilson 1991	Murray and Burmaster
Max Temperature (C)	36.25	30.81	32.50	32.00	28.00	25.00	Not available
Air Conditioner Categories	No A/C; Central or Room A/C; Swamp Cooler only; Swamp + [Central or Room]	Central or Room A/C (Y/N)	Window A/C (Y/N); Evap Coolers (Y/N)	Central or Room A/C (Y/N)	Central A/C (Y/N); Room A/C (Y/N);	Central A/C (Y/N); Room A/C (Y/N); Swamp Cooler(Y/N)	Not available
Air Conditioner Measurements	A/C use in minutes	Not Available	Duration measurements in Hrs and Mins	Not Available	Not Available	Not Available	Not available
Fan Categories	Not available	Fan (Y/N)	Fan (Y/N)	Not Available	Not Available	Not Available	Not available
Fan Measurements	Time on or off for various fan types during sampling was recorded, but not included in database provided.	Not Available	Duration measurements in Hrs and Mins	Not Available	Not Available	Not Available	Not available
Window Open/ Closed Data	Duration open between times 6am-12 pm; 12pm - 6 pm; and 6pm - 6am	Windows (open / closed along with duration open in inch-hours units	Windows (Open / Closed) along with window open duration measurements	Not Available	Not Available	Not Available	Not available
Comments			CA sample was a random sample of homes. NJ and TX homes were deliberately chosen to be near to ambient sources.	Restricted to inner-city homes with high school students.	Contemporaneous temperature data obtained for these analyses from SCRAM and www.wunderground.com meteorological data.	Contemporaneous temperature data obtained for these analyses from SCRAM and www.wunderground.com meteorological data.	

We compiled the data from these seven studies to create the following variables, of which some had missing values:

- Study
- Date
- Time – Time of the day that the AER measurement was made
- House_ID – Residence identifier
- Measurement_ID – Uniquely identifies each AER measurement for a given study
- AER – Air Exchange Rate (per hour)
- AER_Duration – Length of AER measurement period
- Have_AC – Indicates if the residence has any type of air conditioner (A/C), either a room A/C or central A/C or swamp cooler or any of them in combination. “Y” = “Yes.” “N” = “No.”
- Type_of_AC1 – Indicates the types of A/C or swamp cooler available in each house measured. Possible values: “Central A/C” “Central and Room A/C” “Central or Room A/C” “No A/C” “Swamp + (Central or Room)” “Swamp Cooler only” “Window A/C” “Window and Evap”
- Type_of_AC2 – Indicates if a house measured has either no A/C or some A/C. Possible values are “No A/C” and “Central or Room A/C.”
- Have_Fan – Indicates if the house studied has any fans
- Mean_Temp – Daily average outside temperature
- Min_Temp – Minimum hourly outside temperature
- Max_Temp – Maximum hourly outside temperature
- State
- City
- Location – Two character abbreviation
- Flag – Data status. Murray and Burmaster study: “Used” or “Not Used.” Other studies: “Used”; “Missing” (missing values for AER, Type_of_AC2, and/or Mean_Temp); “Outlier”.

The main data analysis was based on the first six studies. The Murray and Burmaster data were excluded because of the absence of information on air conditioner presence. (However, a subset of these data was used for a supplementary analysis described below.) .

Based on our review of the AER data we excluded seven outlying high AER values – above 10 per hour. The main data analysis used all the remaining data that had non-missing values for AER, Type_of_AC2, and Mean_Temp. We decided to base the A/C type variable on the broad characterization “No A/C” versus “Central or Room A/C” since this variable could be calculated from all of the studies (excluding Murray and Burmaster). Information on the presence or absence of swamp coolers was not available from all the studies, and, also importantly, the corresponding information on swamp cooler prevalence for the subsequent ozone modeling cities was not available from the American Housing Survey. It is plausible that AER distributions depend upon the presence or absence of a swamp cooler. It is also plausible that AER distributions also depend upon whether the residence specifically has a central A/C, room or window A/C, or both. However we determined to use the broader A/C type definition, which in effect assumes that the exact A/C type and the presence of a swamp cooler are approximately proportionately represented in the surveyed residences.

Most of the studies had more than one AER measurement for the same house. It is reasonable to assume that the AER varies with the house as well as other factors such as the temperature. (The A/C type can be assumed to be the same for each measurement of the same house). We expected the temperature to be an important factor since the AER will be affected by the use of the available ventilation (air conditioners, windows, fans), which in turn will depend upon the outside meteorology. Therefore it is not appropriate to average data for the same house under different conditions, which might have been one way to account for dependence between multiple measurements on the same house. To simplify the data analysis, we chose to ignore possible dependence between measurements on the same house on different days and treat all the AER values as if they were statistically independent.

Summary Statistics. We computed summary statistics for AER and its natural logarithm LOG_AER on selected strata defined from the study, city, A/C type, and mean temperature. Cities were defined as in the original databases, except that for Los Angeles we combined all the data in the Los Angeles ozone modeling region, i.e. the counties of Los Angeles, Orange, Ventura, Riverside, and San Bernardino. A/C type was defined from the Type_of_AC2 variable, which we abbreviated as “NA” = “No A/C” and “AC” = “Central or Room A/C.” The mean temperature was grouped into the following temperature bins: -10 to 0 ºC, 0 to 10 ºC, 10 to 20 ºC, 20 to 25 ºC, 25 to 30 ºC, 30 to 40 ºC.(Values equal to the lower bounds are excluded from each interval.) Also included were strata defined by study = “All” and/or city = “All,” and/or A/C type = “All” and/or temperature bin = “All.” The following summary statistics for AER and LOG_AER were computed:

- Number of values
- Arithmetic Mean
- Arithmetic Standard Deviation
- Arithmetic Variance
- Deciles (Min, 10^{th}, 20^{th} … 90^{th} percentiles, Max)

These calculations exclude all seven outliers and results are not used for strata with 10 or fewer values, since those summary statistics are extremely unreliable.

Examination of these summary tables clearly demonstrates that the AER distributions vary greatly across cities and A/C types and temperatures, so that the selected AER distributions for the modeled cities should also depend upon the city, A/C type and temperature. For example, the mean AER for residences with A/C ranges from 0.39 for Los Angeles between 30 and 40 ºC to 1.73 for New York between 20 and 25 ºC. The mean AER for residences without A/C ranges from 0.46 for San Francisco between 10 and 20 ºC to 2.29 for New York between 20 and 25 ºC. The need to account for the city as well as the A/C type and temperature is illustrated by the result that for residences with A/C and between 20 and 25 °C, the mean AER ranges from 0.52 for Research Triangle Park to 1.73 for New York. Statistical comparisons are described below.

Statistical Comparisons. Various statistical comparisons were carried out between the different strata, for the AER and its logarithm. The various strata are defined as in the Summary Statistics section, excluding the "All" cases. For each analysis, we fixed one or two of the variables Study, City, A/C type, temperature, and tested for statistically significant differences among other variables. The comparisons are listed in Table A-2.

Table A-2. Summary of Comparisons of Means

Comparison Analysis Number.	Comparison Variable(s) "Groups Compared"	Stratification Variable(s) (not missing in worksheet)	Total Comparisons	Cases with significantly different means (5 % level)	
				AER	Log AER
1.	City	Type of A/C AND Temp. Range	12	8	8
2.	Temp. Range	Study AND City	12	5	5
3.	Type of A/C	Study AND City	15	5	5
4.	City	Type of A/C	2	2	2
5.	City	Temp. Range	6	5	6
6.	Type of A/C AND Temp. Range	Study AND City	17	6	6

For example, the first set of comparisons fix the Type of A/C and the temperature range; there are twelve such combinations. For each of these twelve combinations, we compare the AER distributions across different cities. This analysis determines whether the AER distribution is appropriately defined by the A/C type and temperature range, without specifying the city. Similarly, for the sixth set of comparisons, the study and city are held fixed (17 combinations) and in each case we compare AER distributions across groups defined by the combination of the A/C type and the temperature range.

The F Statistic comparisons compare the mean values between groups using a one way analysis of variance (ANOVA). This test assumes that the AER or log(AER) values are normally distributed with a mean that may vary with the comparison variable(s) and a constant variance. We calculated the F Statistic and its P-value. P-values above 0.05 indicate cases where all the group means are not statistically significantly different at the 5 percent level. Those results are summarized in the last two columns of the above table "Summary of Comparisons of Means" which gives the number of cases where the means are significantly different. Comparison analyses 2, 3, and 6 show that for a given study and city, slightly less than half of the comparisons show significant differences in the means across temperature ranges, A/C types, or both. Comparison analyses 1, 4, and 5 show that for the majority of cases, means vary significantly across cities, whether you first stratify by temperature range, A/C type, or both.

The Kruskal-Wallis Statistic comparisons are non-parametric tests that are extensions of the more familiar Wilcoxon tests to two or more groups. The analysis is valid if the AER minus the group median has the same distribution for each group, and tests whether the group medians are equal. (The test is also consistent under weaker assumptions against more general alternatives) The P-values show similar patterns to the parametric F test comparisons of the means. Since the logarithm is a strictly increasing function and the test is non-parametric, the Kruskal-Wallis tests give identical results for AER and Log (AER).

The Mood Statistic comparisons are non-parametric tests that compare the scale statistics for two or more groups. The scale statistic measures variation about the central value, which is a non-parametric generalization of the standard deviation. Specifically, suppose there is a total of N AER or log(AER) values, summing across all the groups. These N values are ranked from 1 to N, and the j'th highest value is given a score of $\{j - (N+1)/2\}^2$. The Mood statistic uses a one way ANOVA statistic to compare the total scores for each group. Generally, the Mood statistics show that in most cases the scale statistics are not statistically significantly different. Since the logarithm is a strictly increasing function and the test is non-parametric, the Mood tests give identical results for AER and Log (AER).

Fitting Distributions. Based on the summary statistics and the statistical comparisons, the need to fit different AER distributions to each combination of A/C type, city, and temperature is apparent. For each combination with a minimum of 11 AER values, we fitted and compared exponential, log-normal, normal, and Weibull distributions to the AER values.

The first analysis used the same stratifications as in the above "Summary Statistics" and "Statistical Comparisons" sections. Results are not reported for all strata because of the minimum data requirement of 11 values. Results for each combination of A/C type, city, and temperature (i.e., A, C, and T) were analyzed. Each combination has four rows, one for each fitted distribution. For each distribution we report the fitted parameters (mean, standard deviation, scale, shape) and the p-value for three standard goodness-of-fit tests: Kolmogorov-Smirnov (K-S), Cramer-Von-Mises (C-M), Anderson-Darling (A-D). Each goodness-of-fit test compares the empirical distribution of the AER values to the fitted distribution. The K-S and C-M tests are different tests examining the overall fit, while the Anderson-Darling test gives more weight to the fit in the tails of the distribution. For each combination, the best-fitting of the four distributions has the highest p-value and is marked by an x in the final three columns. The mean and standard deviation (Std_Dev) are the values for the fitted distribution. The scale and shape parameters are defined by:

- Exponential: density = $\sigma^{-1} \exp(-x/\sigma)$, where shape = mean = σ
- Log-normal: density = $\{\sigma x\sqrt{(2\pi)}\}^{-1} \exp\{ -(\log x - \zeta)^2 / (2\sigma^2)\}$, where shape = σ and scale = ζ. Thus the geometric mean and geometric standard deviation are given by $\exp(\zeta)$ and $\exp(\sigma)$, respectively.
- Normal: density = $\{\sigma\sqrt{(2\pi)}\}^{-1} \exp\{ -(x - \mu)^2 / (2\sigma^2)\}$, where mean = μ and standard deviation = σ
- Weibull: density = $(c/\sigma)\,(x/\sigma)^{c-1} \exp\{-(x/\sigma)^c\}$, where shape = c and scale = σ

Generally, the log-normal distribution was the best-fitting of the four distributions, and so, for consistency, we recommend using the fitted log-normal distributions for all the cases.

One limitation of the initial analysis was that distributions were available only for selected cities, and yet the summary statistics and comparisons demonstrate that the AER distributions depend upon the city as well as the temperature range and A/C type. As one option to address this issue, we considered modeling cities for which distributions were not available by using the AER distributions across all cities and dates for a given temperature range and A/C type.

Another important limitation of the initial analysis was that distributions were not fitted to all of the temperature ranges due to inadequate data. There are missing values between temperature ranges, and the temperature ranges are all bounded. To address this issue, the temperature ranges were regrouped to cover the entire range of temperatures from minus to plus infinity, although obviously the available data to fit these ranges have finite temperatures. Stratifying by A/C type, city, and the new temperature ranges produces results for four cities: Houston (AC and NA); Los Angeles (AC and NA); New York (AC and NA); Research Triangle Park (AC). For each of the fitted distributions we created histograms to compare the fitted distributions with the empirical distributions.

AER Distributions for The First Nine Cities. Based upon the results for the above four cities and the corresponding graphs, we propose using those fitted distributions for the three cities Houston, Los Angeles, and New York. For another 6 of the cities to be modeled, we propose using the distribution for one of the four cities thought to have similar characteristics to the city to be modeled with respect to factors that might influence AERs. These factors include the age composition of housing stock, construction methods, and other meteorological variables not explicitly treated in the analysis, such as humidity and wind speed patterns. The distributions proposed for these cities are as follows:

- Atlanta, GA, A/C: Use log-normal distributions for Research Triangle Park. Residences with A/C only.
- Boston, MA: Use log-normal distributions for New York
- Chicago, IL: Use log-normal distributions for New York
- Cleveland, OH: Use log-normal distributions for New York
- Detroit, MI: Use log-normal distributions for New York
- Houston, TX: Use log-normal distributions for Houston
- Los Angeles, CA: Use log-normal distributions for Los Angeles
- New York, NY: Use log-normal distributions for New York
- Philadelphia, PA: Use log-normal distributions for New York

Since the AER data for Research Triangle Park was only available for residences with air conditioning, AER distributions for Atlanta residences without air conditioning are discussed below.

To avoid unusually extreme simulated AER values, we propose to set a minimum AER value of 0.01 and a maximum AER value of 10.

Obviously, we would be prefer to model each city using data from the same city, but this approach was chosen as a reasonable alternative, given the available AER data.

AER Distributions for Sacramento and St. Louis. For these two cities, a direct mapping to one of the four cities Houston, Los Angeles, New York, and Research Triangle Park is not recommended because the cities are likely to be too dissimilar. Instead, we decided to use the distribution for the inland parts of Los Angeles to represent Sacramento and to use the aggregate distributions for all cities outside of California to represent St. Louis. The results for the city Sacramento were obtained by combining all the available AER data for Sacramento, Riverside, and San Bernardino counties. The results for the city St. Louis were obtained by combining all non-California AER data.

AER Distributions for Washington DC. Washington DC was judged likely to have similar characteristics both to Research Triangle Park and to New York City. To choose between these two cities, we compared the Murray and Burmaster AER data for Maryland with AER data from each of those cities. The Murray and Burmaster study included AER data for Baltimore and for Gaithersburg and Rockville, primarily collected in March. April, and May 1987, although there is no information on mean daily temperatures or A/C type. We collected all the March, April, and May AER data for Research Triangle Park and for New York City, and compared those distributions with the Murray and Burmaster Maryland data for the same three months.

The results for the means and central values show significant differences at the 5 percent level between the New York and Maryland distributions. Between Research Triangle Park and Maryland, the central values and the mean AER values are not statistically significantly different, and the differences in the mean log (AER) values are much less statistically significant than between New York and Maryland. The scale statistic comparisons are not statistically significantly different between New York and Maryland, but were statistically significantly different between Research Triangle Park and Maryland. Since matching central and mean values is generally more important than matching the scales, we propose to model Washington DC residences with air conditioning using the Research Triangle Park distributions, stratified by temperature:

- Washington DC, A/C: Use log-normal distributions for Research Triangle Park. Residences with A/C only.

Since the AER data for Research Triangle Park was only available for residences with air conditioning, the estimated AER distributions for Washington DC residences without air conditioning are discussed below.

AER Distributions for Washington DC and Atlanta GA Residences With No A/C. For Atlanta and Washington DC we have proposed to use the AER distributions for Research Triangle Park. However, all the Research Triangle Park data (from the RTP Panel study) were from houses with air conditioning, so there are no available distributions for the “No A/C” cases. For these two cities, one option is to use AER distributions fitted to all the study data for residences without A/C, stratified by temperature. We propose applying the “No A/C” distributions for modeling these two cities for residences without A/C. However, since Atlanta and Washington DC residences are expected to be better represented by residences outside of California, we instead propose to use the "No A/C" AER distributions aggregated across cities outside of California, which is the same as the recommended choice for the St. Louis "No A/C" AER distributions.

A/C Type and Temperature Distributions. Since the proposed AER distribution is conditional on the A/C type and temperature range, these values also need to be simulated using APEX in order to select the appropriate AER distribution. Mean daily temperatures are one of the available APEX inputs for each modeled city, so that the temperature range can be determined for each modeled day according to the mean daily temperature. To simulate the A/C type, we obtained estimates of A/C prevalence from the American Housing Survey. Thus for each city/metropolitan area, we obtained the estimated fraction of residences with Central or Room A/C (see Table A-3), which gives the probability p for selecting the A/C type "Central or Room A/C." Obviously, 1-p is the probability for "No A/C." For comparison with Washington DC and Atlanta, we have included the A/C type percentage for Charlotte, NC (representing Research Triangle Park, NC). As discussed above, we propose modeling the 96-97 % of Washington DC and Atlanta residences with A/C using the Research Triangle Park AER distributions, and modeling the 3-4 % of Washington DC and Atlanta residences without A/C using the combined study No A/C AER distributions.

Table A-3. Fraction of residences with central or room A/C (from American Housing Survey)

CITY	SURVEY AREA & YEAR	PERCENTAGE
Atlanta	Atlanta, 2003	97.01
Boston	Boston, 2003	85.23
Chicago	Chicago, 2003	87.09
Cleveland	Cleveland, 2003	74.64
Detroit	Detroit, 2003	81.41
Houston	Houston, 2003	98.70
Los Angeles	Los Angeles, 2003	55.05
New York	New York, 2003	81.57
Philadelphia	Philadelphia, 2003	90.61
Sacramento	Sacramento, 2003	94.63
St. Louis	St. Louis, 2003	95.53
Washington DC	Washington DC, 2003	96.47
Research Triangle Park	Charlotte, 2002	96.56

Other AER Studies

We recently became aware of some additional residential and non-residential AER studies that might provide additional information or data. Indoor / outdoor ozone and PAN distributions were studied by Jakobi and Fabian (1997). Liu et al (1995) studied residential ozone and AER distributions in Toronto, Canada. Weschler and Shields (2000) describes a modeling study of ventilation and air exchange rates. Weschler (2000) includes a useful overview of residential and non-residential AER studies.

AER Distributions for Other Indoor Environments

To estimate AER distributions for non-residential, indoor environments (e.g., offices and schools), we obtained and analyzed two AER data sets: "Turk" (Turk et al, 1989); and "Persily" (Persily and Gorfain 2004; Persily et al. 2005).

The earlier "Turk" data set (Turk et al, 1989) includes 40 AER measurements from offices (25 values), schools (7 values), libraries (3 values), and multi-purpose (5 values), each measured using an SF6 tracer over two- or four-hours in different seasons of the year.

The more recent "Persily" data (Persily and Gorfain 2004; Persily et al. 2005) were derived from the U.S. EPA Building Assessment Survey and Evaluation (BASE) study, which was conducted to assess indoor air quality, including ventilation, in a large number of randomly selected office buildings throughout the U.S. The data base consists of a total of 390 AER measurements in 96 large, mechanically ventilated offices; each office was measured up to four times over two days, Wednesday and Thursday AM and PM. The office spaces were relatively large, with at least 25 occupants, and preferably 50 to 60 occupants. AERs were measured both by a volumetric method and by a CO2 ratio method, and included their uncertainty estimates. For these analyses, we used the recommended "Best Estimates" defined by the values with the lower estimated uncertainty; in the vast majority of cases the best estimate was from the volumetric method.

Another study of non-residential AERs was performed by Lagus Applied Technology (1995) using a tracer gas method. That study was a survey of AERs in 16 small office buildings, 6 large office buildings, 13 retail establishments, and 14 schools. We plan to obtain and analyze these data and compare those results with the Turk and Persily studies.

Due to the small sample size of the Turk data, the data were analyzed without stratification by building type and/or season. For the Persily data, the AER values for each office space were averaged, rather using the individual measurements, to account for the strong dependence of the AER measurements for the same office space over a relatively short period.

Summary statistics of AER and log (AER) for the two studies are presented in Table A-4.

Table A-4. AER summary statistics for offices and other non-residential buildings

Study	Variable	N	Mean	Std Dev	Min	25th %ile	Median	75th %ile	Max
Persily	AER	96	1.9616	2.3252	0.0712	0.5009	1.0795	2.7557	13.8237
Turk	AER	40	1.5400	0.8808	0.3000	0.8500	1.5000	2.0500	4.1000
Persily	Log(AER)	96	0.1038	1.1036	-2.6417	-0.6936	0.0765	1.0121	2.6264
Turk	Log(AER)	40	0.2544	0.6390	-1.2040	-0.1643	0.4055	0.7152	1.4110

The mean values are similar for the two studies, but the standard deviations are about twice as high for the Persily data. The proposed AER distributions were derived from the more recent Persily data only.

Similarly to the analyses of the residential AER distributions, we fitted exponential, log-normal, normal, and Weibull distributions to the 96 office space average AER values. The results are shown in Table A-5.

Table A-5. Best fitting office AER distributions from the Persily et al. (2004, 2005)

Scale	Shape	Mean	Std_Dev	Distribution	P-Value Kolmogorov-Smirnov	P-Value Cramer-von Mises	P-Value Anderson-Darling
1.9616		1.9616	1.9616	Exponential	0.13	0.04	0.05
0.1038	1.1036	2.0397	3.1469	Lognormal	0.15	0.46	0.47
		1.9616	2.3252	Normal	0.01	0.01	0.01
1.9197	0.9579	1.9568	2.0433	Weibull		0.01	0.01

(For an explanation of the Kolmogorov-Smirnov, Cramer-von Mises, and Anderson-Darling P-values see the discussion residential AER distributions above.) According to all three goodness-of-fit measures the best-fitting distribution is the log-normal. Reasonable choices for the lower and upper bounds are the observed minimum and maximum AER values.

We therefore propose the following indoor, non-residential AER distributions.

- AER distribution for indoor, non-residential microenvironments: Lognormal, with scale and shape parameters 0.1038 and 1.1036, i.e., geometric mean = 1.1094, geometric standard deviation = 3.0150. Lower Bound = 0.07. Upper bound = 13.8.

Proximity and Penetration Factors For Outdoors, In-vehicle, and Mass Transit

For the APEX modeling of the outdoor, in-vehicle, and mass transit micro-environments, an approach using proximity and penetration factors is proposed, as follows.

<u>Outdoors Near Road</u>

Penetration factor = 1.

For the Proximity factor, we propose using ratio distributions developed from the Cincinnati Ozone Study (American Petroleum Institute, 1997, Appendix B; Johnson et al. 1995). The field study was conducted in the greater Cincinnati metropolitan area in August and September, 1994. Vehicle tests were conducted according to an experimental design specifying the vehicle type, road type, vehicle speed, and ventilation mode. Vehicle types were defined by the three study vehicles: a minivan, a full-size car, and a compact car. Road types were interstate highways (interstate), principal urban arterial roads (urban), and local roads (local). Nominal vehicle speeds (typically met over one minute intervals within 5 mph) were at 35 mph, 45 mph, or 55 mph. Ventilation modes were as follows:

- Vent Open: Air conditioner off. Ventilation fan at medium. Driver's window half open. Other windows closed.
- Normal A/C. Air conditioner at normal. All windows closed.
- Max A/C: Air conditioner at maximum. All windows closed.

Ozone concentrations were measured inside the vehicle, outside the vehicle, and at six fixed site monitors in the Cincinnati area.

The proximity factor can be estimated from the distributions of the ratios of the outside-vehicle ozone concentrations to the fixed-site ozone concentrations, reported in Table 8 of Johnson et al. (1995). Ratio distributions were computed by road type (local, urban, interstate, all) and by the fixed-site monitor (each of the six sites, as well as the nearest monitor to the test location). For this analysis we propose to use the ratios of outside-vehicle concentrations to the concentrations at the nearest fixed site monitor, as shown in Table A-6.

Table A-6. Ratio of outside-vehicle ozone to ozone at nearest fixed site[1]

Road Type[1]	Number of cases[1]	Mean[1]	Standard Deviation[1]	25th Percentile[1]	50th Percentile[1]	75th Percentile[1]	Estimated 5th Percentile[2]
Local	191	0.755	0.203	0.645	0.742	0.911	0.422
Urban	299	0.754	0.243	0.585	0.722	0.896	0.355
Interstate	241	0.364	0.165	0.232	0.369	0.484	0.093
All	731	0.626	0.278	0.417	0.623	0.808	0.170

1. From Table 8 of Johnson et al. (1995). Data excluded if fixed-site concentration < 40 ppb.
2. Estimated using a normal approximation as Mean – 1.64 × Standard Deviation

For the outdoors-near- road microenvironment, we recommend using the distribution for local roads, since most of the outdoors-near-road ozone exposure will occur on local roads. The summary data from the Cincinnati Ozone Study are too limited to allow fitting of distributions, but the 25th and 75th percentiles appear to be approximately equidistant from the median (50th percentile). Therefore we propose using a normal distribution with the observed mean and standard deviation. A plausible upper bound for the proximity factor equals 1. Although the normal distribution allows small positive values and can even produce impossible, negative values (with a very low probability), the titration of ozone concentrations near a road is limited. Therefore, as an empirical approach, we recommend a lower bound of the estimated 5th percentile, as shown in the final column of the above table. Therefore in summary we propose:

- Penetration factor for outdoors, near road: 1.

- Proximity factor for outdoors, near road: Normal distribution. Mean = 0.755. Standard Deviation = 0.203. Lower Bound = 0.422. Upper Bound = 1.

Outdoors, Public Garage / Parking Lot

This micro-environment is similar to the outdoors-near-road microenvironment. We therefore recommend the same distributions as for outdoors-near-road:

- Penetration factor for outdoors, public garage / parking lot: 1.
- Proximity factor for outdoors, public garage / parking lot: Normal distribution. Mean = 0.755. Standard Deviation = 0.203. Lower Bound = 0.422. Upper Bound = 1.

Outdoors, Other

The outdoors, other ozone concentrations should be well represented by the ambient monitors. Therefore we propose:

- Penetration factor for outdoors, other: 1.
- Proximity factor for outdoors, other: 1.

In-Vehicle

For the proximity factor for in-vehicle, we also recommend using the results of the Cincinnati Ozone Study presented in Table A-6. For this microenvironment, the ratios depend upon the road type, and the relative prevalences of the road types can be estimated by the proportions of vehicle miles traveled in each city. The proximity factors are assumed, as before, to be normally distributed, the upper bound to be 1, and the lower bound to be the estimated 5th percentile.

- Proximity factor for in-vehicle, local roads: Normal distribution. Mean = 0.755. Standard Deviation = 0.203. Lower Bound = 0.422. Upper Bound = 1.
- Proximity factor for in-vehicle, urban roads: Normal distribution. Mean = 0.754. Standard Deviation = 0.243. Lower Bound = 0.355. Upper Bound = 1.
- Proximity factor for in-vehicle, interstates: Normal distribution. Mean = 0.364. Standard Deviation = 0.165. Lower Bound = 0.093. Upper Bound = 1.

To complete the specification, the distribution of road type needs to be estimated for each city to be modeled. Vehicle miles traveled (VMT) in 2003 by city (defined by the Federal-Aid urbanized area) and road type were obtained from the Federal Highway Administration. (http://www.fhwa.dot.gov/policy/ohim/hs03/htm/hm71.htm). For local and interstate road types, the VMT for the same DOT categories were used. For urban roads, the VMT for all other road types was summed (Other freeways/expressways, Other principal arterial, Minor arterial, Collector). The computed VMT ratios for each city are shown in Table A-7.

Table A-7. Vehicle Miles Traveled by City and Road Type in 2003 (FHWA, October 2004)

FEDERAL-AID URBANIZED AREA	FRACTION VMT BY ROAD TYPE		
	INTERSTATE	URBAN	LOCAL
Atlanta	0.38	0.45	0.18
Boston	0.31	0.55	0.14
Chicago	0.30	0.59	0.12
Cleveland	0.39	0.45	0.16
Detroit	0.26	0.63	0.11
Houston	0.24	0.72	0.04
Los Angeles	0.29	0.65	0.06
New York	0.18	0.67	0.15
Philadelphia	0.23	0.65	0.11
Sacramento	0.21	0.69	0.09
St. Louis	0.36	0.45	0.19
Washington	0.31	0.61	0.08

Note that a "Federal-Aid Urbanized Area" is an area with 50,000 or more persons that at a minimum encompasses the land area delineated as the urbanized area by the Bureau of the Census. Urbanized areas that have been combined with others for reporting purposes are not shown separately. The Illinois portion of Round Lake Beach-McHenry-Grayslake has been reported with Chicago.

Thus to simulate the proximity factor in APEX, we propose to first select the road type according to the above probability table of road types, then select the AER distribution (normal) for that road type as defined in the last set of bullets.

For the penetration factor for in-vehicle, we recommend using the inside-vehicle to outside-vehicle ratios from the Cincinnati Ozone Study. The ratio distributions were summarized for all the data and for stratifications by vehicle type, vehicle speed, road type, traffic (light, moderate, or heavy), and ventilation. The overall results and results by ventilation type are shown in Table A-8.

Table A-8. Ratio of inside-vehicle ozone to outside-vehicle ozone[1]

Ventilation[1]	Number of cases[1]	Mean[1]	Standard Deviation[1]	25^{th} Percentile[1]	50^{th} Percentile[1]	75^{th} Percentile[1]	Estimated 5^{th} Percentile[2]
Vent Open	226	0.361	0.217	0.199	0.307	0.519	0.005
Normal A/C	332	0.417	0.211	0.236	0.408	0.585	0.071
Maximum A/C	254	0.093	0.088	0.016	0.071	0.149	0.000[3]
All	812	0.300	0.232	0.117	0.251	0.463	0.000[3]

1. From Table 7 of Johnson et al.(1995). Data excluded if outside-vehicle concentration < 20 ppb.
2. Estimated using a normal approximation as Mean – 1.64 × Standard Deviation
3. Negative estimate (impossible value) replaced by zero.

Although the data in Table A-8 indicate that the inside-to-outside ozone ratios strongly depend upon the ventilation type, it would be very difficult to find suitable data to estimate the ventilation type distributions for each modeled city. Furthermore, since the Cincinnati Ozone Study was scripted, the ventilation conditions may not represent real-world vehicle ventilation scenarios. Therefore, we propose to use the overall average distributions.

- Penetration factor for in-vehicle: Normal distribution. Mean = 0.300. Standard Deviation = 0.232. Lower Bound = 0.000. Upper Bound = 1.

Mass Transit

The mass transit microenvironment is expected to be similar to the in-vehicle microenvironment. Therefore we recommend using the same APEX modeling approach:

- Proximity factor for mass transit, local roads: Normal distribution. Mean = 0.755. Standard Deviation = 0.203. Lower Bound = 0.422. Upper Bound = 1.
- Proximity factor for mass transit, urban roads: Normal distribution. Mean = 0.754. Standard Deviation = 0.243. Lower Bound = 0.355. Upper Bound = 1.
- Proximity factor for mass transit, interstates: Normal distribution. Mean = 0.364. Standard Deviation = 0.165. Lower Bound = 0.093. Upper Bound = 1.
- Road type distributions for mass transit: See Table A-6
- Penetration factor for mass transit: Normal distribution. Mean = 0.300. Standard Deviation = 0.232. Lower Bound = 0.000. Upper Bound = 1.

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ATTACHMENT 7. TECHNICAL MEMORANDUM ON THE UNCERTAINTY ANALYSIS OF RESIDENTIAL AIR EXCHANGE RATE DISTRIBUTIONS

ICF INTERNATIONAL

MEMORANDUM

To: John Langstaff, EPA OAQPS

From: Jonathan Cohen, Arlene Rosenbaum, ICF International

Date: June 5, 2006

Re: Uncertainty analysis of residential air exchange rate distributions

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This memorandum describes our assessment of some of the sources of the uncertainty of city-specific distributions of residential air exchange rates that were fitted to the available study data. City-specific distributions for use with the APEX ozone model were developed for 12 modeling cities, as detailed in the memorandum by Cohen, Mallya and Rosenbaum, 20056 (Appendix A of this report). In the first part of the memorandum, we analyze the between-city uncertainty by examining the variation of the geometric means and standard deviations across cities and studies. In the second part of the memorandum, we assess the within-city uncertainty by using a bootstrap distribution to estimate the effects of sampling variation on the fitted geometric means and standard deviations for each city. The bootstrap distributions assess the uncertainty due to random sampling variation but do not address uncertainties due to the lack of representativeness of the available study data, the matching of the study locations to the modeled cities, and the variation in the lengths of the AER monitoring periods.

Variation of geometric means and standard deviations across cities and studies

The memorandum by Cohen, Mallya and Rosenbaum, 2005 (Attachment 6 of this report) describes the analysis of residential air exchange rate (AER) data that were obtained from seven studies. The AER data were subset by location, outside temperature range, and the A/C type, as defined by the presence or absence of an air conditioner (central or window). In each case we chose to fit a log-normal distribution to the AER data, so that the logarithm of the AER for a given city, temperature range, and A/C type is assumed to be normally distributed. If the AER data has geometric mean GM and geometric standard deviation GSD, then the logarithm of the AER is assumed to have a normal distribution with mean log(GM) and standard deviation log(GSD).

Table D-1 shows the assignment of the AER data to the 12 modeled cities. Note that for Atlanta, GA and Washington DC, the Research Triangle Park, NC data for houses with A/C was used to represent the AER distributions for houses with A/C, and the non-California data for houses without A/C was used to represent the AER distributions for houses without A/C. Sacramento, CA AER distributions were estimated using the AER data from the inland California counties of Sacramento, Riverside, and San Bernardino; these combined data are referred to by the City

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6 Cohen, J., H. Mallya, and A. Rosenbaum. 2005. Memorandum to John Langstaff. *EPA 68D01052, Work Assignment 3-08. Analysis of Air Exchange Rate Data*. September 30, 2005.

Name "Inland California." St Louis, MO AER distributions were estimated using the AER data from all states except for California and so are referred to be the City Name "Outside California."

Table D-1. Assignment of Residential AER distributions to modeled cities

Modeled city	AER distribution
Atlanta, GA, A/C	Research Triangle Park, A/C only
Atlanta, GA, no A/C	All non-California, no A/C ("Outside California")
Boston, MA	New York
Chicago, IL	New York
Cleveland, OH	New York
Detroit, MI	New York
Houston, TX	Houston
Los Angeles, CA	Los Angeles
New York, NY	New York
Philadelphia, PA	New York
Sacramento	Inland parts of Los Angeles ("Inland California")
St. Louis	All non-California ("Outside California")
Washington, DC, A/C	Research Triangle Park, A/C only
Washington, DC, no A/C	All non-California, no A/C ("Outside California")

It is evident from Table D-1 that for some of the modeled cities, some potentially large uncertainty was introduced because we modeled their AER distributions using available data from another city or group of cities thought to be representative of the first city on the basis of geography and other characteristics. This was necessary for cities where we did not have any or sufficient AER data measured in the same city that also included the necessary temperature and A/C type information. One way to assess the impact of these assignments on the uncertainty of the AER distributions is to evaluate the variation of the fitted log-normal distributions across the cities with AER data. In this manner we can examine the effect on the AER distribution if a different allocation of study data to the modeled cities had been used.

Even for the cities where we have study AER data, there is uncertainty about the fitted AER distributions. First, the studies used different measurement and residence selection methods. In some cases the residences were selected by a random sampling method designed to represent the entire population. In other cases the residences were selected to represent sub-populations. For example, for the RTP study, the residences belong to two specific cohorts: a mostly Caucasian, non-smoking group aged at least 50 years having cardiac defibrillators living in Chapel Hill; a group of non-smoking, African Americans aged at least 50 years with controlled hypertension living in a low-to-moderate SES neighborhood in Raleigh. The TEACH study was restricted to residences of inner-city high school students. The RIOPA study was a random sample for Los Angeles, but was designed to preferentially sample locations near major air toxics sources for Elizabeth, NJ and Houston TX. Furthermore, some of the studies focused on different towns or cities within the larger metropolitan areas, so that, for example, the Los Angeles data from the Avol study was only measured in Lancaster, Lake Gregory, Riverside, and San Dimas but the Los Angeles data from the Wilson studies were measured in multiple cities in Southern California. One way to assess the uncertainty of the AER distributions due to variations of study methodologies and study sampling locations is to evaluate the variation of the fitted log-normal distributions within each modeled city across the different studies.

We evaluated the variation between cities, and the variation within cities and between studies, by tabulating and plotting the AER distributions for all the study/city combinations. Since the original analyses by Cohen, Mallya and Rosenbaum, 2005 clearly showed that the AER distribution depends strongly on the outside temperature and the A/C type (whether or not the residence has air conditioning), this analysis was stratified by the outside temperature range and the A/C type. Otherwise, study or city differences would have been confounded by the temperature and A/C type differences and you would not be able to tell how much of the AER difference was due to the variation of temperature and A/C type across cities or studies. In order to be able to compare cities and studies we could not use different temperature ranges for the different modeled cities as we did for the original AER distribution modeling. For these analyses we stratified the temperature into the ranges <= 10, 10-20, 20-25, and >25 ºC and categorized the A/C type as "Central or Window A/C" versus 'No A/C," giving 8 temperature and A/C type strata.

Table D-2 shows the geometric means and standard deviations by city and study. These geometric mean and standard deviation pairs are plotted in Figure D-1 through D-8. Each figure shows the variation across cities and studies for a given temperature range and A/C type. The results for a city with only one available study are shown with a blank study name. For cities with multiple studies, results are shown for the individual studies and the city overall distribution is designated by a blank value for the study name.

Table D-2. Geometric means and standard deviations by city and study.

A/C Type	Temperature	City	Study*	N	Geo Mean	Geo Std Dev**
Central or Room A/C	<= 10	Houston		2	0.32	1.80
Central or Room A/C	<= 10	Los Angeles		5	0.62	1.51
Central or Room A/C	<= 10	Los Angeles	Avol	2	0.72	1.22
Central or Room A/C	<= 10	Los Angeles	RIOPA	1	0.31	
Central or Room A/C	<= 10	Los Angeles	Wilson 1991	2	0.77	1.12
Central or Room A/C	<= 10	New York City		20	0.71	2.02
Central or Room A/C	<= 10	Research Triangle Park		157	0.96	1.81
Central or Room A/C	<= 10	Sacramento		3	0.38	1.82
Central or Room A/C	<= 10	San Francisco		2	0.43	1.00
Central or Room A/C	<= 10	Stockton		7	0.48	1.64
Central or Room A/C	10-20	Arcata		1	0.17	
Central or Room A/C	10-20	Bakersfield		2	0.36	1.34

Table D-2. Geometric means and standard deviations by city and study.

A/C Type	Temperature	City	Study*	N	Geo Mean	Geo Std Dev**
Central or Room A/C	10-20	Fresno		8	0.30	1.62
Central or Room A/C	10-20	Houston		13	0.42	2.19
Central or Room A/C	10-20	Los Angeles		716	0.59	1.90
Central or Room A/C	10-20	Los Angeles	Avol	33	0.48	1.87
Central or Room A/C	10-20	Los Angeles	RIOPA	11	0.60	1.87
Central or Room A/C	10-20	Los Angeles	TEACH	1	0.68	
Central or Room A/C	10-20	Los Angeles	Wilson 1984	634	0.59	1.89
Central or Room A/C	10-20	Los Angeles	Wilson 1991	37	0.64	2.11
Central or Room A/C	10-20	New York City		5	1.36	2.34
Central or Room A/C	10-20	New York City	RIOPA	4	1.20	2.53
Central or Room A/C	10-20	New York City	TEACH	1	2.26	
Central or Room A/C	10-20	Redding		1	0.31	
Central or Room A/C	10-20	Research Triangle Park		320	0.56	1.91
Central or Room A/C	10-20	Sacramento		7	0.26	1.67
Central or Room A/C	10-20	San Diego		23	0.41	1.55
Central or Room A/C	10-20	San Francisco		5	0.42	1.25
Central or Room A/C	10-20	Santa Maria		1	0.23	
Central or Room A/C	10-20	Stockton		4	0.73	1.42
Central or Room A/C	20-25	Houston		20	0.47	1.94
Central or Room A/C	20-25	Los Angeles		273	1.10	2.36
Central or Room A/C	20-25	Los Angeles	Avol	32	0.61	1.95
Central or Room A/C	20-25	Los Angeles	RIOPA	26	0.90	2.42
Central or Room A/C	20-25	Los Angeles	Wilson 1984	215	1.23	2.33
Central or Room A/C	20-25	New York City		37	1.11	2.74
Central or Room A/C	20-25	New York City	RIOPA	20	0.93	2.91
Central or Room A/C	20-25	New York City	TEACH	17	1.37	2.52
Central or Room A/C	20-25	Red Bluff		2	0.61	3.20
Central or Room A/C	20-25	Research Triangle Park		196	0.40	1.89
Central or Room A/C	> 25	Houston		79	0.43	2.17
Central or Room A/C	> 25	Los Angeles		114	0.72	2.60
Central or Room A/C	> 25	Los Angeles	Avol	25	0.37	3.10
Central or Room A/C	> 25	Los Angeles	RIOPA	10	0.94	1.71
Central or Room A/C	> 25	Los Angeles	Wilson 1984	79	0.86	2.33
Central or Room A/C	> 25	New York City		19	1.24	2.18
Central or Room A/C	> 25	New York City	RIOPA	14	1.23	2.28
Central or Room A/C	> 25	New York City	TEACH	5	1.29	2.04
Central or Room A/C	> 25	Research Triangle Park		145	0.38	1.71
No A/C	<= 10	Houston		13	0.66	1.68
No A/C	<= 10	Los Angeles		18	0.54	3.09
No A/C	<= 10	Los Angeles	Avol	14	0.51	3.60
No A/C	<= 10	Los Angeles	RIOPA	2	0.72	1.11
No A/C	<= 10	Los Angeles	Wilson 1991	2	0.60	1.00
No A/C	<= 10	New York City		48	1.02	2.14
No A/C	<= 10	New York City	RIOPA	44	1.04	2.20
No A/C	<= 10	New York City	TEACH	4	0.79	1.28
No A/C	<= 10	Sacramento		3	0.58	1.30

Table D-2. Geometric means and standard deviations by city and study.

A/C Type	Temperature	City	Study*	N	Geo Mean	Geo Std Dev**
No A/C	<= 10	San Francisco		9	0.39	1.42
No A/C	10-20	Bakersfield		1	0.85	
No A/C	10-20	Fresno		4	0.90	2.42
No A/C	10-20	Houston		28	0.63	2.92
No A/C	10-20	Los Angeles		390	0.75	2.09
No A/C	10-20	Los Angeles	Avol	23	0.78	2.55
No A/C	10-20	Los Angeles	RIOPA	87	0.78	1.96
No A/C	10-20	Los Angeles	TEACH	9	2.32	2.05
No A/C	10-20	Los Angeles	Wilson 1984	241	0.70	2.06
No A/C	10-20	Los Angeles	Wilson 1991	30	0.75	1.82
No A/C	10-20	New York City		59	0.79	2.04
No A/C	10-20	Sacramento		1	1.09	
No A/C	10-20	San Diego		49	0.47	1.95
No A/C	10-20	San Francisco		15	0.34	3.05
No A/C	10-20	Santa Maria		2	0.27	1.23
No A/C	20-25	Houston		10	0.92	2.41
No A/C	20-25	Los Angeles		148	1.37	2.28
No A/C	20-25	Los Angeles	Avol	19	0.95	1.87
No A/C	20-25	Los Angeles	RIOPA	38	1.30	2.11
No A/C	20-25	Los Angeles	Wilson 1984	91	1.52	2.40
No A/C	20-25	New York City		26	1.62	2.24
No A/C	20-25	New York City	RIOPA	19	1.50	2.30
No A/C	20-25	New York City	TEACH	7	1.99	2.11
No A/C	20-25	Red Bluff		1	0.55	
No A/C	> 25	Houston		2	0.92	3.96
No A/C	> 25	Los Angeles		25	0.99	1.97
No A/C	> 25	Los Angeles	Avol	6	1.56	1.36
No A/C	> 25	Los Angeles	RIOPA	4	1.33	1.37
No A/C	> 25	Los Angeles	TEACH	3	0.86	1.02
No A/C	> 25	Los Angeles	Wilson 1984	12	0.74	2.29
No A/C	> 25	New York City		6	1.54	1.65
No A/C	> 25	New York City	RIOPA	3	1.73	2.00
No A/C	> 25	New York City	TEACH	3	1.37	1.38

* For a given city, if AER data were available from only one study, then the study name is missing. If AER data were available for two or more studies, then the overall city distribution is shown in the row where the study name is missing, and the distributions by study and city are shown in the rows with a specific study name.
** The geometric standard deviation is undefined if the sample size equals 1.

In general, there is a relatively wide variation across different cities. This implies that the AER modeling results would be very different if the matching of modeled cities to study cities was changed, although a sensitivity study using the APEX model would be needed to assess the impact on the ozone exposure estimates. In particular the ozone exposure estimates may be sensitive to the assumption that the St. Louis AER distributions can be represented by the combined non-California AER data. One way to address this is to perform a Monte Carlo analysis where the first stage is to randomly select a city outside of California, the second stage picks the A/C type, and the third stage picks the AER value from the assigned distribution for the city, A/C type and temperature range. Note that this will result in a very different distribution to the current approach that fits a single log-normal distribution to all the non-California data for a given temperature range and A/C type. The current approach weights each data point equally, so that cities like New York with most of the data values get the greatest statistical weight. The Monte Carlo approach gives the same total statistical weight for each city and fits a mixture of log-normal distributions rather than a single distribution.

In general, there is also some variation within studies for the same city, but this is much smaller than the variation across cities. This finding tends to support the approach of combining different studies. Note that the graphs can be deceptive in this regard because some of the data points are based on very small sample sizes (N) ; those data points are less precise and the differences would not be statistically significant. For example, for the No A/C data in the range 10-20 ºC, the Los Angeles TEACH study had a geometric mean of 2.32 based on only nine AER values, but the overall geometric mean, based on 390 values, was 0.75 and the geometric means for the Los Angeles Avol, RIOPA, Wilson 1984, and Wilson 1991 studies were each close to 0.75. One noticeable case where the studies show big differences for the same city is for the A/C houses in Los Angeles in the range 20-25 ºC where the study geometric means are 0.61 (Avol, N=32), 0.90 (RIOPA, N=26) and 1.23 (Wilson 1984, N=215).

Bootstrap analyses

The 39 AER subsets defined in the Cohen, Mallya, and Rosenbaum, 2005 memorandum (Appendix A of this report) and their allocation to the 12 modeled cities are shown in Table D-3. To make the distributions sufficiently precise in each AER subset and still capture the variation across temperature and A/C type, different modeled cities were assigned different temperature range and A/C type groupings. Therefore these temperature range groupings are sometimes different to those used to develop Table D-2 and Figure D-1 through D-8.

Table D-3. AER subsets by city, A/C type, and temperature range.

Subset City Name	Study Cities	Represents Modeled Cities:	A/C Type	Temperature Range (ºC)
Houston	Houston	Houston, TX	Central or Room A/C	<=20
Houston	Houston	Houston, TX	Central or Room A/C	20-25
Houston	Houston	Houston, TX	Central or Room A/C	25-30
Houston	Houston	Houston, TX	Central or Room A/C	>30
Houston	Houston	Houston, TX	No A/C	<=10
Houston	Houston	Houston, TX	No A/C	10-20
	Houston	Houston, TX	No A/C	>20
Inland California	Sacramento, Riverside, and San Bernardino counties, CA	Sacramento, CA	Central or Room A/C	<=25
Inland California	Sacramento, Riverside, and San Bernardino counties, CA	Sacramento, CA	Central or Room A/C	>25
Inland California	Sacramento, Riverside, and San Bernardino counties, CA	Sacramento, CA	No A/C	<=10
Inland California	Sacramento, Riverside, and San Bernardino counties, CA	Sacramento, CA	No A/C	10-20
Inland California	Sacramento, Riverside,	Sacramento, CA	No A/C	20-25

Table D-3. AER subsets by city, A/C type, and temperature range.

Subset City Name	Study Cities	Represents Modeled Cities:	A/C Type	Temperature Range (ºC)
	and San Bernardino counties, CA			
Inland California	Sacramento, Riverside, and San Bernardino counties, CA	Sacramento, CA	No A/C	>25
Los Angeles	Los Angeles, Orange, Riverside, San Bernardino, and Ventura counties, CA	Los Angeles, CA	Central or Room A/C	<=20
Los Angeles	Los Angeles, Orange, Riverside, San Bernardino, and Ventura counties, CA	Los Angeles, CA	Central or Room A/C	20-25
Los Angeles	Los Angeles, Orange, Riverside, San Bernardino, and Ventura counties, CA	Los Angeles, CA	Central or Room A/C	25-30
Los Angeles	Los Angeles, Orange, Riverside, San Bernardino, and Ventura counties, CA	Los Angeles, CA	Central or Room A/C	>30
Los Angeles	Los Angeles, Orange, Riverside, San Bernardino, and Ventura counties, CA	Los Angeles, CA	No A/C	<=10
Los Angeles	Los Angeles, Orange, Riverside, San Bernardino, and Ventura counties, CA	Los Angeles, CA	No A/C	10-20
Los Angeles	Los Angeles, Orange, Riverside, San Bernardino, and Ventura counties, CA	Los Angeles, CA	No A/C	20-25
Los Angeles	Los Angeles, Orange, Riverside, San Bernardino, and Ventura counties, CA	Los Angeles, CA	No A/C	>25
New York City	New York, NY	Boston, MA, Chicago, IL, Cleveland, OH, Detroit, MI, New York, NY, Philadelphia, PA	Central or Room A/C	<=10
New York City	New York, NY	Boston, MA, Chicago, IL, Cleveland, OH, Detroit, MI, New York, NY, Philadelphia, PA	Central or Room A/C	10-25
New York City	New York, NY	Boston, MA, Chicago, IL, Cleveland, OH, Detroit, MI, New York, NY, Philadelphia, PA	Central or Room A/C	>25
New York City	New York, NY	Boston, MA, Chicago, IL,	No A/C	<=10

Table D-3. AER subsets by city, A/C type, and temperature range.

Subset City Name	Study Cities	Represents Modeled Cities:	A/C Type	Temperature Range (°C)
		Cleveland, OH, Detroit, MI, New York, NY, Philadelphia, PA		
New York City	New York, NY	Boston, MA, Chicago, IL, Cleveland, OH, Detroit, MI, New York, NY, Philadelphia, PA	No A/C	10-20
New York City	New York, NY	Boston, MA, Chicago, IL, Cleveland, OH, Detroit, MI, New York, NY, Philadelphia, PA	No A/C	>20
Outside California	Cities outside CA	St. Louis, MO	Central or Room A/C	<=10
Outside California	Cities outside CA	St. Louis, MO	Central or Room A/C	10-20
Outside California	Cities outside CA	St. Louis, MO	Central or Room A/C	20-25
Outside California	Cities outside CA	St. Louis, MO	Central or Room A/C	25-30
Outside California	Cities outside CA	St. Louis, MO	Central or Room A/C	>30
Outside California	Cities outside CA	St. Louis, MO Atlanta, GA Washington DC	No A/C	<=10
Outside California	Cities outside CA	St. Louis, MO Atlanta, GA Washington DC	No A/C	10-20
Outside California	Cities outside CA	St. Louis, MO Atlanta, GA Washington DC	No A/C	>20
Research Triangle Park	Research Triangle Park, NC	Atlanta, GA Washington DC	Central or Room A/C	<=10
Research Triangle Park	Research Triangle Park, NC	Atlanta, GA Washington DC	Central or Room A/C	10-20
Research Triangle Park	Research Triangle Park, NC	Atlanta, GA Washington DC	Central or Room A/C	20-25
Research Triangle Park	Research Triangle Park, NC	Atlanta, GA Washington DC	Central or Room A/C	>25

The GM and GSD values that define the fitted log-normal distributions for these 39 AER subsets are shown in Table D-4. Examples of these pairs are also plotted in Figures D-9 through D-19, to be further described below. Each of the example figures D-9 through D-19 corresponds to a single GM/GSD "Original Data" pair. The GM and GSD values for the "Original Data" are at the intersection of the horizontal and vertical lines that are parallel to the x- and y-axes in the figures.

Table D-4. Geometric means and standard deviations for AER subsets by city, A/C type, and temperature range.

Subset City Name	A/C Type	Temperature Range (°C)	N	Geometric Mean	Geometric Standard Deviation
Houston	Central or Room A/C	<=20	15	0.4075	2.1135
Houston	Central or Room A/C	20-25	20	0.4675	1.9381
Houston	Central or Room A/C	25-30	65	0.4221	2.2579
Houston	Central or Room A/C	>30	14	0.4989	1.7174
Houston	No A/C	<=10	13	0.6557	1.6794
Houston	No A/C	10-20	28	0.6254	2.9162
	No A/C	>20	12	0.9161	2.4512
Inland California	Central or Room A/C	<=25	226	0.5033	1.9210
Inland California	Central or Room A/C	>25	83	0.8299	2.3534
Inland California	No A/C	<=10	17	0.5256	3.1920
Inland California	No A/C	10-20	52	0.6649	2.1743
Inland California	No A/C	20-25	13	1.0536	1.7110
Inland California	No A/C	>25	14	0.8271	2.2646
Los Angeles	Central or Room A/C	<=20	721	0.5894	1.8948
Los Angeles	Central or Room A/C	20-25	273	1.1003	2.3648
Los Angeles	Central or Room A/C	25-30	102	0.8128	2.4151
Los Angeles	Central or Room A/C	>30	12	0.2664	2.7899
Los Angeles	No A/C	<=10	18	0.5427	3.0872
Los Angeles	No A/C	10-20	390	0.7470	2.0852
Los Angeles	No A/C	20-25	148	1.3718	2.2828
Los Angeles	No A/C	>25	25	0.9884	1.9666
New York City	Central or Room A/C	<=10	20	0.7108	2.0184
New York City	Central or Room A/C	10-25	42	1.1392	2.6773
New York City	Central or Room A/C	>25	19	1.2435	2.1768
New York City	No A/C	<=10	48	1.0165	2.1382
New York City	No A/C	10-20	59	0.7909	2.0417
New York City	No A/C	>20	32	1.6062	2.1189
Outside California	Central or Room A/C	<=10	179	0.9185	1.8589
Outside California	Central or Room A/C	10-20	338	0.5636	1.9396
Outside California	Central or Room A/C	20-25	253	0.4676	2.2011
Outside California	Central or Room A/C	25-30	219	0.4235	2.0373

Table D-4. Geometric means and standard deviations for AER subsets by city, A/C type, and temperature range.

Subset City Name	A/C Type	Temperature Range (°C)	N	Geometric Mean	Geometric Standard Deviation
Outside California	Central or Room A/C	>30	24	0.5667	1.9447
Outside California	No A/C	<=10	61	0.9258	2.0836
Outside California	No A/C	10-20	87	0.7333	2.3299
Outside California	No A/C	>20	44	1.3782	2.2757
Research Triangle Park	Central or Room A/C	<=10	157	0.9617	1.8094
Research Triangle Park	Central or Room A/C	10-20	320	0.5624	1.9058
Research Triangle Park	Central or Room A/C	20-25	196	0.3970	1.8887
Research Triangle Park	Central or Room A/C	>25	145	0.3803	1.7092

To evaluate the uncertainty of the GM and GSD values, a bootstrap simulation was performed, as follows. Suppose that a given AER subset has N values. A bootstrap sample is obtained by sampling N times at random with replacement from the N AER values. The first AER value in the bootstrap sample is selected randomly from the N values, so that each of the N values is equally likely. The second, third, …, N'th values in the bootstrap sample are also selected randomly from the N values, so that for each selection, each of the N values is equally likely. The same value can be selected more than once. Using this bootstrap sample, the geometric mean and geometric standard deviation of the N values in the bootstrap sample was calculated. This pair of values is plotted as one of the points in a figure for that AER subset. 1,000 bootstrap samples were randomly generated for each AER subset, producing a set of 1,000 geometric mean and geometric standard deviation pairs, which were plotted in example Figures D-9 through D-19.

The bootstrap distributions display the part of the uncertainty of the GM and GSD that is entirely due to random sampling variation. The analysis is based on the assumption that the study AER data are a random sample from the population distribution of AER values for the given city, temperature range, and A/C type. On that basis, the 1,000 bootstrap GM and GSD pairs estimate the variation of the GM and GSD across all possible samples of N values from the population. Since each GM, GSD pair uniquely defines a fitted log-normal distribution, the pairs also estimate the uncertainty of the fitted log-normal distribution. The choice of 1,000 was made as a compromise between having enough pairs to accurately estimate the GM, GSD distribution and not having too many pairs so that the graph appears as a smudge of overlapped points. Note that even if there were infinitely many bootstrap pairs, the uncertainty distribution would still be an estimate of the true uncertainty because the N is finite, so that the empirical distribution of the N measured AER values does not equal the unknown population distribution.

In most cases the uncertainty distribution appears to be a roughly circular or elliptical geometric mean and standard deviation region. The size of the region depends upon the sample size and on the variability of the AER values; the region will be smallest when the sample size N is large and/or the variability is small, so that there are a large number of values that are all close together.

The bootstrap analyses show that the geometric standard deviation uncertainty for a given CMSA/air-conditioning-status/temperature-range combination tends to have a range of at most from "fitted GSD-1.0 hr^{-1}" to "fitted GSD+1.0 hr^{-1}", but the intervals based on larger AER sample sizes are frequently much narrower. The ranges for the geometric means tend to be approximately from "fitted GM-0.5 hr^{-1}" to "fitted GM+0.5 hr^{-1}", but in some cases were much smaller.

The bootstrap analysis only evaluates the uncertainty due to the random sampling. It does not account for the uncertainty due to the lack of representativeness, which in turn is due to the fact that the samples were not always random samples from the entire population of residences in a city, and were sometimes used to represent different cities. Since only the GM and GSD were used, the bootstrap analyses does not account for uncertainties about the true distributional shape, which may not necessarily be log-normal. Furthermore, the bootstrap uncertainty does not account for the effect of the calendar year (possible trends in AER values) or of the uncertainty due to the AER measurement period; the distributions were intended to represent distributions of 24 hour average AER values although the study AER data were measured over a variety of measurement periods.

To use the bootstrap distributions to estimate the impact of sample size on the fitted distributions, a Monte Carlo approach could be used with the APEX model. Instead of using the Original Data distributions, a bootstrap GM, GSD pair could be selected at random and the AER value could be selected randomly from the log-normal distribution with the bootstrap GM and GSD.

Figure D-1

Geometric mean and standard deviation of air exchange rate
For different cities and studies
Air Conditioner Type: Central or Room A/C
Temperature Range: <= 10 Degrees Celsius

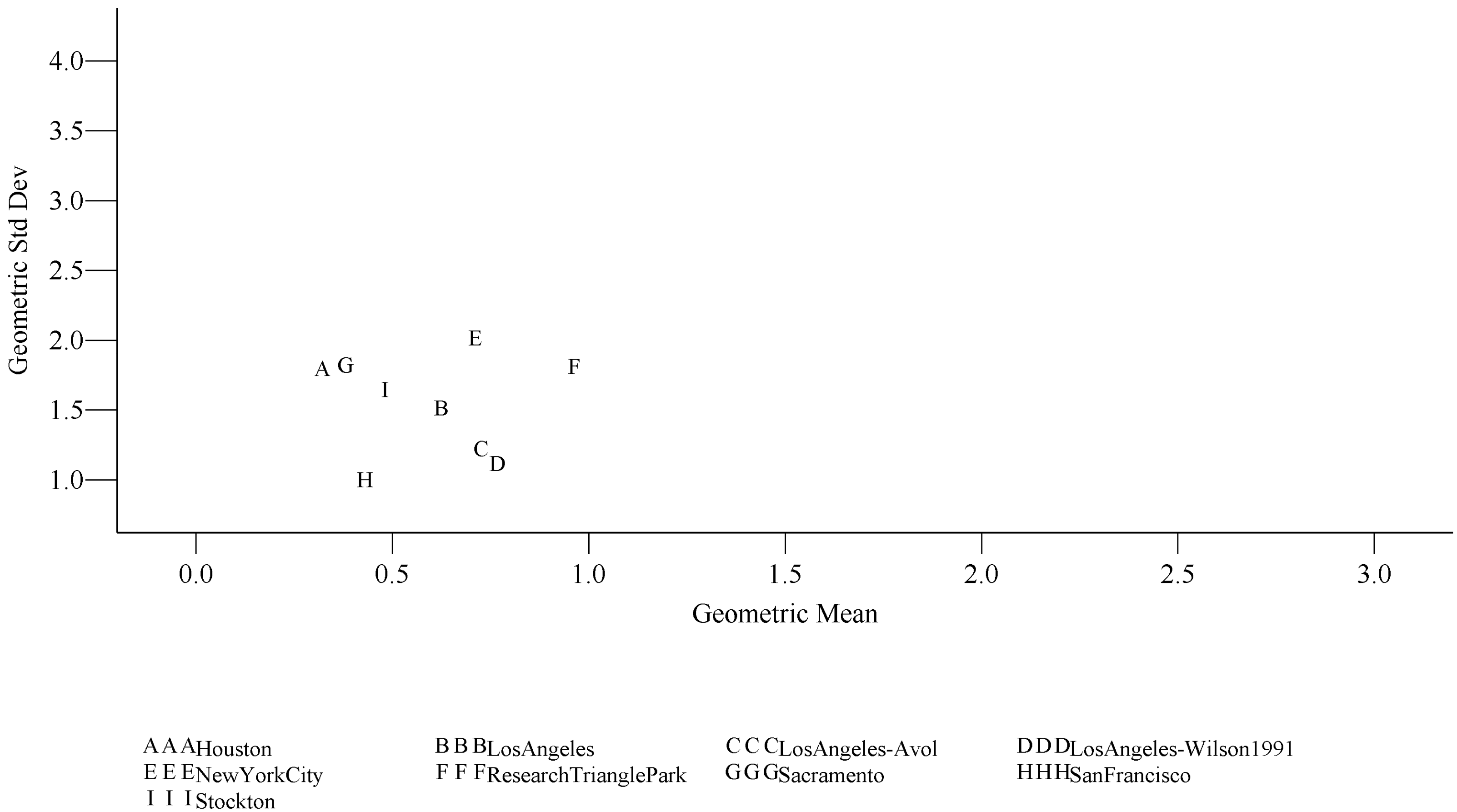


Figure D-2

Geometric mean and standard deviation of air exchange rate
For different cities and studies
Air Conditioner Type: Central or Room A/C
Temperature Range: 10-20 Degrees Celsius

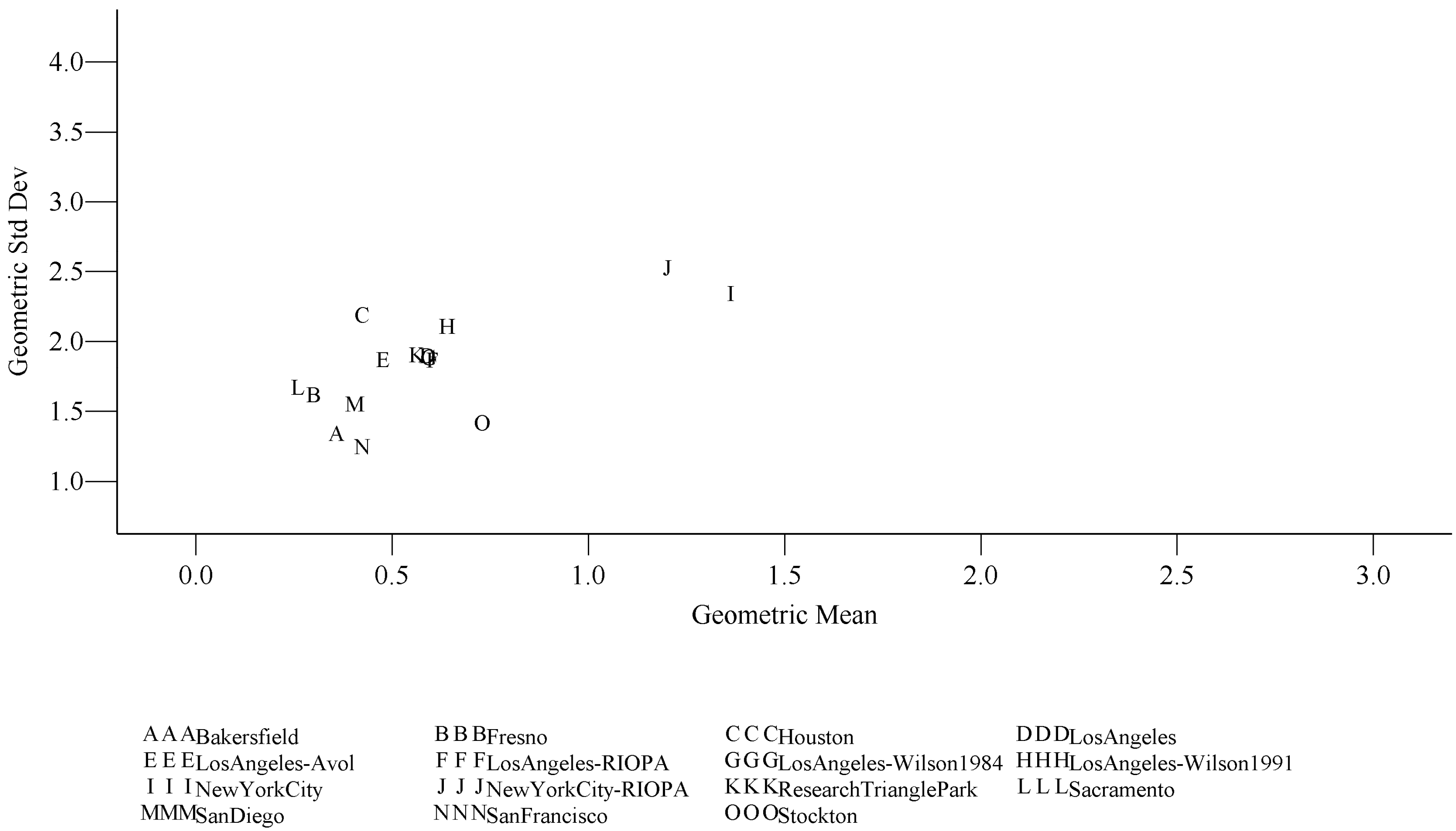


Figure D-3

Geometric mean and standard deviation of air exchange rate
For different cities and studies
Air Conditioner Type: Central or Room A/C
Temperature Range: 20-25 Degrees Celsius

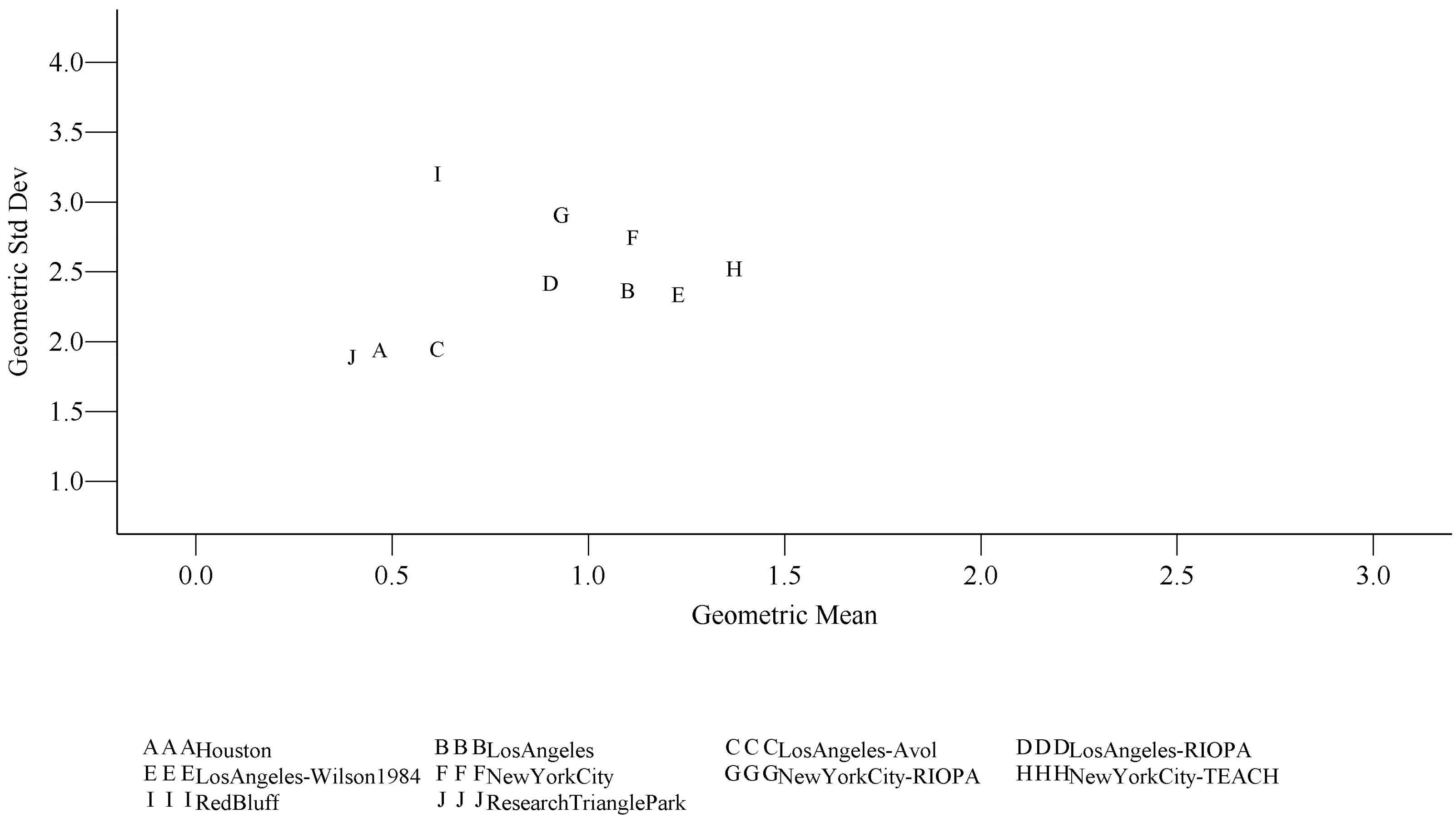


Figure D-4

Geometric mean and standard deviation of air exchange rate
For different cities and studies
Air Conditioner Type: Central or Room A/C
Temperature Range: > 25 Degrees Celsius

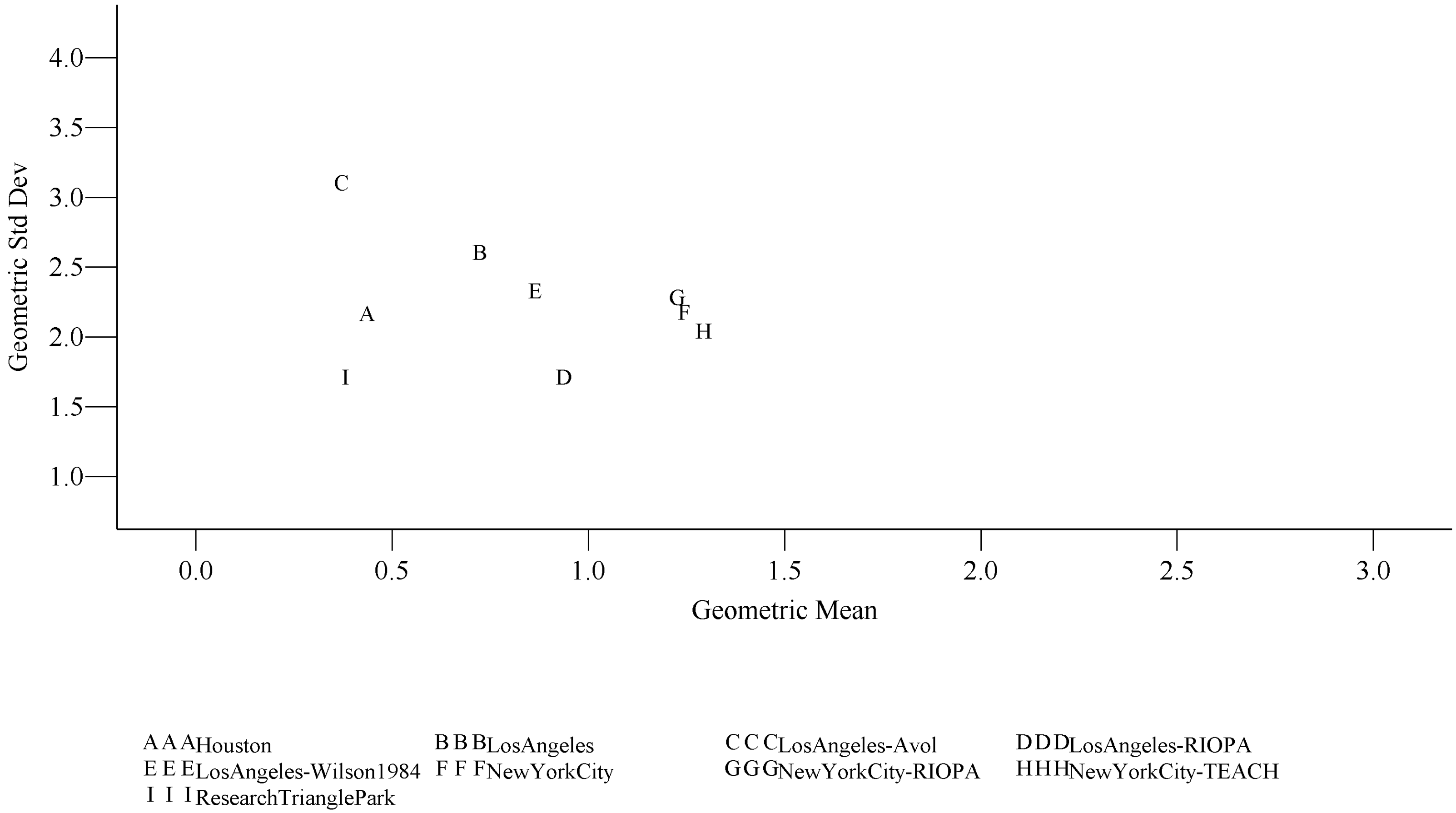


Figure D-5

Geometric mean and standard deviation of air exchange rate
For different cities and studies
Air Conditioner Type: No A/C
Temperature Range: <= 10 Degrees Celsius

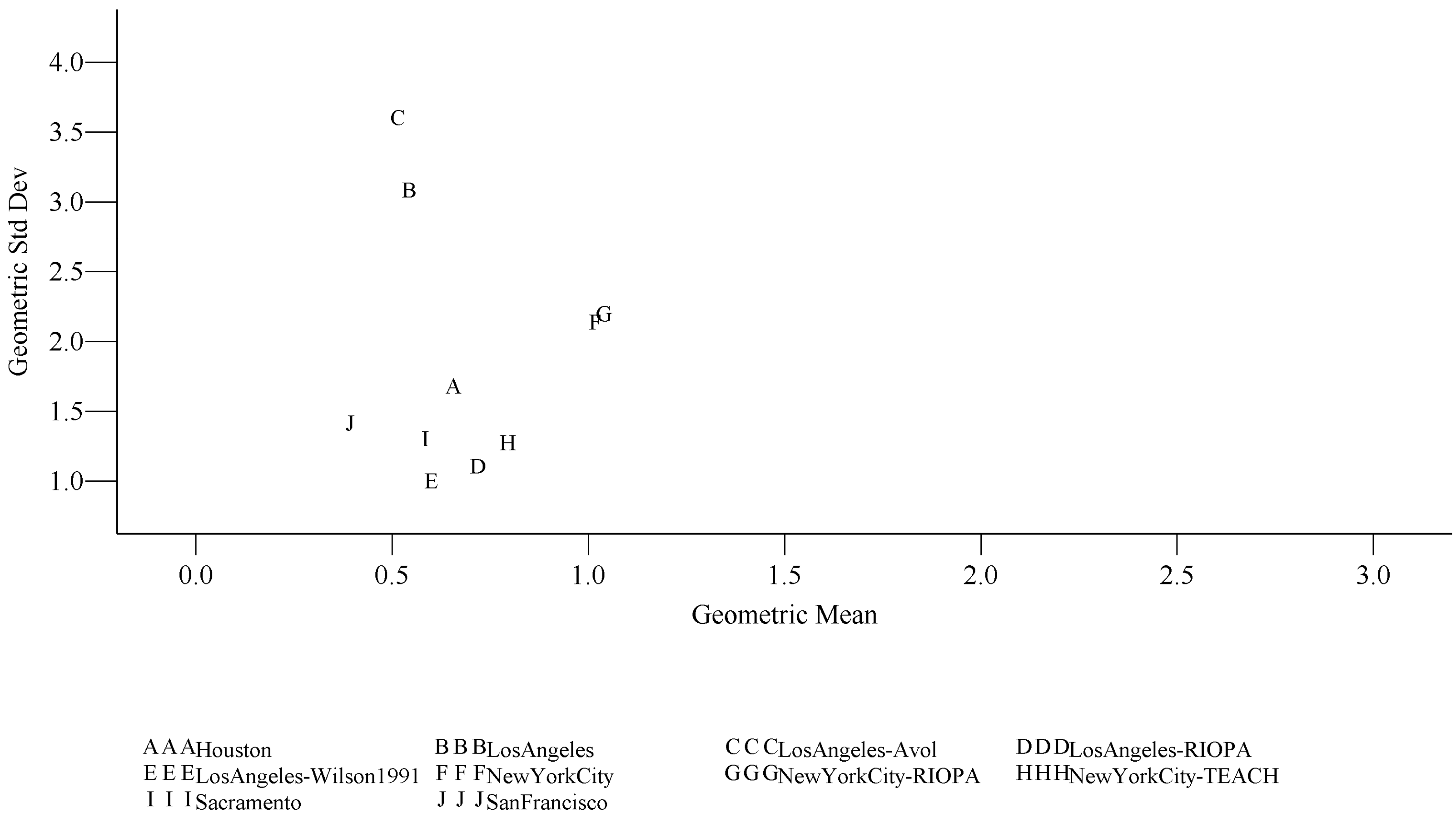


Figure D-6

Geometric mean and standard deviation of air exchange rate
For different cities and studies
Air Conditioner Type: No A/C
Temperature Range: 10-20 Degrees Celsius

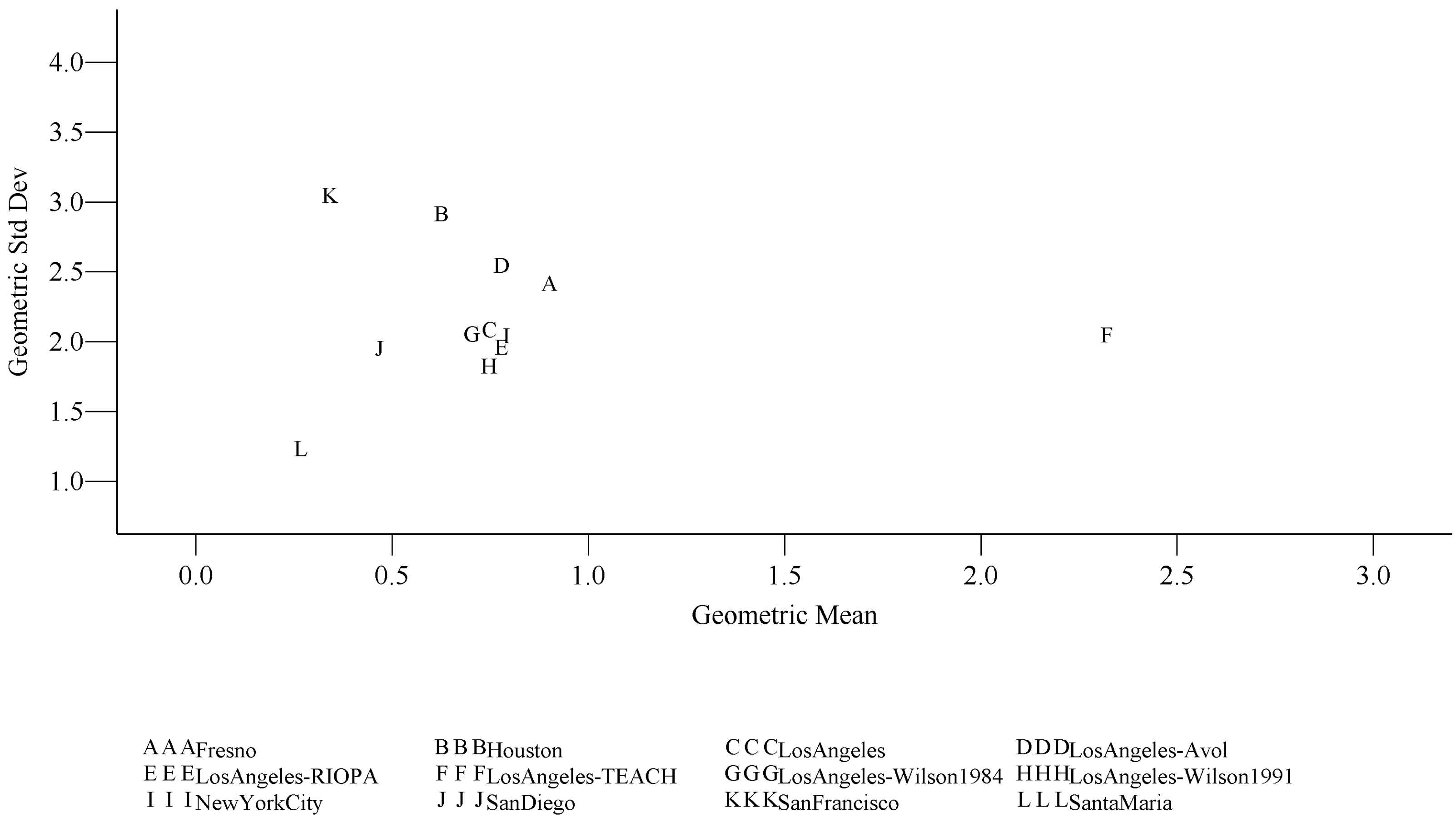


Figure D-7

Geometric mean and standard deviation of air exchange rate
For different cities and studies
Air Conditioner Type: No A/C
Temperature Range: 20-25 Degrees Celsius

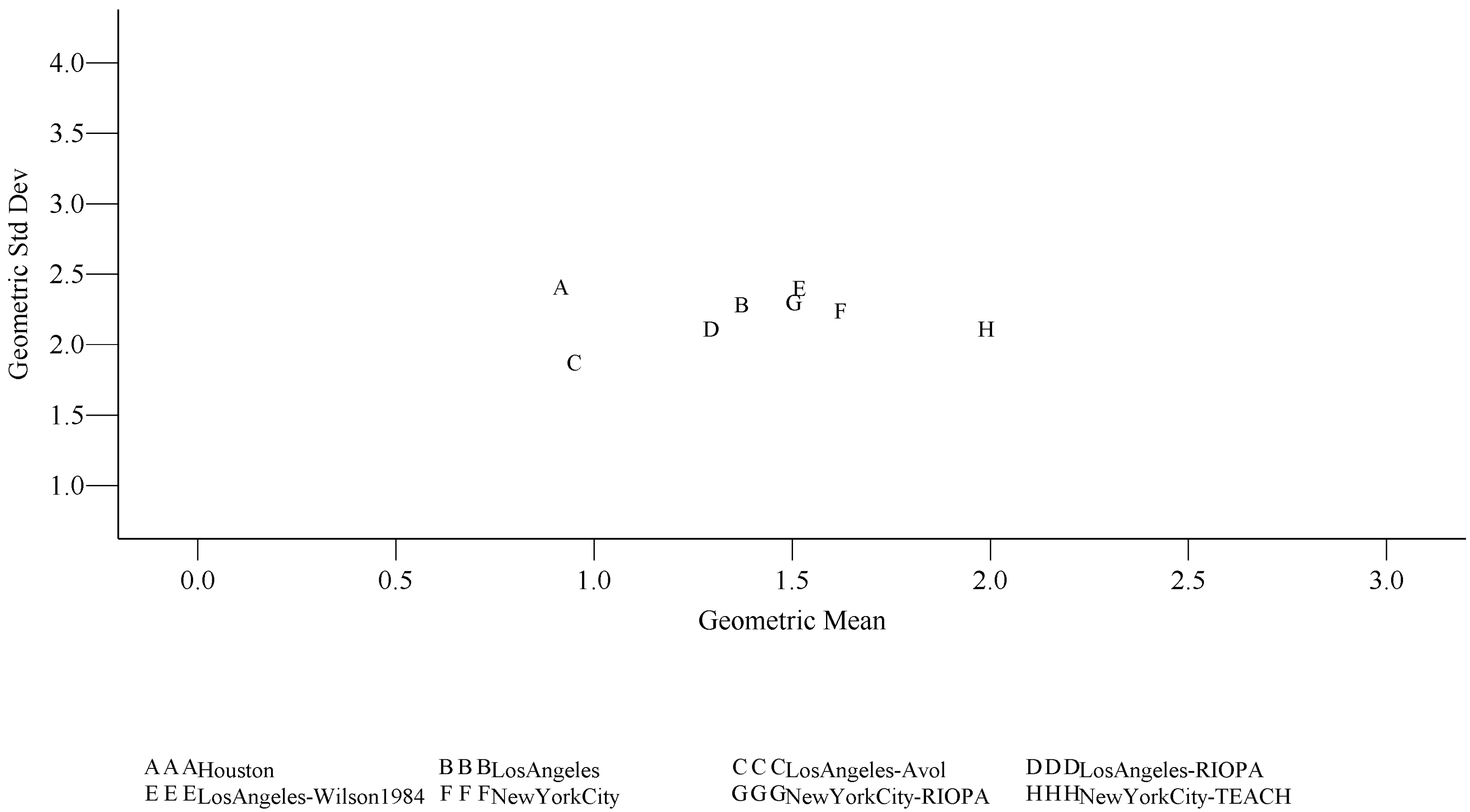


Figure D-8

Geometric mean and standard deviation of air exchange rate
For different cities and studies
Air Conditioner Type: No A/C
Temperature Range: > 25 Degrees Celsius

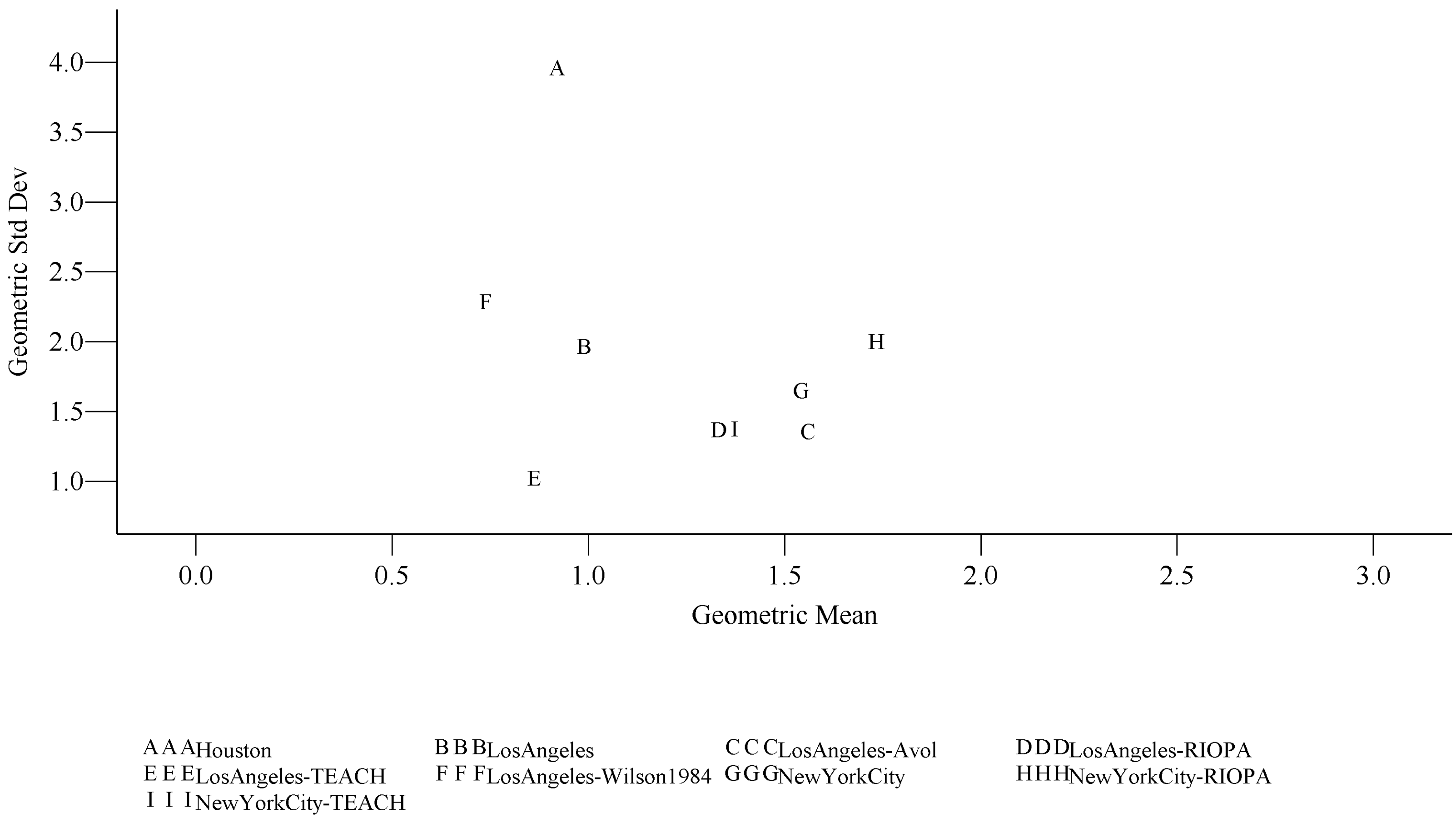


Figure D-9

Geometric mean and standard deviation of air exchange rate
Bootstrapped distributions for different cities
City: Houston
Air Conditioner Type: Central or Room A/C
Temperature Range: 20-25 Degrees Celsius

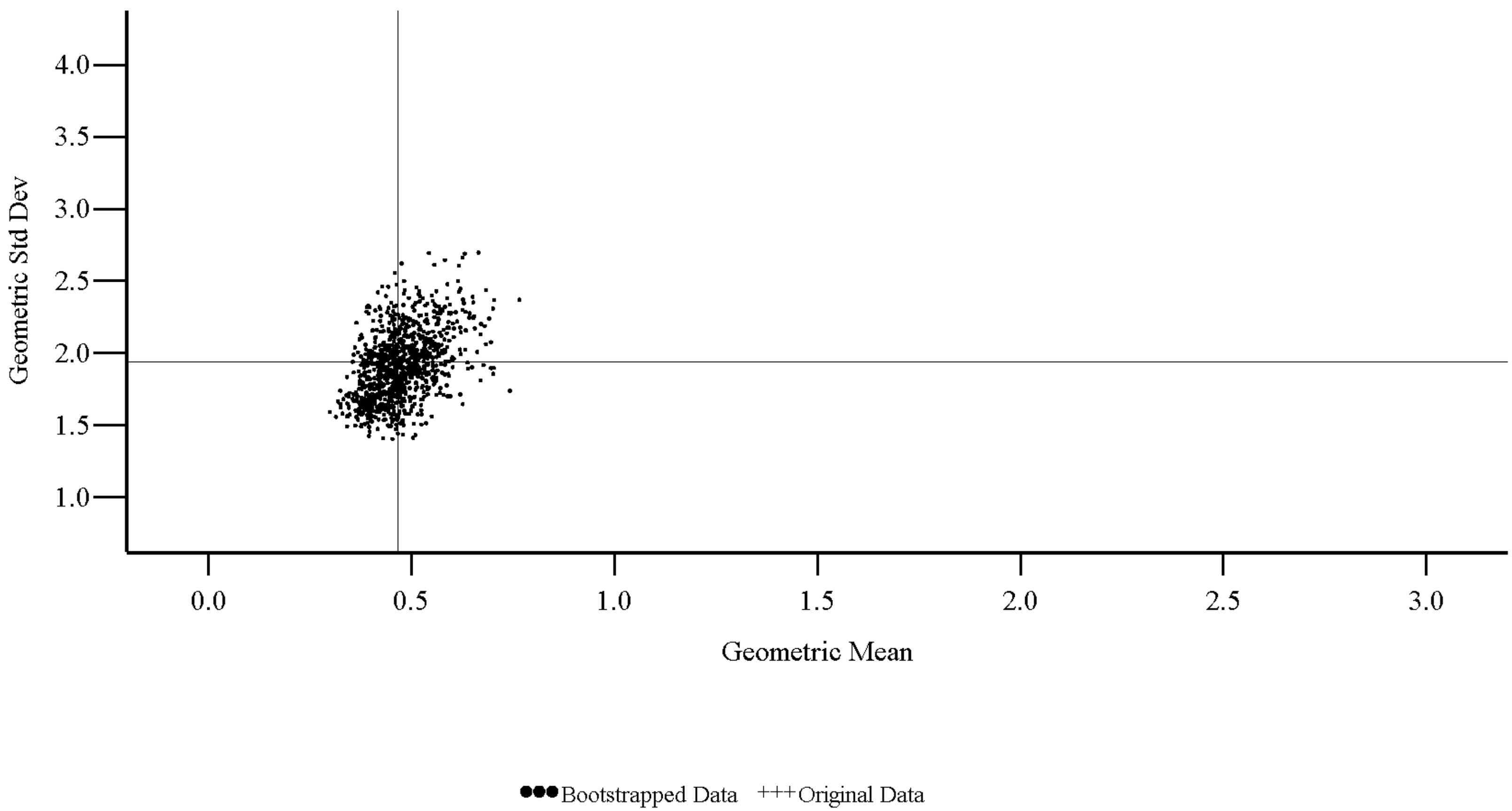


Figure D-10

Geometric mean and standard deviation of air exchange rate
Bootstrapped distributions for different cities
City: Houston
Air Conditioner Type: No A/C
Temperature Range: >20 Degrees Celsius

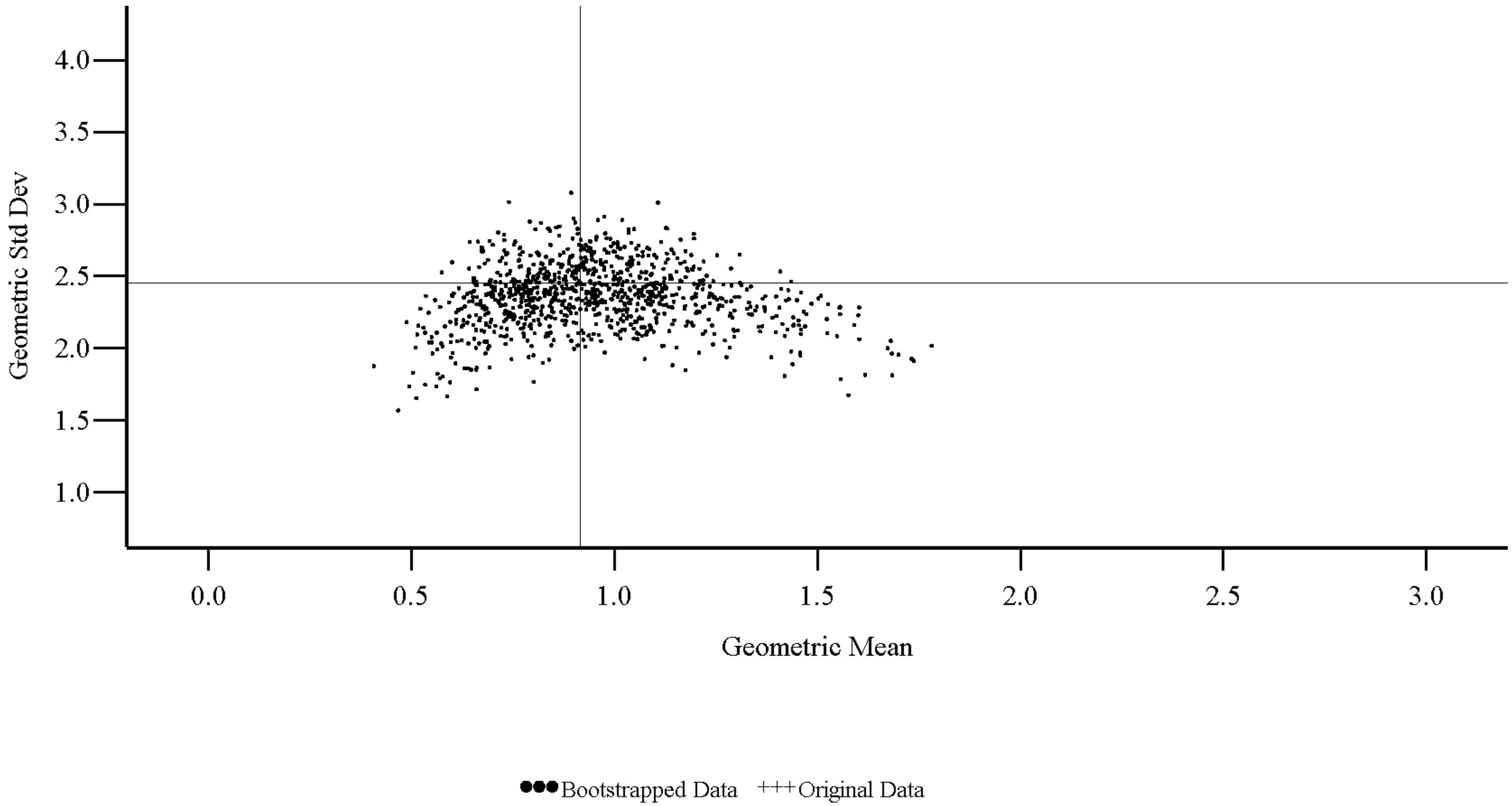


Figure D-11

Geometric mean and standard deviation of air exchange rate
Bootstrapped distributions for different cities
City: Inland California
Air Conditioner Type: Central or Room A/C
Temperature Range: <=25 Degrees Celsius

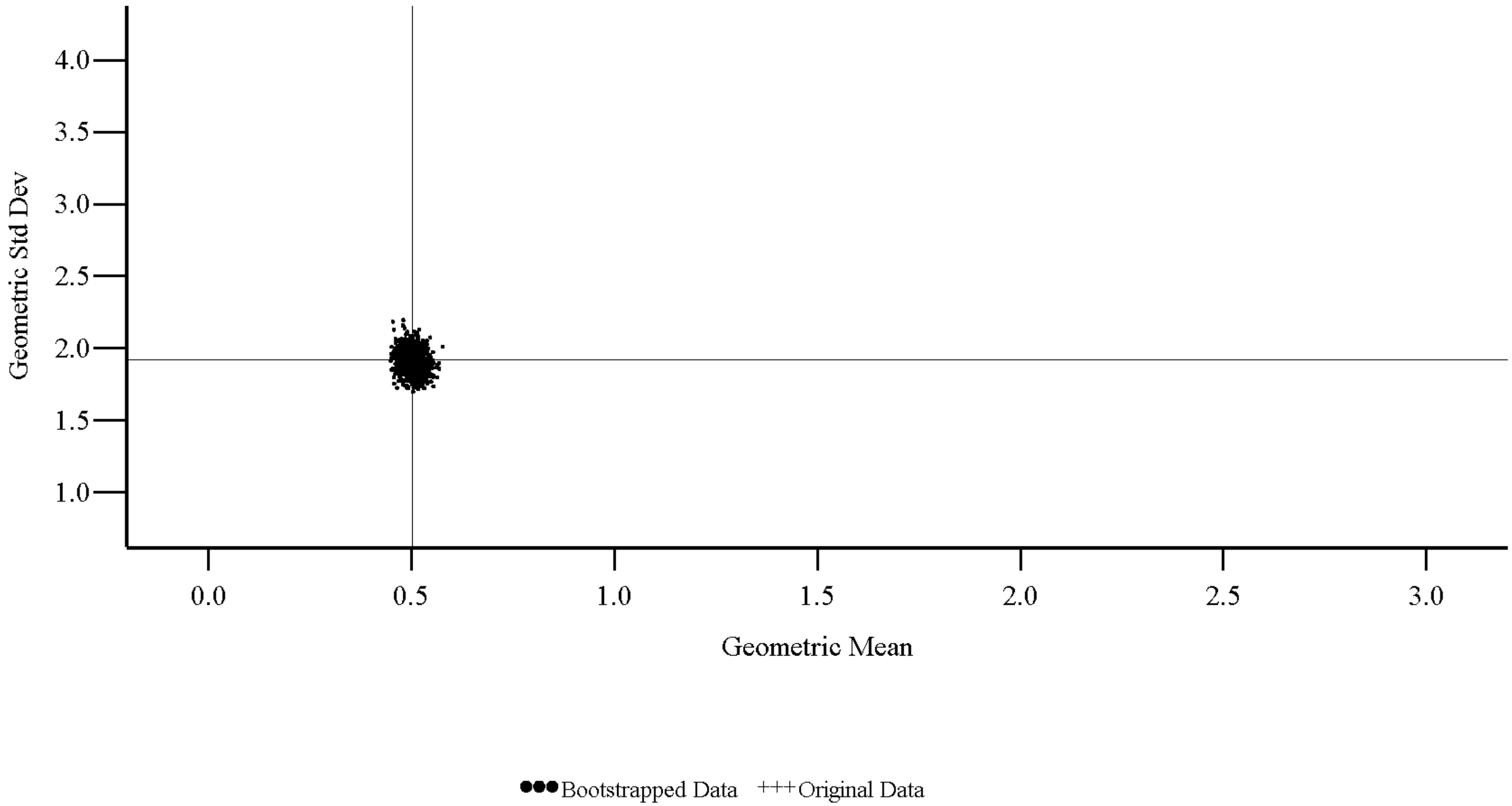


Figure D-12

Geometric mean and standard deviation of air exchange rate
Bootstrapped distributions for different cities
City: Inland California
Air Conditioner Type: No A/C
Temperature Range: 20-25 Degrees Celsius

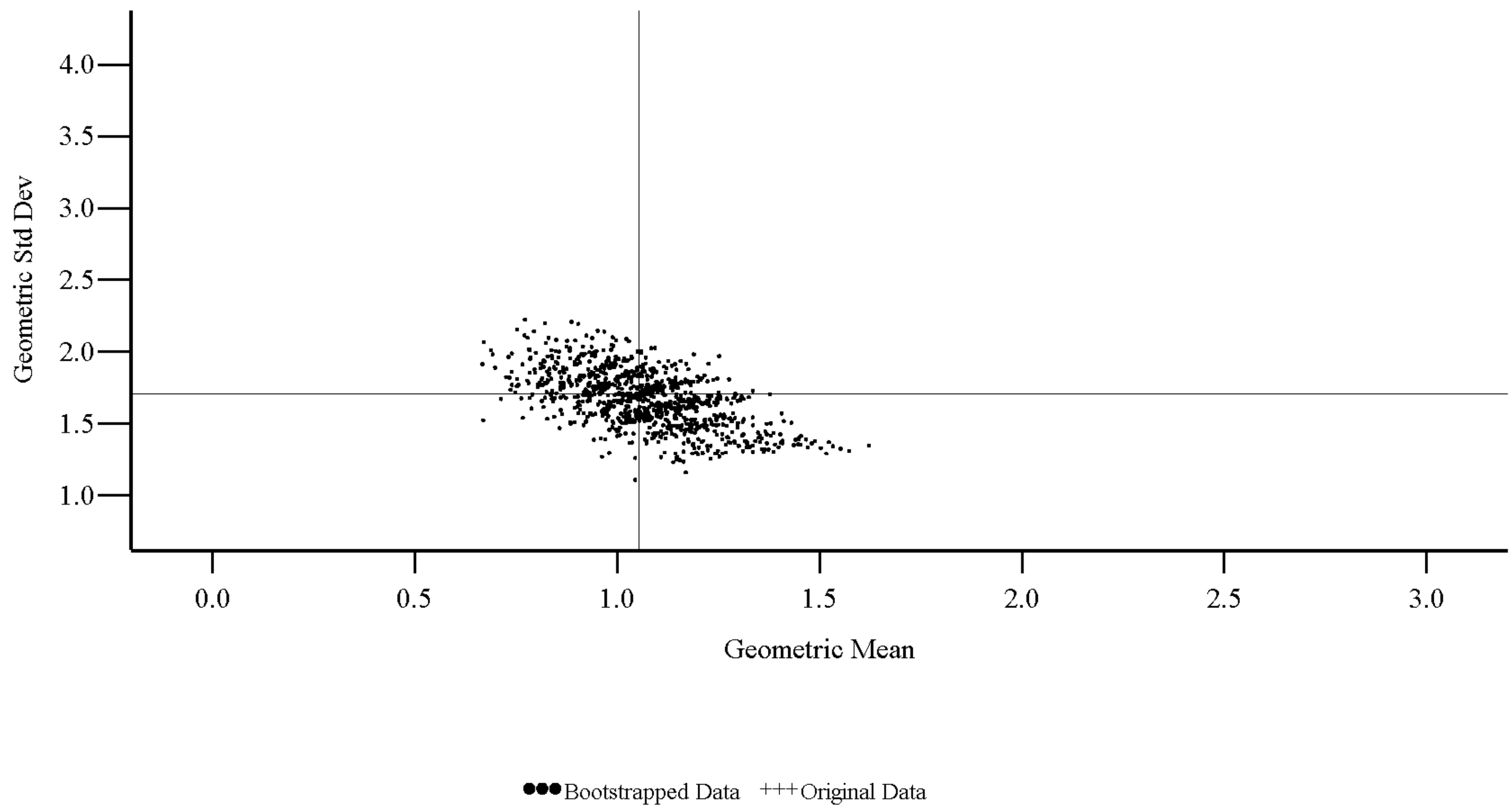


Figure D-13

Geometric mean and standard deviation of air exchange rate
Bootstrapped distributions for different cities
City: Los Angeles
Air Conditioner Type: Central or Room A/C
Temperature Range: 20-25 Degrees Celsius

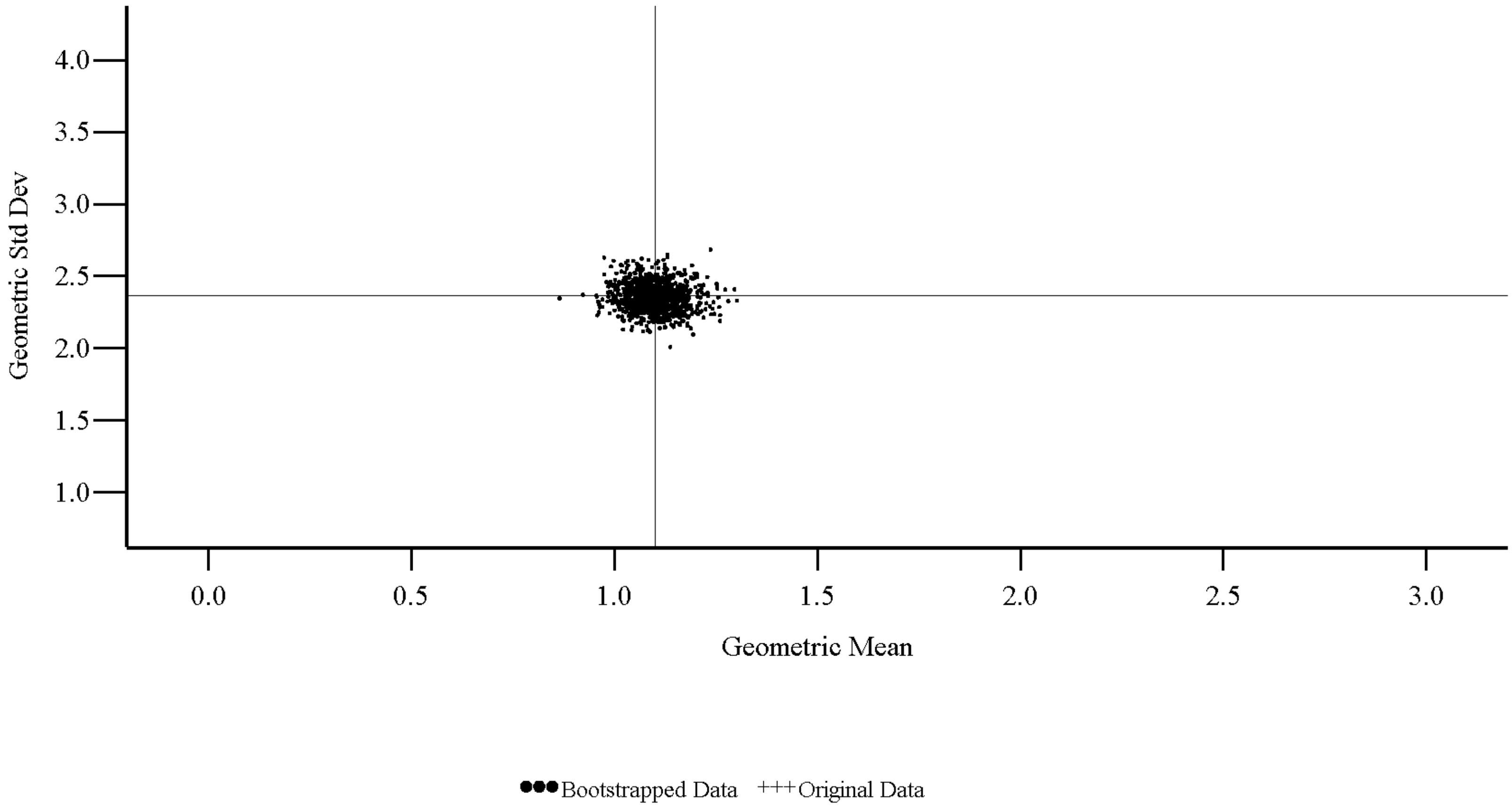


Figure D-14

Geometric mean and standard deviation of air exchange rate
Bootstrapped distributions for different cities
City: Los Angeles
Air Conditioner Type: No A/C
Temperature Range: 20-25 Degrees Celsius

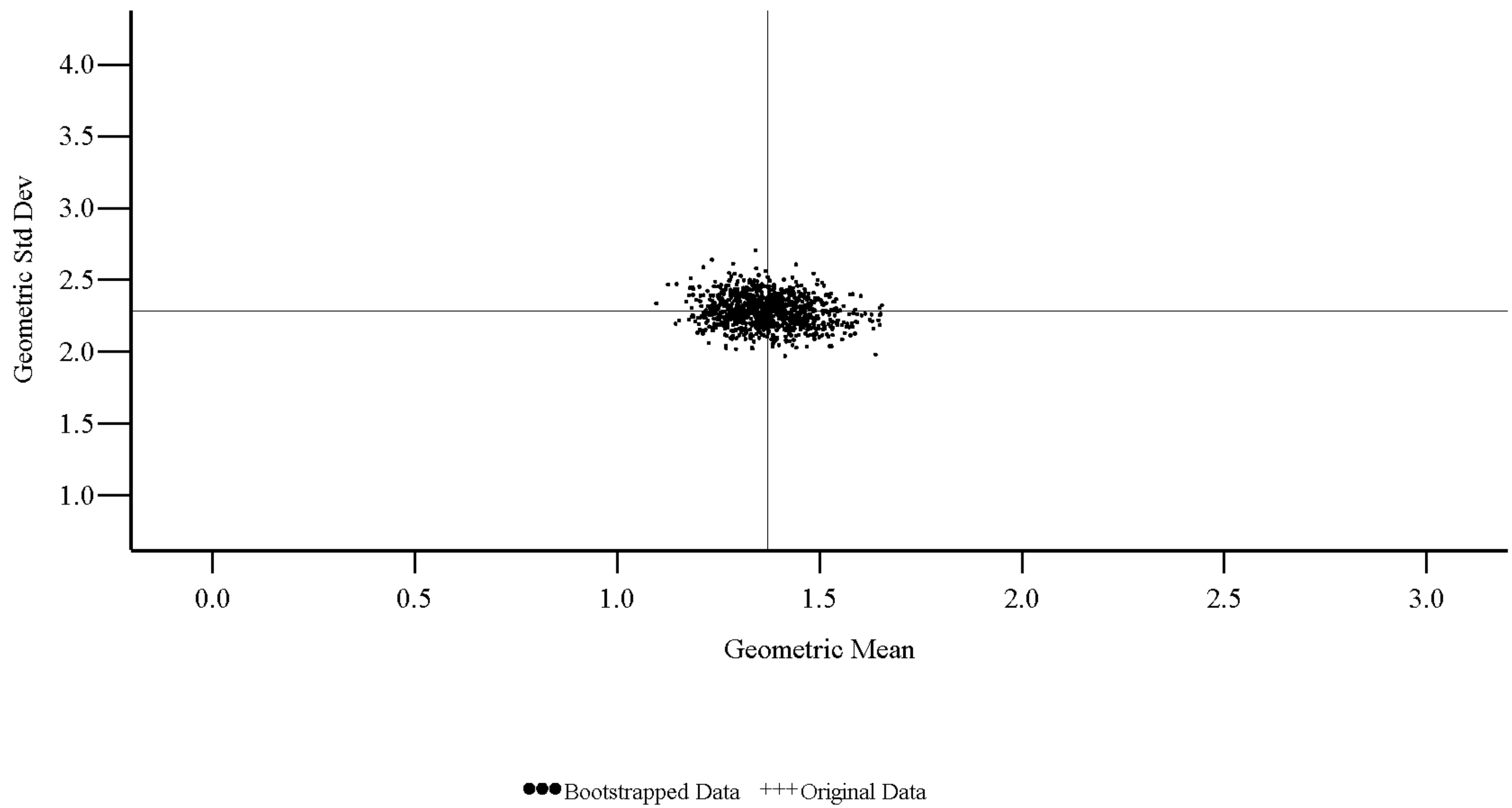


Figure D-15

Geometric mean and standard deviation of air exchange rate
Bootstrapped distributions for different cities
City: New York City
Air Conditioner Type: Central or Room A/C
Temperature Range: 10-25 Degrees Celsius

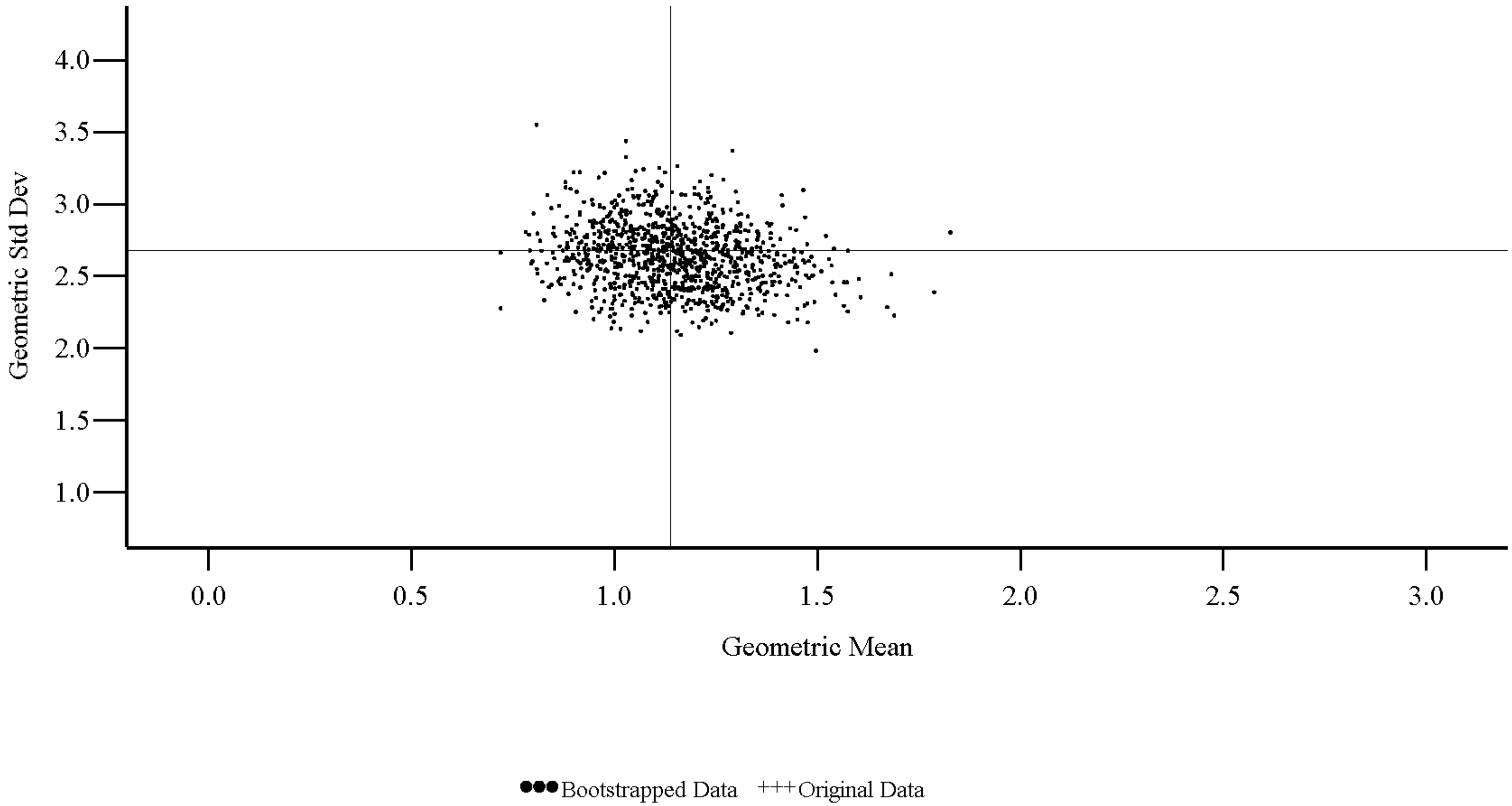


Figure D-16

Geometric mean and standard deviation of air exchange rate
Bootstrapped distributions for different cities
City: New York City
Air Conditioner Type: No A/C
Temperature Range: >20 Degrees Celsius

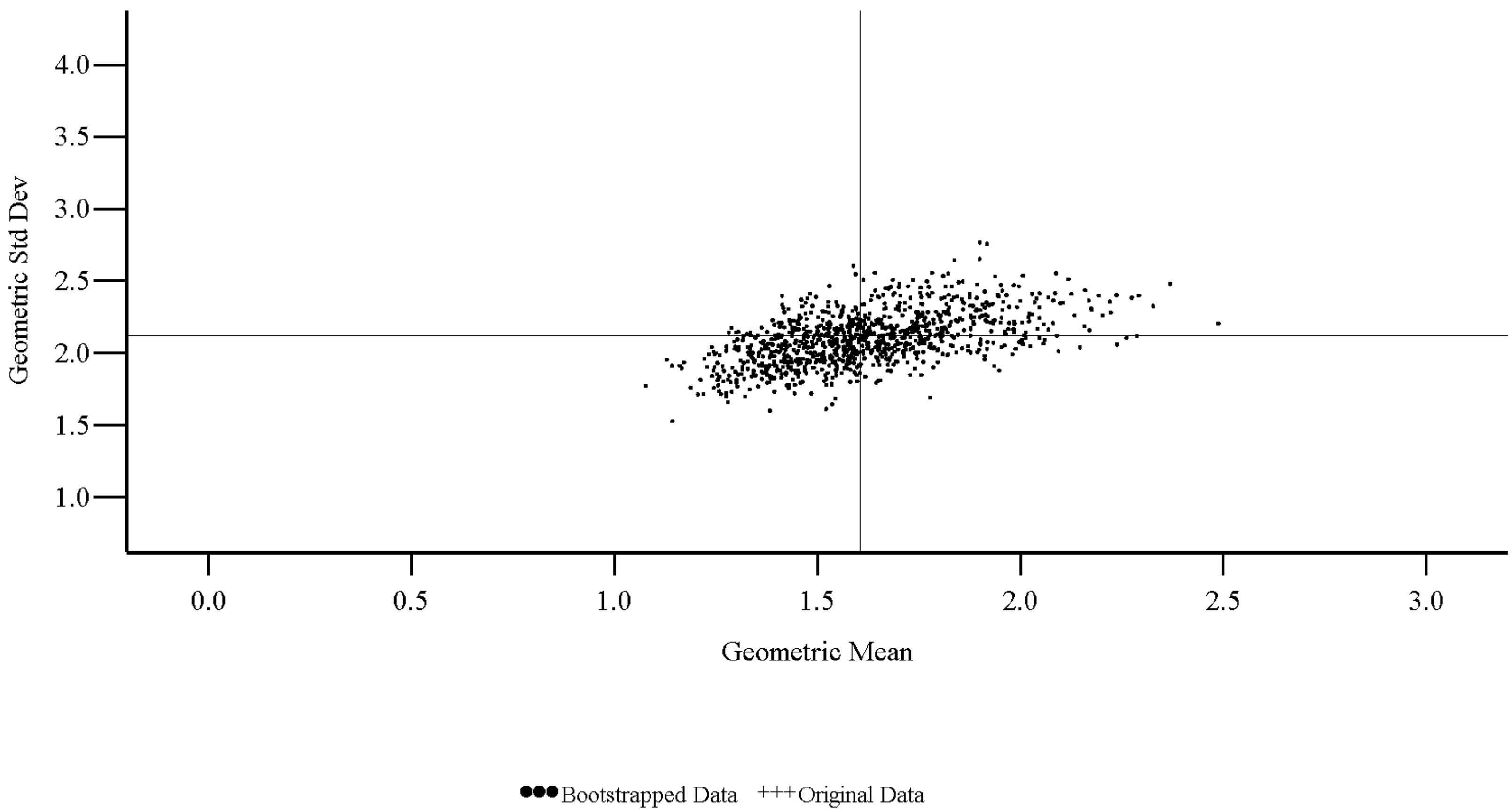


Figure D-17

Geometric mean and standard deviation of air exchange rate
Bootstrapped distributions for different cities
City: Outside California
Air Conditioner Type: Central or Room A/C
Temperature Range: 20-25 Degrees Celsius

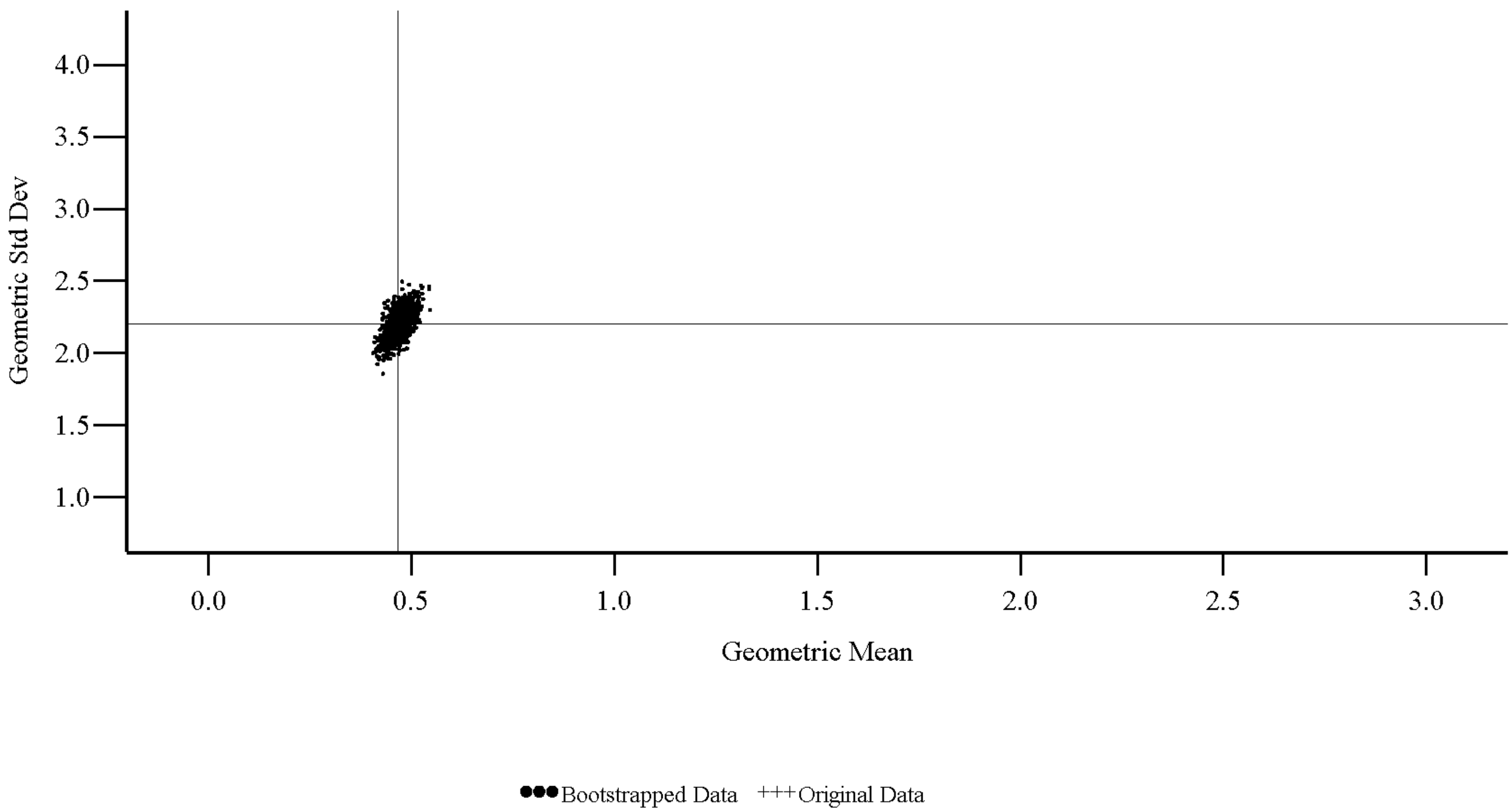


Figure D-18

Geometric mean and standard deviation of air exchange rate
Bootstrapped distributions for different cities
City: Outside California
Air Conditioner Type: No A/C
Temperature Range: >20 Degrees Celsius

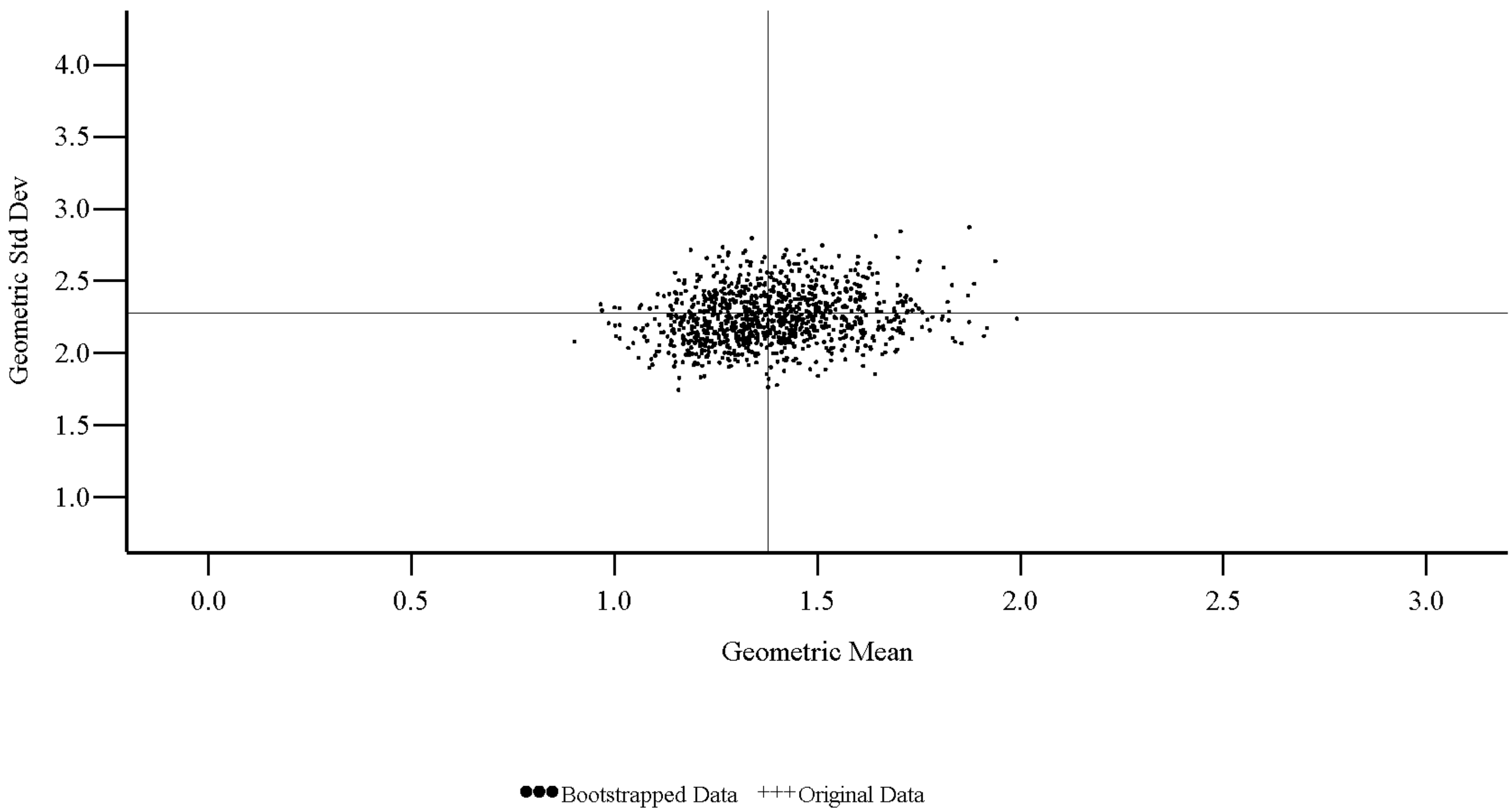
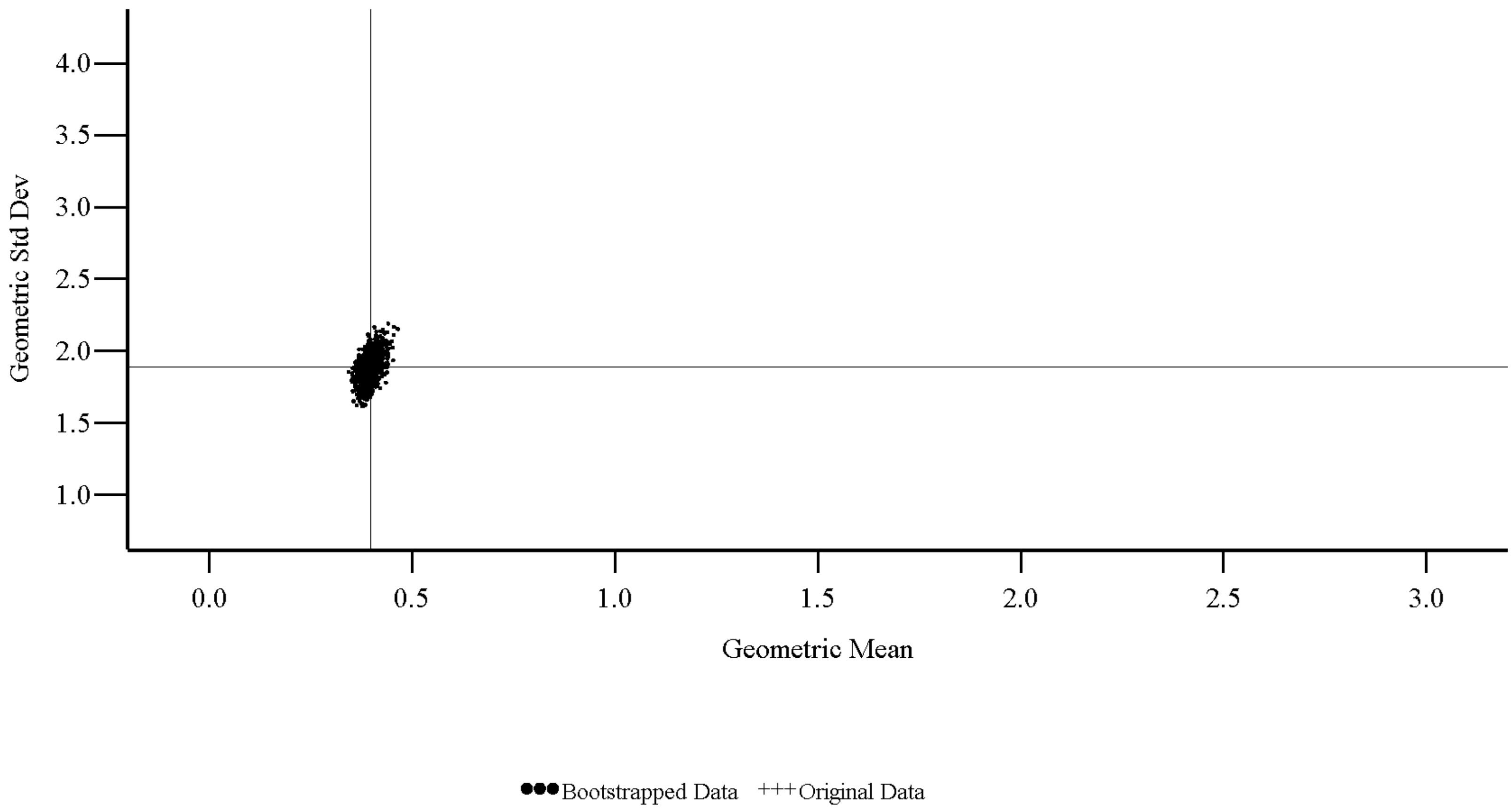


Figure D-19

Geometric mean and standard deviation of air exchange rate
Bootstrapped distributions for different cities
City: Research Triangle Park
Air Conditioner Type: Central or Room A/C
Temperature Range: 20-25 Degrees Celsius



ATTACHMENT 8. TECHNICAL MEMORANDUM ON THE DISTRIBUTIONS OF AIR EXCHANGE RATE AVERAGES OVER MULTIPLE DAYS

ICF INTERNATIONAL

MEMORANDUM

To: John Langstaff, EPA OAQPS
From: Jonathan Cohen, Arlene Rosenbaum, ICF International
Date: June 8, 2006
Re: Distributions of air exchange rate averages over multiple days

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As detailed in the memorandum by Cohen, Mallya and Rosenbaum, 2005[7] (Appendix A of this report) we have proposed to use the APEX model to simulate the residential air exchange rate (AER) using different log-normal distributions for each combination of outside temperature range and the air conditioner type, defined as the presence or absence of an air conditioner (central or room).

Although the averaging periods for the air exchange rates in the study databases varied from one day to seven days, our analyses did not take the measurement duration into account and treated the data as if they were a set of statistically independent daily averages. In this memorandum we present some analyses of the Research Triangle Park Panel Study that show extremely strong correlations between consecutive 24-hour air exchange rates measured at the same house. This provides support for the simplified approach of treating all averaging periods as if they were 24-hour averages.

In the current version of the APEX model, there are several options for stratification of time periods with respect to AER distributions, and for when to re-sample from a distribution for a given stratum. The options selected for this current set of simulations resulted in a uniform AER for each 24-hour period and re-sampling of the 24-hour AER for each simulated day. This re-sampling for each simulated day implies that the simulated AERs on consecutive days in the same microenvironment are statistically independent. Although we have not identified sufficient data to test the assumption of uniform AERs throughout a 24-hour period, the analyses described in this memorandum suggest that AERs on consecutive days are highly correlated. Therefore, we performed sensitivity simulations to assess the impact of the assumption of temporally independent air exchange rates, but found little difference between APEX predictions for the two scenarios (i.e., temporally independent and autocorrelated air exchange rates).

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7 Cohen, J., H. Mallya, and A. Rosenbaum. 2005. Memorandum to John Langstaff. *EPA 68D01052, Work Assignment 3-08. Analysis of Air Exchange Rate Data*. September 30, 2005.

Distributions of multi-day averages from the RTP Panel Study

The RTP Panel study included measurements of 24-hour averages at 38 residences for up to four periods of at least seven days. These periods were in different seasons and/or calendar years. Daily outside temperatures were also provided. All the residences had either window or room air conditioners or both. We used these data to compare the distributions of daily averages taken over 1, 2, 3, .. 7 days.

The analysis is made more complicated because the previous analyses showed the dependence of the air exchange rate on the outside temperature, and the daily temperatures often varied considerably. Two alternative approaches were employed to group consecutive days. For the first approach, A, we sorted the data by the HOUSE_ID number and date and began a new group of days for each new HOUSE_ID and whenever the sorted measurement days on the same HOUSE_ID were 30 days or more apart. In most cases, a home was measured over four different seasons for seven days, potentially giving 38 × 4 = 152 groups; the actual number of groups was 124. For the second approach, B, we again sorted the data by the HOUSE_ID number and date, but this time we began a new group of days for each new HOUSE_ID and whenever the sorted measurement days on the same HOUSE_ID were 30 days or more apart or were for different temperature ranges. We used the same four temperature ranges chosen for the analysis in the Cohen, Mallya, and Rosenbaum, 2005, memorandum (Appendix A): <= 10, 10-20, 20-25, and > 25 ºC. For example, if the first week of measurements on a given HOUSE_ID had the first three days in the <= 10 ºC range, the next day in the 10-20 ºC range, and the last three days in the <= 10 ºC range, then the first approach would treat this as a single group of days. The second approach would treat this as three groups of days, i.e., the first three days, the fourth day, and the last three days. Using the first approach, the days in each group can be in different temperature ranges. Using the second approach, every day in a group is in the same temperature range. Using the first approach we treat groups of days as being independent following a transition to a different house or season. Using the second approach we treat groups of days as being independent following a transition to a different house or season or temperature range.

To evaluate the distributions of multi-day air exchange rate (AER) averages, we averaged the AERs over consecutive days in each group. To obtain a set of one-day averages, we took the AERs for the first day of each group. To obtain a set of two-day averages, we took the average AER over the first two days from each group. We continued this process to obtain three-, four-, five-, six-, and seven-day averages. There were insufficiently representative data for averaging periods longer then seven days. Averages over non-consecutive days were excluded. Each averaging period was assigned the temperature range using the average of the daily temperatures for the averaging period. Using Approach A, some or all of the days in the averaging period might be in different temperature ranges than the overall average. . Using Approach B, every day is in the same temperature range as the overall average. For each averaging period and temperature range, we calculated the mean, standard deviation, and variance of the period average AER and of its natural logarithm. Note than the geometric mean equals *e* raised to the power Mean log (AER) and the geometric standard deviation equals *e* raised to the power Std Dev log (AER). The results are shown in Tables E-1 (Approach A) and E-2 (Approach B).

Table E-1. Distribution of AER averaged over K days and its logarithm. Groups defined by Approach A.

Temperature (ºC)	K	Groups	Mean AER	Mean log(AER)	Std Dev AER	Std Dev log(AER)	Variance AER	Variance log(AER)
<= 10	1	35	1.109	-0.066	0.741	0.568	0.549	0.322
<= 10	2	30	1.149	-0.009	0.689	0.542	0.474	0.294
<= 10	3	28	1.065	-0.088	0.663	0.546	0.440	0.298
<= 10	4	28	1.081	-0.090	0.690	0.584	0.476	0.341
<= 10	5	24	1.103	-0.082	0.754	0.598	0.568	0.358
<= 10	6	24	1.098	-0.083	0.753	0.589	0.567	0.347
<= 10	7	29	1.054	-0.109	0.704	0.556	0.496	0.309
10-20	1	48	0.652	-0.659	0.417	0.791	0.174	0.625
10-20	2	55	0.654	-0.598	0.411	0.607	0.169	0.368
10-20	3	51	0.641	-0.622	0.416	0.603	0.173	0.363
10-20	4	50	0.683	-0.564	0.440	0.619	0.194	0.384
10-20	5	53	0.686	-0.546	0.419	0.596	0.175	0.355
10-20	6	49	0.677	-0.533	0.379	0.544	0.144	0.296
10-20	7	34	0.638	-0.593	0.343	0.555	0.118	0.308
20-25	1	32	0.500	-1.005	0.528	0.760	0.279	0.577
20-25	2	28	0.484	-0.972	0.509	0.623	0.259	0.388
20-25	3	27	0.495	-0.933	0.491	0.604	0.241	0.365
20-25	4	17	0.536	-0.905	0.623	0.652	0.389	0.425
20-25	5	17	0.543	-0.905	0.672	0.649	0.452	0.421
20-25	6	17	0.529	-0.899	0.608	0.617	0.370	0.381
20-25	7	14	0.571	-0.889	0.745	0.683	0.555	0.466
> 25	1	9	0.470	-1.058	0.423	0.857	0.179	0.734
> 25	2	11	0.412	-1.123	0.314	0.742	0.098	0.551
> 25	3	12	0.411	-1.036	0.243	0.582	0.059	0.339
> 25	4	23	0.385	-1.044	0.176	0.429	0.031	0.184
> 25	5	23	0.390	-1.028	0.175	0.425	0.031	0.181
> 25	6	23	0.399	-1.010	0.193	0.435	0.037	0.189
> 25	7	17	0.438	-0.950	0.248	0.506	0.061	0.256

Using both approaches, Tables E-1 and E-2 show that the mean values for the AER and its logarithm are approximately constant for the same temperature range but different averaging periods. This is expected if the daily AER values all have the same statistical distribution, regardless of whether or not they are independent. More interesting is the observation that the standard deviations and variances are also approximately constant for the same temperature range but different averaging periods, except for the data at > 25 ºC where the standard deviations and variances tend to decrease as the length of the averaging period increases. If the daily AER values were statistically independent, then the variance of an average over K days is given by Var / K, where Var is the variance of a single daily AER value. Clearly this formula does not apply. Since the variance is approximately constant for different values of K in the same temperature range (except for the relatively limited data at > 25 ºC), this shows that the daily AER values are strongly correlated. Of course the correlation is not perfect, since otherwise the AER for a given day would be identical to the AER for the next day, if the temperature range were the same, which did not occur.

Table E-2. Distribution of AER averaged over K days and its logarithm. Groups defined by Approach B.

Temperature (°C)	K	Groups	Mean AER	Mean log(AER)	Std Dev AER	Std Dev log(AER)	Variance AER	Variance log(AER)
<= 10	1	62	1.125	-0.081	0.832	0.610	0.692	0.372
<= 10	2	41	1.059	-0.063	0.595	0.481	0.355	0.231
<= 10	3	32	1.104	-0.040	0.643	0.530	0.413	0.281
<= 10	4	17	1.292	0.115	0.768	0.531	0.590	0.282
<= 10	5	5	1.534	0.264	1.087	0.608	1.182	0.370
10-20	1	109	0.778	-0.482	0.579	0.721	0.336	0.520
10-20	2	81	0.702	-0.532	0.451	0.603	0.204	0.363
10-20	3	63	0.684	-0.540	0.409	0.580	0.167	0.336
10-20	4	27	0.650	-0.626	0.414	0.663	0.171	0.440
10-20	5	22	0.629	-0.660	0.417	0.654	0.174	0.428
10-20	6	12	0.614	-0.679	0.418	0.638	0.175	0.407
10-20	7	6	0.720	-0.587	0.529	0.816	0.280	0.667
20-25	1	107	0.514	-0.915	0.518	0.639	0.269	0.409
20-25	2	63	0.511	-0.930	0.584	0.603	0.341	0.364
20-25	3	23	0.577	-0.837	0.641	0.659	0.411	0.434
20-25	4	3	1.308	-0.484	1.810	1.479	3.277	2.187
> 25	1	54	0.488	-0.949	0.448	0.626	0.201	0.392
> 25	2	32	0.486	-0.900	0.351	0.595	0.123	0.354
> 25	3	23	0.427	-0.970	0.218	0.506	0.048	0.256
> 25	4	12	0.401	-1.029	0.207	0.509	0.043	0.259
> 25	5	12	0.410	-1.003	0.207	0.507	0.043	0.257
> 25	6	6	0.341	-1.164	0.129	0.510	0.017	0.261
> 25	7	6	0.346	-1.144	0.125	0.494	0.016	0.244

These arguments suggest that, based on the RTP Panel study data, to a reasonable approximation, the distribution of an AER measurement does not depend upon the length of the averaging period for the measurement, although it does depend upon the average temperature. This supports the methodology used in the Cohen, Mallya, and Rosenbaum, 2005, analyses that did not take into account the length of the averaging period.

The above argument suggests that the assumption that daily AER values are statistically independent is not justified. Statistical modeling of the correlation structure between consecutive daily AER values is not easy because of the problem of accounting for temperature effects, since temperatures vary from day to day. In the next section we present some statistical models of the daily AER values from the RTP Panel Study.

Statistical models of AER auto-correlations from the RTP Panel Study

We used the MIXED procedure from SAS to fit several mixed models with fixed effects and random effects to the daily values of AER and log(AER). The fixed effects are the population average values of AER or log(AER), and are assumed to depend upon the temperature range. The random effects have expected values of zero and define the correlations between pairs of measurements from the same Group, where the Groups are defined either using Approach A or Approach B above. As described above, a Group is a period of up to 14 consecutive days of measurements at the same house. For these mixed model analyses we included periods with one or more missing days. For all the statistical models, we assume that AER values in different Groups are statistically independent, which implies that data from different houses or in different seasons are independent.

The main statistical model for AER was defined as follows:

AER = Mean(Temp Range) + A(Group, Temp Range)
+ B(Group, Day Number) + Error(Group, Day Number)

Mean(Temp Range) is the fixed effects term. There is a different overall mean value for each of the four temperature ranges.

A(Group, Temp Range) is the random effect of temperature. For each Group, four error terms are independently drawn from four different normal distributions, one for each temperature range. These normal distributions all have mean zero, but may have different variances. Because of this term, there is a correlation between AER values measured in the same Group of days for a pair of days in the same temperature range.

B(Group, Day Number) is the repeated effects term. The day number is defined so that the first day of a Group has day number 1, the next calendar day has day number 2, and so on. In some cases AER's were missing for some of the day numbers. B(Group, Day Number) is a normally distributed error term for each AER measurement. The expected value (i.e., the mean) is zero. The variance is V. The covariance between B(Group g, day i) and B(Group h, day j) is zero for days in different Groups g and h, and equals $V \times \exp(d \times |i-j|)$ for days in the same Group. V and d are fitted parameters. This is a first order auto-regressive model. Because of this term, there is a correlation between AER values measured in the same Group of days, and the correlation decreases if the days are further apart.

Finally, Error(Group, Day Number) is the Residual Error term. There is one such error term for every AER measurement, and all these terms are independently drawn from the same normal distribution, with mean 0 and variance W.

We can summarize this rather complicated model as follows. The AER measurements are uncorrelated if they are from different Groups. If they are in the same Group, they have a correlation that decreases with the day difference, and they have an additional correlation if they are in the same temperature range.

Probably the most interesting parameter for these models is the parameter d, which defines the strength of the auto-correlation between pairs of days. This parameter d lies between -1 (perfect negative correlation) and +1 (perfect positive correlation) although values exactly equal to +1 or -1 are impossible for a stationary model. Negative values of d would be unusual since they would imply a tendency for a high AER day to be followed by a low AER day, and vice versa. The case d=0 is for no auto-correlation.

Table E-3 gives the fitted values of d for various versions of the model. The variants considered were:

- model AER or log(AER)
- include or exclude the term A(Group, Temp Range) (the "random" statement in the SAS code)
- use Approach A or Approach B to define the Groups

Since Approach B forces the temperature ranges to be the same for very day in a Group, the random temperature effect term is difficult to distinguish from the other terms. Therefore this term was not fitted using Approach B.

Table E-3. Autoregressive parameter d for various statistical models for the RTP Panel Study AERs.

Dependent variable	Include A(Group, Temp Range)?	Approach	d
AER	Yes	A	0.80
AER	No	A	0.82
AER	No	B	0.80
Log(AER)	Yes	A	0.87
Log(AER)	No	A	0.87
Log(AER)	No	B	0.85

In all cases, the parameter d is 0.8 or above, showing the very strong correlations between AER measurements on consecutive or almost consecutive days.

Impact of accounting for daily average AER auto-correlation

In the current version of the APEX model, there are several options for stratification of time periods with respect to AER distributions, and for when to re-sample from a distribution for a given stratum. The options selected for this current set of simulations resulted in a uniform AER for each 24-hour period and re-sampling of the 24-hour AER for each simulated day. This re-sampling for each simulated day implies that the simulated AERs on consecutive days in the same microenvironment are statistically independent. Although we have not identified sufficient data to test the assumption of uniform AERs throughout a 24-hour period, the analyses described in this memorandum suggest that AERs on consecutive days are highly correlated.

Therefore, in order to determine if bias was introduced into the APEX estimates with respect to either the magnitudes or variability of exposure concentrations by implicitly assuming uncorrelated air exchange rates, we re-ran the 2002 base case simulations using the option to not re-sample the AERs. For this option APEX selects a single AER for each microenvironment/stratum combination and uses it throughout the simulation.

The comparison of the two scenarios indicates little difference in APEX predictions, probably because the AERs pertain only to indoor microenvironments and for the base cases most exposure to elevated concentrations occurs in the "other outdoors" microenvironment. Figures E-

1 and E-2 below present the comparison for exceedances of 8-hour average concentration during moderate exertion for active person in Boston and Houston, respectively.

Figure E-1

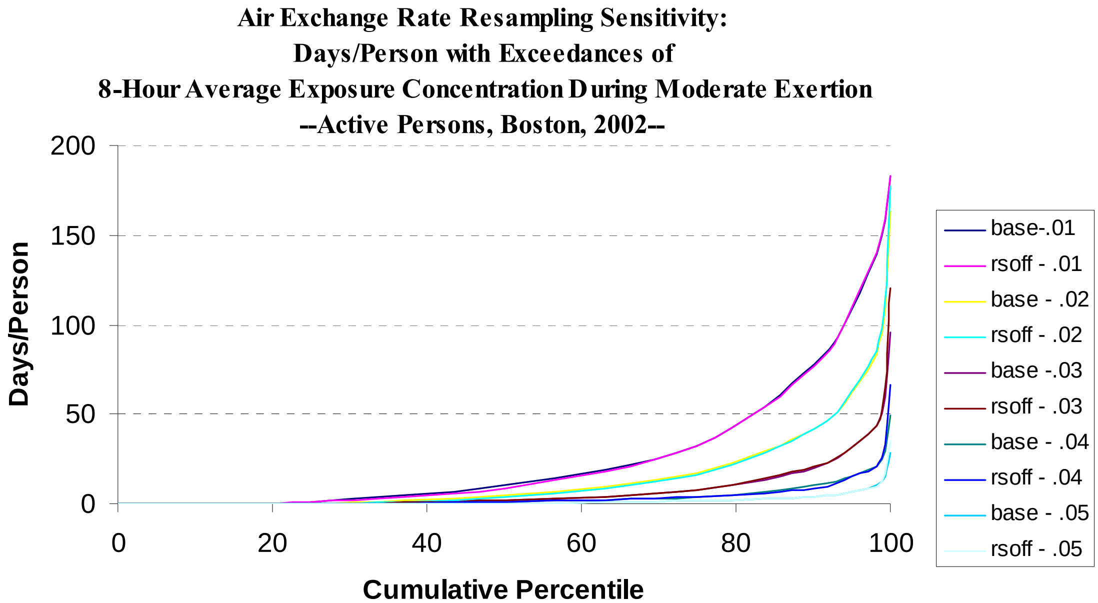
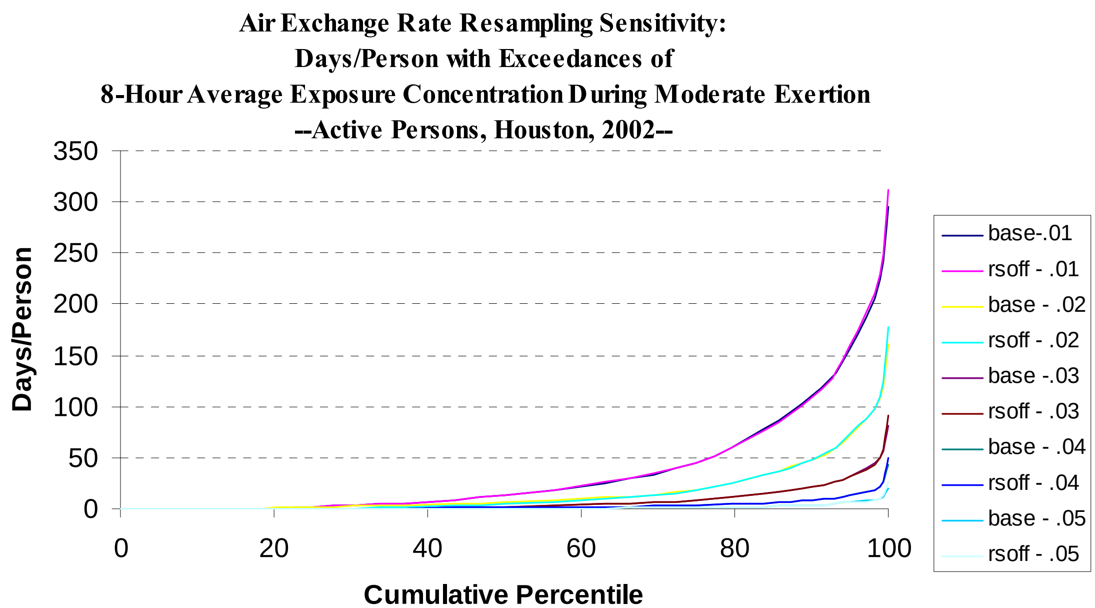


Figure E-2



Appendix C

Sulfur Dioxide Health Risk Assessment

Prepared for
Office of Air Quality Planning and Standards
U.S. Environmental Protection Agency
Research Triangle Park, NC

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June 2009

DISCLAIMER

This report is being furnished to the U.S. Environmental Protection Agency (EPA) by Abt Associates Inc. in partial fulfillment of Contract No. EP-W-05-022, Work Assignments 2-63 and 3-63, and Contract No. EP-D-08-100, Work Assignment 0-4. Any opinions, findings, conclusions, or recommendations are those of the authors and do not necessarily reflect the views of the EPA or Abt Associates. Any questions concerning this document should be addressed to Harvey Richmond, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, C504-06, Research Triangle Park, North Carolina 27711 (email: richmond.harvey@epa.gov).

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Sulfur Dioxide Health Risk Assessment

1 INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is presently conducting a review of the national ambient air quality standards (NAAQS) for sulfur dioxide (SO_2). Sections 108 and 109 of the Clean Air Act (Act) govern the establishment and periodic review of the NAAQS. These standards are established for pollutants that may reasonably be anticipated to endanger public health and welfare, and whose presence in the ambient air results from numerous or diverse mobile or stationary sources. The NAAQS are to be based on air quality criteria, which are to accurately reflect the latest scientific knowledge useful in indicating the kind and extent of identifiable effects on public health or welfare that may be expected from the presence of the pollutant in ambient air. The EPA Administrator is to promulgate and periodically review, at five-year intervals, "primary" (health-based) and "secondary" (welfare-based) NAAQS for such pollutants.[1] Based on periodic reviews of the air quality criteria and standards, the Administrator is to make revisions in the criteria and standards, and promulgate any new standards, as may be appropriate. The Act also requires that an independent scientific review committee advise the Administrator as part of this NAAQS review process, a function performed by the Clean Air Scientific Advisory Committee (CASAC).

EPA's plan and schedule for this SO_2 NAAQS review is presented in the "Integrated Plan for Review of the Primary National Ambient Air Quality Standards for Sulfur Oxides" (U.S. EPA, 2007a). The plan discusses the preparation of two key components in the NAAQS review process: an Integrated Science Assessment (ISA) and risk/exposure assessments. The ISA critically evaluates and integrates scientific information on the health effects associated with exposure to oxides of sulfur (SO_x) in the ambient air. The risk/exposure assessments develop, as appropriate, quantitative estimates of human exposure and health risk and related variability and uncertainties, drawing upon the information summarized in the ISA.

In May 2008 EPA's National Center for Environmental Assessment (NCEA) released a draft version of the "Integrated Science Assessment for Oxides of Sulfur – Health Criteria, henceforth referred to as the draft ISA (U.S. EPA, 2008a). In June 2008, EPA's Office of Air Quality Planning and Standards (OAQPS) released a first draft of its "Risk and Exposure Assessment to Support the Review of the SO_2 Primary National Ambient Air Quality Standard," henceforth referred to as the 1st draft REA (U.S. EPA, 2008b). Both of these documents were reviewed by the CASAC SO_2 Panel on July 30-31, 2008. Based on its review of the draft ISA, OAQPS decided to expand the health risk assessment to include a quantitative assessment of lung function responses indicative of

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[1] Section 109(b)(1) [42 U.S.C. 7409] of the Act defines a primary standard as one "the attainment and maintenance of which in the judgment of the Administrator, based on such criteria and allowing an adequate margin of safety, are requisite to protect the public health."

bronchoconstriction experienced by asthmatic subjects associated with 5 to 10 minute exposures to SO_2 while engaged in moderate or greater exertion. In September 2008, NCEA released the final version of the ISA, "Integrated Science Assessment for Oxides of Sulfur – Health Criteria, henceforth referred to as the ISA (U.S. EPA, 2008c). A second draft REA (EPA, 2009a) was made available to the CASAC and public in March 2009. The second draft REA was reviewed by the CASAC SO_2 Panel on April 16-17, 2009. This final report has been informed by comments from CASAC and the public on the second draft REA, as well as findings and conclusions contained in the final ISA.

SO_2 is one of a group of compounds known as sulfur oxides (SO_x), which include multiple chemicals (e.g., SO_2, SO, SO_3). However only SO_2 is present at concentrations significant for human exposures and the ISA indicates there is limited adverse health effect data for the other gaseous compounds. Therefore, as in past NAAQS reviews, SO_2 is considered as a surrogate for gaseous SO_x species in this assessment, with the secondarily formed particulate species (i.e., sulfate or SO_4) addressed as part of the particulate matter (PM) NAAQS review.

In the previous review, concluded in 1996, it was clearly established that subjects with asthma are more sensitive to the respiratory effects of SO_2 exposure than healthy individuals (ISA, section 3.1.3.2). Asthmatics exposed to SO_2 concentrations as low as 0.2-0.3 ppm for 5-10 minutes during exercise have been shown to experience significant bronchoconstriction, measured as an increase in specific airway resistance (sRaw) ($\geq$100%) or a decrease in forced expiratory volume in one second (FEV_1) ($\geq$15%) after correction for exercise-induced responses in clean air.

The basic structure of the SO_2 health risk assessment described in this document reflects the fact that we have available controlled human exposure study data from several studies involving volunteer asthmatic subjects who were exposed to SO_2 concentrations at specified exposure levels while engaged in moderate or greater exertion for 5- or 10-minute exposures.[2] The risk assessment estimates lung function risks for (1) recent ambient levels of SO_2, (2) air quality adjusted to simulate just meeting the current primary 24-hour and annual standards,[3] and (3) air quality adjusted to simulate just meeting selected alternative 1-hour standards in selected locations encompassing a variety of SO_2 emission source types in the Greene County and the St. Louis area within Missouri.

The SO_2 health risk assessment builds upon the methodology, analyses, and lessons learned from the assessments conducted for the last SO_2 NAAQS review in 1996, as well as the methodology and lessons learned from the health risk assessment work conducted for the recently concluded O_3 NAAQS review (Abt Associates, 2007a) – in

[2] An additional characterization of risk may involve use of concentration-response functions, if sufficient and relevant epidemiological data are identified in the ISA to support development of functions that are related to ambient SO_2 concentrations.

[3] There is a 3-hr secondary standard as well. However, this risk assessment is taking into account only the primary standards. The current primary SO_2 standards include a 24-hour standard set at 0.14 parts per million (ppm), not to be exceeded more than once per year, and an annual standard set at 0.03 ppm, calculated as the arithmetic mean of hourly averages.

particular, the assessment of risk based on controlled human exposure studies described in Chapter 3 of that document. The SO_2 risk assessment is based on our current understanding of the SO_2 scientific literature as reflected in the evaluation provided in the final ISA.

The goals of this SO_2 health risk assessment are: (1) to develop health risk estimates of the number and percent of the asthmatic population in the selected study area locations that would experience moderate or greater lung function decrements in response to daily 5-minute maximum peak exposures while engaged in moderate or greater exertion for a recent year of air quality and under a scenario in which the SO_2 concentrations are adjusted to simulate just meeting the current 24-hour standard; (2) to develop a better understanding of the influence of various inputs and assumptions on the risk estimates; and (3) to gain insights into the risk levels and patterns of risk reductions associated with air quality simulating just meeting alternative 1-hour SO_2 standards. The risk assessment is intended as a tool that, together with other information on lung function and other health effects evaluated in the SO_2 ISA, can aid the Administrator in judging whether the current primary standards protect public health with an adequate margin of safety, or whether revisions to the standards are appropriate.

Preliminary considerations and the basic structure of the risk assessment are described in section 2. Section 3 describes the methods used, and section 4 presents the results of the risk assessment.

2 PRELIMINARY CONSIDERATIONS

The health risk assessment described in this document estimated lung function decrements (measured as increases in sRaw or decreases in FEV_1) associated with SO_2 exposures under several scenarios: (1) recent ambient levels of SO_2, (2) air quality adjusted to simulate just meeting the current 24-hour and annual standards, and (3) air quality adjusted to simulate just meeting several alternative 1-hour standards. In this section we address preliminary considerations. Section 2.1 briefly discusses the broad empirical basis for a relationship between SO_2 exposures and adverse health effects. Section 2.2 describes the basic structure of the risk assessment. Finally, section 2.3 addresses air quality considerations.

2.1 The Broad Empirical Basis for a Relationship Between SO_2 and Adverse Health Effects

The ISA concludes that the health evidence "is *sufficient to infer a causal relationship between respiratory morbidity and short-term exposure* to SO_2" (ISA, p. 3-33). In support of this conclusion, the ISA notes the following:

> The strongest evidence for this causal relationship comes from human clinical studies reporting respiratory symptoms and decreased lung function following peak exposures of 5-10 min duration to SO_2. These effects have been observed consistently across studies involving exercising mild to moderate asthmatics. Statistically significant decrements in lung function accompanied by respiratory symptoms including wheeze and chest tightness have been clearly demonstrated following exposure to 0.4-0.6 ppm SO_2. Although studies have not reported statistically significant respiratory effects following exposure to 0.2-0.3 ppm SO_2, some asthmatic subjects (5-30%) have been shown to experience moderate to large decrements in lung function at these exposure concentrations.
>
> A larger body of evidence supporting this determination of causality comes from numerous epidemiological studies reporting associations with respiratory symptoms, ED visits, and hospital admissions with short-term SO_2 exposures, generally of 24-h avg. Important new multicity studies and several other studies have found an association between 24-h avg ambient SO_2 concentrations and respiratory symptoms in children, particularly those with asthma.…
>
> … Collectively, the findings from both human clinical and epidemiological studies provide a strong basis for concluding a causal relationship between respiratory morbidity and short-term exposure to SO_2.

2.2 Basic Structure of the Risk Assessment

As noted above, this SO_2 health risk assessment is based on controlled human exposure studies involving volunteer subjects who were exposed while engaged in different exercise regimens to specified levels of SO_2 under controlled conditions for 5 or 10 minute periods. The responses measured in these studies were measures of lung function decrements, including increases in sRaw and decreases in FEV_1. We used probabilistic exposure-response relationships, based on analysis of individual data, that describe the relationships between a measure of personal exposure to SO_2 and the measure(s) of lung function recorded in these studies. These probabilistic exposure-response relationships were combined with daily 5-minute maximum peak exposure estimates associated with the air quality scenarios mentioned above for mild and moderate asthmatics engaged in moderate or greater exertion. Estimates of personal exposures to varying ambient concentrations associated with several air quality scenarios including recent air quality levels, and air quality levels simulating just meeting the current SO_2 primary standard and several alternative primary 1-hour standards were derived through exposure modeling. The details of the exposure modeling are described in Chapter 8 and Appendix B of the final REA (EPA, 2009b).

The characteristics that are relevant to carrying out a risk assessment based on controlled human exposure studies can be summarized as follows:

- A risk assessment based on controlled human exposure studies uses exposure-response functions, and therefore requires as input (modeled) personal exposures to SO_2.

- Controlled human exposure studies, carried out in laboratory settings, are generally not specific to any particular real world location. A controlled human exposure studies-based risk assessment can therefore appropriately be carried out for any location for which there are adequate air quality data on which to base the modeling of personal exposures.

The methods for the SO_2 risk assessment are discussed in section 3 below. The risk assessment was implemented within a new probabilistic version of TRIM.Risk, the component of EPA's Total Risk Integrated Methodology (TRIM) model that estimates human health risks.[4]

2.3 Air Quality Considerations

The SO_2 health risk assessment estimates lung function risks associated with (1) "as is" ambient levels of SO_2, (2) air quality simulating just meeting the current 24-hour and annual standards, and (3) air quality simulating just meeting several alternative 1-

[4] TRIM.Risk was most recently applied to EPA's O_3 health risk assessment. A User's Guide for the Application of TRIM.Risk to the O_3 health risk assessment (Abt Associates, 2007b) is available online at: http://epa.gov/ttn/fera/data/trim/trimrisk_ozone_ra_userguide_8-6-07.pdf.

hour standards in a recent year (2002) in two selected locations encompassing a variety of SO_2 emission source types in Greene County, Missouri and St. Louis, Missouri.

In order to estimate health risks associated with just meeting the current 24-hour and annual standards and alternative 1-hour SO_2 standards, it is necessary to estimate the distribution of short-term (5-minute) SO_2 concentrations that would occur under any given standard. Since compliance with the current SO_2 standards is based on a single year, air quality data from 2002 were used to determine the change in SO_2 concentrations required to meet the current standards. Estimated design values were used to determine the adjustment necessary to just meet the current 24-hour and annual standards. The approach to simulating just meeting the current standards and alternative 1-hour standards is described in section 8.8.1 of the final REA (EPA, 2009b).

The risk estimates developed for the recently concluded PM and O_3 NAAQS reviews represented risks associated with PM and O_3 levels in excess of estimated policy-relevant background (PRB) levels in the U.S. PRB levels have been historically defined by EPA as concentrations of a pollutant that would occur in the U.S. in the absence of anthropogenic emissions in continental North America (defined as the United States, Canada, and Mexico). The ISA notes that PRB SO_2 concentrations are below 10 parts per trillion (ppt) over much of the United States and are generally less than 30 ppt. With the exception of a few locations on the West Coast and locations in Hawaii, where volcanic SO_2 emissions cause high PRB concentrations, PRB contributes less than 1% to present-day SO_2 concentrations in surface air. Since PRB is well below concentrations that might cause potential health effects, there was no adjustment made for risks associated with PRB concentrations in the current SO_2 health risk assessment.

3 METHODS

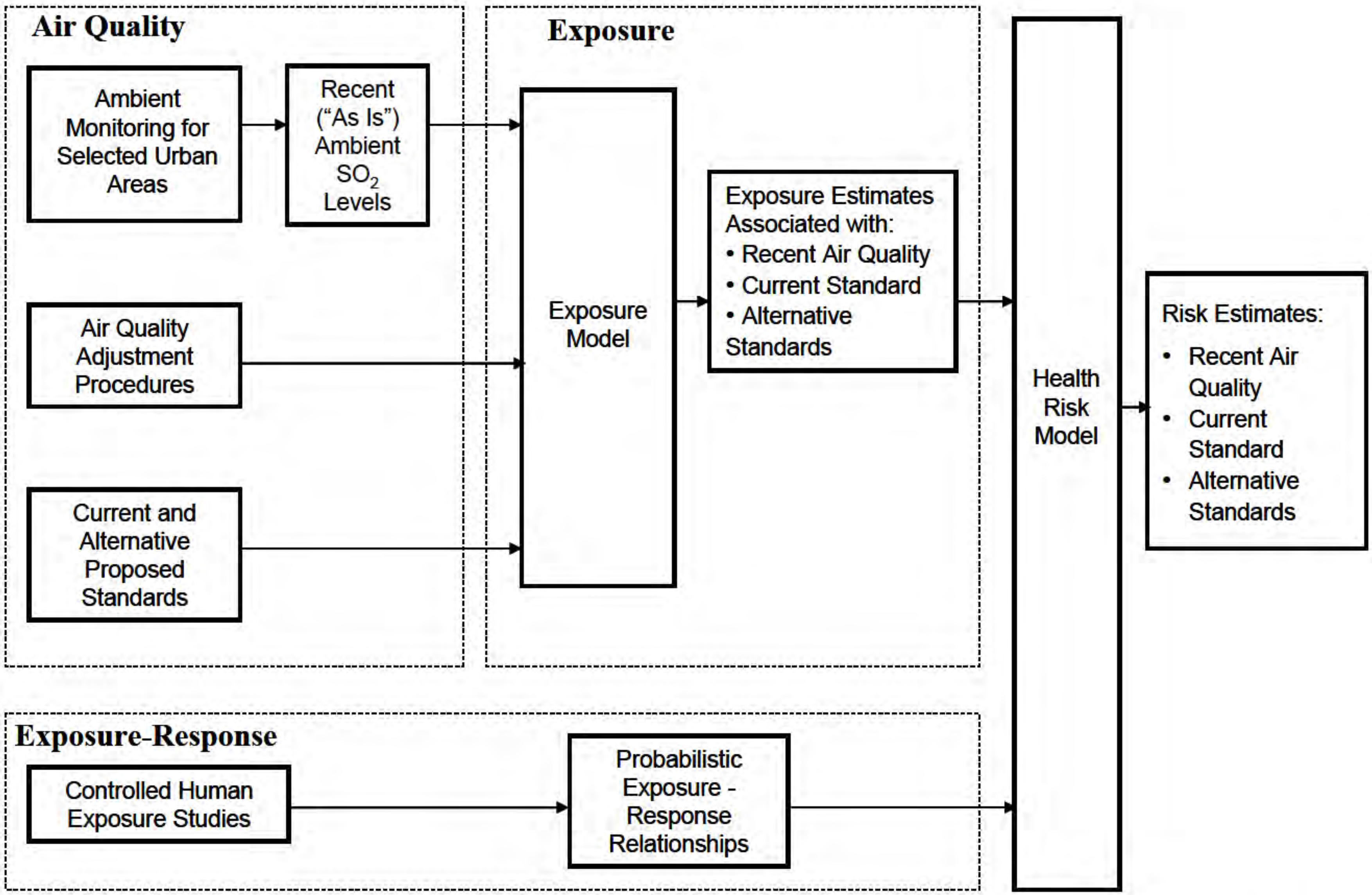
The major components of the SO_2 lung function risk assessment are illustrated in Figure 3-1. The air quality and exposure analysis components that are integral to the risk assessment are discussed in Chapters 6 and 7, respectively, of the 2nd draft REA. As described in the ISA and the 2nd draft REA, there are numerous controlled human exposure studies reporting lung function decrements (as measured by increases in SRaw and/or decreases in FEV_1) among mild and/or moderate asthmatic adults associated with short-term (5 or 10 minute) peak exposures to various levels of SO_2 while engaged in moderate or greater exercise. The SO_2 lung function risk assessment focuses on these lung function responses among asthmatic children and adults.

3.1 Selection of health endpoints and target population

The ISA concluded that there is sufficient evidence to infer a causal relationship between respiratory morbidity and short-term exposure to SO_2 (ISA, section 5.2). This determination was based in large part on controlled human exposure studies demonstrating a relationship between short-term (5- or 10-minute) peak SO_2 exposures and adverse effects on the respiratory system in exercising asthmatics. More specifically, the ISA found consistent evidence from numerous controlled human exposure studies demonstrating increased respiratory symptoms (e.g. cough, chest tightness, wheeze) and decrements in lung function in a substantial proportion of exercising asthmatics (generally classified as mild to moderate asthmatics) following short-term peak exposures to SO_2 at concentrations $\geq$ 0.4 ppm (400 ppb). As in previous reviews, the ISA also concluded that at concentrations below 1.0 ppm (1,000 ppb), healthy individuals are relatively insensitive to the respiratory effects of short-term peak SO_2 exposures (ISA, sections 3.1.3.2). Therefore, the SO_2 lung function risk assessment focuses on asthmatics. Exposure estimates for asthmatic children and adult asthmatics were combined separately with probabilistic exposure-response relationships (described below) for lung function response associated with daily 5-minute maximum peak exposures while engaged in moderate or greater exertion.[5]

[5] Only the highest 5-minute peak exposure (with moderate or greater exertion) on each day will be considered in the lung function risk assessment, since the controlled human exposure studies have shown an acute-phase response that was followed by a short refractory period where the individual was relatively insensitive to additional SO_2 challenges.

Figure 3-1. Components of SO_2 Health Risk Assessment Based on Controlled Human Exposure Studies



Two measures of lung function response – specific airway resistance (sRaw) and forced expiratory volume in one second (FEV_1) – have been used in the controlled human exposure studies that have focused on the effects of exposure to SO_2 on exercising asthmatics. Negative effects are measured as the percent increase in sRaw or the percent decrease in FEV_1. As explained below, we estimated exposure-response relationships for four different definitions of response:

- An increase in sRaw ≥ 100%
- An increase in sRaw ≥ 200%
- A decrease in FEV_1 ≥ 15%
- A decrease in FEV_1 ≥ 20%.

3.2 Development of exposure-response functions

We used a Bayesian Markov Chain Monte Carlo approach to estimate probabilistic exposure-response relationships for lung function decrements associated with 5- or 10-minute exposures at moderate or greater exertion, using the WinBUGS software (Spiegelhalter et al. (1996)). For an explanation of these methods, see Gelman et al. (1995) or Gilks et al. (1996). We treated both 5- and 10-minute exposures as if they were all 5-minute exposures.

The combined data set from Linn et al. (1987, 1988, 1990), Bethel et al. (1983, 1985), Roger et al. (1985), and Kehrl et al. (1987) provide data with which to estimate exposure-response relationships between responses defined in terms of sRaw and 5- or 10-minute exposures to SO_2 at levels of 0.2, 0.25, 0.3, 0.4, 0.5, 0.6, and 1.0 ppm.[6] As noted above, two definitions of response were used: (1) an increase in sRaw ≥ 100% and (2) an increase in sRaw ≥ 200%.

The combined data set from Linn et al. (1987, 1988, 1990) provide data with which to estimate exposure-response relationships between responses defined in terms of FEV_1 and 5- or 10-minute exposures to SO_2 at levels of 0.2, 0.3, 0.4, and 0.6 ppm. As noted above, two definitions of response were used: a decrease in FEV_1 ≥ 15% and a decrease in FEV_1 ≥ 20%.

Before being used to estimate exposure-response relationships for 5-minute exposures, the data from these controlled human exposure studies were corrected for the effect of exercising in clean air to remove any systematic bias that might be present in the data attributable to an exercise effect.[7] Generally, this correction for exercise in clean air is small relative to the total effects measures in the SO_2-exposed cases. The resulting study-specific results, based on the corrected data, are shown in Table 3-1.

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[6] Data from Magnussen et al. (1990) were not used in the estimation of sRaw exposure-response functions because exposures in this study were conducted using a mouthpiece rather than a chamber.

[7] Corrections were subject-specific. A correction was made by subtracting the subject's percent change (in FEV_1 or sRaw) under the no-SO_2 protocol from his or her percent change (in FEV_1 or sRaw) under the given SO_2 protocol, and rounding the result to the nearest integer. For example, if a subject's percent change in sRaw under the no-SO_2 protocol was 110.12% and his percent change in sRaw under the 0.6 ppm (600 ppb) SO_2 protocol was 185.92%, then his percent change in sRaw *due to* SO_2 is 185.92% - 110.12% = 75.8%, which rounds to 76%.

Table 3-1. Study-Specific SO_2 Exposure-Response Data for Lung Function Decrements

Study and SO_2 Level	Increase in sRaw ≥ 100%		Increase in sRaw ≥ 200%		Decrease in $FEV_1 \geq 15\%$		Decrease in $FEV_1 \geq 20\%$	
	Number Exposed	Number Responding	Number Exposed	Number Responding	Number Exposed	Number Responding	Number Exposed	Number Responding
0.2 ppm SO_2								
Linn et al. (1987)	40	2	40	0	40	5	40	2
0.25 ppm SO_2								
Bethel et al. (1985)	19	6	19	3				
	9	2	9	0				
Roger et al. (1985)	28	1	28	0				
0.3 ppm SO_2								
Linn et al. (1988)	20	2	20	1	20	3	20	0
Linn et al. (1990)	21	7	21	2	21	5	21	3
0.4 ppm SO_2								
Linn et al. (1987)	40	9	40	3	40	12	40	9
0.5 ppm SO_2								
Bethel et al. (1983)	10	6	10	4				
Roger et al. (1985)	28	5	28	1				
Magnussen et al. (1990)*	45	16	45	7				
0.6 ppm SO_2								
Linn et al. (1987)	40	14	40	11	40	21	40	19
Linn et al. (1988)	20	12	20	7	20	11	20	11
Linn et al. (1990)	21	13	21	6	21	9	21	7
1.0 ppm SO_2								
Roger et al. (1985)	28	14	28	7				
Kehrl et al. (1987)	10	6	10	2				

*Data from Magnussen et al. (1990) were not used in the estimation of sRaw exposure-response functions because exposures in this study were conducted using a mouthpiece rather than a chamber.

We considered two different functional forms for the exposure-response functions: a 2-parameter logistic model and a probit model. In particular, we used the data in Table 3-1 to estimate the logistic function,

$$y(x;\ \beta,\gamma) = \frac{1}{(1+e^{\beta+\gamma*\ln(x)})} \tag{3-1}$$

and the probit function,

$$y(x;\beta,\gamma) = \frac{1}{(2\pi)^{1/2}} \int_{-\infty}^{\beta+\gamma\ln(x)} e^{-t^2/2}dt \tag{3-2}$$

for each of the four lung function responses defined above, where *x* denotes the SO_2 concentration (in ppb) to which the individual is exposed, ln(*x*) is the natural logarithm of *x*, *y* denotes the corresponding probability of response (increase in sRaw $\geq$ 100% or $\geq$ 200% or decrease in $FEV_1 \geq$ 15% or $\geq$ 20%), and β and γ are the two parameters whose values are estimated.[8]

We assumed that the number of responses, s_i, out of N_i subjects exposed to a given SO_2 concentration, x_i, has a binomial distribution with response probability given by equation (3-1) when we assume the logistic model and equation (3-2) when we assume the probit model. The likelihood function is therefore

$$L(\beta,\gamma;data) = \prod_i \binom{N_i}{s_i} y(x_i;\beta,\gamma)^{s_i}\,[1-y(x_i;\ \beta,\gamma)]^{N_i-s_i}\ .$$

In some of the controlled human exposure studies, subjects were exposed to a given SO_2 concentration more than once. However, because there were insufficient data to estimate subject-specific response probabilities, we assumed a single response probability (for a given definition of response) for all individuals and treated the repeated exposures for a single subject as independent exposures in the binomial distribution.

For each model, we derived a Bayesian posterior distribution using this binomial likelihood function in combination with uniform prior distributions for each of the unknown parameters.[9] We used 4000 iterations as the "burn-in" period followed by a sufficient number of iterations to ensure convergence of the resulting posterior density. Each iteration corresponds to a set of values for the parameters of the logistic or probit exposure-response function.

[8] For ease of exposition, we use the same two Greek letters to indicate two unknown parameters in the logistic and probit models; this does not imply, however, that the values of these two parameters are the same in the two models.

[9] We used the following uniform prior distributions for the 2-parameter logistic model: $\beta \sim U(-10, 0)$; and $\gamma \sim U(-10,0)$; we used the following normal prior distributions for the probit model: $\beta \sim N(0, 1000)$; and $\gamma \sim N(0,1000)$.

For any SO_2 concentration, *x*, we could then derive the n^{th} percentile response value, for any *n*, by evaluating the exposure-response function at *x* using each of the 18,000 sets of parameter values. The resulting median (50^{th} percentile) logistic and probit exposure-response functions are shown together, along with the data used to estimate these functions, for increases in sRaw $\geq$ 100% and $\geq$ 200% and decreases in FEV_1 $\geq$ 15% and $\geq$ 20% in Figures 3-2, 3-3, 3-4, and 3-5, respectively.

As can be seen in Figures 3-2 through 3-5, there were only limited data with which to estimate the logistic and probit exposure-response functions, and in all cases it wasn't clear that one function fit the data better than the other. In fact, for each of the four lung function response definitions there was little difference between the estimated logistic and probit models in the range of the data used to estimate the functions. However, most of the exposures occur below the range of the data, where there are differences between the two functions.[10] We therefore estimated the risks associated with exposure to SO_2 under the different air quality scenarios considered using both the logistic and the probit exposure-response functions. The 2.5^{th} percentile, median, and 97.5^{th} percentile logistic and probit exposure-response curves, along with the response data to which they were fit, are shown separately for each of the four response definitions in Appendix A.

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[10] The differences are relatively small, as can be seen in Figures 3-2 through 3-2; however, even these relatively small differences result in substantial differences in estimates of risk.

Figure 3-2. Bayesian-Estimated Median Exposure-Response Functions: Increase in sRaw ≥ 100% for 5-Minute Exposures of Asthmatics Engaged in Moderate or Greater Exertion

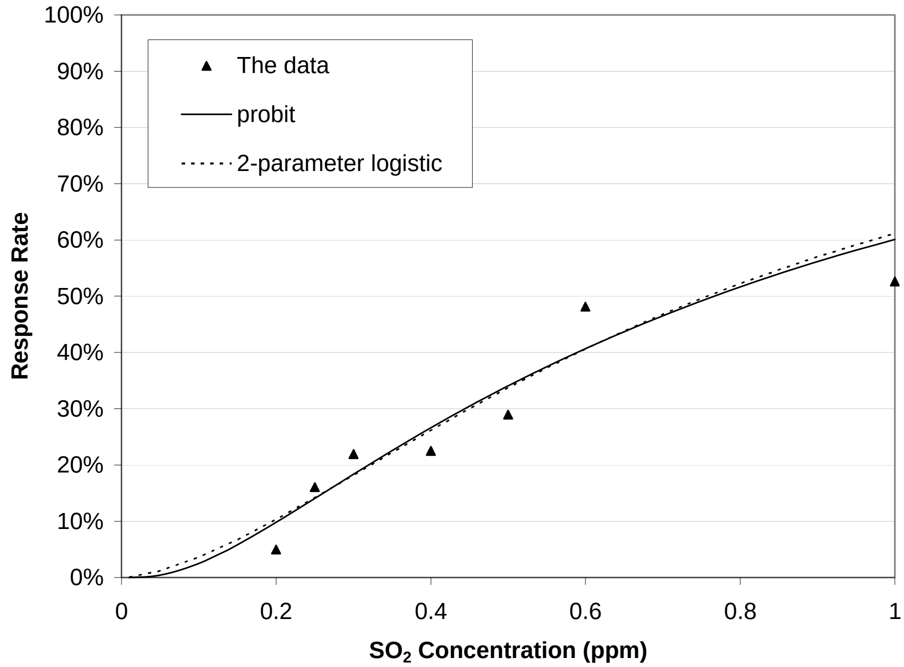


Figure 3-3. Bayesian-Estimated Median Exposure-Response Functions: Increase in sRaw ≥ 200% for 5-Minute Exposures of Asthmatics Engaged in Moderate or Greater Exertion

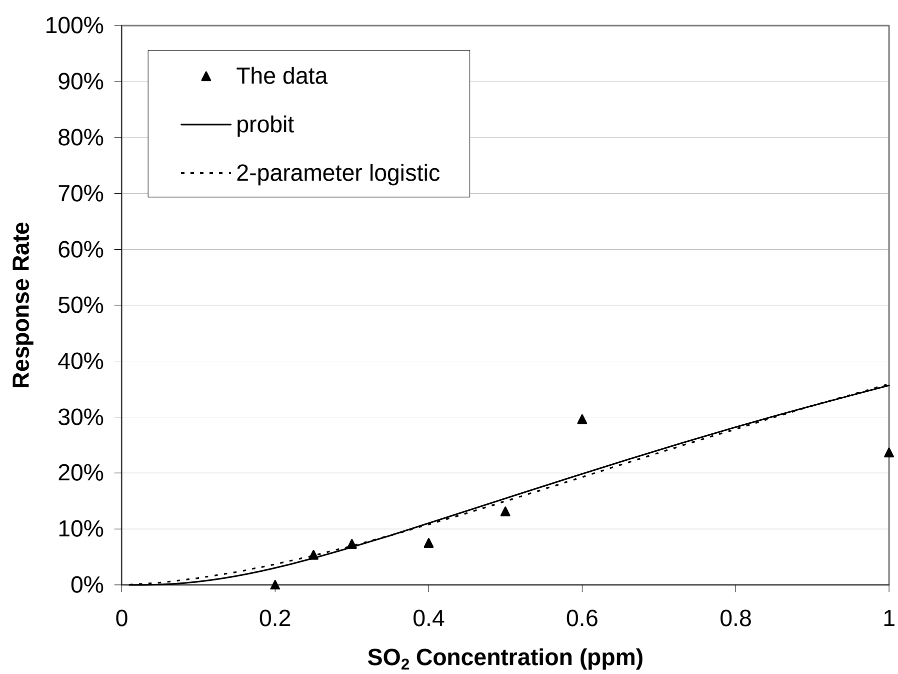


Figure 3-4. Bayesian-Estimated Median Exposure-Response Functions: Decrease in $FEV_1 \geq 15\%$ for 5-Minute Exposures of Asthmatics Engaged in Moderate or Greater Exertion

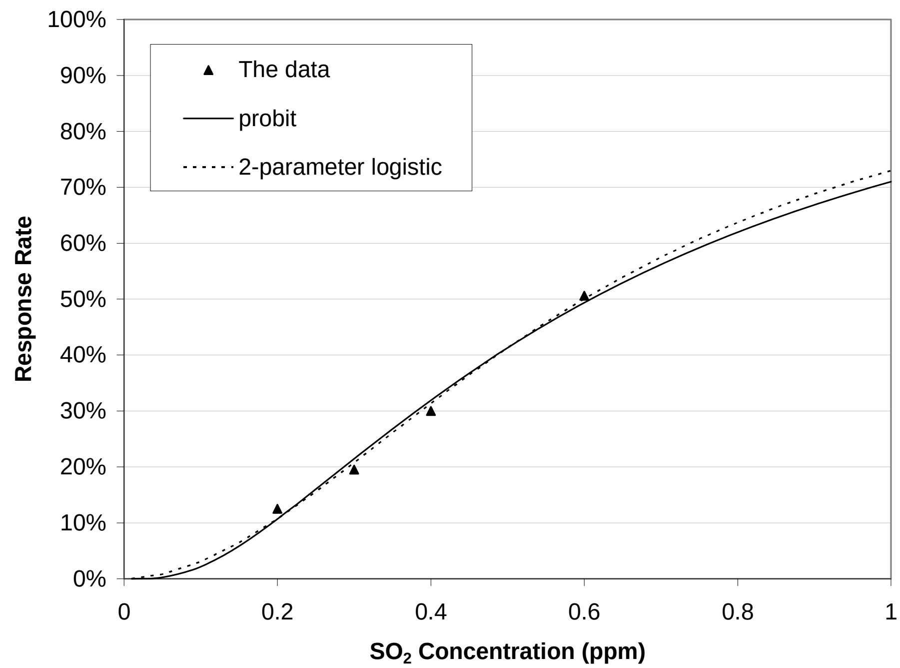
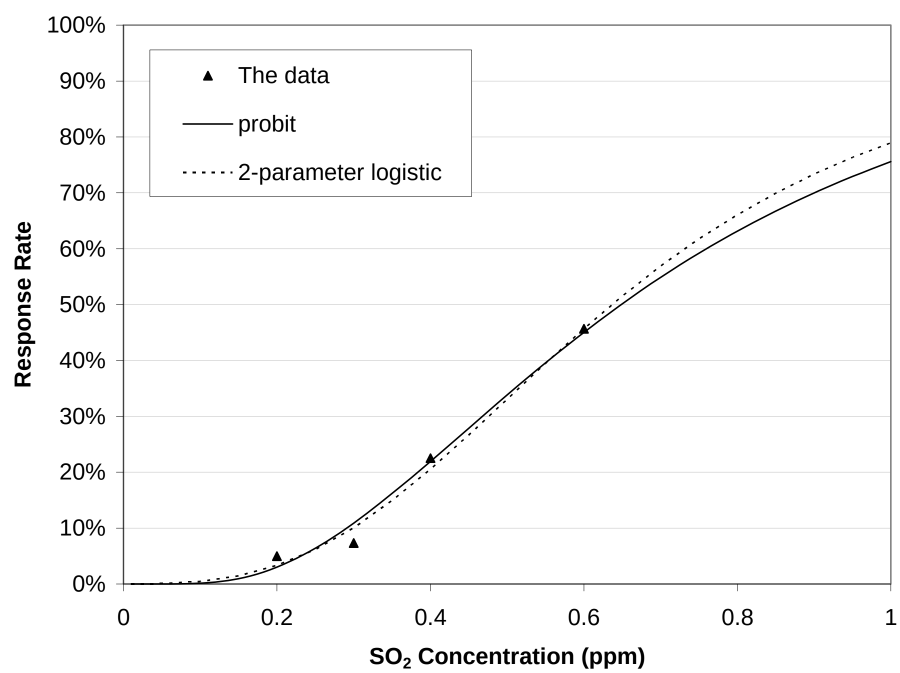


Figure 3-5. Bayesian-Estimated Median Exposure-Response Functions: Decrease in $FEV_1 \geq 20\%$ for 5-Minute Exposures of Asthmatics Engaged in Moderate or Greater Exertion



3.2.1 Calculation of risk estimates

We generated two measures of risk for each of the lung function response definitions. The first measure of risk is simply the number of occurrences of the lung function response in the designated population (e.g., asthmatics) in a year associated with SO_2 concentrations under a given air quality scenario. To calculate this measure of risk we started with the number of exposures among the population that are at or above each benchmark level (i.e., 0 ppb, 50 ppb, 100 ppb, etc.), estimated from the exposure modeling. From this we calculated the number of exposures within each 50 ppb exposure "bin" (e.g., < 50 ppb, 50 – 100 ppb, etc.).[11] We then calculated the number of occurrences of lung function response by multiplying the number of exposures in an exposure bin by the response probability (given by our logistic or probit exposure-response function for the specified definition of lung function response) associated with the midpoint of that bin and summing the results across the bins.

Because response probabilities are calculated for each of several percentiles of a probabilistic exposure-response distribution, estimated numbers of occurrences are similarly percentile-specific. The kth percentile number of occurrences, O_k, associated with SO_2 concentrations under a given air quality scenario is:

$$O_k = \sum_{j=1}^{n} N_j \; x \; (R_k \mid e_j) \qquad (3\text{-}3)$$

where:

e_j = (the midpoint of) the jth category of personal exposure to SO_2;

N_j = the number of exposures to e_j ppb SO_2, given ambient SO_2 concentrations under the specified air quality scenario;

$R_k \mid e_j$ = the kth percentile response probability at SO_2 concentration e_j; and

n = the number of intervals (categories) of SO_2 personal exposure concentration.

An example calculation, using the logistic exposure-response function, is given in Table 3-2.

[11] The final exposure bin was from 750 to 800 ppb SO_2. In at least one of the alternative standard scenarios, there were exposures greater than 800 ppb. For any exposures that exceeded 800 ppb, we assumed a final bin from 800 to 850 ppb, and assigned them the midpoint value of that bin, 825 ppb. This will result in a slight downward bias in the estimate of risk.

Table 3-2. Example: Calculation of Number of Occurrences of Lung Function Response, Defined as an Increase in sRaw ≥ 100%, Among Asthmatics in St. Louis Engaged in Moderate or Greater Exertion Associated with Exposure to SO_2 Concentrations that Just Meet an Alternative 1-Hour 99th Percentile 100 ppb Standard*

SO_2 Exposure Bin (ppb)			Number of	Probability of	Expected Number of
Lower Bound	Upper Bound	Midpoint (1)	Exposures (2)	Response at Midpoint SO_2 Level (3)	Occurrences of Lung Function Response =(2) x (3)
0	50	25	16519000	0.00406	67067
50	100	75	136621	0.02334	3189
100	150	125	15760	0.05162	814
150	200	175	3826	0.08563	328
200	250	225	1051	0.12300	129
250	300	275	413	0.16220	67
300	350	325	175	0.20210	35
350	400	375	83	0.24190	20
400	450	425	31	0.28060	9
450	500	475	24	0.31830	8
500	550	525	8	0.35430	3
550	600	575	0	0.38850	0
600	650	625	0	0.42090	0
650	700	675	8	0.45150	4
700	750	725	0	0.46600	0
750	800	775	0	0.49380	0
Total Number of Exposures:			16677000	Expected Number of Occurrences:	71672

*Calculations were made using the logistic exposure-response function.

The second measure of risk generated for each lung function response definition is the number of individuals in the designated population to experience at least one lung function response in a year associated with SO_2 concentrations under a specified air quality scenario. The calculation of this measure of risk is similar to the calculation of the first measure of risk – however, here we started with estimates, from the exposure modeling, of the number of individuals exposed at least once to *x* ppb SO_2 or higher, for $x = 0$, 50, 100, etc. From this we calculated the number of individuals exposed at least once to SO_2 concentrations within each SO_2 exposure bin defined above. We then multiplied the numbers of individuals in an exposure bin by the response probability (given by our logistic or probit exposure-response function for the specified definition of lung function response) corresponding to the midpoint of the exposure bin, and summed the results across the bins.

Because response probabilities are calculated for each of several percentiles of a probabilistic exposure-response distribution, estimated numbers of individuals with at least one lung function response are similarly percentile-specific. The kth percentile number of individuals, Y_k, associated with SO_2 concentrations under a given air quality scenario is:

$$Y_k = \sum_{j=1}^{n} NI_j \; x \; (R_k \mid e_j) \qquad (3\text{-}4)$$

Where e_j, $R_k \mid e_j$, and n are as defined above, and NI_j is the number of individuals whose highest exposure is to e_j ppb SO_2, given ambient SO_2 concentrations under the specified air quality scenario. An example calculation, using the logistic exposure-response function, is given in Table 3-3.

Table 3-3. Example: Calculation of the Number of Asthmatics in St. Louis Engaged in Moderate or Greater Exertion Estimated to Experience at Least One Lung Function Response, Defined as an Increase in sRaw ≥ 100%, Associated with Exposure to SO_2 Concentrations that Just Meet an Alternative 1-Hour 99th Percentile 100 ppb Standard*

SO_2 Exposure Bin (ppb)			Number of Asthmatics with At Least One Exposure in Bin	Probability of Response at Midpoint SO_2 Level	Estimated Number of Asthmatics Experiencing at Least One Lung Function Response
Lower Bound	Upper Bound	Midpoint (1)	(2)	(3)	=(2) x (3)
0	50	25	53711	0.00406	218
50	100	75	34236	0.02334	799
100	150	125	9835	0.05162	508
150	200	175	3059	0.08563	262
200	250	225	929	0.12300	114
250	300	275	368	0.16220	60
300	350	325	145	0.20210	29
350	400	375	84	0.24190	20
400	450	425	31	0.28060	9
450	500	475	22	0.31830	7
500	550	525	8	0.35430	3
550	600	575	0	0.38850	0
600	650	625	0	0.42090	0
650	700	675	8	0.45150	4
700	750	725	0	0.46600	0
750	800	775	0	0.49380	0
		Total :	102436	Total:	2032

*Calculations were made using the logistic exposure-response function.

Note that this calculation assumes that individuals who do not respond at the highest SO_2 concentration to which they are exposed will not respond to any lower SO_2 concentrations to which they are exposed.

Note also that, in contrast to the risk estimates calculated for the O_3 health risk assessment, the risk estimates calculated for the SO_2 health risk assessment do not subtract out risk given the personal exposures associated with estimated policy relevant background (PRB) ambient SO_2 concentrations, because PRB SO_2 concentrations are so low (see section 2.3).

3.2.2 Selection of urban areas

Although it would be useful to characterize SO_2-related lung function risks associated with "as is" SO_2 ambient concentrations and SO_2 concentrations that just meet the current and alternative SO_2 standards nationwide, because the modeling of personal exposures is both time and labor intensive, a regional and source-oriented approach was selected instead. The selection of areas to include in the exposure analysis, and therefore the risk assessment, took into consideration the availability of ambient monitoring, the desire to represent a range of geographic areas considering SO_2 emission sources, population demographics, general climatology, and results of the ambient air quality characterization.

The first area of interest was initially identified based on the results of a preliminary screening of the 5-minute ambient SO_2 monitoring data that were available. The state of Missouri was one of only a few states having both 5-minute maximum and continuous 5-minute SO_2 ambient monitoring, as well as having over 30 1-hour SO_2 monitors in operation at some time during the period from 1997 to 2007. In addition, the air quality characterization, described in Chapter 6 of the 1st draft REA (EPA, 2008b), estimated frequent exceedances above the potential health effect benchmark levels at several of the 1-hour ambient monitors. In a ranking of estimated SO_2 emissions reported in the National Emissions Inventory (NEI), Missouri ranked 7th for the number of stacks with > 1000 tpy SO_x emissions out of all U.S. states. These stack emissions were associated with a variety of source types such as electrical power generating units, chemical manufacturing, cement processing, and smelters. For all these reasons, the current SO_2 lung function risk assessment focuses on Missouri and, within Missouri, on those areas within 20 km of a major point source of SO_2 emissions in Greene County and the St. Louis area.

3.2.3 Addressing variability and uncertainty

Any estimation of risks associated with "as is" SO_2 concentrations or with SO_2 concentrations that just meet the current or alternative SO_2 standards should address both the variability and uncertainty that generally underlie such an analysis. *Uncertainty* refers to the lack of knowledge regarding the actual values of model input variables (parameter uncertainty) and of physical systems or relationships (model uncertainty – e.g., the shapes of exposure-response and concentration-response functions). The goal of the analyst is to reduce uncertainty to the maximum extent possible. Uncertainty can be reduced by improved measurement and improved model formulation. In a health risk assessment, however, significant uncertainty often remains.

The degree of uncertainty can be characterized, sometimes quantitatively. For example, the statistical uncertainty surrounding the estimated SO_2 coefficients in the exposure-response functions is reflected in confidence or credible intervals provided for the risk estimates.

As described in section 3.2 above, we used a Bayesian Markov Chain Monte Carlo approach to estimate exposure-response functions as well as to characterize uncertainty attributable to sampling error based on sample size considerations. Using this approach, we could derive the n^{th} percentile response value, for any n, for any SO_2concentration, x, as described above (see section 3.2). Because our exposure estimates were generated at the midpoints of 0.05 ppm intervals (i.e., for 0.025 ppm, 0.075 ppm, etc.), we derived 2.5^{th} percentile, 50^{th} percentile (median), and 97.5^{th} percentile response estimates for SO_2 concentrations at these midpoint values. The 2.5^{th} percentile and 97.5^{th} percentile response estimates comprise the lower and upper bounds of the credible interval around each point estimate (median estimate) of response.

In addition to uncertainties arising from sampling variability, other uncertainties associated with the use of the exposure-response relationships for lung function responses are briefly summarized below. Additional uncertainties with respect to the exposure inputs to the risk assessment are described in section 8.11 of the final REA (EPA, 2009b). The main additional uncertainties with respect to the approach used to estimate exposure-response relationships include:

- Length of exposure. The 5-minute lung function risk estimates are based on a combined data set from several controlled human exposure studies, most of which evaluated responses associated with 10-minute exposures. However, since some studies which evaluated responses after 5-minute exposures found responses occurring as early as 5-minutes after exposure, we used all of the 5- and 10- minute exposure data to represent responses associated with 5-minute exposures. We do not believe that this approach would appreciably impact the risk estimates.

- Exposure-response for mild/moderate asthmatics. The data set that was used to estimate exposure-response relationships included mild and/or moderate asthmatics. There is uncertainty with regard to how well the population of mild and moderate asthmatics included in the series of controlled human exposure studies represent the distribution of mild and moderate asthmatics in the U.S. population. As indicated in the ISA (p. 3-9), the subjects studied represent the responses "among groups of relatively healthy asthmatics and cannot necessarily be extrapolated to the most sensitive asthmatics in the population who are likely more susceptible to the respiratory effects of exposure to SO_2."

- Extrapolation of exposure-response relationships. It was necessary to estimate responses at SO_2 levels below the lowest exposure levels used in free-breathing controlled human studies (i.e., 0.2 ppm or 200 ppb). We did not include alternative models that incorporate hypothetical population thresholds, given the lack of evidence supporting the choice of potential hypothetical threshold levels. As discussed later in this document, we have presented information on the contribution of different exposure intervals to the total estimated lung function risk. This information provides insights on how much of the estimated risk is attributed to SO_2 exposures at the lower exposure levels (i.e., 0 to 50 ppb, 50 to 100 ppb, 100 to 150 ppb, etc.). One can use this information to get a rough sense of the SO_2-related risk that would exist under alternative threshold assumptions.

- Reproducibility of SO_2-induced responses. The risk assessment assumed that the SO_2-induced responses for individuals are reproducible. We note that this assumption has some support in that one study (Linn et al., 1987) exposed the same subjects on two occasions to 0.6 ppm (600 ppb) and the authors reported a high degree of correlation ($r > 0.7$ for mild asthmatics and $r > 0.8$ for moderate asthmatics, $p < 0.001$), while observing much lower and nonsignificant correlations ($r = 0.0 – 0.4$) for the lung function response observed in the clean air with exercise exposures.

- Age and lung function response. Because the vast majority of controlled human exposure studies investigating lung function responses were conducted with adult subjects, the risk assessment relies on data from adult asthmatic subjects to estimate exposure-response relationships that were applied to all asthmatic individuals, including children. The ISA (section 3.1.3.5) indicates that there is a strong body of evidence that suggests adolescents may experience many of the same respiratory effects at similar SO_2 levels, but recognizes that these studies administered SO_2 via inhalation through a mouthpiece rather than an exposure chamber. This technique bypasses nasal absorption of SO_2 and can result in an increase in lung SO_2 uptake. Therefore, the uncertainty will be greater in the risk estimates for asthmatic children.

- Exposure history. The risk assessment assumed that the SO_2-induced response on any given day is independent of previous SO_2 exposures.

- Interaction between SO_2 and other pollutants. Because the controlled human exposure studies used in the risk assessment involved only SO_2 exposures, it was assumed that estimates of SO_2-induced health responses would not be affected by the presence of other pollutants (e.g., $PM_{2.5}$, O_3, NO_2).

Variability refers to the heterogeneity in a population or parameter. Even if there is no uncertainty surrounding inputs to the analysis, there may still be variability. For example, there may be variability among exposure-response functions describing the relationship between SO_2 and lung function in different locations. This variability does not imply uncertainty about the exposure-response function in any location, but only that these functions are different in the different locations, reflecting differences in the populations and/or other factors that may affect the relationship between SO_2 and the associated health endpoint. In general, it is possible to have uncertainty but no variability (if, for instance, there is a single parameter whose value is uncertain) or variability but little or no uncertainty (for example, people's heights vary considerably but can be accurately measured with little uncertainty).

The SO_2 lung function risk assessment addresses variability-related concerns by using location-specific inputs for the exposure analysis (e.g., location-specific population data, air exchange rates, air quality and temperature data). The extent to which there may be variability in exposure-response relationships for the populations included in the risk assessment residing in different geographic areas is currently unknown.

Temporal variability is more difficult to address, because the risk assessment focuses on some unspecified time in the future. To minimize the degree to which values of inputs to the analysis may be different from the values of those inputs at that unspecified time, we are using the most current inputs available.

4 RESULTS

The results of the SO_2 risk assessment are presented in Tables 4-1 through 4-12. Each table includes results for both of the locations included in the risk assessment and for all of the air quality scenarios considered, using both 2-parameter logistic and probit exposure-response functions. Tables 4-1 and 4-2 show the numbers of occurrences of lung function response in a year, defined in terms of sRaw, for asthmatics and for asthmatic children, respectively, engaged in moderate or greater exertion associated with SO_2 concentrations under each of the different air quality scenarios considered in each of the two locations. Tables 4-3 and 4-4 show the corresponding results when lung function response is defined in terms of FEV_1. Tables 4-5 and 4-6 show the numbers of asthmatics and asthmatic children, respectively, engaged in moderate or greater exertion estimated to experience at least one lung function response in a year, defined in terms of sRaw, under each of the different air quality scenarios in each of the two locations. Tables 4-7 and 4-8 show the corresponding results when lung function response is defined in terms of FEV_1. Finally, Tables 4-9 through 4-12 show results analogous to those shown in Tables 4-5 through 4-8, only as percentages of all asthmatics (asthmatic children) engaged in moderate or greater exertion.

In addition, responses attributable to exposure to SO_2 within different concentration ranges are shown in Figures 4-1 through 4-16. The exposure ranges are in 50 ppb increments – i.e., $SO_2 < 50$ ppb, 50 ppb $\leq SO_2 <$ 100 ppb, 100 ppb $\leq SO_2 <$ 150 ppb, … , $SO_2 \geq$ 500 ppb. Figures 4-1a and b show the percent of asthmatics engaged in moderate or greater exertion in St. Louis, MO, using the logistic and probit exposure-response functions, respectively, estimated to experience at least one lung function response in a year, defined as an increase in sRaw ≥ 100%, attributable to exposure to SO_2 in each exposure "bin." Figures 4-2a and b show the corresponding percents for asthmatic children engaged in moderate or greater exertion in St. Louis, MO, using the logistic and probit exposure-response functions, respectively. Figures 4-3a and b, and 4-4a and b, show the corresponding percents for asthmatics and asthmatic children, respectively, in St. Louis, MO, when lung function response is defined as a decrease in $FEV_1 \geq$ 15%.

Figures 4-5a and b show the number of occurrences of lung function response, defined as an increase in sRaw ≥ 100%, among asthmatics engaged in moderate or greater exertion in St. Louis, MO, using the logistic and probit exposure-response functions, respectively, attributable to exposure to SO_2 in each exposure "bin." Figures 4-6a and b show the corresponding numbers of occurrences among asthmatic children in St. Louis, MO. Figures 4-7a and b and 4-8a and b show the corresponding numbers of occurrences of lung function response for asthmatics and asthmatic children, respectively, when lung function response is defined as a decrease in $FEV_1 \geq$ 15%. Figures 4-9a and b through 4-16a and b are the corresponding figures for Greene Co., MO. Figure 4-17 shows the legend that is used in Figures 4-1 through 4-16.

Table 4-1. Number of Occurrences (in Hundreds) of Lung Function Response (Defined in Terms of sRaw) Among Asthmatics Engaged in Moderate or Greater Exertion Associated with Exposure to "As Is" SO_2 Concentrations, SO_2 Concentrations that Just Meet the Current Standards, and SO_2 Concentrations that Just Meet Alternative Standards*

Exposure-Response Model	"As is" SO_2 Concentrations**	SO_2 Concentrations that Just Meet the Current Standards***	SO_2 Concentrations that Just Meet Alternative nth Percentile 1-Hr Daily Maximum Standards, with Levels (in ppb) of m (Standard Denoted n/m):					
			99/50	99/100	99/150	99/200	99/250	98/200
Response = Increase in sRaw >= 100%								
Greene County, MO								
2-Parameter Logistic	125 (24 - 572)	127 (25 - 577)	125 (24 - 572)	125 (24 - 572)	125 (24 - 573)	126 (24 - 573)	126 (24 - 575)	126 (24 - 574)
Probit	16 (0 - 256)	18 (1 - 261)	16 (0 - 256)	16 (0 - 256)	16 (1 - 257)	16 (1 - 257)	17 (1 - 258)	17 (1 - 258)
St. Louis, MO								
2-Parameter Logistic	657 (128 - 2985)	1672 (663 - 4740)	652 (125 - 2975)	686 (141 - 3041)	762 (176 - 3184)	880 (234 - 3398)	1036 (315 - 3673)	997 (295 - 3604)
Probit	90 (4 - 1346)	933 (393 - 3107)	86 (3 - 1336)	111 (11 - 1402)	170 (33 - 1543)	264 (72 - 1756)	392 (128 - 2031)	360 (114 - 1963)
Response = Increase in sRaw >= 200%								
Greene County, MO								
2-Parameter Logistic	38 (4 - 310)	39 (4 - 312)	38 (4 - 310)	38 (4 - 310)	38 (4 - 310)	38 (4 - 310)	39 (4 - 311)	39 (4 - 311)
Probit	2 (0 - 123)	3 (0 - 124)	2 (0 - 122)	2 (0 - 123)	2 (0 - 123)	2 (0 - 123)	2 (0 - 123)	2 (0 - 123)
St. Louis, MO								
2-Parameter Logistic	201 (21 - 1614)	560 (165 - 2407)	199 (20 - 1609)	211 (24 - 1639)	237 (32 - 1703)	278 (47 - 1799)	332 (68 - 1923)	319 (63 - 1892)
Probit	13 (0 - 643)	258 (86 - 1388)	12 (0 - 639)	18 (1 - 666)	33 (5 - 725)	59 (12 - 814)	95 (24 - 930)	86 (21 - 901)

*Numbers are median (50th percentile) numbers of asthmatics. Numbers in parentheses below the median are 95% cred ble intervals based on statistical uncertainty surrounding the SO_2 coefficient in the logistic and probit exposure-response functions. Numbers are rounded to the nearest whole number.

**The "as is" exposure scenario was based on monitoring and modeling using 2002 air quality information.

***The current primary SO_2 standards include a 24-hour standard set at 0.14 parts per million (ppm), not to be exceeded more than once per year, and an annual standard set at 0.03 ppm, calculated as the arithmetic mean of hourly averages.

Table 4-2. Number of Occurrences (in Hundreds) of Lung Function Response (Defined in Terms of sRaw) Among Asthmatic Children Engaged in Moderate or Greater Exertion Associated with Exposure to "As Is" SO_2 Concentrations, SO_2 Concentrations that Just Meet the Current Standards, and SO_2 Concentrations that Just Meet Alternative Standards*

Exposure-Response Model	"As is" SO_2 Concentrations**	SO_2 Concentrations that Just Meet the Current Standards***	SO_2 Concentrations that Just Meet Alternative nth Percentile 1-Hr Daily Maximum Standards, with Levels (in ppb) of m (Standard Denoted n/m):					
			99/50	99/100	99/150	99/200	99/250	98/200
Response = Increase in sRaw >= 100%								
Greene County, MO								
2-Parameter Logistic	71 (13 - 324)	72 (14 - 327)	71 (13 - 324)	71 (14 - 324)	71 (14 - 324)	71 (14 - 325)	71 (14 - 325)	71 (14 - 325)
Probit	9 (0 - 145)	10 (1 - 148)	9 (0 - 145)	9 (0 - 145)	9 (0 - 145)	9 (0 - 146)	10 (0 - 146)	10 (0 - 146)
St. Louis, MO								
2-Parameter Logistic	417 (81 - 1893)	1179 (484 - 3209)	413 (80 - 1885)	439 (91 - 1935)	497 (118 - 2043)	586 (162 - 2206)	704 (222 - 2413)	674 (207 - 2361)
Probit	58 (3 - 855)	692 (296 - 2176)	55 (2 - 847)	74 (8 - 896)	118 (25 - 1004)	189 (53 - 1166)	286 (96 - 1373)	262 (85 - 1321)
Response = Increase in sRaw >= 200%								
Greene County, MO								
2-Parameter Logistic	22 (2 - 175)	22 (2 - 177)	22 (2 - 175)	22 (2 - 175)	22 (2 - 175)	22 (2 - 176)	22 (2 - 176)	22 (2 - 176)
Probit	1 (0 - 69)	2 (0 - 71)	1 (0 - 69)	1 (0 - 69)	1 (0 - 69)	1 (0 - 70)	1 (0 - 70)	1 (0 - 70)
St. Louis, MO								
2-Parameter Logistic	128 (13 - 1023)	397 (122 - 1618)	126 (13 - 1019)	135 (15 - 1042)	155 (22 - 1091)	186 (33 - 1164)	227 (49 - 1257)	217 (45 - 1234)
Probit	8 (0 - 408)	192 (65 - 967)	8 (0 - 405)	12 (1 - 425)	24 (4 - 470)	43 (9 - 538)	70 (18 - 625)	63 (16 - 603)

*Numbers are median (50th percentile) numbers of asthmatics. Numbers in parentheses below the median are 95% cred ble intervals based on statistical uncertainty surrounding the SO_2 coefficient in the logistic and probit exposure-response functions. Numbers are rounded to the nearest whole number.

**The "as is" exposure scenario was based on monitoring and modeling using 2002 air quality information.

***The current primary SO_2 standards include a 24-hour standard set at 0.14 parts per million (ppm), not to be exceeded more than once per year, and an annual standard set at 0.03 ppm, calculated as the arithmetic mean of hourly averages.

Table 4-3. Number of Occurrences (in Hundreds) of Lung Function Response (Defined in Terms of FEV_1) Among Asthmatics Engaged in Moderate or Greater Exertion Associated with Exposure to "As Is" SO_2 Concentrations, SO_2 Concentrations that Just Meet the Current Standards, and SO_2 Concentrations that Just Meet Alternative Standards*

Exposure-Response Model	"As is" SO_2 Concentrations**	SO_2 Concentrations that Just Meet the Current Standards***	SO_2 Concentrations that Just Meet Alternative nth Percentile 1-Hr Daily Maximum Standards, with Levels (in ppb) of m (Standard Denoted n/m):					
			99/50	99/100	99/150	99/200	99/250	98/200
Response = Decrease in FEV1 >= 15%								
Greene County, MO								
2-Parameter Logistic	69 (6 - 675)	71 (7 - 680)	69 (6 - 675)	69 (6 - 675)	69 (6 - 675)	69 (6 - 676)	70 (6 - 677)	70 (6 - 677)
Probit	6 (0 - 418)	8 (0 - 424)	6 (0 - 417)	6 (0 - 418)	6 (0 - 418)	6 (0 - 419)	7 (0 - 421)	6 (0 - 420)
St. Louis, MO								
2-Parameter Logistic	366 (33 - 3520)	1341 (454 - 5632)	361 (32 - 3507)	391 (41 - 3587)	461 (66 - 3759)	570 (108 - 4016)	718 (169 - 4346)	681 (154 - 4264)
Probit	36 (1 - 2189)	866 (322 - 4471)	33 (0 - 2175)	55 (5 - 2262)	109 (20 - 2448)	198 (49 - 2727)	322 (94 - 3084)	291 (82 - 2995)
Response = Decrease in FEV1 >= 20%								
Greene County, MO								
2-Parameter Logistic	3 (0 - 53)	3 (0 - 54)	3 (0 - 53)	3 (0 - 53)	3 (0 - 53)	3 (0 - 53)	3 (0 - 53)	3 (0 - 53)
Probit	0 (0 - 5)	0 (0 - 7)	0 (0 - 5)	0 (0 - 5)	0 (0 - 5)	0 (0 - 6)	0 (0 - 6)	0 (0 - 6)
St. Louis, MO								
2-Parameter Logistic	15 (1 - 279)	310 (133 - 1045)	14 (0 - 276)	20 (2 - 299)	35 (7 - 351)	62 (17 - 435)	104 (34 - 550)	93 (30 - 521)
Probit	1 (0 - 32)	240 (120 - 697)	0 (0 - 30)	3 (1 - 47)	13 (5 - 89)	33 (14 - 158)	65 (29 - 256)	57 (25 - 232)

*Numbers are median (50th percentile) numbers of asthmatics. Numbers in parentheses below the median are 95% cred ble intervals based on statistical uncertainty surrounding the SO_2 coefficient in the logistic and probit exposure-response functions. Numbers are rounded to the nearest whole number.

**The "as is" exposure scenario was based on monitoring and modeling using 2002 air quality information.

***The current primary SO_2 standards include a 24-hour standard set at 0.14 parts per million (ppm), not to be exceeded more than once per year, and an annual standard set at 0.03 ppm, calculated as the arithmetic mean of hourly averages.

Table 4-4. Number of Occurrences (in Hundreds) of Lung Function Response (Defined in Terms of FEV_1) Among Asthmatic Children Engaged in Moderate or Greater Exertion Associated with Exposure to "As Is" SO_2 Concentrations, SO_2 Concentrations that Just Meet the Current Standards, and SO_2 Concentrations that Just Meet Alternative Standards*

Exposure-Response Model	"As is" SO_2 Concentrations**	SO_2 Concentrations that Just Meet the Current Standards***	SO_2 Concentrations that Just Meet Alternative nth Percentile 1-Hr Daily Maximum Standards, with Levels (in ppb) of m (Standard Denoted n/m):					
			99/50	99/100	99/150	99/200	99/250	98/200
Response = Decrease in FEV1 >= 15%								
Greene County, MO								
2-Parameter Logistic	39 (3 - 382)	40 (4 - 386)	39 (3 - 382)	39 (3 - 382)	39 (3 - 382)	39 (3 - 383)	40 (4 - 384)	40 (4 - 383)
Probit	3 (0 - 236)	4 (0 - 240)	3 (0 - 236)	3 (0 - 236)	3 (0 - 237)	4 (0 - 237)	4 (0 - 238)	4 (0 - 238)
St. Louis, MO								
2-Parameter Logistic	232 (21 - 2231)	965 (338 - 3816)	229 (20 - 2222)	252 (27 - 2282)	304 (46 - 2412)	387 (77 - 2608)	499 (123 - 2857)	471 (112 - 2795)
Probit	23 (1 - 1389)	648 (242 - 3101)	21 (0 - 1379)	38 (4 - 1444)	79 (15 - 1585)	146 (37 - 1797)	239 (70 - 2066)	216 (62 - 1999)
Response = Decrease in FEV1 >= 20%								
Greene County, MO								
2-Parameter Logistic	1 (0 - 30)	2 (0 - 31)	1 (0 - 30)	1 (0 - 30)	1 (0 - 30)	2 (0 - 30)	2 (0 - 30)	2 (0 - 30)
Probit	0 (0 - 3)	0 (0 - 4)	0 (0 - 3)	0 (0 - 3)	0 (0 - 3)	0 (0 - 3)	0 (0 - 3)	0 (0 - 3)
St. Louis, MO								
2-Parameter Logistic	10 (0 - 178)	231 (99 - 753)	9 (0 - 175)	13 (1 - 192)	24 (5 - 232)	45 (13 - 295)	76 (26 - 382)	68 (22 - 360)
Probit	0 (0 - 21)	180 (90 - 521)	0 (0 - 19)	2 (1 - 32)	10 (3 - 63)	25 (10 - 116)	49 (21 - 190)	43 (18 - 171)

*Numbers are median (50th percentile) numbers of asthmatics. Numbers in parentheses below the median are 95% cred ble intervals based on statistical uncertainty surrounding the SO_2 coefficient in the logistic and probit exposure-response functions. Numbers are rounded to the nearest whole number.

**The "as is" exposure scenario was based on monitoring and modeling using 2002 air quality information.

***The current primary SO_2 standards include a 24-hour standard set at 0.14 parts per million (ppm), not to be exceeded more than once per year, and an annual standard set at 0.03 ppm, calculated as the arithmetic mean of hourly averages.

Table 4-5. Number of Asthmatics Engaged in Moderate or Greater Exertion Estimated to Experience At Least One Lung Function Response (Defined in Terms of sRaw) Associated with Exposure to "As Is" SO_2 Concentrations, SO_2 Concentrations that Just Meet the Current Standards, and SO_2 Concentrations that Just Meet Alternative Standards*

Exposure-Response Model	"As is" SO_2 Concentrations**	SO_2 Concentrations that Just Meet the Current Standards***	SO_2 Concentrations that Just Meet Alternative nth Percentile 1-Hr Daily Maximum Standards, with Levels (in ppb) of m (Standard Denoted n/m):					
			99/50	99/100	99/150	99/200	99/250	98/200
Response = Increase in sRaw >= 100%								
Greene County, MO								
2-Parameter Logistic	90 (20 - 390)	210 (80 - 620)	80 (20 - 380)	90 (20 - 390)	100 (20 - 420)	120 (30 - 460)	160 (50 - 520)	140 (40 - 500)
Probit	10 (0 - 180)	110 (40 - 410)	10 (0 - 170)	10 (0 - 180)	20 (0 - 210)	40 (10 - 250)	70 (20 - 310)	60 (20 - 280)
St. Louis, MO								
2-Parameter Logistic	1010 (340 - 3010)	13460 (9740 - 18510)	730 (220 - 2490)	1990 (860 - 4690)	3650 (1900 - 7100)	5520 (3230 - 9490)	7500 (4770 - 11850)	7050 (4410 - 11320)
Probit	500 (140 - 1990)	13050 (9430 - 18100)	290 (70 - 1470)	1340 (520 - 3690)	2930 (1450 - 6200)	4810 (2760 - 8710)	6860 (4310 - 11190)	6400 (3950 - 10640)
Response = Increase in sRaw >= 200%								
Greene County, MO								
2-Parameter Logistic	30 (0 - 210)	70 (20 - 310)	30 (0 - 210)	30 (0 - 210)	30 (0 - 220)	40 (10 - 240)	50 (10 - 270)	50 (10 - 260)
Probit	0 (0 - 80)	30 (10 - 180)	0 (0 - 80)	0 (0 - 90)	10 (0 - 100)	10 (0 - 110)	20 (0 - 140)	10 (0 - 130)
St. Louis, MO								
2-Parameter Logistic	330 (70 - 1520)	5520 (3400 - 8960)	230 (40 - 1290)	670 (210 - 2270)	1280 (510 - 3360)	2010 (940 - 4470)	2830 (1470 - 5590)	2640 (1340 - 5330)
Probit	120 (20 - 880)	5180 (3150 - 8570)	60 (10 - 660)	350 (90 - 1590)	870 (310 - 2680)	1560 (690 - 3820)	2380 (1200 - 5000)	2190 (1070 - 4730)

*Numbers are median (50th percentile) numbers of asthmatics. Numbers in parentheses below the median are 95% cred ble intervals based on statistical uncertainty surrounding the SO_2 coefficient in the logistic and probit exposure-response functions. Numbers are rounded to the nearest ten.

**The "as is" exposure scenario was based on monitoring and modeling using 2002 air quality information.

***The current primary SO_2 standards include a 24-hour standard set at 0.14 parts per million (ppm), not to be exceeded more than once per year, and an annual standard set at 0.03 ppm, calculated as the arithmetic mean of hourly averages.

Table 4-6. Number of Asthmatic Children Engaged in Moderate or Greater Exertion Estimated to Experience At Least One Lung Function Response (Defined in Terms of sRaw) Associated with Exposure to "As Is" SO_2 Concentrations, SO_2 Concentrations that Just Meet the Current Standards, and SO_2 Concentrations that Just Meet Alternative Standards*

Exposure-Response Model	"As is" SO_2 Concentrations**	SO_2 Concentrations that Just Meet the Current Standards***	SO_2 Concentrations that Just Meet Alternative nth Percentile 1-Hr Daily Maximum Standards, with Levels (in ppb) of m (Standard Denoted n/m):					
			99/50	99/100	99/150	99/200	99/250	98/200
Response = Increase in sRaw >= 100%								
Greene County, MO								
2-Parameter Logistic	30 (10 - 130)	110 (40 - 270)	30 (10 - 130)	30 (10 - 140)	40 (10 - 150)	50 (20 - 180)	70 (30 - 210)	60 (20 - 200)
Probit	10 (0 - 60)	60 (20 - 200)	0 (0 - 60)	10 (0 - 60)	10 (0 - 80)	20 (10 - 100)	40 (10 - 140)	30 (10 - 130)
St. Louis, MO								
2-Parameter Logistic	590 (220 - 1570)	8020 (6080 - 10370)	400 (130 - 1210)	1220 (560 - 2620)	2240 (1240 - 4010)	3370 (2090 - 5350)	4560 (3060 - 6680)	4290 (2840 - 6390)
Probit	340 (100 - 1150)	7950 (6020 - 10320)	190 (50 - 790)	890 (360 - 2220)	1910 (1000 - 3690)	3080 (1860 - 5110)	4330 (2870 - 6510)	4060 (2640 - 6210)
Response = Increase in sRaw >= 200%								
Greene County, MO								
2-Parameter Logistic	10 (0 - 70)	40 (10 - 130)	10 (0 - 70)	10 (0 - 70)	10 (0 - 80)	20 (0 - 90)	20 (10 - 110)	20 (10 - 100)
Probit	0 (0 - 30)	20 (0 - 90)	0 (0 - 30)	0 (0 - 30)	0 (0 - 40)	10 (0 - 50)	10 (0 - 60)	10 (0 - 60)
St. Louis, MO								
2-Parameter Logistic	190 (50 - 780)	3380 (2190 - 5070)	130 (30 - 610)	410 (140 - 1240)	800 (340 - 1870)	1250 (620 - 2500)	1750 (970 - 3140)	1640 (890 - 3000)
Probit	80 (10 - 500)	3290 (2110 - 5000)	40 (10 - 350)	240 (60 - 950)	580 (220 - 1590)	1030 (480 - 2250)	1560 (830 - 2940)	1440 (740 - 2790)

*Numbers are median (50th percentile) numbers of asthmatic children. Numbers in parentheses below the median are 95% credible intervals based on statistical uncertainty surrounding the SO_2 coefficient in the logistic and probit exposure-response functions. Numbers are rounded to the nearest ten.

**The "as is" exposure scenario was based on monitoring and modeling using 2002 air quality information.

***The current primary SO_2 standards include a 24-hour standard set at 0.14 parts per million (ppm), not to be exceeded more than once per year, and an annual standard set at 0.03 ppm, calculated as the arithmetic mean of hourly averages.

Table 4-7. Number of Asthmatics Engaged in Moderate or Greater Exertion Estimated to Experience At Least One Lung Function Response (Defined in Terms of FEV_1) Associated with Exposure to "As Is" SO_2 Concentrations, SO_2 Concentrations that Just Meet the Current Standards, and SO_2 Concentrations that Just Meet Alternative Standards*

Exposure-Response Model	"As is" SO_2 Concentrations**	SO_2 Concentrations that Just Meet the Current Standards***	SO_2 Concentrations that Just Meet Alternative nth Percentile 1-Hr Daily Maximum Standards, with Levels (in ppb) of m (Standard Denoted n/m):					
			99/50	99/100	99/150	99/200	99/250	98/200
Response = Decrease in FEV_1 >= 15%								
Greene County, MO								
2-Parameter Logistic	50 (10 - 460)	170 (50 - 730)	50 (0 - 450)	50 (10 - 460)	60 (10 - 490)	80 (20 - 540)	110 (30 - 610)	100 (20 - 590)
Probit	10 (0 - 290)	100 (30 - 590)	0 (0 - 280)	10 (0 - 290)	20 (0 - 330)	30 (10 - 380)	50 (10 - 460)	50 (10 - 430)
St. Louis, MO								
2-Parameter Logistic	750 (180 - 3580)	15220 (10280 - 22530)	510 (100 - 2950)	1700 (580 - 5590)	3460 (1520 - 8500)	5570 (2880 - 11400)	7910 (4550 - 14280)	7370 (4160 - 13640)
Probit	410 (80 - 2880)	15040 (10140 - 22670)	220 (30 - 2200)	1250 (370 - 5070)	2970 (1230 - 8210)	5130 (2580 - 11280)	7550 (4280 - 14280)	6990 (3880 - 13610)
Response = Decrease in FEV_1 >= 20%								
Greene County, MO								
2-Parameter Logistic	0 (0 - 40)	30 (10 - 130)	0 (0 - 40)	0 (0 - 40)	0 (0 - 50)	10 (0 - 60)	20 (0 - 80)	10 (0 - 80)
Probit	0 (0 - 10)	20 (10 - 80)	0 (0 - 0)	0 (0 - 10)	0 (0 - 10)	0 (0 - 20)	10 (0 - 40)	10 (0 - 40)
St. Louis, MO								
2-Parameter Logistic	100 (20 - 570)	9240 (6110 - 13840)	50 (10 - 380)	350 (110 - 1290)	1020 (430 - 2680)	2100 (1060 - 4450)	3540 (1990 - 6540)	3190 (1760 - 6050)
Probit	40 (10 - 320)	9260 (6200 - 13820)	20 (0 - 170)	240 (80 - 960)	870 (390 - 2340)	1950 (1020 - 4170)	3430 (1980 - 6340)	3070 (1740 - 5830)

*Numbers are median (50th percentile) numbers of asthmatics. Numbers in parentheses below the median are 95% credible intervals based on statistical uncertainty surrounding the SO_2 coefficient in the logistic and probit exposure-response functions. Numbers are rounded to the nearest ten.

**The "as is" exposure scenario was based on monitoring and modeling using 2002 air quality information.

***The current primary SO_2 standards include a 24-hour standard set at 0.14 parts per million (ppm), not to be exceeded more than once per year, and an annual standard set at 0.03 ppm, calculated as the arithmetic mean of hourly averages.

Table 4-8. Number of Asthmatic Children Engaged in Moderate or Greater Exertion Estimated to Experience At Least One Lung Function Response (Defined in Terms of FEV_1) Associated with Exposure to "As Is" SO_2 Concentrations, SO_2 Concentrations that Just Meet the Current Standards, and SO_2 Concentrations that Just Meet Alternative Standards*

Exposure-Response Model	"As is" SO_2 Concentrations**	SO_2 Concentrations that Just Meet the Current Standards***	SO_2 Concentrations that Just Meet Alternative nth Percentile 1-Hr Daily Maximum Standards, with Levels (in ppb) of m (Standard Denoted n/m):					
			99/50	99/100	99/150	99/200	99/250	98/200
Response = Decrease in FEV_1 >= 15%								
Greene County, MO								
2-Parameter Logistic	20 (0 - 160)	90 (30 - 320)	20 (0 - 150)	20 (0 - 160)	30 (0 - 180)	40 (10 - 210)	50 (10 - 250)	50 (10 - 240)
Probit	0 (0 - 100)	60 (20 - 280)	0 (0 - 100)	0 (0 - 100)	10 (0 - 120)	20 (0 - 160)	30 (10 - 200)	30 (10 - 180)
St. Louis, MO								
2-Parameter Logistic	460 (120 - 1870)	9310 (6620 - 12680)	290 (60 - 1440)	1080 (390 - 3130)	2200 (1030 - 4810)	3510 (1930 - 6440)	4950 (3030 - 8070)	4630 (2780 - 7720)
Probit	280 (50 - 1630)	9320 (6630 - 12800)	150 (20 - 1160)	840 (260 - 2990)	1970 (860 - 4800)	3350 (1790 - 6510)	4870 (2930 - 8190)	4530 (2660 - 7830)
Response = Decrease in FEV_1 >= 20%								
Greene County, MO								
2-Parameter Logistic	0 (0 - 10)	20 (10 - 70)	0 (0 - 10)	0 (0 - 10)	0 (0 - 20)	0 (0 - 30)	10 (0 - 40)	10 (0 - 40)
Probit	0 (0 - 0)	10 (0 - 40)	0 (0 - 0)	0 (0 - 0)	0 (0 - 10)	0 (0 - 10)	0 (0 - 20)	0 (0 - 20)
St. Louis, MO								
2-Parameter Logistic	70 (10 - 350)	6150 (4190 - 8700)	30 (10 - 220)	240 (80 - 820)	700 (300 - 1710)	1430 (740 - 2830)	2410 (1400 - 4160)	2170 (1240 - 3850)
Probit	30 (10 - 220)	6210 (4280 - 8780)	10 (0 - 110)	170 (60 - 650)	610 (280 - 1560)	1370 (730 - 2750)	2380 (1410 - 4140)	2140 (1240 - 3820)

*Numbers are median (50th percentile) numbers of asthmatic children. Numbers in parentheses below the median are 95% credible intervals based on statistical uncertainty surrounding the SO_2 coefficient in the logistic and probit exposure-response functions. Numbers are rounded to the nearest hundred.

**The "as is" exposure scenario was based on monitoring and modeling using 2002 air quality information.

***The current primary SO_2 standards include a 24-hour standard set at 0.14 parts per million (ppm), not to be exceeded more than once per year, and an annual standard set at 0.03 ppm, calculated as the arithmetic mean of hourly averages.

Table 4-9. Percent of Asthmatics Engaged in Moderate or Greater Exertion Estimated to Experience At Least One Lung Function Response (Defined in Terms of sRaw) Associated with Exposure to "As Is" SO_2 Concentrations, SO_2 Concentrations that Just Meet the Current Standards, and SO_2 Concentrations that Just Meet Alternative Standards*

Exposure-Response Model	"As is" SO_2 Concentrations**	SO_2 Concentrations that Just Meet the Current Standards***	SO_2 Concentrations that Just Meet Alternative nth Percentile 1-Hr Daily Maximum Standards, with Levels (in ppb) of m (Standard Denoted n/m):					
			99/50	99/100	99/150	99/200	99/250	98/200
Response = Increase in sRaw >= 100%								
Greene County, MO								
2-Parameter Logistic	0.4% (0.1% - 1.8%)	1% (0.4% - 2.9%)	0.4% (0.1% - 1.8%)	0.4% (0.1% - 1.8%)	0.5% (0.1% - 2%)	0.6% (0.2% - 2.1%)	0.7% (0.2% - 2.4%)	0.7% (0.2% - 2.3%)
Probit	0.1% (0% - 0.8%)	0.5% (0.2% - 1.9%)	0.1% (0% - 0.8%)	0.1% (0% - 0.8%)	0.1% (0% - 1%)	0.2% (0% - 1.2%)	0.3% (0.1% - 1.4%)	0.3% (0.1% - 1.3%)
St. Louis, MO								
2-Parameter Logistic	1% (0.3% - 2.9%)	13.1% (9.5% - 18.1%)	0.7% (0.2% - 2.4%)	1.9% (0.8% - 4.6%)	3.6% (1.9% - 6.9%)	5.4% (3.2% - 9.3%)	7.3% (4.7% - 11.6%)	6.9% (4.3% - 11.1%)
Probit	0.5% (0.1% - 1.9%)	12.7% (9.2% - 17.7%)	0.3% (0.1% - 1.4%)	1.3% (0.5% - 3.6%)	2.9% (1.4% - 6.1%)	4.7% (2.7% - 8.5%)	6.7% (4.2% - 10.9%)	6.2% (3.9% - 10.4%)
Response = Increase in sRaw >= 200%								
Greene County, MO								
2-Parameter Logistic	0.1% (0% - 1%)	0.3% (0.1% - 1.5%)	0.1% (0% - 1%)	0.1% (0% - 1%)	0.2% (0% - 1%)	0.2% (0% - 1.1%)	0.2% (0% - 1.3%)	0.2% (0% - 1.2%)
Probit	0% (0% - 0.4%)	0.1% (0% - 0.8%)	0% (0% - 0.4%)	0% (0% - 0.4%)	0% (0% - 0.5%)	0% (0% - 0.5%)	0.1% (0% - 0.6%)	0.1% (0% - 0.6%)
St. Louis, MO								
2-Parameter Logistic	0.3% (0.1% - 1.5%)	5.4% (3.3% - 8.7%)	0.2% (0% - 1.3%)	0.7% (0.2% - 2.2%)	1.3% (0.5% - 3.3%)	2% (0.9% - 4.4%)	2.8% (1.4% - 5.5%)	2.6% (1.3% - 5.2%)
Probit	0.1% (0% - 0.9%)	5.1% (3.1% - 8.4%)	0.1% (0% - 0.6%)	0.3% (0.1% - 1.6%)	0.8% (0.3% - 2.6%)	1.5% (0.7% - 3.7%)	2.3% (1.2% - 4.9%)	2.1% (1% - 4.6%)

*Percents are median (50th percentile) percents of asthmatic children. Percents in parentheses below the median are 95% credible intervals based on statistical uncertainty surrounding the SO_2 coefficient in the logistic and probit exposure-response functions. Percents are rounded to the nearest tenth.

**The "as is" exposure scenario was based on monitoring and modeling using 2002 air quality information.

***The current primary SO_2 standards include a 24-hour standard set at 0.14 parts per million (ppm), not to be exceeded more than once per year, and an annual standard set at 0.03 ppm, calculated as the arithmetic mean of hourly averages.

Table 4-10. Percent of Asthmatic Children Engaged in Moderate or Greater Exertion Estimated to Experience At Least One Lung Function Response (Defined in Terms of sRaw) Associated with Exposure to "As Is" SO_2 Concentrations, SO_2 Concentrations that Just Meet the Current Standards, and SO_2 Concentrations that Just Meet Alternative Standards*

Exposure-Response Model	"As is" SO_2 Concentrations**	SO_2 Concentrations that Just Meet the Current Standards***	SO_2 Concentrations that Just Meet Alternative nth Percentile 1-Hr Daily Maximum Standards, with Levels (in ppb) of m (Standard Denoted n/m):					
			99/50	99/100	99/150	99/200	99/250	98/200
Response = Increase in sRaw >= 100%								
Greene County, MO								
2-Parameter Logistic	0.4% (0.1% - 1.8%)	1.4% (0.6% - 3.7%)	0.4% (0.1% - 1.8%)	0.4% (0.1% - 1.9%)	0.5% (0.1% - 2.1%)	0.7% (0.2% - 2.4%)	1% (0.3% - 2.9%)	0.9% (0.3% - 2.7%)
Probit	0.1% (0% - 0.9%)	0.9% (0.3% - 2.7%)	0.1% (0% - 0.8%)	0.1% (0% - 0.9%)	0.2% (0% - 1.1%)	0.3% (0.1% - 1.4%)	0.5% (0.2% - 1.9%)	0.4% (0.1% - 1.7%)
St. Louis, MO								
2-Parameter Logistic	1.4% (0.5% - 3.8%)	19.2% (14.6% - 24.9%)	0.9% (0.3% - 2.9%)	2.9% (1.3% - 6.3%)	5.4% (3% - 9.6%)	8.1% (5% - 12.8%)	10.9% (7.3% - 16%)	10.3% (6.8% - 15.3%)
Probit	0.8% (0.2% - 2.8%)	19.1% (14.4% - 24.7%)	0.4% (0.1% - 1.9%)	2.1% (0.9% - 5.3%)	4.6% (2.4% - 8.8%)	7.4% (4.5% - 12.3%)	10.4% (6.9% - 15.6%)	9.7% (6.3% - 14.9%)
Response = Increase in sRaw >= 200%								
Greene County, MO								
2-Parameter Logistic	0.1% (0% - 1%)	0.5% (0.1% - 1.8%)	0.1% (0% - 1%)	0.1% (0% - 1%)	0.2% (0% - 1.1%)	0.2% (0% - 1.3%)	0.3% (0.1% - 1.5%)	0.3% (0.1% - 1.4%)
Probit	0% (0% - 0.4%)	0.2% (0.1% - 1.2%)	0% (0% - 0.4%)	0% (0% - 0.4%)	0% (0% - 0.5%)	0.1% (0% - 0.6%)	0.1% (0% - 0.8%)	0.1% (0% - 0.8%)
St. Louis, MO								
2-Parameter Logistic	0.5% (0.1% - 1.9%)	8.1% (5.3% - 12.2%)	0.3% (0.1% - 1.5%)	1% (0.3% - 3%)	1.9% (0.8% - 4.5%)	3% (1.5% - 6%)	4.2% (2.3% - 7.5%)	3.9% (2.1% - 7.2%)
Probit	0.2% (0% - 1.2%)	7.9% (5% - 12%)	0.1% (0% - 0.8%)	0.6% (0.2% - 2.3%)	1.4% (0.5% - 3.8%)	2.5% (1.2% - 5.4%)	3.7% (2% - 7%)	3.4% (1.8% - 6.7%)

*Percents are median (50th percentile) percents of asthmatic children. Percents in parentheses below the median are 95% credible intervals based on statistical uncertainty surrounding the SO_2 coefficient in the logistic and probit exposure-response functions. Percents are rounded to the nearest tenth.

**The "as is" exposure scenario was based on monitoring and modeling using 2002 air quality information.

***The current primary SO_2 standards include a 24-hour standard set at 0.14 parts per million (ppm), not to be exceeded more than once per year, and an annual standard set at 0.03 ppm, calculated as the arithmetic mean of hourly averages.

Table 4-11. Percent of Asthmatics Engaged in Moderate or Greater Exertion Estimated to Experience At Least One Lung Function Response (Defined in Terms of FEV_1) Associated with Exposure to "As Is" SO_2 Concentrations, SO_2 Concentrations that Just Meet the Current Standards, and SO_2 Concentrations that Just Meet Alternative Standards*

Exposure-Response Model	"As is" SO_2 Concentrations**	SO_2 Concentrations that Just Meet the Current Standards***	SO_2 Concentrations that Just Meet Alternative nth Percentile 1-Hr Daily Maximum Standards, with Levels (in ppb) of m (Standard Denoted n/m):					
			99/50	99/100	99/150	99/200	99/250	98/200
Response = Decrease in FEV1 >= 15%								
Greene County, MO								
2-Parameter Logistic	0.2% (0% - 2.1%)	0.8% (0.2% - 3.4%)	0.2% (0% - 2.1%)	0.2% (0% - 2.1%)	0.3% (0% - 2.3%)	0.4% (0.1% - 2.5%)	0.5% (0.1% - 2.9%)	0.5% (0.1% - 2.8%)
Probit	0% (0% - 1.3%)	0.5% (0.1% - 2.8%)	0% (0% - 1.3%)	0% (0% - 1.4%)	0.1% (0% - 1.5%)	0.1% (0% - 1.8%)	0.3% (0.1% - 2.1%)	0.2% (0% - 2%)
St. Louis, MO								
2-Parameter Logistic	0.7% (0.2% - 3.5%)	14.9% (10% - 22%)	0.5% (0.1% - 2.9%)	1.7% (0.6% - 5.5%)	3.4% (1.5% - 8.3%)	5.4% (2.8% - 11.1%)	7.7% (4.4% - 13.9%)	7.2% (4.1% - 13.3%)
Probit	0.4% (0.1% - 2.8%)	14.7% (9.9% - 22.1%)	0.2% (0% - 2.1%)	1.2% (0.4% - 4.9%)	2.9% (1.2% - 8%)	5% (2.5% - 11%)	7.4% (4.2% - 13.9%)	6.8% (3.8% - 13.3%)
Response = Decrease in FEV1 >= 20%								
Greene County, MO								
2-Parameter Logistic	0% (0% - 0.2%)	0.1% (0% - 0.6%)	0% (0% - 0.2%)	0% (0% - 0.2%)	0% (0% - 0.2%)	0% (0% - 0.3%)	0.1% (0% - 0.4%)	0.1% (0% - 0.4%)
Probit	0% (0% - 0%)	0.1% (0% - 0.4%)	0% (0% - 0%)	0% (0% - 0%)	0% (0% - 0.1%)	0% (0% - 0.1%)	0% (0% - 0.2%)	0% (0% - 0.2%)
St. Louis, MO								
2-Parameter Logistic	0.1% (0% - 0.6%)	9% (6% - 13.5%)	0.1% (0% - 0.4%)	0.3% (0.1% - 1.3%)	1% (0.4% - 2.6%)	2.1% (1% - 4.3%)	3.5% (1.9% - 6.4%)	3.1% (1.7% - 5.9%)
Probit	0% (0% - 0.3%)	9% (6% - 13.5%)	0% (0% - 0.2%)	0.2% (0.1% - 0.9%)	0.8% (0.4% - 2.3%)	1.9% (1% - 4.1%)	3.4% (1.9% - 6.2%)	3% (1.7% - 5.7%)

*Percents are median (50th percentile) percents of asthmatic children. Percents in parentheses below the median are 95% credible intervals based on statistical uncertainty surrounding the SO_2 coefficient in the logistic and probit exposure-response functions. Percents are rounded to the nearest tenth.

**The "as is" exposure scenario was based on monitoring and modeling using 2002 air quality information.

***The current primary SO_2 standards include a 24-hour standard set at 0.14 parts per million (ppm), not to be exceeded more than once per year, and an annual standard set at 0.03 ppm, calculated as the arithmetic mean of hourly averages.

Table 4-12. Percent of Asthmatic Children Engaged in Moderate or Greater Exertion Estimated to Experience At Least One Lung Function Response (Defined in Terms of FEV_1) Associated with Exposure to "As Is" SO_2 Concentrations, SO_2 Concentrations that Just Meet the Current Standards, and SO_2 Concentrations that Just Meet Alternative Standards*

Exposure-Response Model	"As is" SO_2 Concentrations**	SO_2 Concentrations that Just Meet the Current Standards***	SO_2 Concentrations that Just Meet Alternative nth Percentile 1-Hr Daily Maximum Standards, with Levels (in ppb) of m (Standard Denoted n/m):					
			99/50	99/100	99/150	99/200	99/250	98/200
Response = Decrease in FEV1 >= 15%								
Greene County, MO								
2-Parameter Logistic	0.2% (0% - 2.2%)	1.2% (0.4% - 4.4%)	0.2% (0% - 2.1%)	0.2% (0% - 2.2%)	0.3% (0.1% - 2.4%)	0.5% (0.1% - 2.9%)	0.7% (0.2% - 3.5%)	0.6% (0.2% - 3.2%)
Probit	0% (0% - 1.4%)	0.8% (0.2% - 3.8%)	0% (0% - 1.3%)	0% (0% - 1.4%)	0.1% (0% - 1.7%)	0.2% (0% - 2.1%)	0.4% (0.1% - 2.8%)	0.3% (0.1% - 2.5%)
St. Louis, MO								
2-Parameter Logistic	1.1% (0.3% - 4.5%)	22.3% (15.9% - 30.4%)	0.7% (0.2% - 3.5%)	2.6% (0.9% - 7.5%)	5.3% (2.5% - 11.5%)	8.4% (4.6% - 15.4%)	11.9% (7.3% - 19.3%)	11.1% (6.7% - 18.5%)
Probit	0.7% (0.1% - 3.9%)	22.3% (15.9% - 30.7%)	0.4% (0.1% - 2.8%)	2% (0.6% - 7.2%)	4.7% (2.1% - 11.5%)	8% (4.3% - 15.6%)	11.7% (7% - 19.6%)	10.9% (6.4% - 18.8%)
Response = Decrease in FEV1 >= 20%								
Greene County, MO								
2-Parameter Logistic	0% (0% - 0.2%)	0.2% (0.1% - 0.9%)	0% (0% - 0.2%)	0% (0% - 0.2%)	0% (0% - 0.3%)	0.1% (0% - 0.4%)	0.1% (0% - 0.5%)	0.1% (0% - 0.5%)
Probit	0% (0% - 0%)	0.1% (0.1% - 0.6%)	0% (0% - 0%)	0% (0% - 0%)	0% (0% - 0.1%)	0% (0% - 0.2%)	0.1% (0% - 0.3%)	0% (0% - 0.3%)
St. Louis, MO								
2-Parameter Logistic	0.2% (0% - 0.8%)	14.7% (10.1% - 20.8%)	0.1% (0% - 0.5%)	0.6% (0.2% - 2%)	1.7% (0.7% - 4.1%)	3.4% (1.8% - 6.8%)	5.8% (3.4% - 10%)	5.2% (3% - 9.2%)
Probit	0.1% (0% - 0.5%)	14.9% (10.3% - 21%)	0% (0% - 0.3%)	0.4% (0.1% - 1.6%)	1.5% (0.7% - 3.7%)	3.3% (1.7% - 6.6%)	5.7% (3.4% - 9.9%)	5.1% (3% - 9.2%)

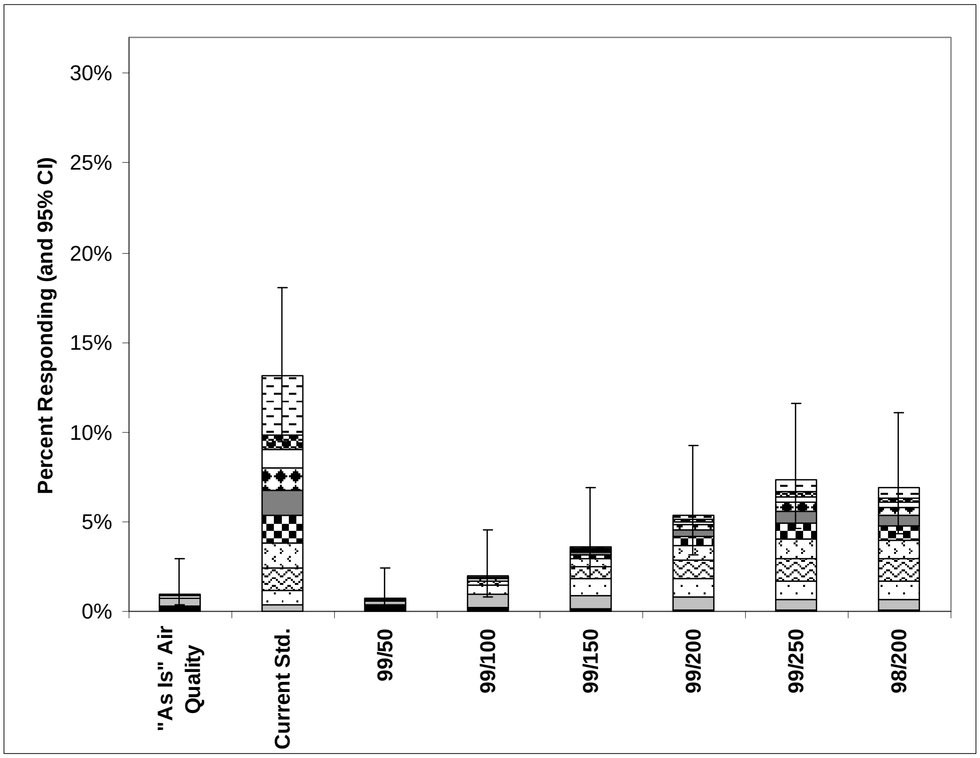
*Percents are median (50th percentile) percents of asthmatic children. Percents in parentheses below the median are 95% credible intervals based on statistical uncertainty surrounding the SO_2 coefficient in the logistic and probit exposure-response functions. Percents are rounded to the nearest tenth.

**The "as is" exposure scenario was based on monitoring and modeling using 2002 air quality information.

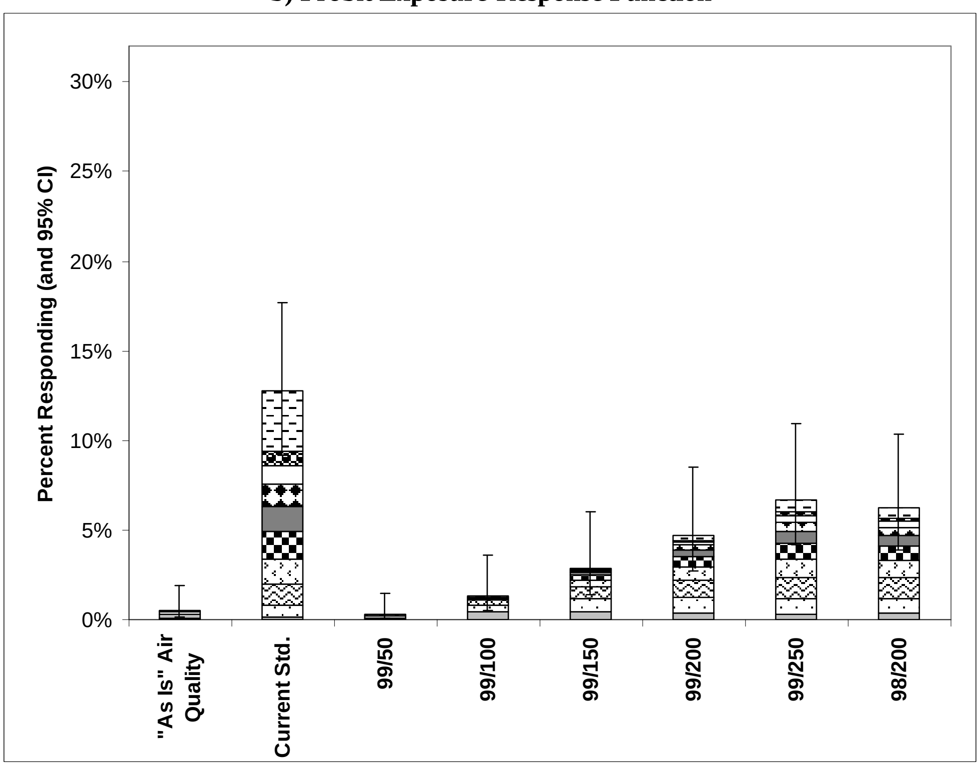
**The current primary SO_2 standards include a 24-hour standard set at 0.14 parts per million (ppm), not to be exceeded more than once per year, and an annual standard set at 0.03 ppm, calculated as the arithmetic mean of hourly averages.

Figure 4-1. Percent of Asthmatics Engaged in Moderate or Greater Exertion in St. Louis Exhibiting Lung Function Response (Defined as an Increase in sRaw ≥ 100%) Attributable to SO_2 Within Given Ranges Under Different Air Quality Scenarios*

a) Logistic Exposure-Response Function



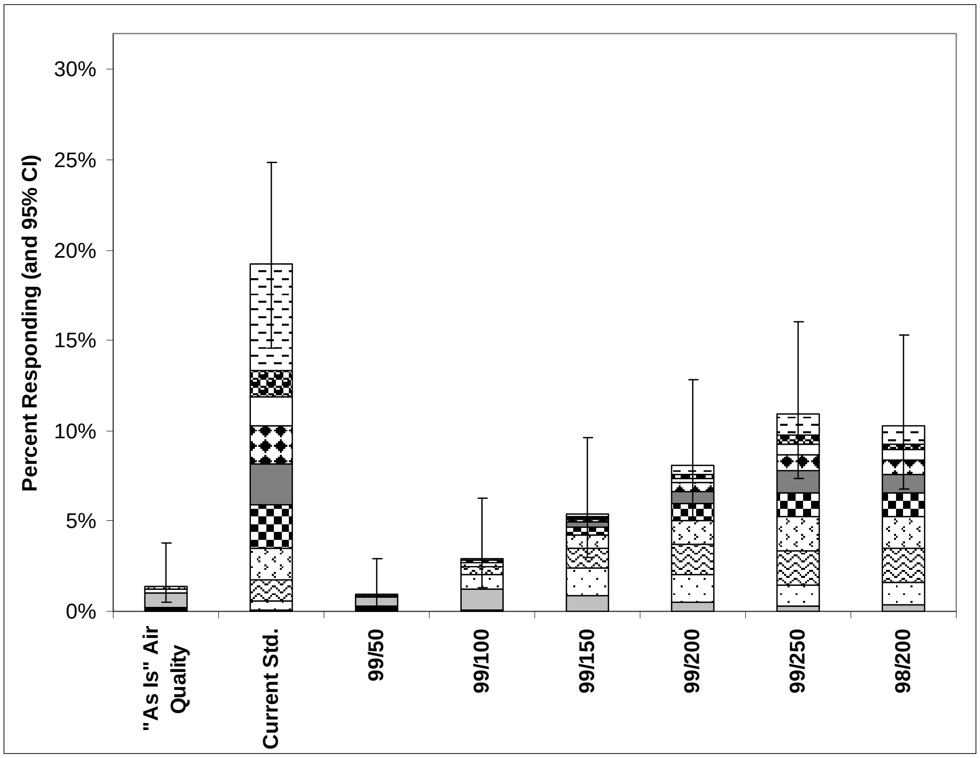
b) Probit Exposure-Response Function



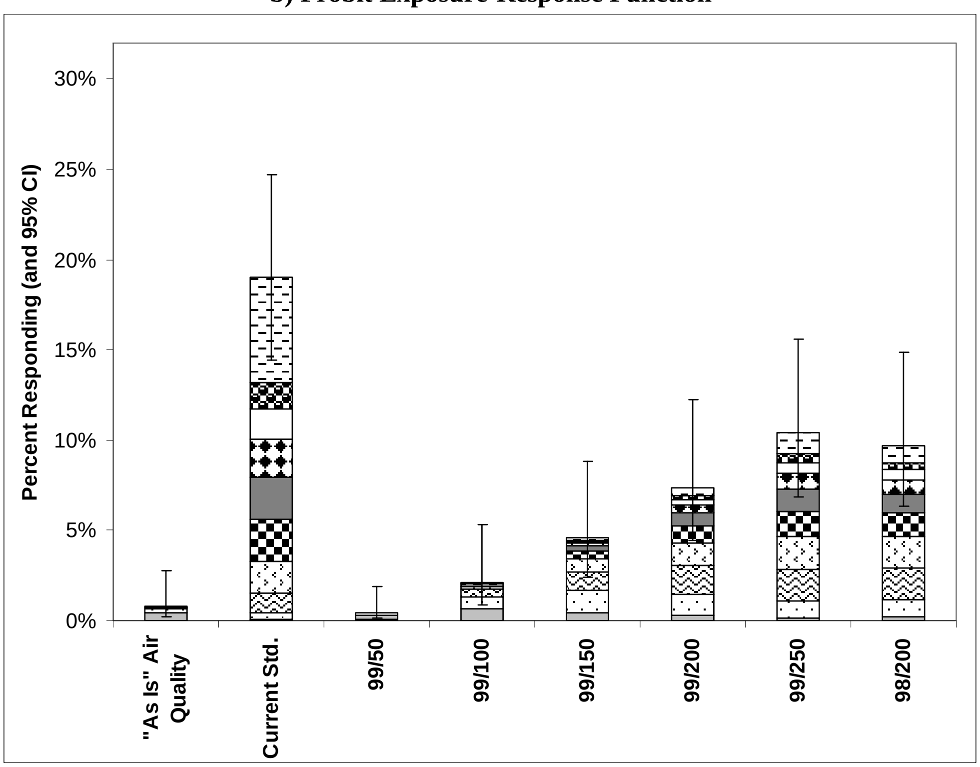
*For the legend for these figures see Figure 4-17.

Figure 4-2. Percent of Asthmatic Children Engaged in Moderate or Greater Exertion in St. Louis Exhibiting Lung Function Response (Defined as an Increase in sRaw ≥ 100%) Attributable to SO_2 Within Given Ranges Under Different Air Quality Scenarios*

a) Logistic Exposure-Response Function



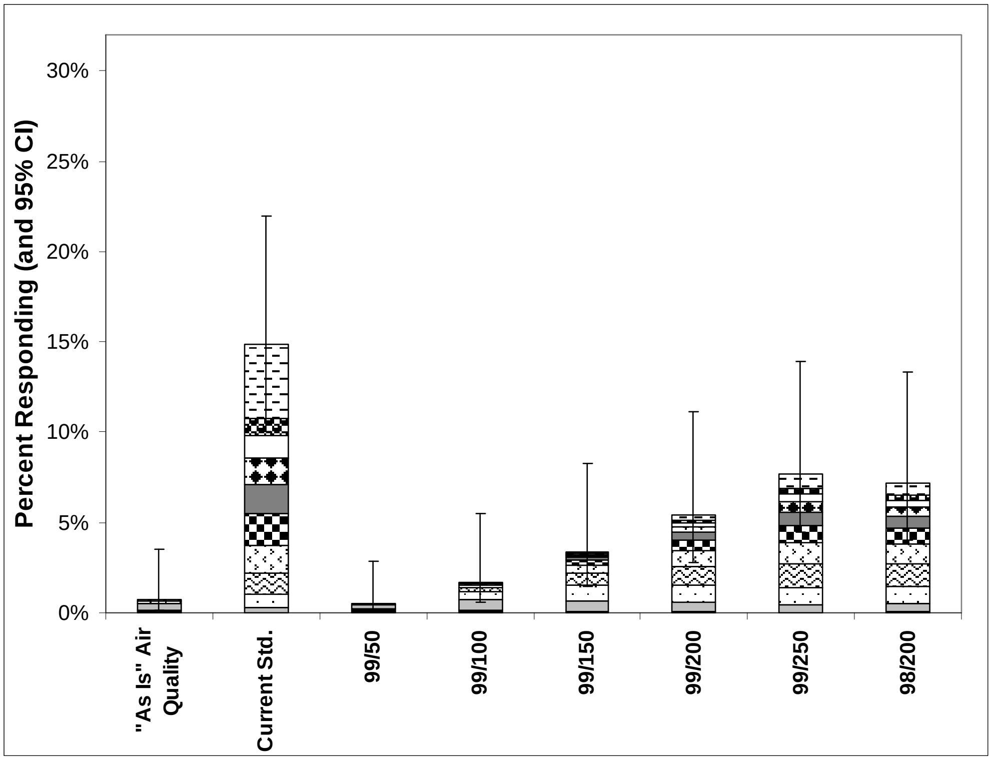
b) Probit Exposure-Response Function



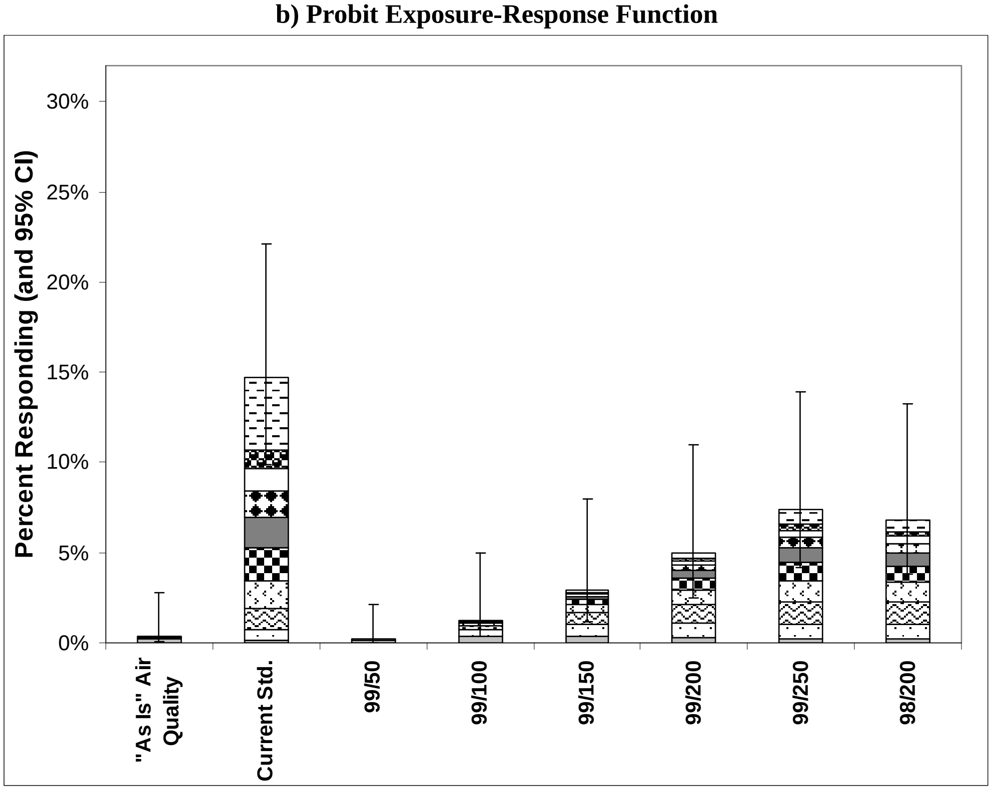
*For the legend for these figures see Figure 4-17.

Figure 4-3. Percent of Asthmatics Engaged in Moderate or Greater Exertion in St. Louis Exhibiting Lung Function Response (Defined as a Decrease in $FEV_1 \geq 15\%$) Attributable to SO_2 Within Given Ranges Under Different Air Quality Scenarios*

a) Logistic Exposure-Response Function



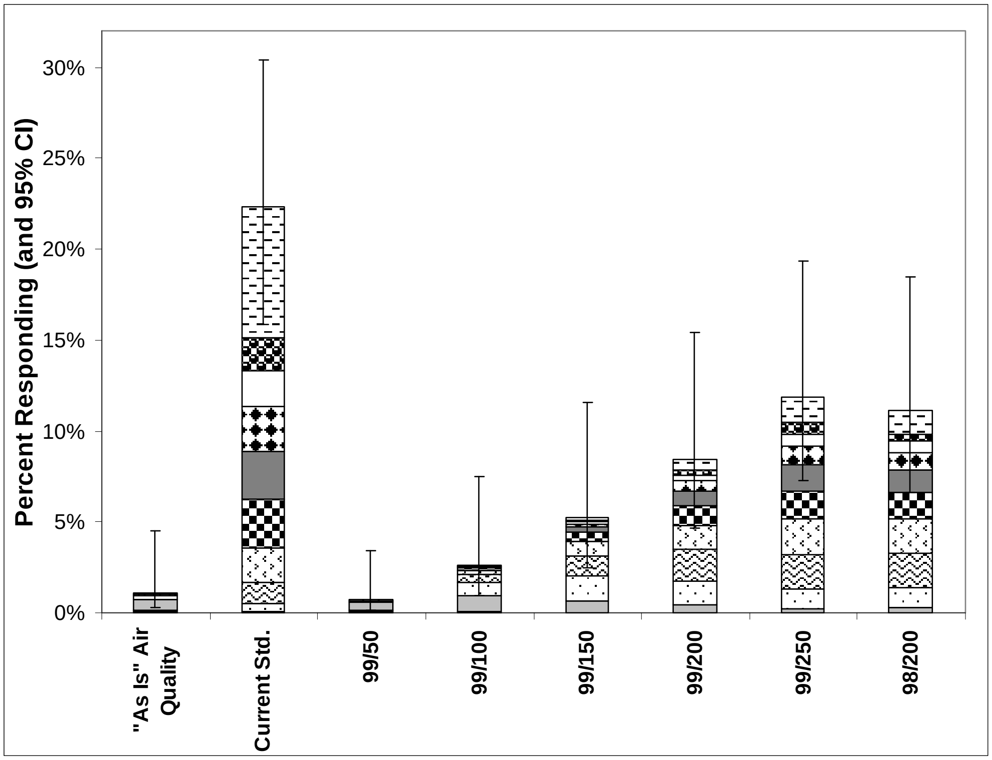
b) Probit Exposure-Response Function



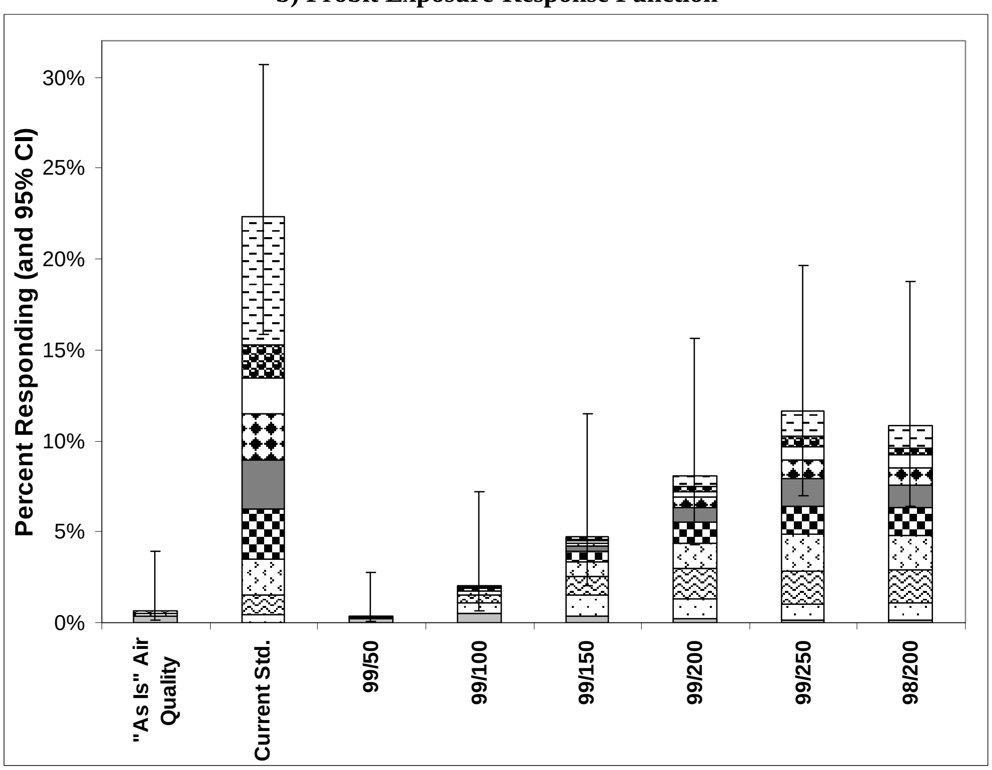
*For the legend for these figures see Figure 4-17.

Figure 4-4. Percent of Asthmatic Children Engaged in Moderate or Greater Exertion in St. Louis Exhibiting Lung Function Response (Defined as a Decrease in $FEV_1 \geq 15\%$) Attributable to SO_2 Within Given Ranges Under Different Air Quality Scenarios*

a) Logistic Exposure-Response Function



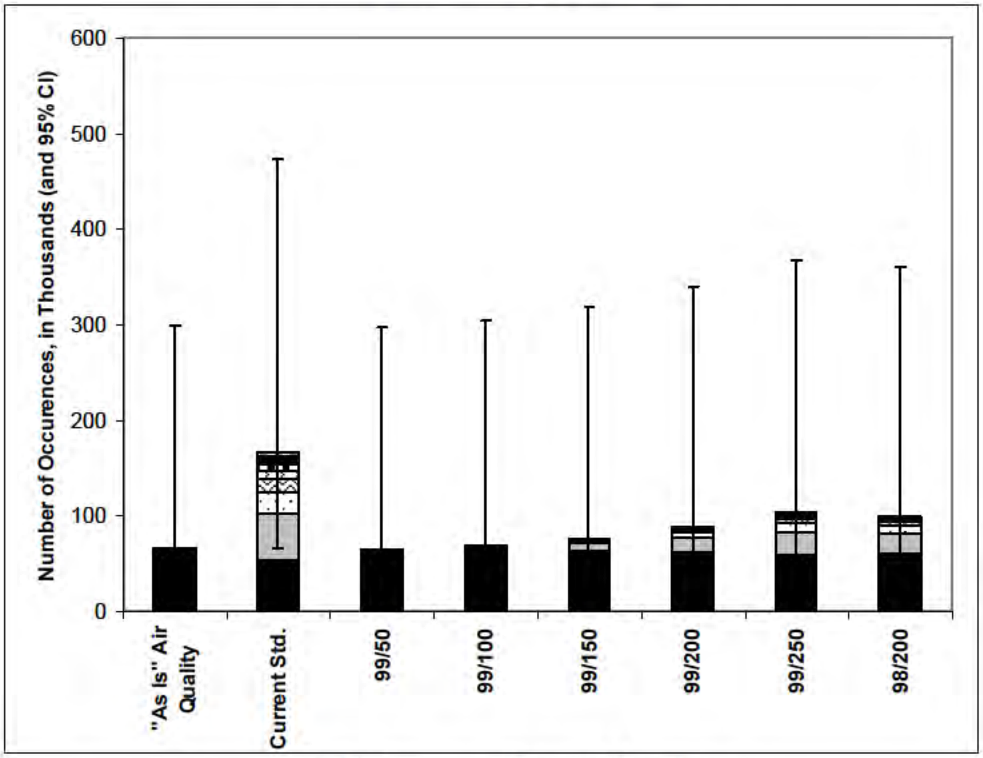
b) Probit Exposure-Response Function



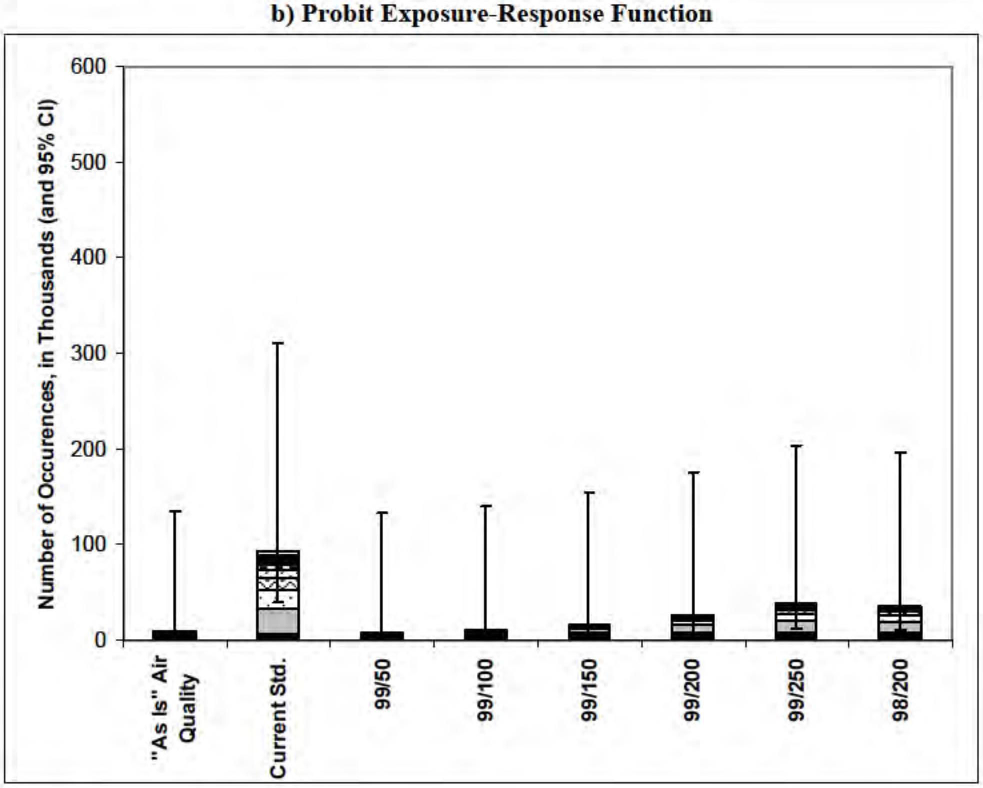
*For the legend for these figures see Figure 4-17.

Figure 4-5. Number of Occurrences of Lung Function Response (Defined as an Increase in sRaw ≥ 100%) Among Asthmatics Engaged in Moderate or Greater Exertion in St. Louis Attributable to SO_2 Within Given Ranges Under Different Air Quality Scenarios*

a) Logistic Exposure-Response Function



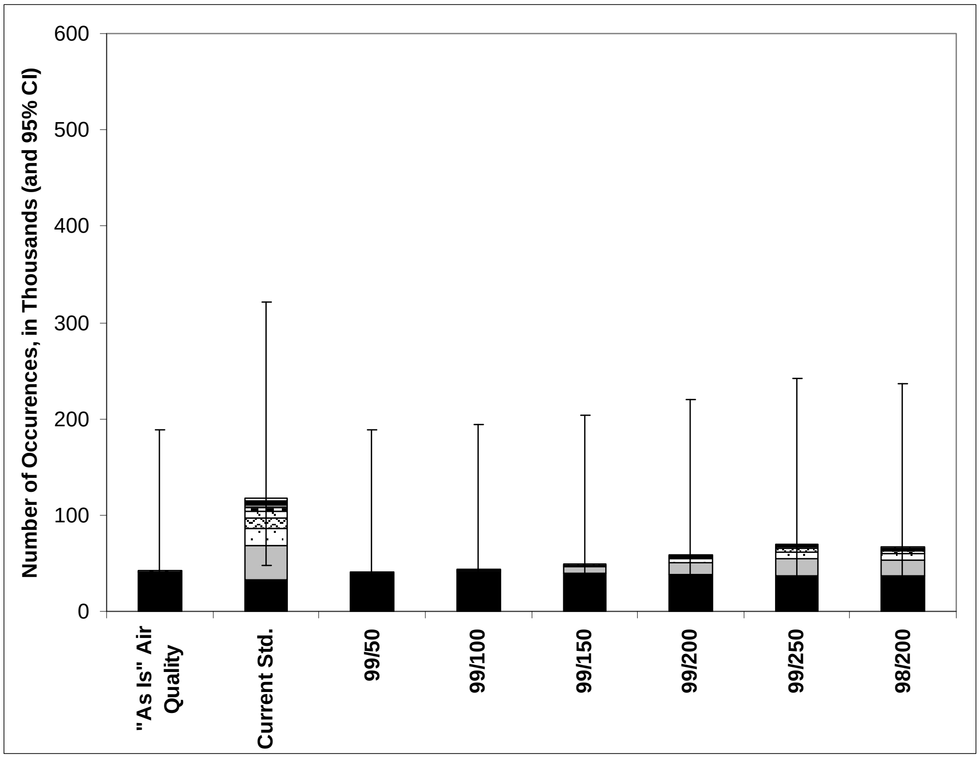
b) Probit Exposure-Response Function



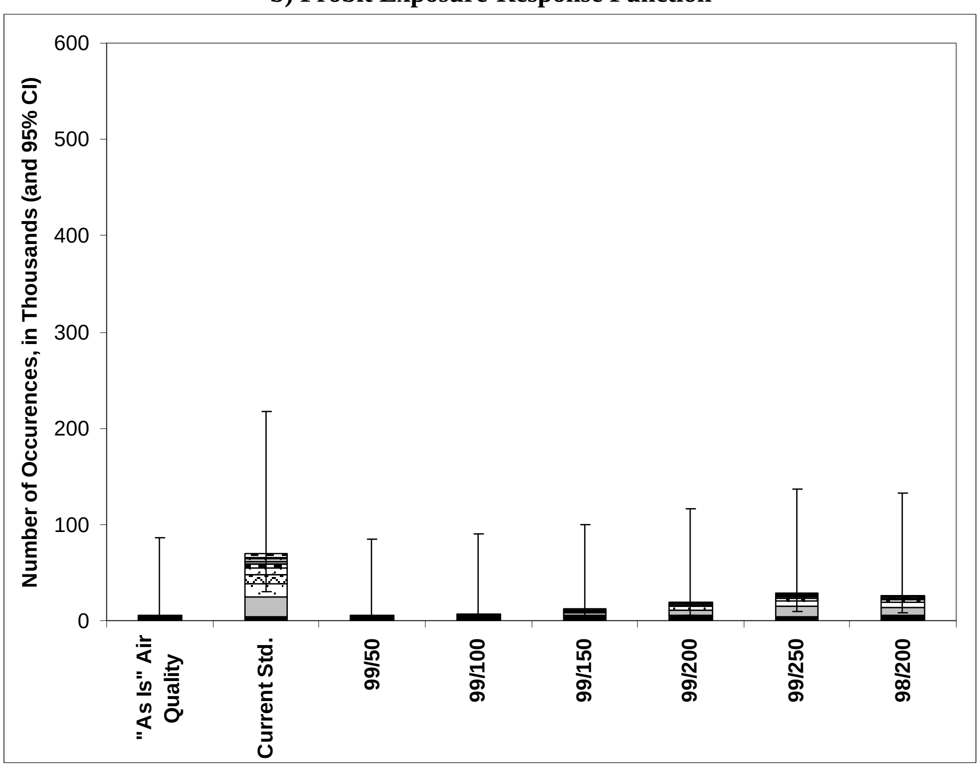
*For the legend for these figures see Figure 4-17.

Figure 4-6. Number of Occurrences of Lung Function Response (Defined as an Increase in sRaw ≥ 100%) Among Asthmatic Children Engaged in Moderate or Greater Exertion in St. Louis Attributable to SO_2 Within Given Ranges Under Different Air Quality Scenarios*

a) Logistic Exposure-Response Function



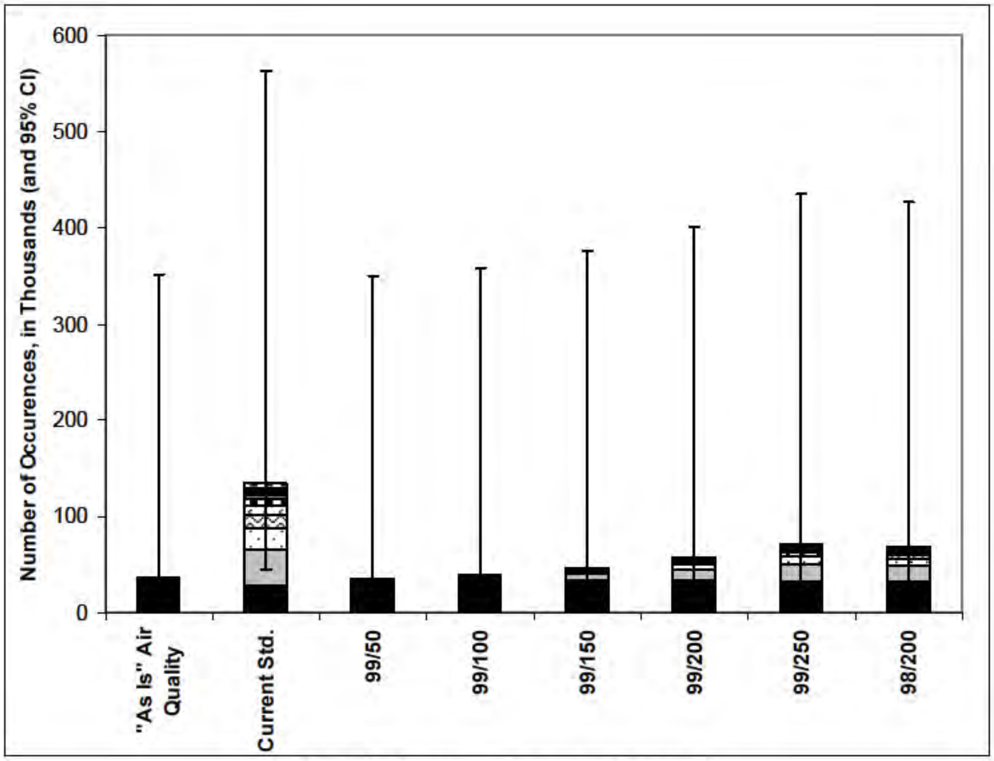
b) Probit Exposure-Response Function



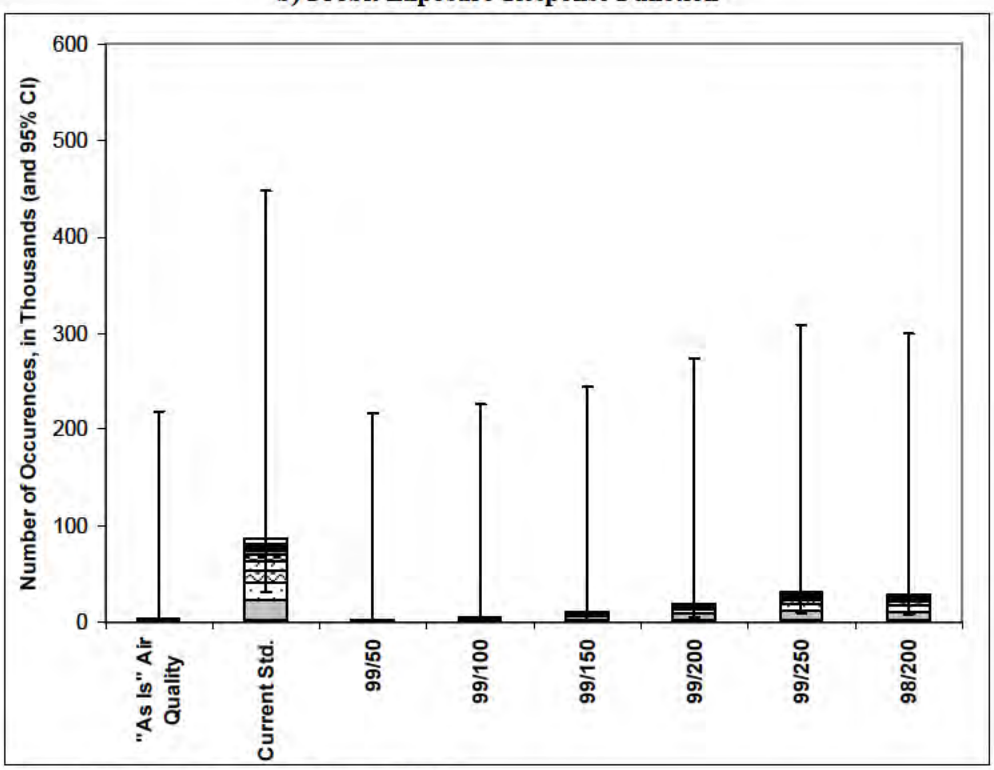
*For the legend for these figures see Figure 4-17.

Figure 4-7. Number of Occurrences of Lung Function Response (Defined as a Decrease in $FEV_1 \geq$ 15%) Among Asthmatics Engaged in Moderate or Greater Exertion in St. Louis Attributable to SO_2 Within Given Ranges Under Different Air Quality Scenarios*

a) Logistic Exposure-Response Function



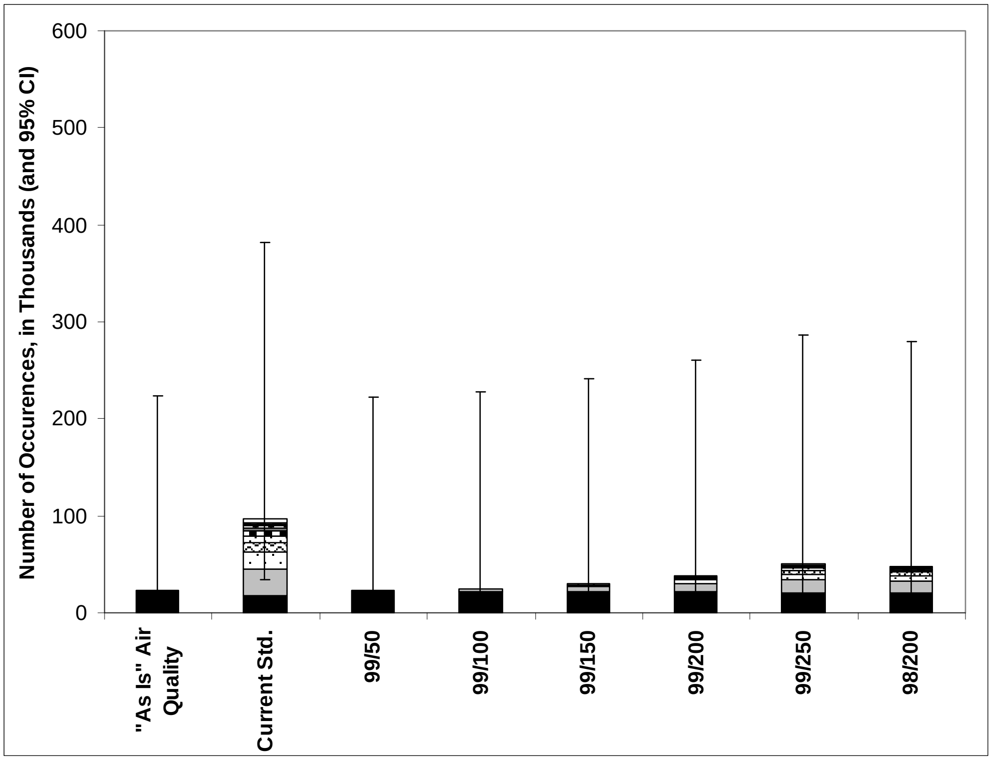
b) Probit Exposure-Response Function



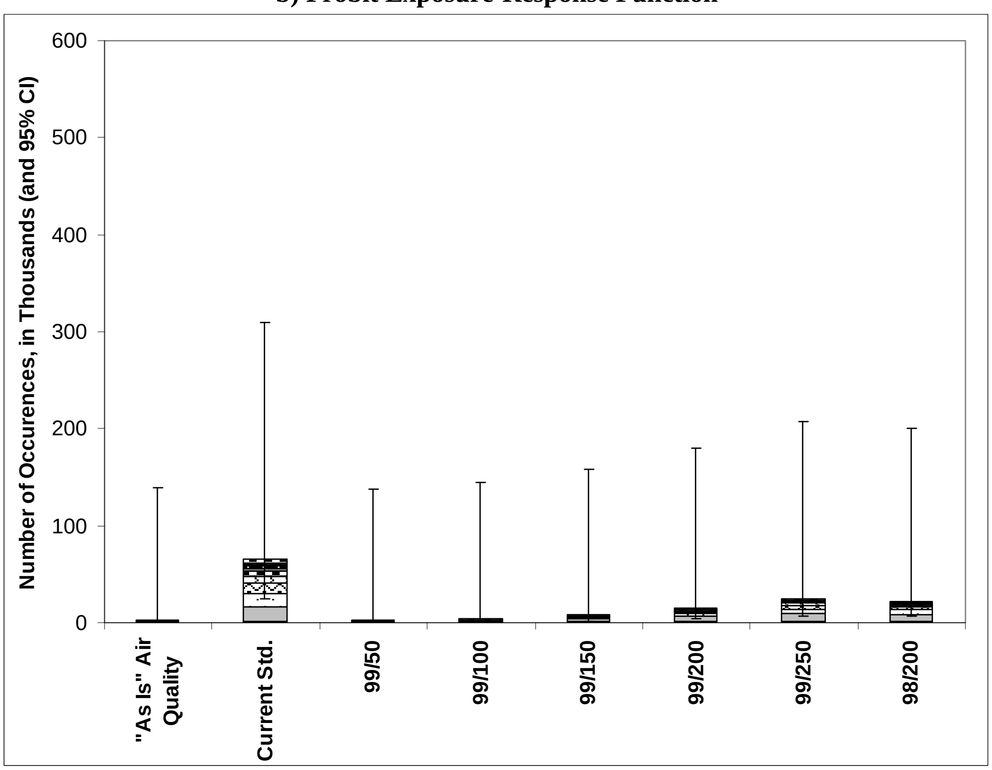
*For the legend for these figures see Figure 4-17.

Figure 4-8. Number of Occurrences of Lung Function Response (Defined as a Decrease in $FEV_1 \geq$ 15%) Among Asthmatic Children Engaged in Moderate or Greater Exertion in St. Louis Attributable to SO_2 Within Given Ranges Under Different Air Quality Scenarios*

a) Logistic Exposure-Response Function



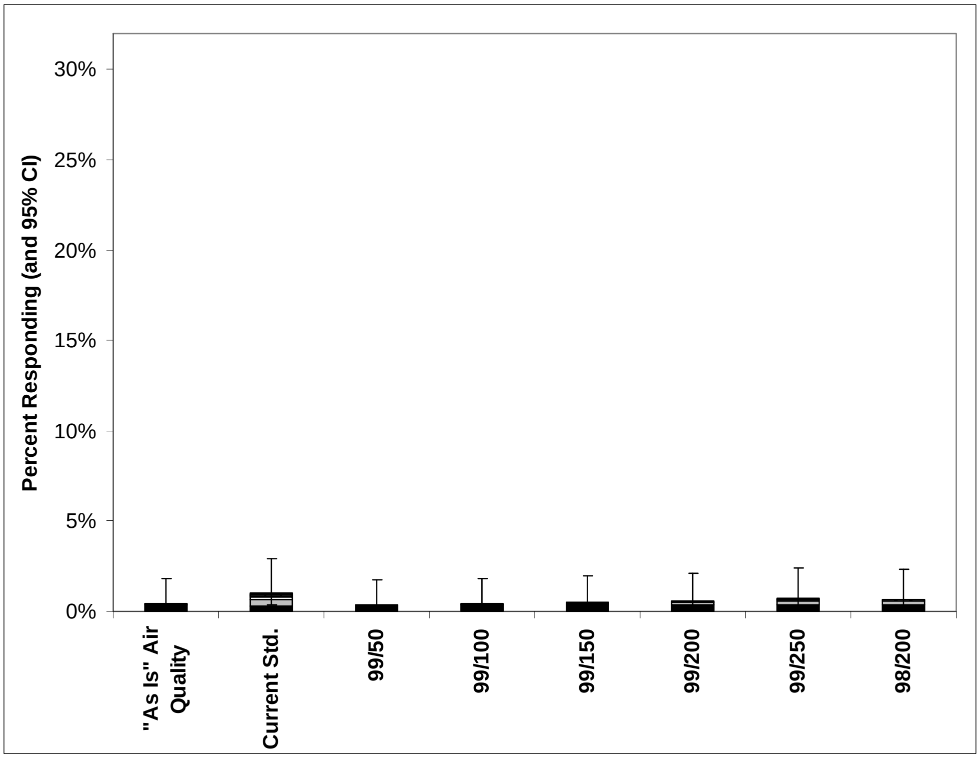
b) Probit Exposure-Response Function



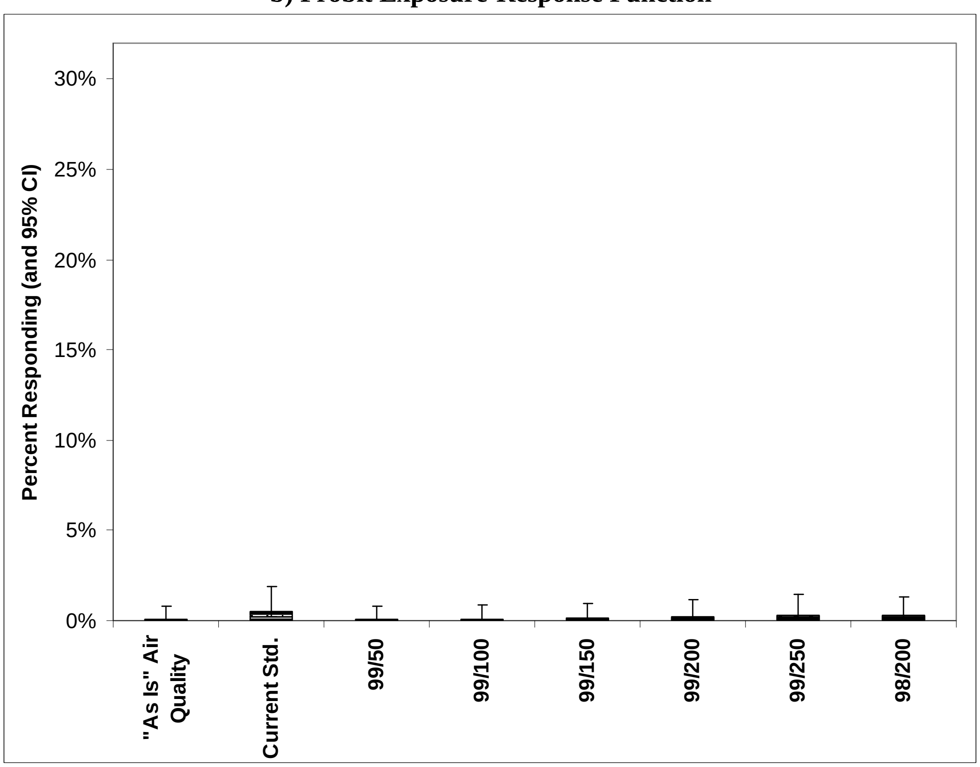
*For the legend for these figures see Figure 4-17.

Figure 4-9. Percent of Asthmatics Engaged in Moderate or Greater Exertion in Greene Co. Exhibiting Lung Function Response (Defined as an Increase in sRaw ≥ 100%) Attributable to SO_2 Within Given Ranges Under Different Air Quality Scenarios*

a) Logistic Exposure-Response Function



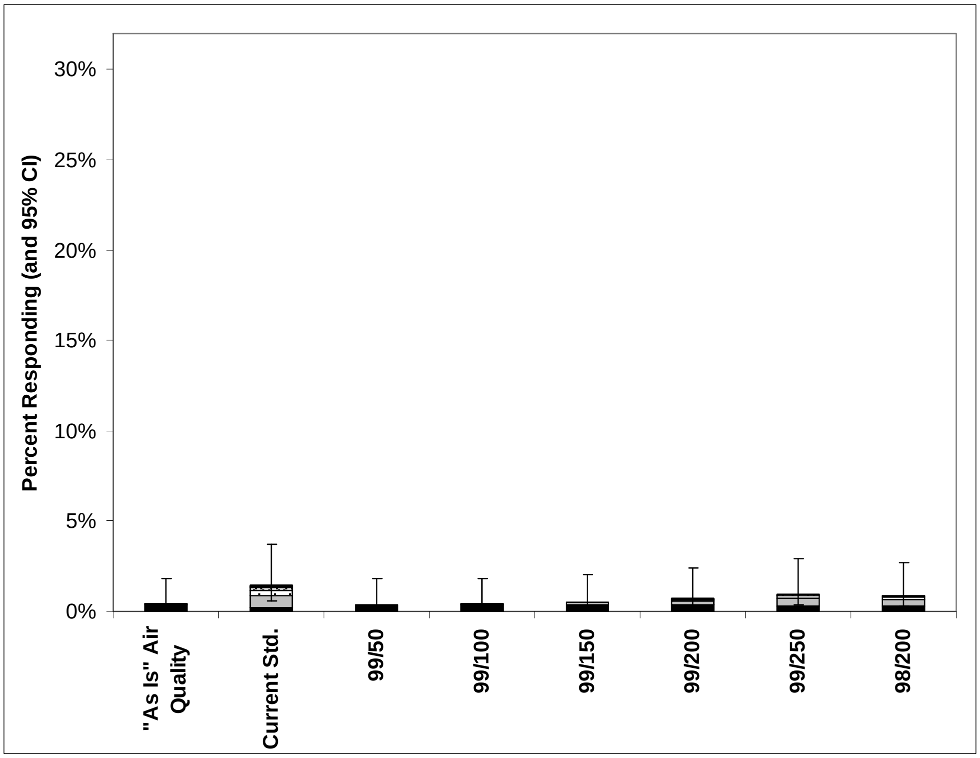
b) Probit Exposure-Response Function



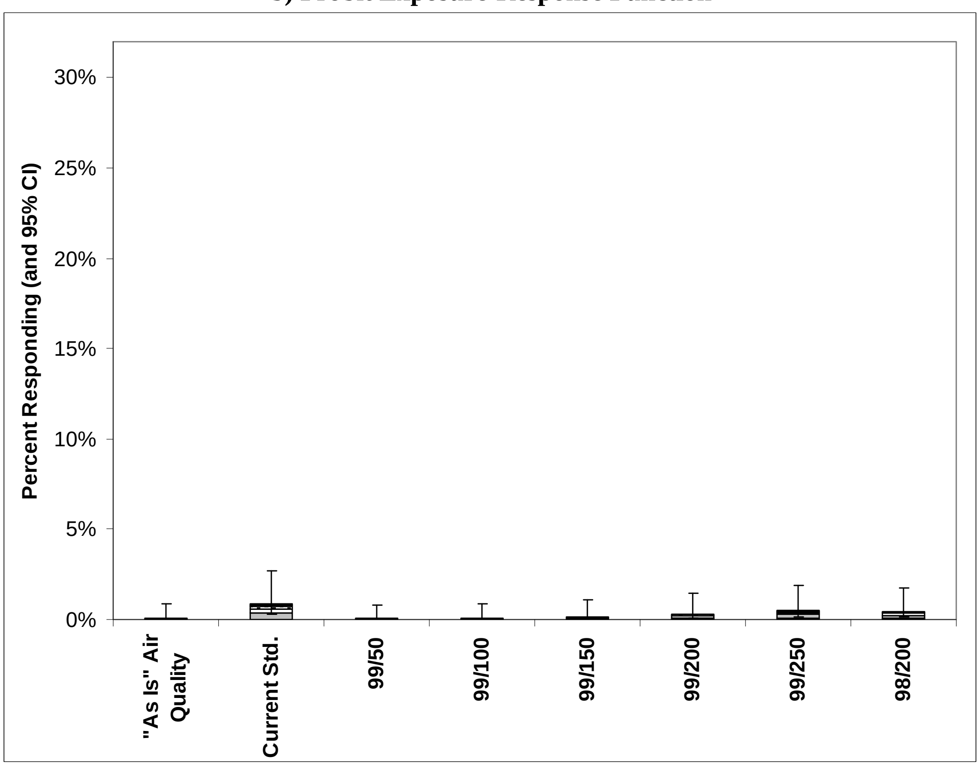
*For the legend for these figures see Figure 4-17.

Figure 4-10. Percent of Asthmatic Children Engaged in Moderate or Greater Exertion in Greene Co. Exhibiting Lung Function Response (Defined as an Increase in sRaw ≥ 100%) Attributable to SO_2 Within Given Ranges Under Different Air Quality Scenarios*

a) Logistic Exposure-Response Function



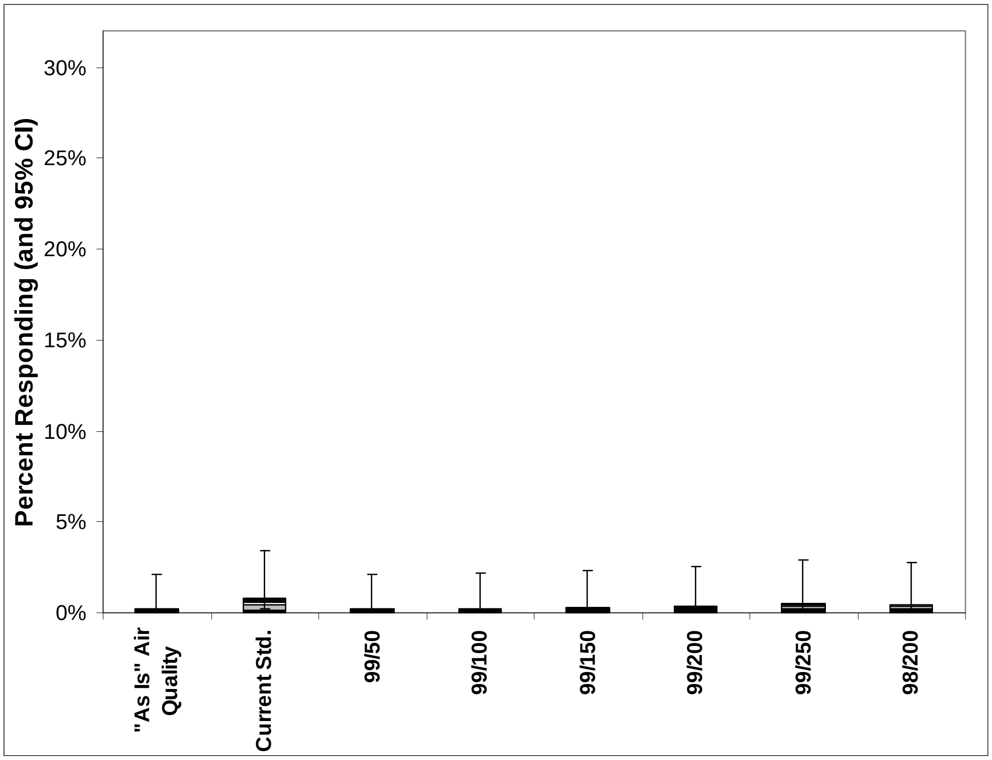
b) Probit Exposure-Response Function



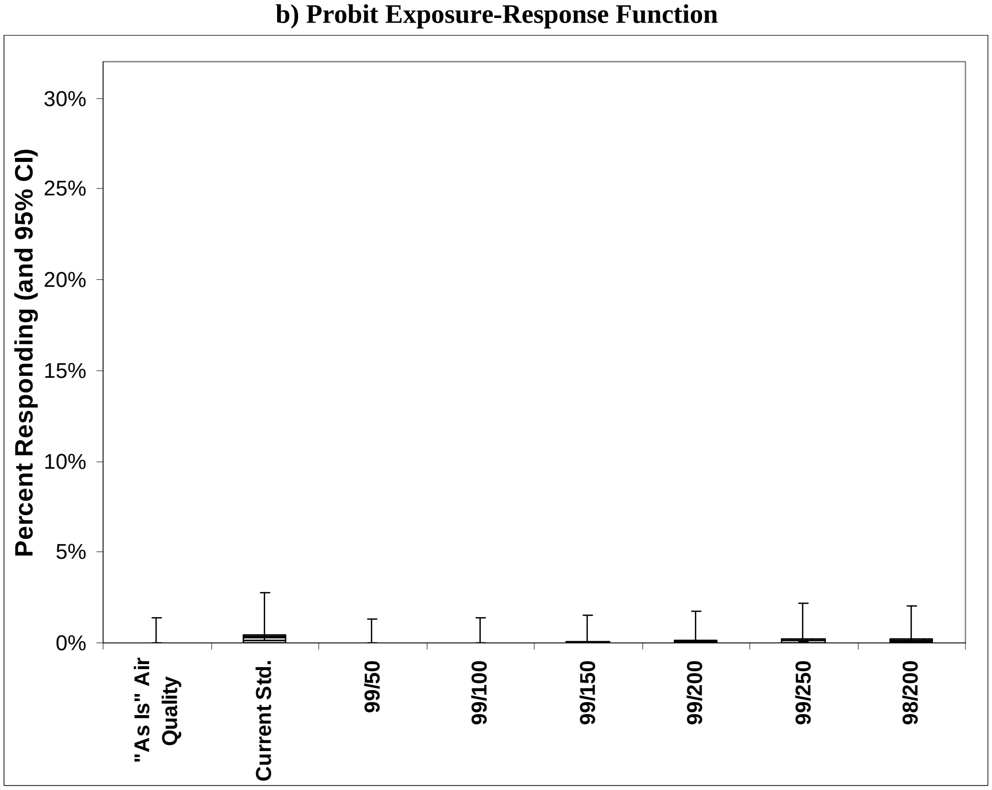
*For the legend for these figures see Figure 4-17.

Figure 4-11. Percent of Asthmatics Engaged in Moderate or Greater Exertion in Greene Co. Exhibiting Lung Function Response (Defined as a Decrease in $FEV_1 \geq 15\%$) Attributable to SO_2 Within Given Ranges Under Different Air Quality Scenarios*

a) Logistic Exposure-Response Function



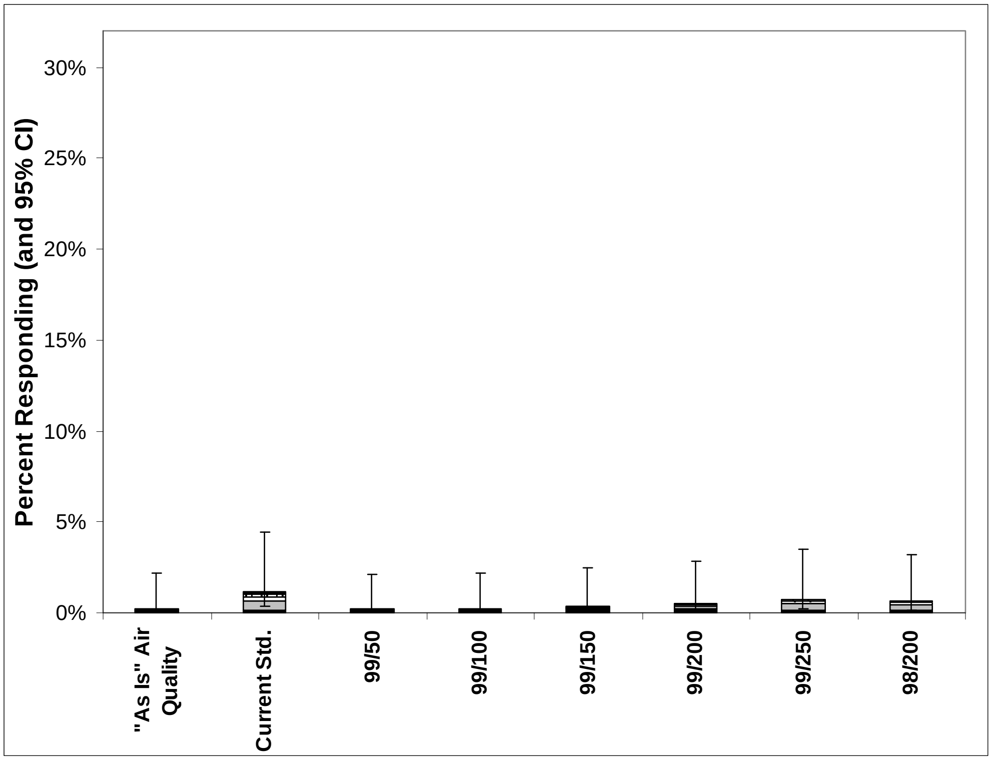
b) Probit Exposure-Response Function



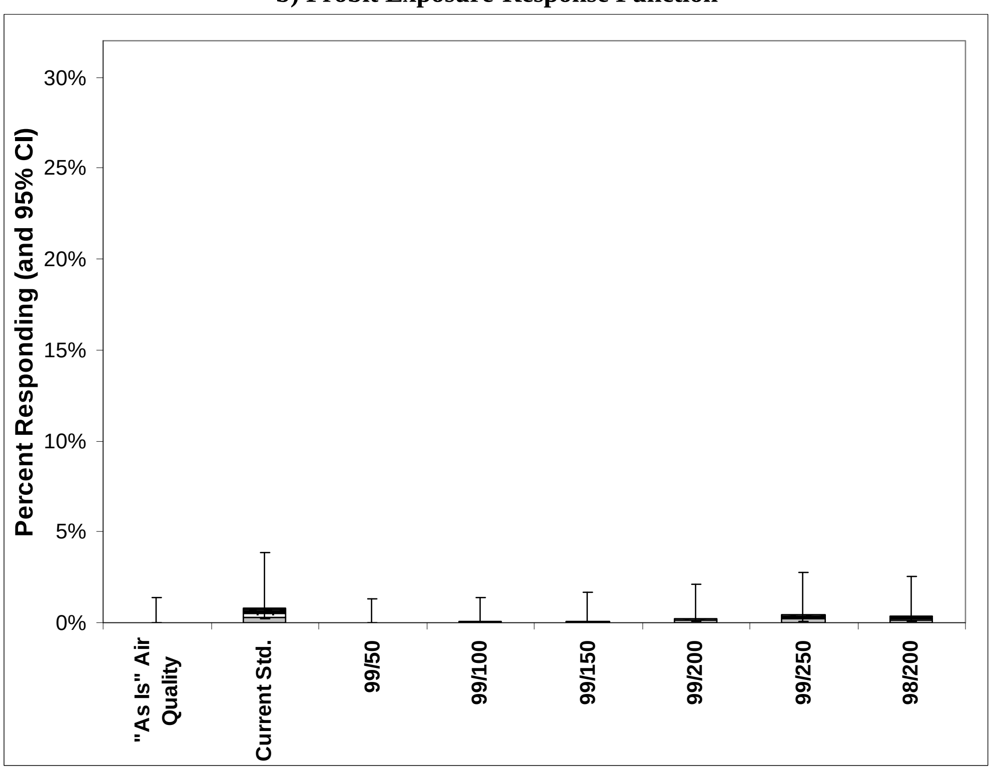
*For the legend for these figures see Figure 4-17.

Figure 4-12. Percent of Asthmatic Children Engaged in Moderate or Greater Exertion in Greene Co. Exhibiting Lung Function Response (Defined as a Decrease in $FEV_1 \geq 15\%$) Attributable to SO_2 Within Given Ranges Under Different Air Quality Scenarios*

a) Logistic Exposure-Response Function



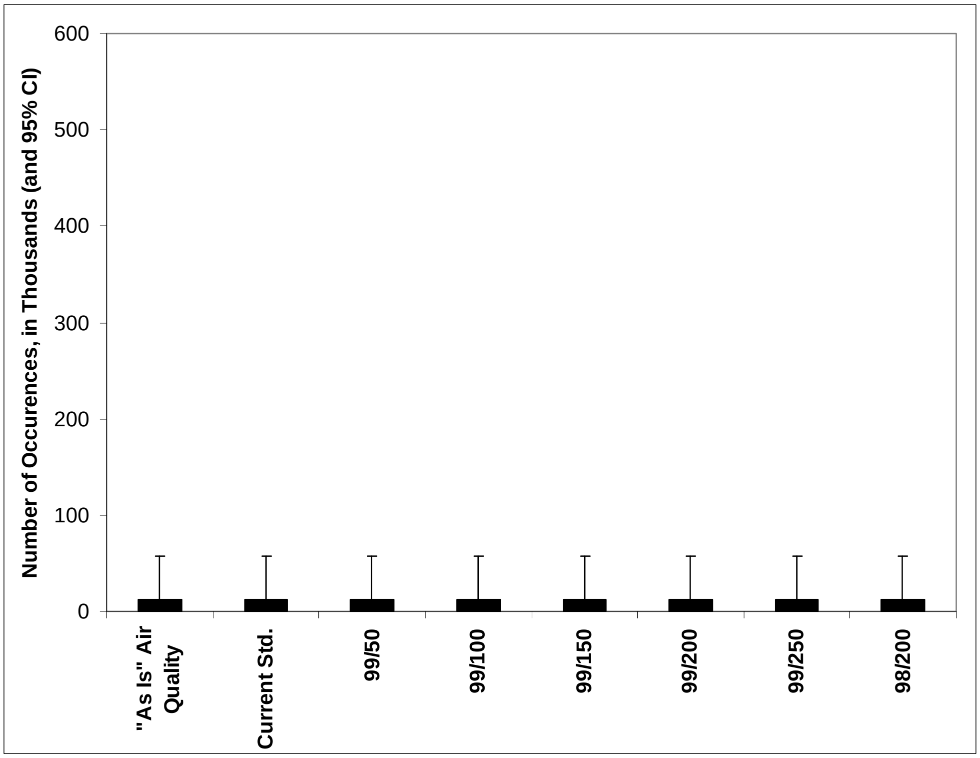
b) Probit Exposure-Response Function



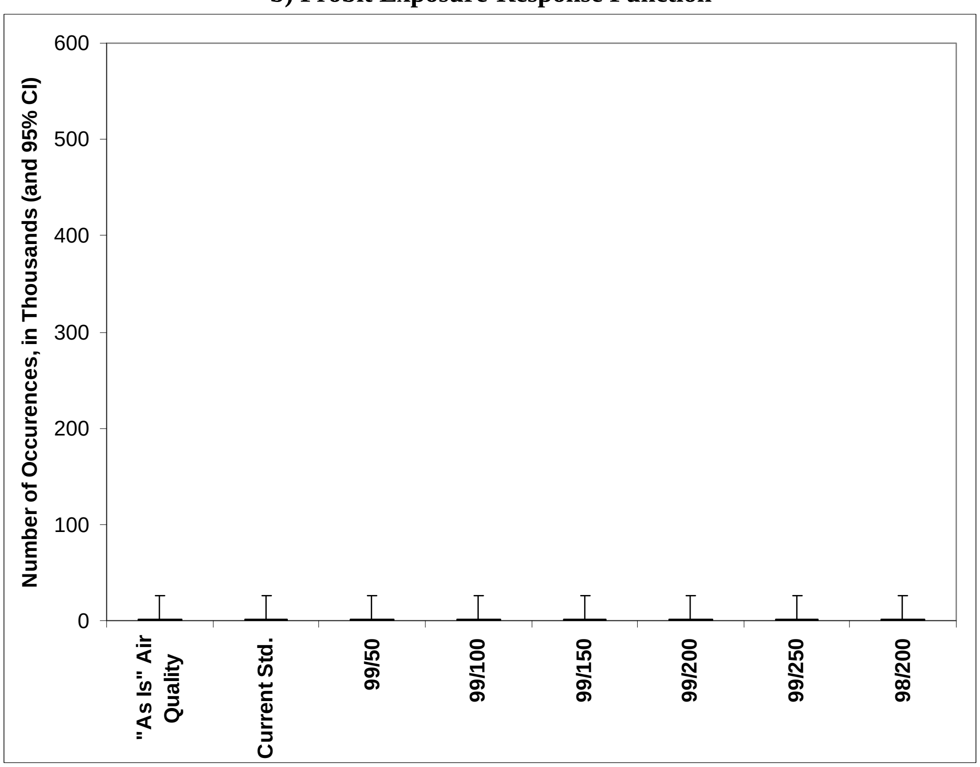
*For the legend for these figures see Figure 4-17.

Figure 4-13. Number of Occurrences of Lung Function Response (Defined as an Increase in sRaw ≥ 100%) Among Asthmatics Engaged in Moderate or Greater Exertion in Greene Co. Attributable to SO_2 Within Given Ranges Under Different Air Quality Scenarios*

a) Logistic Exposure-Response Function



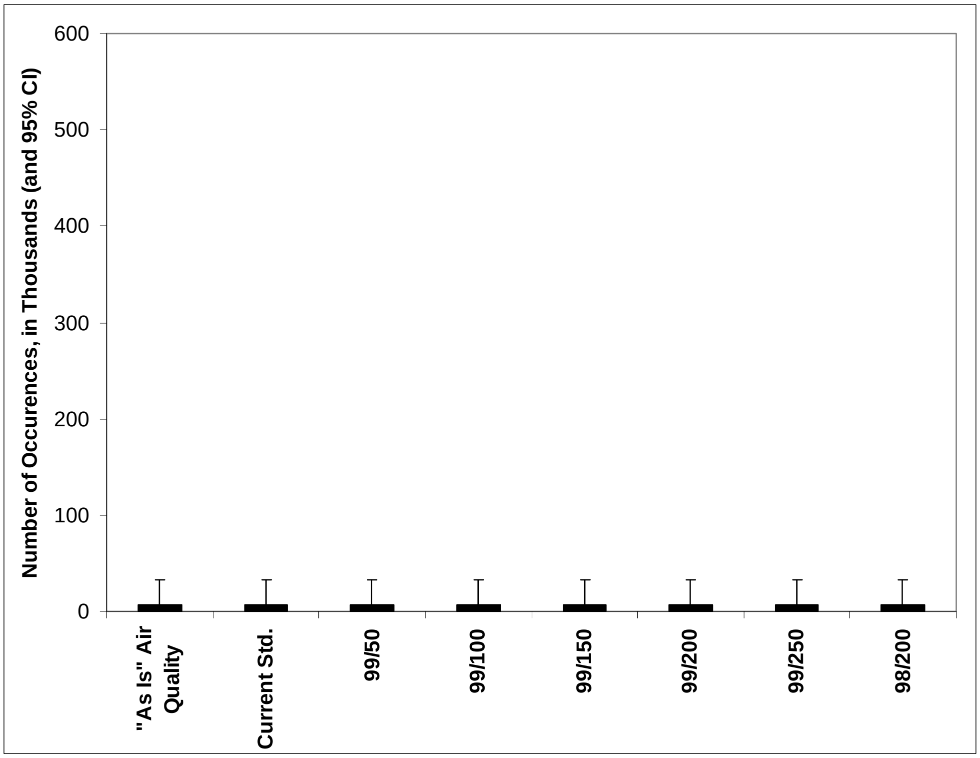
b) Probit Exposure-Response Function



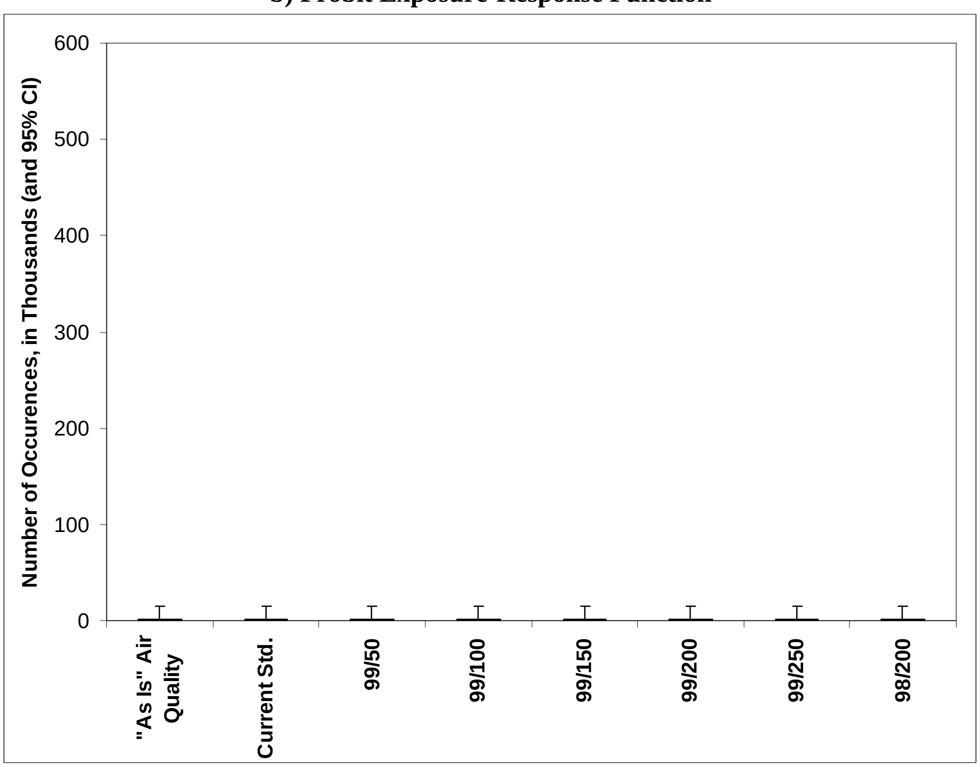
*For the legend for these figures see Figure 4-17.

Figure 4-14. Number of Occurrences of Lung Function Response (Defined as an Increase in sRaw ≥ 100%) Among Asthmatic Children Engaged in Moderate or Greater Exertion in Greene Co. Attributable to SO_2 Within Given Ranges Under Different Air Quality Scenarios*

a) Logistic Exposure-Response Function



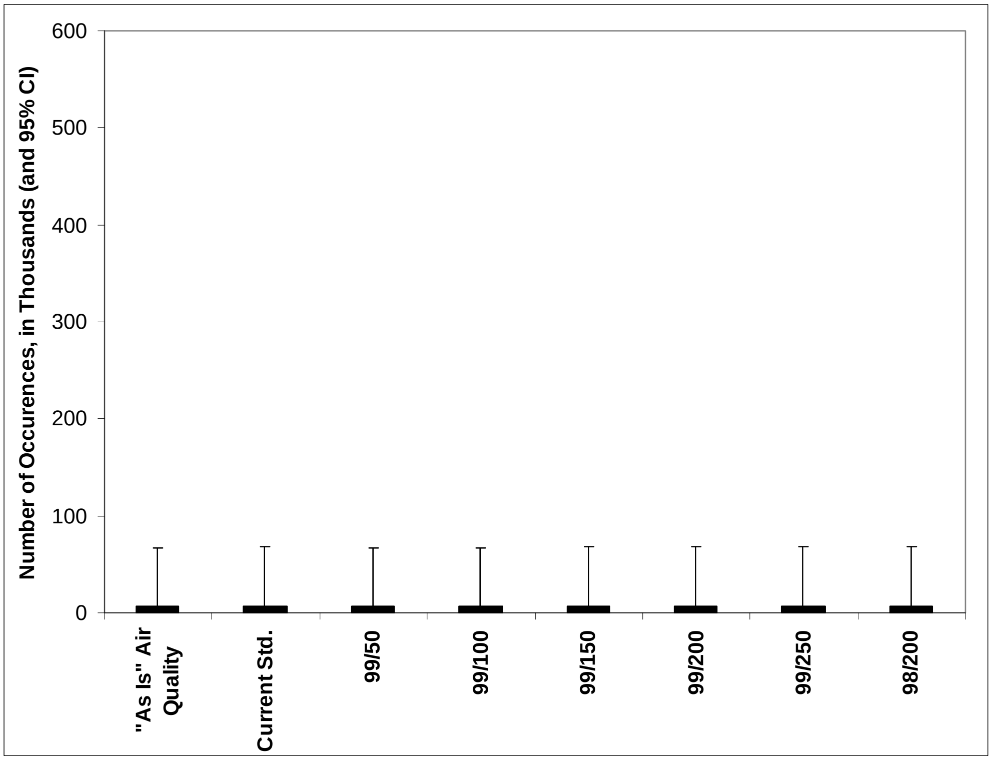
b) Probit Exposure-Response Function



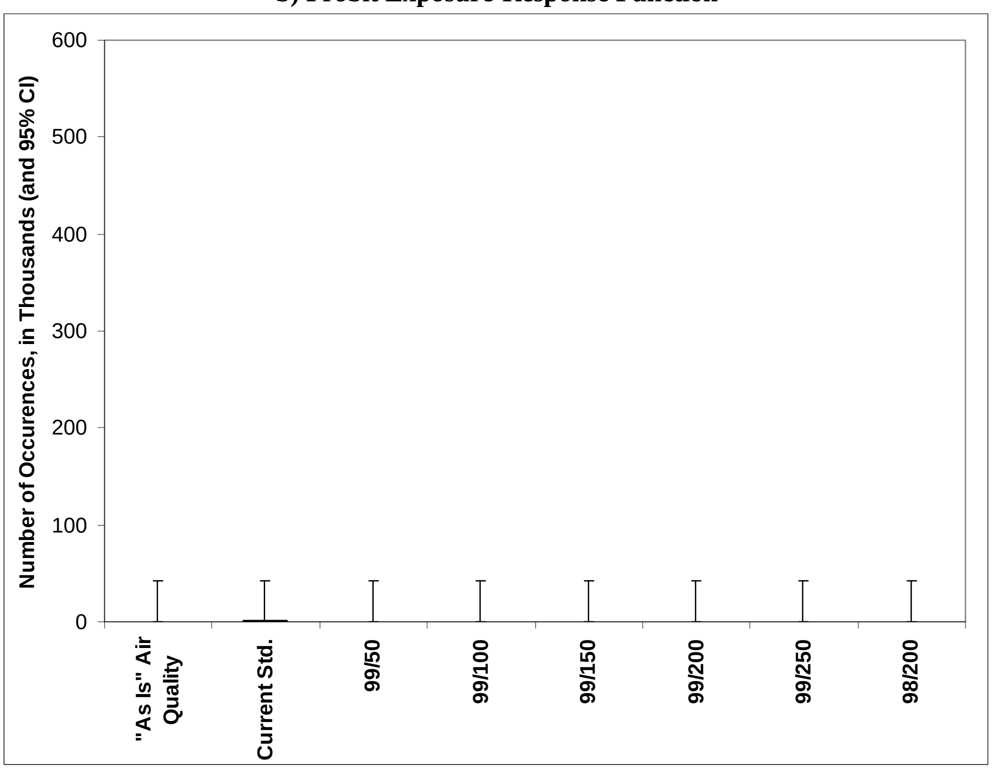
*For the legend for these figures see Figure 4-17.

Figure 4-15. Number of Occurrences of Lung Function Response (Defined as a Decrease in $FEV_1 \geq$ 15%) Among Asthmatics Engaged in Moderate or Greater Exertion in Greene Co. Attributable to SO_2 Within Given Ranges Under Different Air Quality Scenarios*

a) Logistic Exposure-Response Function



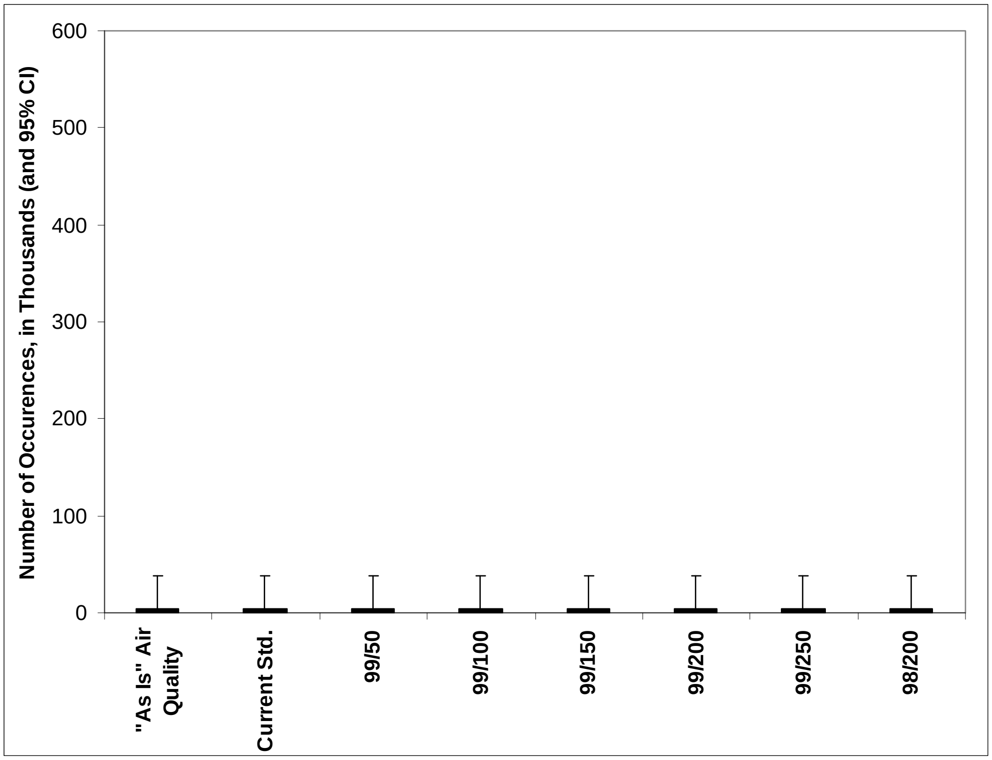
b) Probit Exposure-Response Function



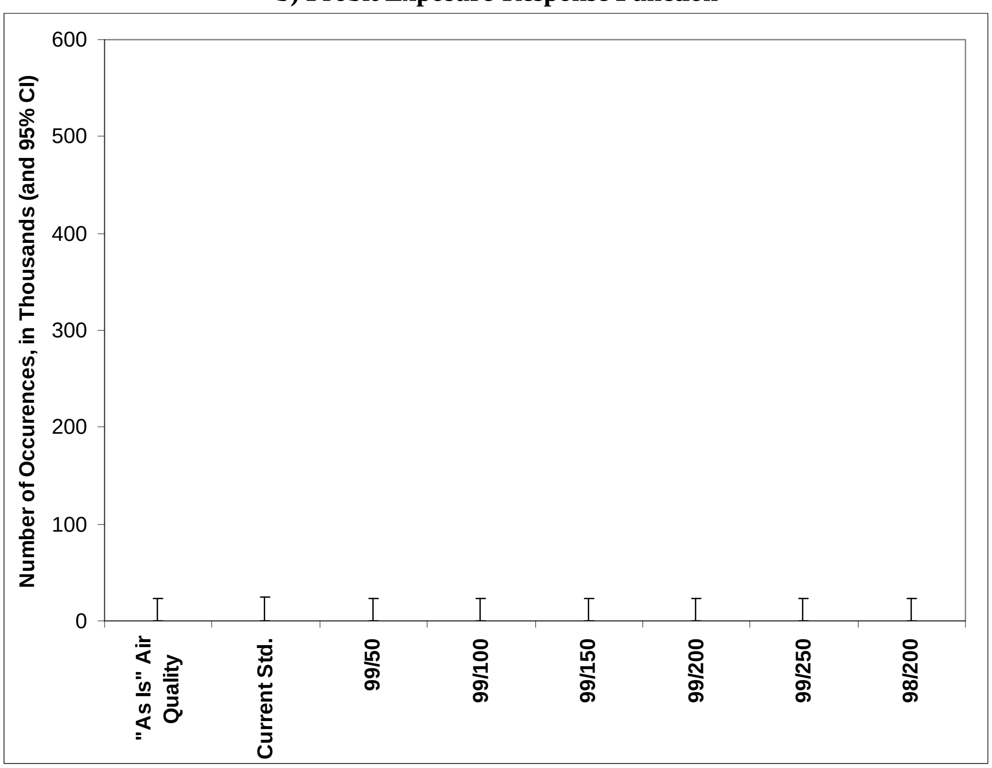
*For the legend for these figures see Figure 4-17.

Figure 4-16. Number of Occurrences of Lung Function Response (Defined as a Decrease in $FEV_1 \geq 15\%$) Among Asthmatic Children Engaged in Moderate or Greater Exertion in Greene Co. Attributable to SO_2 Within Given Ranges Under Different Air Quality Scenarios*

a) Logistic Exposure-Response Function

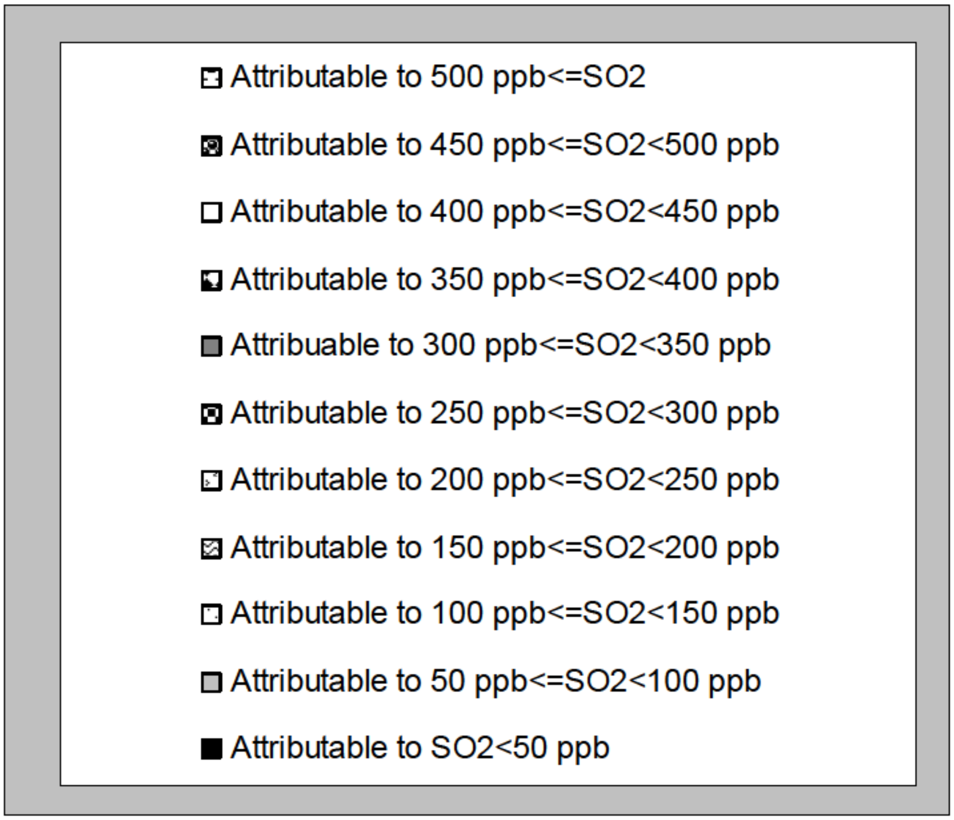


b) Probit Exposure-Response Function



*For the legend for these figures see Figure 4-17.

Figure 4-17. Legend for Figures 4-1 - 4-16.



The current primary SO_2 standards include a 24-hour standard set at 0.14 parts per million (ppm), not to be exceeded more than once per year, and an annual standard set at 0.03 ppm, calculated as the arithmetic mean of hourly averages. In St. Louis, SO_2 concentrations that are predicted to occur if the current standards were just met are substantially higher than "as is" air quality (based on 2002 monitoring and modeling data) and also substantially higher than they would be under any of the alternative 1-hr standards considered in this analysis. Consequently, the levels of response that would be seen if the current standard were just met are well above the levels that would be seen under the "as is" air quality scenario or under any of the alternative 1-hr standards – for asthmatics and for asthmatic children, and for all four definitions of lung function response.

For example, of the estimated approximately 102,400 asthmatics engaged in moderate or greater exertion in St. Louis, about 13,500 (or 13.1%) are estimated to have at least one lung function response, defined as an increase in sRaw ≥ 100%, if the current standards were just met. Under "as is" air quality conditions, the corresponding number is about 1,000 (1%). Only the most stringent alternative 99^{th} percentile 1-hr standard, set at 50 ppb (denoted "99/50" in the above tables of results), is predicted to lower the numbers of responders below the levels estimated under the "as is" scenario. As the alternative 1-hr standards become less stringent (i.e., as the level is raised from 50 ppb to 100 ppb, to 150 ppb, etc.), the numbers responding correspondingly rise.

The pattern seen in St. Louis for lung function response, defined as an increase in sRaw ≥ 100%, is also seen for the other definitions of lung function response. For example, of the estimated roughly 102,400 asthmatics engaged in moderate or greater exertion, 750 are estimated to have at least one lung function response, defined as a decrease in FEV_1 ≥ 15%, under the "as is" air quality scenario; the corresponding number (percent) if the current standards were just met is about 15,200 (14.9%); the corresponding numbers for the alternative 1-hr standards denoted 99/50, 99/100, 99/150, 99/200, 99/250, and 98/200 are about 500 (0.5%), 1700 (1.7%), 3500 (3.4%), 5600 (5.4%), 7900 (7.7%), and 7400 (7.2%), respectively.

Although the basic pattern across air quality scenarios seen in St. Louis is repeated in Greene County, the impact of changing from one air quality scenario to another is substantially dampened in Greene County. This is because of the different patterns of exposures in the two locations. In St. Louis there is a wide range of SO_2 concentrations to which asthmatics are exposed under the current standards scenario – i.e., substantial percentages of asthmatics are exposed to relatively higher concentrations of SO_2 under this scenario. There is thus much room for improvement. Under the most stringent alternative 1-hr standard (99/50), much of that exposure is pushed down to the lowest SO_2 concentration "bins." Under the current standards scenario, for example, only about 22 percent of asthmatics in St. Louis have exposures no greater than 100 ppb; under the most stringent alternative 1-hr standard (99/50), that increases to 98 percent.

In Greene County, in contrast, about 95 percent of asthmatics have exposures no greater than 100 ppb under the current standards scenario. There is therefore little room for improvement. Under the most stringent alternative 1-hr standard (99/50), that 95 percent becomes 100 percent. The situation is even more extreme for person days of exposure. Under the current standards scenario, 99.9 percent of person days of exposure are to ≤ 100 ppb SO_2 in Greene County; the corresponding figure for St. Louis is 95.2 percent.

The generally lower levels of SO_2 to which asthmatics in Greene County are exposed, relative to asthmatics in St. Louis, and the corresponding greater preponderance of responses associated with the lowest SO_2 concentration "bins" in Greene County, can be readily seen in Figures 4-1 through 4-8.[12]

Although the numbers are smaller for asthmatic children (because the underlying populations are smaller), the patterns seen in St. Louis and in Greene County across the different air quality scenarios, and the comparisons between the two locations, are fairly similar for asthmatic children as for asthmatics for all lung function response definitions.

[12] In several cases, responses associated with exposures in SO_2 bins cannot be seen in the figures, because the percent responding, or numbers of occurrences of lung function response are so small. We chose to scale the y-axis the same on all comparable figures to facilitate comparisons between figures. This meant, however, that some "response bars" essentially became visually undetectable.

In general, however, the percentages of asthmatic children engaged in moderate or greater exertion who experience at least one lung function response, for each of the different lung function response definitions, tend to be greater than the corresponding percentages of asthmatics. This presumably is a reflection of the greater amount of time spent outdoors by asthmatic children relative to adults.

Finally, we note that, while in several air quality scenarios the great majority of occurrences of lung function response are in the lowest exposure bin, the numbers of individuals with at least one lung function response attributable to exposures in that lowest bin are typically quite small. This is because the calculation of numbers of individuals with at least one lung function response uses individuals' highest exposure only. While individuals may be exposed mostly to low SO_2 concentrations, many are exposed at least occasionally to higher levels. Thus, the percentage of individuals in a designated population with at least one lung function response associated with SO_2 concentrations in the lowest bin is likely to be very small, since most individuals are exposed at least once to higher SO_2 levels. For example, defining lung function response as an increase in sRaw ≥ 100%, under a scenario in which SO_2 concentrations just meet an alternative 1-hour 99^{th} percentile 100 ppb standard, about 93 percent of occurrences of lung function response among asthmatics in St. Louis are associated with SO_2 exposures in the lowest exposure bin (0 – 50 ppb). However, the lowest SO_2 exposure bin accounts for only about 0.2 percent of asthmatics estimated to experience at least 1 SO_2-related lung function response. For this very small percent of the population, the lowest exposure bin represents their highest SO_2 exposures under moderate exertion in a year. Thus Figure 4-5b shows virtually all of the occurrences among asthmatics in St. Louis associated with the lowest SO_2 exposure bin; however, Figure 4-1b shows a relatively small proportion of asthmatics in St. Louis experiencing at least one response to be experiencing those responses because of exposures in that lowest exposure bin.

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Appendix A: Bayesian-Estimated Logistic and Probit Exposure-Response Functions: Median, 2.5th Percentile, and 97.5th Percentile Curves

Figure A-1a. Bayesian-Estimated Logistic Exposure-Response Function: Increase in sRaw ≥ 100% for 5-Minute Exposures of Asthmatics Engaged in Moderate or Greater Exertion

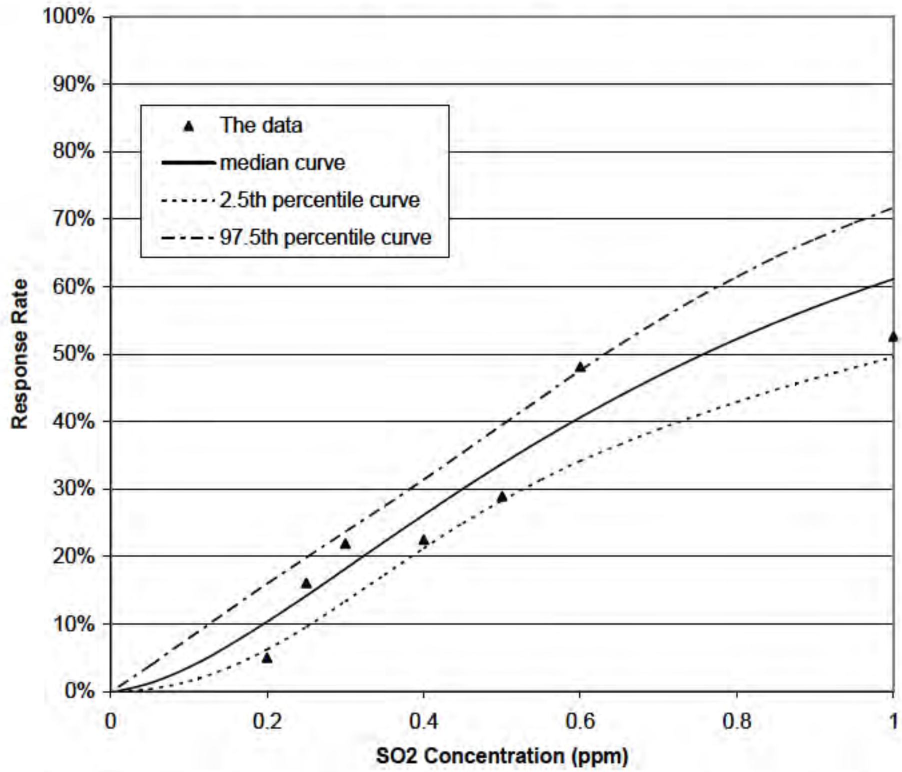


Figure A-1b. Bayesian-Estimated Probit Exposure-Response Function: Increase in sRaw ≥ 100% for 5-Minute Exposures of Asthmatics Engaged in Moderate or Greater Exertion

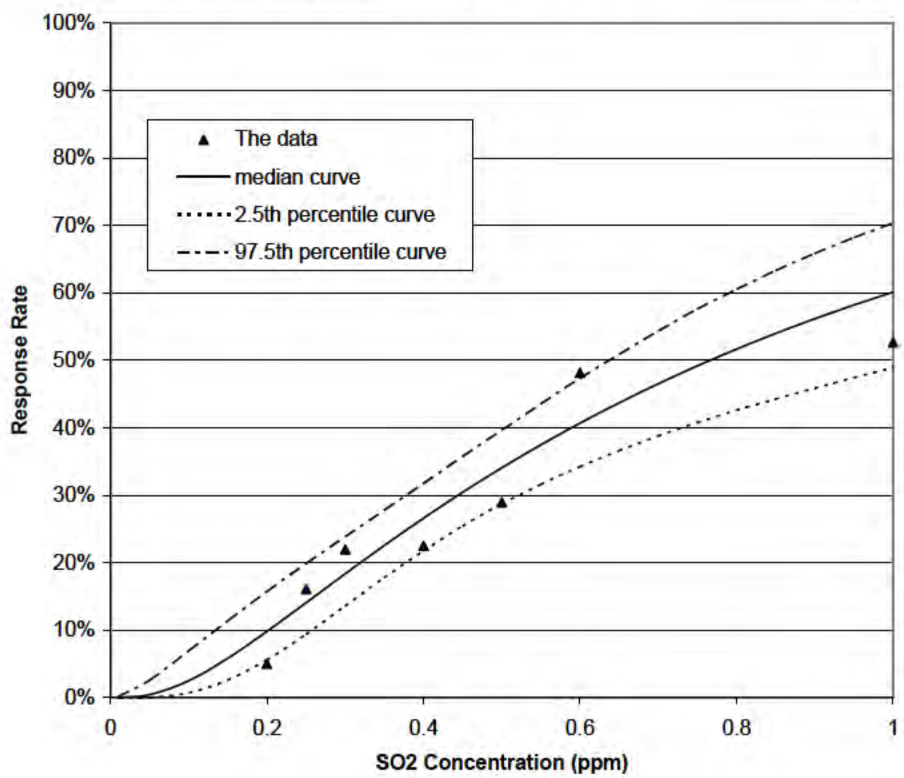


Figure A-2a. Bayesian-Estimated Logistic Exposure-Response Function: Increase in sRaw ≥ 200% for 5-Minute Exposures of Asthmatics Engaged in Moderate or Greater Exertion

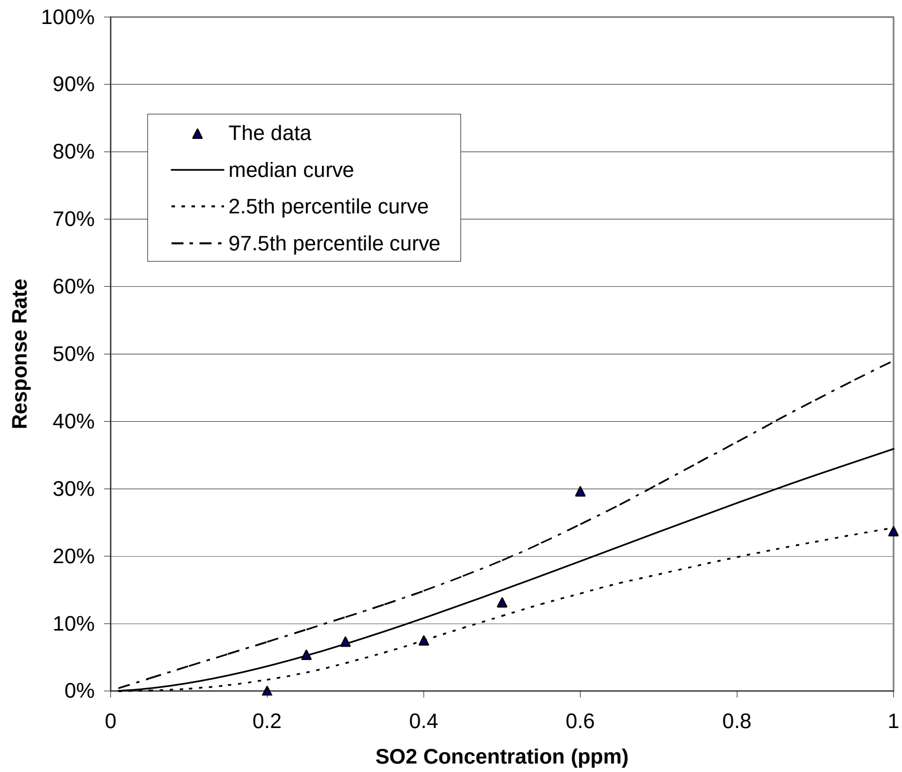


Figure A-2b. Bayesian-Estimated Probit Exposure-Response Function: Increase in sRaw ≥ 200% for 5-Minute Exposures of Asthmatics Engaged in Moderate or Greater Exertion

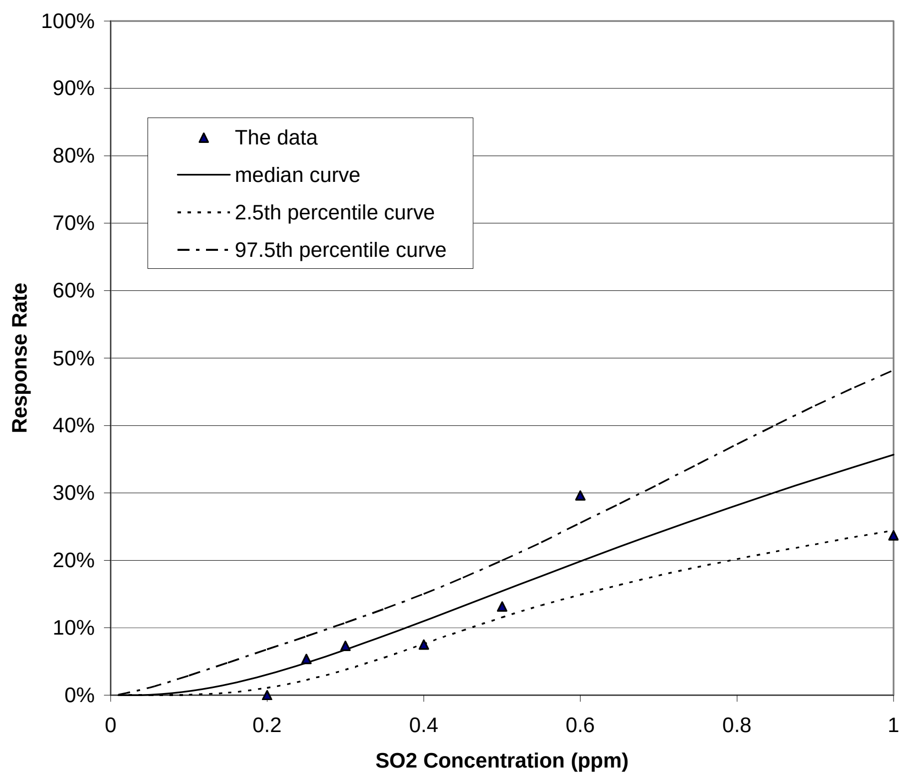


Figure A-3a. Bayesian-Estimated Logistic Exposure-Response Function: Decrease in $FEV_1 \geq 15\%$ for 5-Minute Exposures of Asthmatics Engaged in Moderate or Greater Exertion

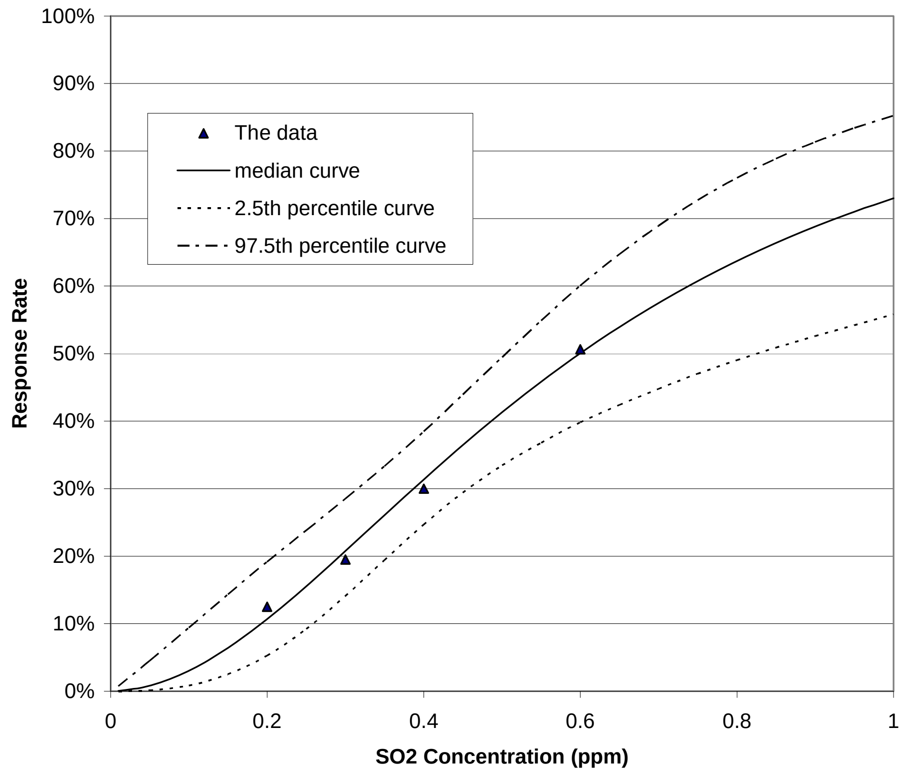


Figure A-3b. Bayesian-Estimated Probit Exposure-Response Function: Decrease in $FEV_1 \geq 15\%$ for 5-Minute Exposures of Asthmatics Engaged in Moderate or Greater Exertion

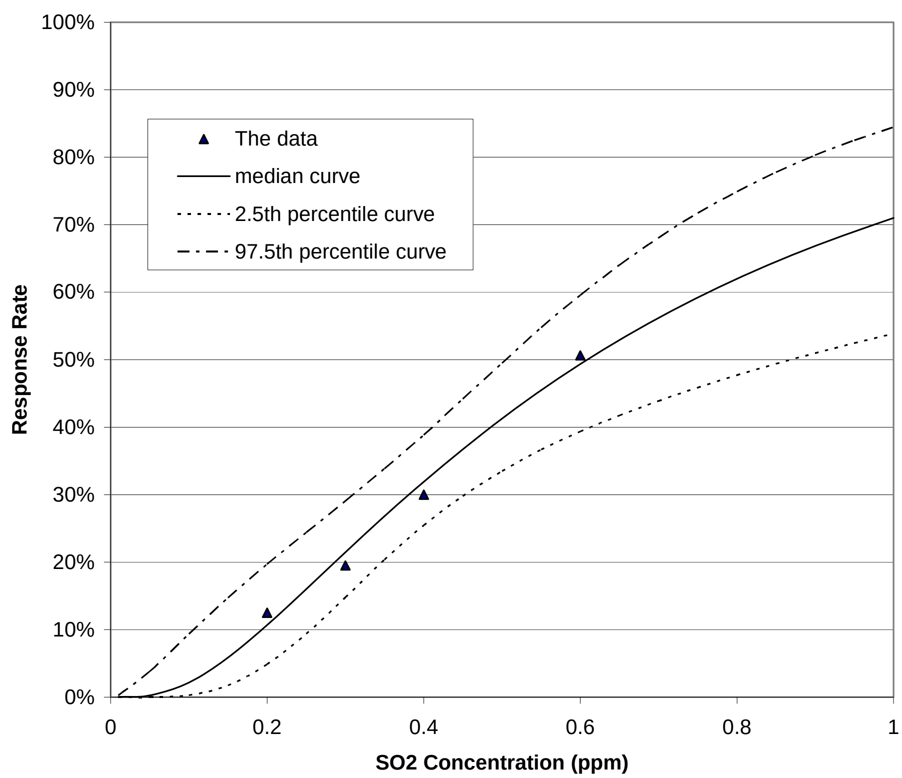


Figure A-4a. Bayesian-Estimated Logistic Exposure-Response Function: Decrease in $FEV_1 \geq 20\%$ for 5-Minute Exposures of Asthmatics Engaged in Moderate or Greater Exertion

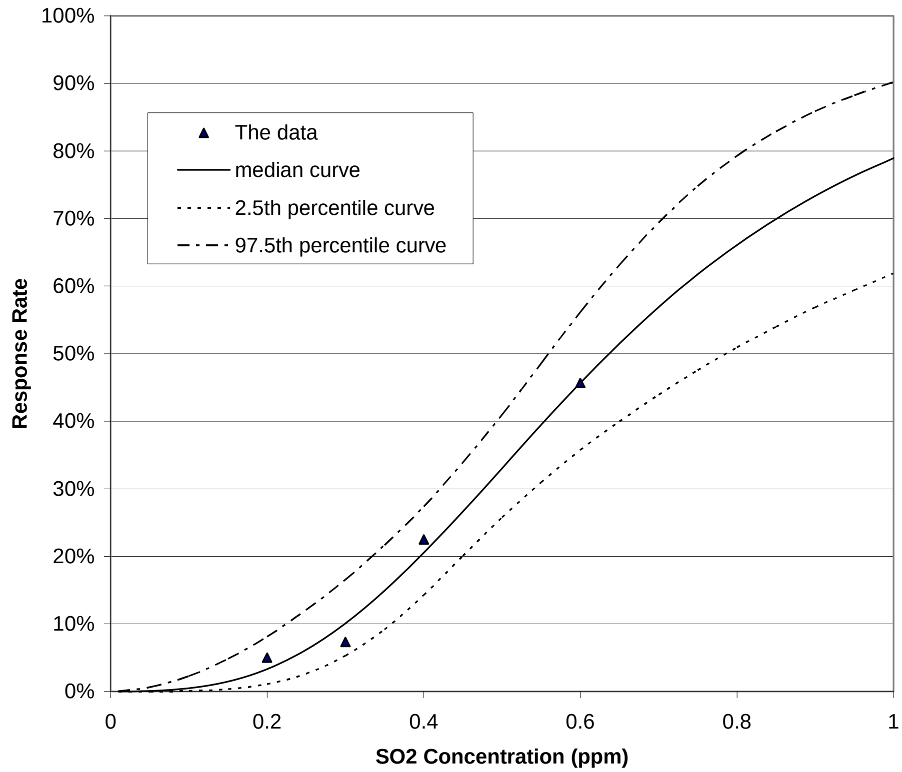
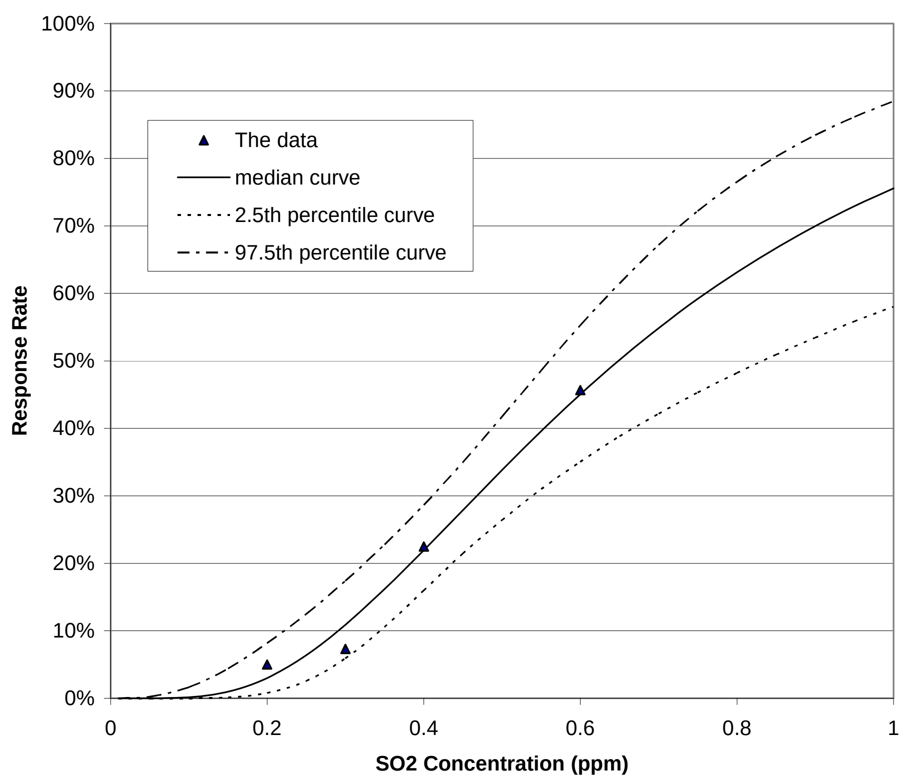


Figure A-4b. Bayesian-Estimated Probit Exposure-Response Function: Decrease in $FEV_1 \geq 20\%$ for 5-Minute Exposures of Asthmatics Engaged in Moderate or Greater Exertion



APPENDIX D: SUPPLEMENT TO THE POLICY ASSESSMENT

Table D-1. 99th percentile 24-hour average SO_2 concentrations for 2005 given just meeting the alternative 1-hour daily maximum standards analyzed in the risk assessment (concentrations in ppb).

		99th percentile					98th percentile	
State County		50 10	0	150	200	250	100	200
AZ Gi	la	7	14	20	27	34	18	36
DE New	Castle	14	27	41	55	69	33	66
FL Hillsb	orough	10	20	31	41	51	28	56
IL M	adison	11	22	33	44	55	26	51
IL Waba	sh	10	20	29	39	49	28	56
IN Fl	oyd	8	15	23	31	38	20	40
IN Gi	bson	5	9	14	19	24	11	21
IN Lake		14	27	41	54	68	35	71
IN Vi	go	9	17	26	34	43	21	43
IA Li	nn	17	35	52	70	87	40	80
IA M	uscatine	16	32	48	64	79	36	72
MI Way	ne	13	26	39	52	65	29	58
MO Gree	ne	14	28	43	57	71	37	73
MO Jeffe	rson	8	17	25	34	42	24	48
NH M	errimack	12	25	37	50	62	29	59
NJ Hu	dson	19	38	57	76	96	48	97
NJ Uni	on	18	36	55	73	91	45	90
NY B	ronx	25	49	74	98	123	57	113
NY C	hautauqua	9	18	28	37	46	22	44
NY Eri	e	12	25	37	50	62	28	56
OH C	uyahoga	17	33	50	66	83	39	78
OH Lake		19	37	56	74	93	45	89
OH Sum	mit	12	24	35	47	59	27	53
OK Tul	sa	15	30	44	59	74	34	67
PA Al	legheny	14	29	43	58	72	37	73
PA B	eaver	10	20	29	39	49	24	47
PA No	rthampton	11	22	33	45	56	36	71
PA War	ren	16	32	48	65	81	41	81
PA Was	hington	19	38	57	76	95	44	87
TN B	lount	19	38	56	75	94	43	87
TN Shel	by	17	35	52	70	87	41	83
TN Su	llivan	7	13	20	27	33	19	38
TX Jeffe	rson	9	18	26	35	44	21	42
VA Fai	rfax	21	43	64	86	107	48	96
WV B	rooke	13	25	38	51	64	32	64
WV Hanc	ock	14	27	41	54	68	32	64
WV M	onongalia	11	21	32	42	53	27	54
WV	Wayne	43	87 13	0 17	3	217	97	194

Table D-2. 99th percentile 24-hour average SO_2 concentrations for 2006 given just meeting the alternative 1-hour daily maximum standards analyzed in the risk assessment (concentrations in ppb).

		99th percentile					98th percentile	
State County		**50 10**	**0**	**150**	**200**	**250**	**100**	**200**
DE New	Castle	11	23	34	46	57	27	55
IL M	adison	9	18	28	37	46	22	43
IN Fl	oyd	8	15	23	30	38	20	40
IN Lake		5	10	14	19	24	12	25
IN Vi	go	5	11	16	22	27	13	27
IA Li	nn	11	23	34	45	56	26	52
IA M	uscatine	15	31	46	62	77	35	70
MI Way	ne	17	34	51	68	85	38	76
MO Gree	ne	17	33	50	66	83	43	86
MO Jeffe	rson	7	13	20	26	33	19	37
NH M	errimack	14	28	41	55	69	33	66
NY B	ronx	23	46	69	92	115	53	106
NY C	hautauqua	7	13	20	27	33	16	32
NY Eri	e	7	15	22	29	36	16	33
OH C	uyahoga	14	28	43	57	71	34	67
OH Lake		11	23	34	46	57	28	55
OH Sum	mit	12	24	35	47	59	27	53
PA Al	legheny	12	23	35	46	58	30	59
PA B	eaver	9	19	28	38	47	23	46
PA No	rthampton	16	32	48	63	79	50	101
PA War	ren	15	29	44	59	73	37	74
PA Was	hington	11	22	33	45	56	26	51
TN B	lount	16	32	48	65	81	37	75
TN Shel	by	16	31	47	62	78	37	74
TN Su	llivan	8	17	25	34	42	24	49
TX Jeffe	rson	11	23	34	45	56	26	53
VA Fai	rfax	17	35	52	70	87	39	78
WV B	rooke	12	24	36	49	61	31	61
WV Hanc	ock	14	28	42	56	70	33	66
WV M	onongalia	10	21	31	42	52	27	53

Table D-3. 2nd highest 24-hour average SO_2 concentrations (i.e. the current 24-hour standard) for 2005 given just meeting the alternative 1-hour daily maximum standards analyzed in the risk assessment (concentrations in ppb)

		99th percentile					98th percentile	
State Cou	**nty**	**50 10**	**0**	**150**	**200**	**250**	**100**	**200**
AZ Gi	la	7	15	22	29	37	19	39
DE New	Castle	18	36	54	72	90	43	86
FL Hillsb	orough	13	26	38	51	64	35	71
IL M	adison	12	24	36	48	60	28	56
IL Waba	sh	8	20	30	41	51	29	58
IN Fl	oyd	9	18	28	37	46	24	49
IN Gi	bson	5	11	16	22	27	12	25
IN Lake		19	38	56	75	94	49	98
IN Vi	go	12	23	35	46	58	29	57
IA Li	nn	19	38	57	76	95	44	88
IA M	uscatine	18	37	55	73	92	41	83
MI Way	ne	17	34	50	67	84	37	75
MO Gree	ne	18	37	55	73	92	47	95
MO	Jefferson 10		20 29		39	49	28	55
NH M	errimack	18	35	53	71	88	42	84
NJ Hu	dson	22	45	67	89	111	56	113
NJ Uni	on	18	45	68	90	113	56	112
NY	Bronx	29	57 86 11		5	144	66	132
NY C	hautauqua	12	19	37	49	62	23	59
NY Eri	e	14	27	41	54	68	30	61
OH	Cuyahoga	26	53 79 10		5	132	63	125
OH Lake		22	44	66	88	110	53	106
OH Sum	mit	12	24	36	49	61	27	55
OK Tul	sa	16	31	47	63	79	36	72
PA Al	legheny	18	36	55	73	91	46	93
PA B	eaver	11	21	32	42	53	26	52
PA No	rthampton	11	23	35	47	58	37	74
PA War	ren	17	33	50	66	83	42	84
PA Was	hington	23	46	69	92	115	53	106
TN B	lount	23	46	69	92	115	53	107
TN Shel	by	22	43	65	87	108	51	103
TN Su	llivan	9	19	28	37	46	27	54
TX	Jefferson 10		20 30		39	49	23	46
VA Fai	rfax	22	49	74	98	123	55	110
WV B	rooke	14	28	42	56	70	35	71
WV Hanc	ock	16	32	48	64	80	38	76
WV M	onongalia	12	23	35	47	58	30	59
WV	Wayne	48	95 14	3	190 23	8	106	213

Table D-4. 2nd highest 24-hour average SO_2 concentrations (i.e. the current 24-hour standard) for 2006 given just meeting the alternative 1-hour daily maximum standards analyzed in the risk assessment (concentrations in ppb)

		99th percentile					98th percentile	
State Cou	nty	50 10	0	150	200	250	100	200
DE New	Castle	18	37	55	73	92	44	88
IL M	adison	10	20	31	41	51	24	48
IN Fl	oyd	12	23	35	47	58	31	61
IN Lake		6	11	17	27	34	18	36
IN Vi	go	7	14	21	28	35	17	35
IA Li	nn	16	32	48	63	79	36	73
IA M	uscatine	18	36	54	72	90	41	82
MI Way	ne	24	48	72	96	120	54	107
MO Gree	ne	20	40	60	80	100	52	103
MO	Jefferson 7		14	32	43 54		20	61
NH M	errimack	19	38	57	76	95	45	90
NY B	ronx	25	49	74	99	124	57	114
NY C	hautauqua	8	15	23	30	38	18	36
NY Eri	e	12	24	36	47	59	27	54
OH C	uyahoga	21	43	64	85	106	51	101
OH Lake		16	33	49	65	82	39	79
OH Sum	mit	13	26	39	52	65	29	58
PA Al	legheny	13	27	40	53	66	34	68
PA B	eaver	12	24	35	47	59	29	57
PA No	rthampton	50	101	151	202	252	161	321
PA War	ren	19	38	57	76	95	48	96
PA Was	hington	14	29	43	58	72	33	66
TN B	lount	21	41	62	83	104	48	96
TN Shel	by	20	41	61	82	102	48	97
TN Su	llivan	10	21	31	42	52	30	60
TX	Jefferson 13		26 39		52	65	31	61
VA Fai	rfax	20	41	61	82	102	46	91
WV B	rooke	14	28	42	56	70	35	71
WV Hanc	ock	15	31	46	61	76	36	72
WV M	onongalia	11	22	34	45	56	29	57

Table D-5. Annual average SO_2 concentrations for 2005 given just meeting the alternative 1-hour daily maximum standards analyzed in the risk assessment (concentrations in ppb).

		99th percentile					98th percentile	
State Cou	**nty**	**50**	**100 15**	**0 20**	**0**	**250**	**100**	**200**
AZ	Gila	1.5	2.9 4.	3 5.	8	7.2	3.8	7.7
DE	New Castle	2.3	4.6 6.	9 9.	2	11.5	5.5	11.0
FL	Hillsborough	1.5	2.9 4	.4 5	.8	7.3	4.0	8.0
IL	Madison	1.8	3.7 5.	5 7.	4	9.2	4.3	8.6
IL	Wabash	1.5	3.0 4.	5 6.	0	7.5	4.3	8.6
IN	Floyd	2.3	4.5 6.	8 9.	0	11.3	5.9	11.9
IN	Gibson	0.8	1.7 2.	5 3.	4	4.2	1.9	3.8
IN	Lake	1.8	3.6 5.	4 7.	1	8.9	4.7	9.3
IN	Vigo	1.9	3.7 5.	5 7.	4	9.2	4.6	9.1
IA	Linn	2.0	4.1 6.	1 8.	2	10.2	4.7	9.4
IA	Muscatine	2.3	4.6 6.	9 9.	1	11.4	5.2	10.3
MI	Wayne	2.4	4.9 7.	3 9.	7	12.1	5.4	10.8
MO	Greene	1.9	3.8 5.	7 7.	6	9.5	4.9	9.8
MO	Jefferson	1.4	2.8 4.	2 5.	6	7.1	4.0	8.0
NH	Merrimack 2.	4 4.	8	7.2	9.5	11.9	5.7	11.4
NJ	Hudson	6.4	12.9 19	.3 25	.7	32.1	16.3	32.5
NJ	Union	6.2	12.3 18	.4 24	.6	30.7	15.2	30.4
NY	Bronx	6.9	13.7 20	.6 27	.4	34.3	15.8	31.6
NY	Chautauqua	2.1	4.3 6.	4 8.	6	10.7	5.1	10.3
NY	Erie	2.3	4.5 6.	8 9.	1	11.3	5.1	10.2
OH C	uyahoga	4.6	9.3	13.9	18.6	23.2	11.0	22.1
OH Lake		2.8	5.7	8.5	11.3	14.1	6.8	13.6
OH Sum	mit	2.7	5.4	8.1	10.8	13.5	6.1	12.1
OK Tul	sa	3.6	7.2	10.7	14.3	17.9	8.2	16.3
PA Al	legheny	3.6	7.1	10.7	14.2	17.8	9.0	18.1
PA B	eaver	2.8	5.5	8.3	11.0	13.8	6.7	13.4
PA No	rthampton	2.9	5.9	8.8	11.7	14.6	9.3	18.7
PA War	ren	3.2	6.5	9.7	13.0	16.2	8.2	16.3
PA Was	hington	4.7	9.3	14.0	18.7	23.3	10.7	21.5
TN B	lount	2.9	5.8	8.7	11.7	14.6	6.7	13.5
TN Shel	by	2.9	5.7	8.6	11.5	14.4	6.8	13.6
TN	Sullivan	1.5	3.0 4	.5 6	.1	7.6	4.4	8.7
TX	Jefferson	1.4	2.8 4.	2 5.	6	7.1	3.3	6.6
VA	Fairfax	7.8	15.5 23	.2 31	.0	38.7	17.3	34.7
WV B	rooke	4.5	8.9	13.4	17.9	22.4	11.3	22.6
WV Hanc	ock	4.3	8.6	13.0	17.3	21.6	10.2	20.5
WV M	onongalia	2.6	5.2	7.8	10.3	12.9	6.6	13.2
WV	Wayne	6.0	12.0 18	.0 24	.0	30.0	13.4	26.8

Table D-6. Annual average SO_2 concentrations for 2006 given just meeting the alternative 1-hour daily maximum standards analyzed in the risk assessment (concentrations in ppb).

		99th percentile					98th percentile	
State Cou	**nty**	**50**	**100 15**	**0 20**	**0**	**250**	**100**	**200**
DE	New Castle	2.2	4.4 6.	7 8.	9	11.1	5.3	10.6
IL	Madison	1.7	3.5 5.	2 6.	9	8.6	4.0	8.1
IN	Floyd	1.6	3.2 4.	8 6.	3	7.9	4.2	8.4
IN	Lake	1.7	3.3 5.	0 6.	6	8.3	4.3	8.7
IN	Vigo	1.4	2.8 4.	2 5.	6	7.0	3.4	6.9
IA	Linn	1.8	3.6 5.	4 7.	2	9.1	4.2	8.3
IA	Muscatine	1.7	3.4 5.	2 6.	9	8.6	3.9	7.8
MI	Wayne	2.2	4.4 6.	6 8.	8	10.9	4.9	9.8
MO	Greene	2.0	4.0 6.	1 8.	1	10.1	5.2	10.4
MO	Jefferson	1.5	3.0 4.	5 5.	9	7.4	4.2	8.4
NH	Merrimack 2.	1 4.	3	6.4	8.5	10.7	5.1	10.1
NY	Bronx	6.5	13.0 19	.5 26	.0	32.5	15.0	29.9
NY	Chautauqua	1.6	3.1 4.	6 6.	2	7.7	3.7	7.4
NY	Erie	1.5	3.1 4.	6 6.	1	7.6	3.4	6.9
OH C	uyahoga	4.1	8.2	12.4	16.5	20.6	9.8	19.6
OH	Lake	2.4	4.8 7.	2 9.	6	12.0	5.8	11.6
OH	Summit	2.2	4.3 6.	5 8.	7	10.9	4.9	9.8
PA Al	legheny	2.7	5.5	8.2	10.9	13.7	7.0	13.9
PA	Beaver	2.0	4.0 6.	0 8.	0	10.0	4.9	9.7
PA No	rthampton	3.7	7.3	11.0	14.6	18.3	11.6	23.3
PA	Warren	2.5	4.9 7.	4 9.	9	12.3	6.2	12.4
PA Was	hington	4.3	8.5	12.8	17.1	21.3	9.8	19.6
TN B	lount	3.0	6.0	8.9	11.9	14.9	6.9	13.8
TN Shel	by	3.7	7.5	11.2	14.9	18.6	8.8	17.7
TN	Sullivan	1.8	3.6 5	.3 7	.1	8.9	5.1	10.3
TX	Jefferson	1.4	2.9 4.	3 5.	7	7.2	3.4	6.7
VA	Fairfax	6.9	13.9 20	.8 27	.7	34.6	15.5	31.0
WV B	rooke	3.9	7.7	11.6	15.5	19.3	9.8	19.5
WV Hanc	ock	4.1	8.2	12.3	16.3	20.4	9.7	19.4
WV	Monongalia	2.0	3.9 5.	8 7.	8	9.7	5.0	9.9

Exhibit 4

United States Environmental Protection Agency | Office of Air Quality Planning and Standards, Health and Environmental Impacts Division, Research Triangle Park, NC | EPA-452/R-09-007, July 2009

EXHIBIT 5

Federal Register

Tuesday,
June 22, 2010

Part II

Environmental Protection Agency

40 CFR Parts 50, 53, and 58
Primary National Ambient Air Quality Standard for Sulfur Dioxide; Final Rule

ENVIRONMENTAL PROTECTION AGENCY

40 CFR Parts 50, 53, and 58

[EPA–HQ–OAR–2007–0352; 9160–4]

RIN 2060–A048

Primary National Ambient Air Quality Standard for Sulfur Dioxide

AGENCY: Environmental Protection Agency (EPA).

ACTION: Final rule.

SUMMARY: Based on its review of the air quality criteria for oxides of sulfur and the primary national ambient air quality standard (NAAQS) for oxides of sulfur as measured by sulfur dioxide (SO_2), EPA is revising the primary SO_2 NAAQS to provide requisite protection of public health with an adequate margin of safety. Specifically, EPA is establishing a new 1-hour SO_2 standard at a level of 75 parts per billion (ppb), based on the 3-year average of the annual 99th percentile of 1-hour daily maximum concentrations. The EPA is also revoking both the existing 24-hour and annual primary SO_2 standards.

DATES: This final rule is effective on August 23, 2010.

ADDRESSES: EPA has established a docket for this action under Docket ID No. EPA–HQ–OAR–2007–0352. All documents in the docket are listed on the *http://www.regulations.gov* Web site. Although listed in the index, some information is not publicly available, *e.g.,* confidential business information or other information whose disclosure is restricted by statute. Certain other material, such as copyrighted material, will be publicly available only in hard copy form. Publicly available docket materials are available either electronically through *http://www.regulations.gov* or in hard copy at the Air and Radiation Docket and Information Center, EPA/DC, EPA West, Room 3334, 1301 Constitution Ave., NW., Washington, DC. The Public Reading Room is open from 8:30 a.m. to 4:30 p.m., Monday through Friday, excluding legal holidays. The telephone number for the Public Reading Room is (202) 566–1744 and the telephone number for the Air and Radiation Docket and Information Center is (202) 566–1742.

FOR FURTHER INFORMATION CONTACT: Dr. Michael J. Stewart, Health and Environmental Impacts Division, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Mail code C504–06, Research Triangle Park, NC 27711; telephone: 919–541–7524; fax: 919–541–0237; e-mail: *stewart.michael@epa.gov*.

SUPPLEMENTARY INFORMATION:

Table of Contents

The following topics are discussed in this preamble:

I. Background

A. Summary of Revisions to the SO_2 Primary NAAQS

Based on its review of the air quality criteria for oxides of sulfur and the primary national ambient air quality standard (NAAQS) for oxides of sulfur as measured by sulfur dioxide (SO_2), EPA is making revisions to the primary SO_2 NAAQS so the standards are requisite to protect public health with an adequate margin of safety, as appropriate under section 109 of the Clean Air Act (Act or CAA). Specifically, EPA is replacing the current 24-hour and annual standards with a new short-term standard based on the 3-year average of the 99th percentile of the yearly distribution of 1-hour daily maximum SO_2 concentrations. EPA is setting the level of this new standard at 75 ppb. EPA is adding data handling conventions for SO_2 by adding provisions for this new 1-hour primary standard. EPA is also establishing requirements for an SO_2 monitoring network. These new provisions require monitors in areas where there is an increased coincidence of population and SO_2 emissions. EPA is also making conforming changes to the Air Quality Index (AQI).

B. Statutory Requirements

Two sections of the Clean Air Act (Act or CAA) govern the establishment and revision of National Ambient Air Quality Standards NAAQS. Section 108 of the Act directs the Administrator to identify and list air pollutants that meet certain criteria, including that the air pollutant "in his judgment, cause[s] or contribute[s] to air pollution which may reasonably be anticipated to endanger public health and welfare" and "the presence of which in the ambient air results from numerous or diverse mobile or stationary sources." CAA section 108(a)(1)(A) and (B). For those air pollutants listed, section 108 requires the Administrator to issue air quality criteria that "accurately reflect the latest scientific knowledge useful in indicating the kind and extent of all identifiable effects on public health or welfare which may be expected from the presence of [a] pollutant in ambient air * * *" Section 108(a)(2).

Section 109(a) of the Act directs the Administrator to promulgate "primary" and "secondary" NAAQS for pollutants for which air quality criteria have been issued. Section 109(b)(1) defines a primary standard as one "the attainment and maintenance of which in the judgment of the Administrator, based on [the air quality] criteria and allowing an adequate margin of safety, are requisite to protect the public health." [1] Section 109(b)(1). A secondary standard, in turn, must "specify a level of air quality the attainment and maintenance of which, in the judgment of the Administrator, based on [the air quality] criteria, is requisite to protect the public welfare from any known or anticipated adverse effects associated with the presence of such pollutant in the ambient air." [2] Section 109(b)(2) This rule concerns exclusively the primary NAAQS for oxides of sulfur.

The requirement that primary standards include an adequate margin of safety is intended to address uncertainties associated with inconclusive scientific and technical information available at the time of standard setting. It is also intended to provide a reasonable degree of protection against hazards that research has not yet identified. *Lead Industries Association* v. *EPA,* 647 F.2d 1130, 1154 (DC Cir 1980), *cert. denied,* 449 U.S. 1042 (1980); *American Petroleum Institute* v. *Costle,* 665 F.2d 1176, 1186 (DC Cir. 1981), *cert. denied,* 455 U.S. 1034 (1982). Both kinds of uncertainties are components of the risk associated with pollution at levels below those at which human health effects can be said to occur with reasonable scientific certainty. Thus, in selecting primary standards that include an adequate margin of safety, the Administrator is seeking not only to prevent pollution levels that have been demonstrated to be harmful but also to prevent lower pollutant levels that may pose an unacceptable risk of harm, even if the risk is not precisely identified as to nature or degree. The CAA does not require the Administrator to establish a primary NAAQS at a zero-risk level or at background concentration levels, *see Lead Industries Association* v. *EPA,* 647 F.2d at 1156 n. 51, but rather at a level that reduces risk sufficiently so as to protect public health with an adequate margin of safety.

In addressing the requirement for a margin of safety, EPA considers such factors as the nature and severity of the health effects involved, the size of the at-risk population(s), and the kind and degree of the uncertainties that must be addressed. The selection of any particular approach to providing an adequate margin of safety is a policy choice left specifically to the Administrator's judgment. *Lead Industries Association* v. *EPA,* 647 F.2d at 1161–62.

In setting standards that are "requisite" to protect public health and welfare, as provided in section 109(b), EPA's task is to establish standards that are neither more nor less stringent than necessary for these purposes. In so doing, EPA may not consider the costs of implementing the standards. *Whitman* v. *American Trucking*

[1] The legislative history of section 109 indicates that a primary standard is to be set at "the maximum permissible ambient air level * * * which will protect the health of any [sensitive] group of the population," and that for this purpose "reference should be made to a representative sample of persons comprising the sensitive group rather than to a single person in such a group." S. Rep. No. 91–1196, 91st Cong., 2d Sess. 10 (1970). *See also American Lung Ass'n* v. *EPA,* 134 F. 3d 388, 389 (DC Cir. 1998) ("NAAQS must protect not only average healthy individuals, but also 'sensitive citizens'—children, for example, or people with asthma, emphysema, or other conditions rendering them particularly vulnerable to air pollution. If a pollutant adversely affects the health of these sensitive individuals, EPA must strengthen the entire national standard."); *Coalition of Battery Recyclers Ass'n* v. *EPA,* No. 09–1011 (DC Cir. May 14, 2010) slip op. at 7 (same).

[2] EPA is currently conducting a separate review of the secondary SO_2 NAAQS jointly with a review of the secondary NO_2 NAAQS (*see http://www.epa.gov/ttn/naaqs/standards/no2so2sec/index.html* for more information).

Associations, 531 U.S. 457, 471, 475–76 (2001).

Section 109(d)(1) of the Act requires the Administrator to periodically undertake a thorough review of the air quality criteria published under section 108 and the NAAQS and to revise the criteria and standards as may be appropriate. The Act also requires the Administrator to appoint an independent scientific review committee composed of seven members, including at least one member of the National Academy of Sciences, one physician, and one person representing State air pollution control agencies, to review the air quality criteria and NAAQS and to "recommend to the Administrator any new * * * standards and revisions of existing criteria and standards as may be appropriate under section 108 and subsection (b) of this section." CAA section 109(d)(2). This independent review function is performed by the Clean Air Scientific Advisory Committee (CASAC) of EPA's Science Advisory Board.

C. Related SO_2 Control Programs

States are primarily responsible for ensuring attainment and maintenance of ambient air quality standards once EPA has established them. Under section 110 of the Act, and related provisions, States are to submit, for EPA approval, State implementation plans (SIPs) that provide for the attainment and maintenance of such standards through control programs directed to sources of the pollutants involved. The States, in conjunction with EPA, also administer the prevention of significant deterioration program that covers these pollutants. *See* CAA sections 160–169. In addition, Federal programs provide for nationwide reductions in emissions of these and other air pollutants through the Federal motor vehicle and motor vehicle fuel control program under title II of the Act (CAA sections 202–250) which involves controls for emissions from all moving sources and controls for the fuels used by these sources; new source performance standards under section 111; and title IV of the Act (CAA sections 402–416), which specifically provides for major reductions in SO_2 emissions. EPA has also promulgated the Clean Air Interstate Rule (CAIR) to require additional SO_2 emission reductions needed in the eastern half of the United States to address emissions which contribute significantly to nonattainment with, or interfere with maintenance of, the PM NAAQS by downwind States in the CAIR region. This rule was remanded by the DC Circuit, and although it remains in effect, EPA is reevaluating it pursuant to the court remand.

Currently, there are several areas designated as being in nonattainment of the primary SO_2 NAAQS (*see* section VI). Moreover, as a result of this final rule, additional areas could be classified as non-attainment. Certain States would then be required to develop SIPs that identify and implement specific air pollution control measures to reduce ambient SO_2 concentrations to attain and maintain the revised SO_2 NAAQS, most likely by requiring air pollution controls on sources that emit oxides of sulfur (SO_x).

D. History of Reviews of the Primary NAAQS for Sulfur Oxides

On April 30, 1971, the EPA promulgated primary SO_2 NAAQS (36 FR 8187). These primary standards, which were based on the findings outlined in the original 1969 Air Quality Criteria for Sulfur Oxides, were set at 0.14 parts per million (ppm) averaged over a 24-hour period, not to be exceeded more than once per year, and 0.030 ppm annual arithmetic mean. In 1982, EPA published the Air Quality Criteria for Particulate Matter and Sulfur Oxides (EPA, 1982) along with an addendum of newly published controlled human exposure studies, which updated the scientific criteria upon which the initial standards were based (EPA, 1982). In 1986, EPA published a second addendum presenting newly available evidence from epidemiologic and controlled human exposure studies (EPA, 1986). In 1988, EPA published a proposed decision not to revise the existing standards (53 FR 14926) (April 26, 1988). However, EPA specifically requested public comment on the alternative of revising the current standards and adding a new 1-hour primary standard of 0.4 ppm (400 ppb) to protect asthmatics against 5–10 minute peak SO_2 concentrations.

As a result of public comments on the 1988 proposal and other post-proposal developments, EPA published a second proposal on November 15, 1994 (59 FR 58958). The 1994 re-proposal was based in part on a supplement to the second addendum of the criteria document, which evaluated new findings on 5–10 minute SO_2 exposures in asthmatics (EPA, 1994a; EPA, 1994b). As in the 1988 proposal, EPA proposed to retain the existing 24-hour and annual standards. EPA also solicited comment on three regulatory alternatives to further reduce the health risk posed by exposure to high 5-minute peaks of SO_2 if additional protection were judged to be necessary. The three alternatives were: (1) Revising the existing primary SO_2 NAAQS by adding a new 5-minute standard of 0.6 ppm (600 ppb) SO_2; (2) establishing a new regulatory program under section 303 of the Act to supplement protection provided by the existing NAAQS, with a trigger level of 0.6 ppm (600 ppb) SO_2, one expected exceedance; and (3) augmenting implementation of existing standards by focusing on those sources or source types likely to produce high 5-minute peak concentrations of SO_2.

On May 22, 1996, EPA announced its final decision not to revise the NAAQS for SO_x (61 FR 25566). EPA found that asthmatics—a susceptible population group—could be exposed to short-term SO_2 bursts resulting in repeated 'exposure events' such that tens or hundreds of thousands of asthmatics could be exposed annually to lung function effects "distinctly exceeding * * * [the] typical daily variation in lung function" that asthmatics routinely experience, and found further that repeated occurrences should be regarded as significant from a public health standpoint. 61 FR at 25572, 25573. Nonetheless, the agency concluded that "the likelihood that asthmatic individuals will be exposed * * * is very low when viewed from a national perspective", that "5-minute peak SO[2] levels do not pose a broad public health problem when viewed from a national perspective", and that "short-term peak concentrations of SO[2] do not constitute the type of ubiquitous public health problem for which establishing a NAAQS would be appropriate." *Id.* at 25575. EPA concluded, therefore, that it would not revise the existing standards or add a standard to specifically address 5-minute exposures. EPA also announced an intention to propose guidance, under section 303 of the Act, to assist States in responding to short-term peaks of SO_2 and later initiated a rulemaking to do so (62 FR 210 (Jan. 2, 1997).

The American Lung Association and the Environmental Defense Fund challenged EPA's decision not to establish a 5-minute standard. On January 30, 1998, the Court of Appeals for the District of Columbia Circuit found that EPA had failed to adequately explain its determination that no revision to the SO_2 NAAQS was appropriate and remanded the determination back to EPA for further explanation. *American Lung Ass'n* v. *EPA,* 134 F. 3d 388 (DC Cir. 1998). Specifically, the court held that EPA had failed to adequately explain the basis for its conclusion that short-term SO_2 exposures to asthmatics do not constitute a public health problem, noting that the agency had failed to explain the link between its finding that repeated short-term exposures were significant, and that there would be tens to hundreds of thousands of such exposures annually to a susceptible subpopulation. 134 F. 3d at 392. The court also rejected the explanation that short-term SO_2 bursts were "localized, infrequent, and site-specific" as a rational basis for the conclusion that no public health problem existed for purposes of section 109: "[N]othing in the Final Decision explains why 'localized', 'site-specific', or even 'infrequent' events might nevertheless create a public health problem, particularly since, in some sense, all pollution is local and site-specific * * *". *Id.* The court accordingly remanded the case to EPA to adequately explain its determination or otherwise take action in accordance with the opinion. In response, EPA has collected and analyzed additional air quality data focused on 5-minute concentrations of SO_2. These air quality analyses conducted since the last review helped inform the current review, which (among other things) address the issues raised in the court's remand of the Agency's last decision.

EPA formally initiated the current review of the air quality criteria for oxides of sulfur and the SO_2 primary NAAQS on May 15, 2006 (71 FR 28023) with a general call for information. EPA's draft Integrated Review Plan for the Primary National Ambient Air Quality Standards for Sulfur Dioxide (EPA, 2007a) was made available in April 2007 for public comment and was discussed by the CASAC via a publicly accessible teleconference on May 11, 2007. As noted in that plan, SO_X includes multiple gaseous (*e.g.,* SO_3) and particulate (*e.g.,* sulfate) species. Because the health effects associated with particulate species of SO_X have been considered within the context of the health effects of ambient particles in the Agency's review of the NAAQS for particulate matter (PM), the current review of the primary SO_2 NAAQS is focused on the gaseous species of SO_X and does not consider health effects directly associated with particulate species.

The first draft of the Integrated Science Assessment for Oxides of Sulfur-Health Criteria (ISA) and the Sulfur Dioxide Health Assessment Plan: Scope and Methods for Exposure and Risk Assessment (EPA, 2007b) were reviewed by CASAC at a public meeting held on December 5–6, 2007. Based on comments received from CASAC and from the public, EPA developed the second draft of the ISA and the first draft of the Risk and Exposure Assessment to Support the Review of the SO_2 Primary National Ambient Air Quality Standard (Risk and Exposure Assessment (REA)). These documents were reviewed by CASAC at a public meeting held on July 30–31, 2008. Based on comments received from CASAC and the public at this meeting, EPA released the final ISA in September of 2008 (EPA, 2008a; henceforth referred to as ISA). In addition, comments received were considered in developing the second draft of the REA. Importantly, the second draft of the REA contained a draft staff policy assessment that considered the evidence presented in the final ISA and the air quality, exposure, and risk characterization results presented in the second draft REA, as they related to the adequacy of the current SO_2 NAAQS and potential alternative primary SO_2 standards. This document was reviewed by CASAC at a public meeting held on April 16–17, 2009. In preparing the final REA report, which included the final staff policy assessment, EPA considered comments received from CASAC and the public at and subsequent to that meeting. The final REA containing the final staff policy assessment was completed in August 2009 (EPA 2009a; henceforth referred to as REA)).

On December 8, 2009 EPA published its proposed revisions to the primary SO_2 NAAQS. 74 FR 64810 presented a number of conclusions, findings, and determinations proposed by the Administrator. EPA invited general, specific, and/or technical comments on all issues involved with this proposal, including all such proposed judgments, conclusions, findings, and determinations. EPA invited specific comment on the level, or range of levels, appropriate for such a standard, as well as on the rationale that would support that level or range of levels. These comments were carefully considered by the Administrator as she made her final decisions, as described in this notice, on the primary SO_2 NAAQS

The schedule for completion of this review is governed by a judicial order resolving a lawsuit filed in September 2005, concerning the timing of the current review. *Center for Biologic Diversity* v. *Johnson* (Civ. No. 05–1814) (D.D.C. 2007). The order that now governs this review, entered by the court in August 2007 and amended in December 2008, provides that the Administrator will sign, for publication, a final rulemaking concerning the review of the primary SO_2 NAAQS no later than June 2, 2010.

E. Summary of Proposed Revisions to the SO_2 Primary NAAQS

For the reasons discussed in the preamble of the proposal for the SO_2 primary NAAQS, EPA proposed to make revisions to the primary SO_2 NAAQS (and to add SO_2 data handling conventions) so the standards provide requisite protection of public health with an adequate margin of safety. Specifically, EPA proposed to replace the current 24-hour and annual standards with a new short-term SO_2 standard. EPA proposed that this new short-term standard would be based on the 3-year average of the 99th percentile (or 4th highest) of the yearly distribution of 1-hour daily maximum SO_2 concentrations. EPA proposed to set the level of this new 1-hour standard within the range of 50 to 100 ppb and solicited comment on standard levels as high as 150 ppb. EPA also proposed to establish requirements for an SO_2 monitoring network at locations where maximum SO_2 concentrations are expected to occur and to add a new Federal Reference Method (FRM) for measuring SO_2 in the ambient air. Finally, EPA proposed to make corresponding changes to the Air Quality Index for SO_2.

F. Organization and Approach to Final SO_2 Primary NAAQS Decisions

This action presents the Administrator's final decisions regarding the need to revise the current SO_2 primary NAAQS, and what those revisions should be. Revisions to the primary NAAQS for SO_2, and the rationale supporting those revisions, are described below in section II.

An overview of the approach for monitoring and implementation is presented in section III. Requirements for the SO_2 ambient monitoring network and for a new, additional FRM for measuring SO_2 in the ambient air are described in section IV. EPA's current plans for designations and for implementing the revised SO_2 primary NAAQS are discussed in sections V and VI respectively. Related requirements for data completeness, data handling, data reporting, rounding conventions, and exceptional events are described in section VII. Communication of public health information through the AQI is discussed in section VIII. A recitation of statutory authority and a discussion of those executive order reviews which are relevant are provided in section IX.

Today's final decisions are based on a thorough review in the ISA of scientific information on known and potential human health effects associated with exposure to SO_2 in the air. These final decisions also take into account: (1) Assessments in the REA of the most policy-relevant information in the ISA as well as quantitative exposure and risk analyses based on that information; (2) CASAC Panel advice and recommendations, as reflected in its letters to the Administrator and its public discussions of the ISA and REA; (3) public comments received during the development of the ISA and REA; and (4) public comments received on EPA's notice of proposed rulemaking.

II. Rationale for Decisions on the Primary Standards

This section presents the rationale for the Administrator's decision to revise the existing SO_2 primary standards by replacing the current 24-hour and annual standards with a new 1-hour SO_2 standard at a level of 75 ppb, based on the 3-year average of the annual 99th percentile of 1-hour daily maximum concentrations. As discussed more fully below, this rationale takes into account: (1) Judgments and conclusions presented in the ISA and the REA; (2) CASAC advice and recommendations as reflected in the CASAC panel's discussions of drafts of the ISA and REA at public meetings, in separate written comments, and in letters to the Administrator (Henderson 2008a; Henderson 2008b; Samet, 2009); (3) public comments received at CASAC meetings during the development of the ISA and the REA; and (4) public comments received on the notice of proposed rulemaking.

In reaching this decision, EPA has drawn upon an integrative synthesis of the entire body of evidence on human health effects associated with the presence of SO_2 in the ambient air, and upon the results of the quantitative exposure and risk assessments reflecting this evidence. As discussed below, this body of evidence addresses a broad range of health endpoints associated with exposure to SO_2 in the ambient air. In considering this entire body of evidence, EPA chose to focus most on those health endpoints for which the ISA found the strongest evidence of an association with SO_2 (*see* section II.B below). Thus, the rationale for this final decision on the SO_2 NAAQS focused primarily on respiratory morbidity following short-term (5-minutes to 24-hours) exposure to SO_2, for which the ISA found a causal relationship.

As discussed below, a substantial amount of new research has been conducted since EPA's last review of the SO_2 NAAQS, with important new information coming from epidemiologic studies in particular. In addition to the substantial amount of new epidemiologic research, the ISA considered a limited number of new controlled human exposure studies and re-evaluated key older controlled human exposure studies. In evaluating both the new and key older controlled human exposure studies, the ISA utilized updated guidelines published by the American Thoracic Society (ATS) on what constitutes an adverse effect of air pollution (*see* ISA, section 3.1.3; p. 3–4). Importantly, all controlled human exposure and epidemiologic studies evaluated in the ISA have undergone intensive scrutiny through multiple layers of peer review and opportunities for public review and comment. Thus, the review of this information has been extensive and deliberate.

After a background discussion of the principal emitting sources and current patterns of SO_2 air quality and a description of the current SO_2 monitoring network from which those air quality patterns are obtained (section II.A), the remainder of this section discusses the Administrator's rationale for her final decisions on the primary standards. Section II.B includes an overview of the scientific evidence related to the respiratory effects associated with ambient SO_2 exposure. This overview includes a discussion of the at-risk populations considered in the ISA. Section II.C summarizes the key approaches taken by EPA to assess exposures and health risks associated with exposure to ambient SO_2. Section II.D summarizes the approach that was used in the current review of the SO_2 NAAQS with regard to consideration of the scientific evidence and the air quality, exposure, and risk-based results related to the adequacy of the current standards and potential alternative standards. Sections II.E and II.F discuss, respectively, the Administrator's decisions regarding the adequacy of the current standards and the elements of a new short-term standard, taking into consideration public comments on the proposed decisions. Section II.G summarizes the Administrator's decisions with regard to the SO_2 primary NAAQS.

A. Characterization of SO_2 Air Quality

1. Anthropogenic Sources and Current Patterns of SO_2 Air Quality

Anthropogenic SO_2 emissions originate chiefly from point sources, with fossil fuel combustion at electric utilities (~66%) and other industrial facilities (~29%) accounting for the majority of total emissions (ISA, section 2.1). Other anthropogenic sources of SO_2 include both the extraction of metal from ore as well as the burning of high sulfur-containing fuels by locomotives, large ships, and equipment utilizing diesel engines. SO_2 emissions and ambient concentrations follow a strong east to west gradient due to the large numbers of coal-fired electric generating units in the Ohio River Valley and upper Southeast regions. In the 12 Consolidated Metropolitan Statistical Areas (CMSAs) that had at least four SO_2 regulatory monitors from 2003–2005, 24-hour average concentrations in the continental U.S. ranged from a reported low of ~1 ppb in Riverside, CA and San Francisco, CA to a high of ~12 ppb in Pittsburgh, PA and Steubenville, OH (ISA, section 2.5.1). In addition, outside or inside all CMSAs from 2003–2005, the annual average SO_2 concentration was 4 ppb (ISA, Table 2–8). However, spikes in hourly concentrations occurred. The mean 1-hour maximum concentration outside or inside CMSAs was 13 ppb, with a maximum value of greater than 600 ppb outside CMSAs and greater than 700 ppb inside CMSAs (ISA, Table 2–8).

Temporal and spatial patterns of 5-minute peaks of SO_2 are also important given that controlled human exposure studies have demonstrated that exposure to these peaks can result in adverse respiratory effects in exercising asthmatics (*see* section II.B below). For those monitors which voluntarily reported 5-minute block average data,[3] when maximum 5-minute concentrations were reported, the absolute highest concentration over the ten-year period exceeded 4000 ppb, but for all individual monitors, the 99th percentile was below 200 ppb (ISA, section 2.5.2 Table 2–10). Median concentrations from these monitors reporting 5-minute data ranged from 1 ppb to 8 ppb, and the average for each maximum 5-minute level ranged from 3 ppb to 17 ppb. Delaware, Pennsylvania, Louisiana, and West Virginia had mean values for maximum 5-minute data exceeding 10 ppb. Among aggregated within-State data for the 16 monitors from which all 5-minute average intervals were reported, the median values ranged from 1 ppb to 5 ppb, and the means ranged from 3 ppb to 11 ppb (ISA, section 2.5.2 at 2–43). The highest reported concentration was 921 ppb, but the 99th percentile values

[3] A small number of sites, 98 total from 1997 to 2007 of the approximately 500 SO_2 monitors, and not the same sites in all years, voluntarily reported 5-minute block average data to AQS (ISA, section 2.5.2). Of these, 16 reported all twelve 5-minute averages in each hour for at least part of the time between 1997 and 2007. The remainder reported only the maximum 5-minute average in each hour.

for aggregated within-State data were all below 90 ppb (*id*).

2. SO_2 Monitoring

Although EPA established the SO_2 standards in 1971, uniform minimum monitoring network requirements for SO_2 monitoring were only adopted in May 1979. From the time of the implementation of the 1979 monitoring rule through 2008, the SO_2 monitoring network has steadily decreased in size from approximately 1496 sites in 1980 to the approximately 488 sites operating in 2008. At present, except for SO_2 monitoring required at National Core Monitoring Stations (NCore stations), there are no minimum monitoring requirements for SO_2 in 40 CFR part 58 Appendix D, other than a requirement for EPA Regional Administrator approval before removing any existing monitors and a requirement that any ongoing SO_2 monitoring must have at least one monitor sited to measure the maximum concentration of SO_2 in that area. EPA removed the specific minimum monitoring requirements for SO_2 in the 2006 monitoring rule revisions, except for monitoring at NCore stations, based on the fact that there were no SO_2 nonattainment areas at that time, coupled with trends showing an increasing gap between national average SO_2 concentrations and the current 24-hour and annual standards. The rule was also intended to provide State, local, and Tribal air monitoring agencies flexibility in meeting perceived higher priority monitoring needs for other pollutants, or to implement the new multi-pollutant sites (NCore network) required by the 2006 rule revisions (71 FR 61236, (October 6, 2006)). More information on SO_2 monitoring can be found in section IV.

B. Health Effects Information

The ISA concluded that there was sufficient evidence to infer a "causal relationship" between respiratory morbidity and short-term (5-minutes to 24-hours) exposure to SO_2 (ISA, section 5.2). Importantly, we note that a "causal relationship" is the strongest finding the ISA can make.[4] This conclusion was based on the consistency, coherence, and plausibility of findings observed in controlled human exposure studies of 5–10 minutes, epidemiologic studies mostly using 1-hour daily maximum and 24-hour average SO_2 concentrations, and animal toxicological studies using exposures of minutes to hours (ISA, section 5.2). This evidence is briefly summarized below and discussed in more detail in the proposal (*see* sections II.B.1 to II.B.5, *see* 74 FR at 64815–821). We also note that the ISA judged evidence of an association between SO_2 exposure and other health categories to be less convincing; other associations were judged to be suggestive but not sufficient to infer a causal relationship (*i.e.,* short-term exposure to SO_2 and mortality) or inadequate to infer the presence or absence of a causal relationship (*i.e.,* short-term exposure to SO_2 and cardiovascular morbidity, and long-term exposure to SO_2 and respiratory morbidity, other morbidity, and mortality). Key conclusions from the ISA are described in greater detail in Table 5–3 of the ISA.

1. Short-Term (5-minute to 24-hour) SO_2 Exposure and Respiratory Morbidity Effects

The ISA examined numerous controlled human exposure studies and found that moderate or greater decrements in lung function (*i.e.,* ≥ 15% decline in Forced Expiratory Volume (FEV_1) and/or ≥ 100% increase in specific airway resistance (sRaw)) occur in some exercising asthmatics exposed to SO_2 concentrations as low as 200–300 ppb for 5–10 minutes. The ISA also found that among asthmatics, both the percentage of individuals affected, and the severity of the response increased with increasing SO_2 concentrations. That is, at 5–10 minute concentrations ranging from 200–300 ppb, the lowest levels tested in free breathing chamber studies, approximately 5–30% percent of exercising asthmatics experienced moderate or greater decrements in lung function (ISA, Table 3–1). At concentrations of 400–600 ppb, moderate or greater decrements in lung function occurred in approximately 20–60% of exercising asthmatics, and compared to exposures at 200–300 ppb, a larger percentage of asthmatics experienced severe decrements in lung function (*i.e.,* ≥ 20% decrease in FEV_1 and/or ≥ 200% increase in sRaw; ISA, Table 3–1). Moreover, at SO_2 concentrations ≥ 400 ppb (5–10 minute exposures), moderate or greater decrements in lung function were often statistically significant at the group mean level and frequently accompanied by respiratory symptoms. *Id.*

The ISA also found that in locations meeting the current SO_2 NAAQS, numerous epidemiologic studies reported positive associations between ambient SO_2 concentrations and respiratory symptoms in children, as well as emergency department visits and hospitalizations for all respiratory causes and asthma across multiple age groups. Moreover, the ISA concluded that these epidemiologic studies were consistent and coherent. This evidence was consistent in that associations were reported in studies conducted in numerous locations and with a variety of methodological approaches (ISA, section 5.2; p. 5–5). It was coherent in that respiratory symptom results from epidemiologic studies of short-term (predominantly 1-hour daily maximum or 24-hour average) SO_2 concentrations were generally in agreement with respiratory symptom results from controlled human exposure studies of 5–10 minutes. These results were also coherent in that the respiratory effects observed in controlled human exposure studies of 5–10 minutes further provided a basis for a progression of respiratory morbidity that could lead to the increased emergency department visits and hospital admissions observed in epidemiologic studies (ISA, section 5.2; p. 5–5). In addition, the ISA found that when evaluated as a whole, SO_2 effect estimates in multi-pollutant models generally remained positive and relatively unchanged when co-pollutants were included. Therefore, although recognizing the uncertainties associated with separating the effects of SO_2 from those of co-occurring pollutants, the ISA concluded that "the limited available evidence indicates that the effect of SO_2 on respiratory health outcomes appears to be generally robust and independent of the effects of gaseous co-pollutants, including NO_2 and O_3, as well as particulate co-pollutants, particularly $PM_{2.5}$" (ISA, section 5.3; p. 5–9).

The ISA also found that the respiratory effects of SO_2 were consistent with the mode of action as it is currently understood from animal toxicological and controlled human exposure studies (ISA, section 5.2; p. 5–2). The immediate effect of SO_2 on the respiratory system is bronchoconstriction. This response is mediated by chemosensitive receptors in the tracheobronchial tree. Activation of these receptors triggers central nervous system reflexes that result in

[4] A causal relationship is based on "[e]vidence [that] is sufficient to conclude that there is a causal relationship between relevant pollutant exposures and the health outcome. That is, a positive association has been observed between the pollutant and the outcome in studies in which chance, bias, and confounding could be ruled out with reasonable confidence. Evidence includes, for example, controlled human exposure studies; or observational studies that cannot be explain by plausible alternatives or are supported by other lines of evidence (*e.g.* animal studies or mechanism of action information). Evidence includes replicated and consistent high-quality studies by multiple investigators." ISA Table 1–2, at 1–11.

bronchoconstriction and respiratory symptoms that are often followed by rapid shallow breathing (*id*). The ISA noted that asthmatics are likely more sensitive to the respiratory effects of SO_2 due to pre-existing inflammation associated with the disease. For example, pre-existing inflammation may lead to enhanced release of inflammatory mediators, and/or enhanced sensitization of the chemosensitive receptors (*id*).

Taken together, the ISA concluded that the controlled human exposure, epidemiologic, and toxicological evidence supported its determination of a causal relationship between respiratory morbidity and short-term (5-minutes to 24-hours) exposure to SO_2.

a. Adversity of Short-Term Respiratory Morbidity Effects

As discussed more fully in the proposal (section II.B.1.c, 74 FR at 64817) and in section II.E.2.b below, based on: (1) American Thoracic Society (ATS) guidelines; (2) advice and recommendations from CASAC (*see* specific consensus CASAC comments in sections II.E.2.b and II.F.4.b below); and (3) conclusions from previous NAAQS reviews, EPA found that 5–10 minute exposures to SO_2 concentrations at least as low as 200 ppb can result in adverse health effects in some asthmatics (*i.e.,* 5–30% of the tested individuals in controlled human exposure studies of 200–300 ppb). As just mentioned, at SO_2 concentrations ≥ 400 ppb, controlled human exposure studies have reported decrements in lung function that are often statistically significant at the group mean level, and that are frequently accompanied by respiratory symptoms. Being mindful that the ATS guidelines specifically indicate decrements in lung function with accompanying respiratory symptoms as being adverse (*see* proposal section II.B.1.c, 74 FR at 64817 and section II.E.2.b below), exposure to 5–10 minute SO_2 concentrations ≥ 400 ppb can result in health effects that are clearly adverse.

The ATS also indicated that exposure to air pollution that increases the risk of an adverse effect to a population is adverse, even though it may not increase the risk of any individual to an unacceptable level (ATS 2000; *see* proposal section II.B.1.c, 74 FR at 64817). As an example, ATS states:

> A population of children with asthma could have a distribution of lung function such that no individual child has a level associated with significant impairment. Exposure to air pollution could shift the distribution toward lower levels without bringing any individual child to a level that is associated with clinically relevant consequences. Individuals within the population would, however, have diminished reserve function and are at potentially increased risk if affected by another agent, *e.g.,* a viral infection. Assuming that the relationship between the risk factor and the disease is causal, the committee considered that such a shift in the risk factor distribution, and hence the risk profile of the exposed population, should be considered adverse, even in the absence of the immediate occurrence of frank illness (ATS 2000, p. 668).

As mentioned above, the ISA reported that exposure to SO_2 concentrations as low as 200–300 ppb for 5–10 minutes results in approximately 5–30% of exercising asthmatics experiencing moderate or greater decrements in lung function (defined in terms of a ≥ 15% decline in FEV_1 or 100% increase in sRaw; ISA, Table 3–1). Even though these results were not statistically significant at the group mean level, in light of EPA's interpretation of how to apply the ATS guidelines for defining an adverse effect, as described above, the REA found that these results could reasonably indicate an SO_2-induced shift in these lung function measurements for this subset of the population. As a result, an appreciable percentage of exercising asthmatics exposed to SO_2 concentrations as low as 200 ppb would be expected to have diminished reserve lung function and would be expected to be at greater risk if affected by another respiratory agent, for example, viral infection. Importantly, as explained immediately above, diminished reserve lung function in a population that is attributable to air pollution is considered an adverse effect under ATS guidance. In addition to the 2000 ATS guidelines, the REA was also mindful of previous CASAC recommendations (Henderson 2006) and NAAQS review conclusions (EPA 2006, EPA 2007d) indicating that moderate decrements in lung function can be clinically significant in some asthmatics (discussed in detail below, *see* section II.E.2.b). The REA further considered that subjects participating in these controlled human exposure studies do not include severe asthmatics and that it was reasonable to presume that persons with more severe asthma than the study participants would have a more serious health effect from short-term exposure to 200 ppb SO_2.[5] Taken together, the REA concluded that exposure to SO_2 concentrations at least as low as 200 ppb can result in adverse health effects in asthmatics and that this conclusion was in agreement with consensus CASAC comments and recommendations expressed during the current SO_2 NAAQS review (*see* sections II.E.2.b and II.F.4.b below).

In addition to the controlled human exposure evidence, epidemiologic studies also indicate that adverse respiratory morbidity effects are associated with SO_2 (REA, section 4.3). As mentioned above, in reaching the conclusion of a causal relationship between respiratory morbidity and short-term SO_2 exposure, the ISA generally found positive associations between ambient SO_2 concentrations and emergency department visits and hospitalizations for all respiratory causes and asthma. Notably, emergency department visits, hospitalizations, episodic respiratory illness, and aggravation of respiratory diseases (*e.g.* asthma) attributable to air pollution are considered adverse health effects under ATS guidelines.

2. Health Effects and Long-Term Exposures to SO_2

There were numerous studies published since the last review examining possible associations between long-term SO_2 exposure and mortality and morbidity (respiratory morbidity, carcinogenesis, adverse prenatal and neonatal outcomes) endpoints. However, the ISA concluded that the evidence relating long-term (weeks to years) SO_2 exposure to adverse health effects was "inadequate to infer the presence or absence of a causal relationship" (ISA, Table 5–3). That is, the ISA found the long-term health evidence to be of insufficient quantity, quality, consistency, or statistical power to make a determination as to whether SO_2 was truly associated with these health outcomes (ISA, Table 1–2).

3. SO_2-Related Impacts on Public Health

Interindividual variation in human responses to air pollutants indicates that some populations are at increased risk for the detrimental effects of ambient exposure to SO_2. The NAAQS are intended to provide an adequate margin of safety for both the general population and susceptible populations that are potentially at increased risk for health effects in response to exposure to ambient air pollution (*see* footnote 1 above). To facilitate the identification of populations at increased risk for SO_2-related health effects, studies have identified factors that contribute to the susceptibility of individuals to SO_2. Susceptible individuals are broadly defined as those with a greater

[5] We also note that very young children were not included in the controlled human exposure studies and this absence of data on what is likely to be a sensitive life stage is a source of uncertainty for children's susceptibility to SO_2.

likelihood of an adverse outcome given a specific exposure in comparison with the general population (American Lung Association, 2001). The susceptibility of an individual to SO_2 can encompass a multitude of factors which represent normal developmental phases or life stages (*e.g.,* age) or biologic attributes (*e.g.,* gender); however, other factors (*e.g.,* socioeconomic status (SES)) may influence the manifestation of disease and also increase an individual's susceptibility (American Lung Association, 2001). In addition, populations may be at increased risk to SO_2 due to an increase in their exposure during certain life stages (*e.g.,* childhood or old age) or as a result of external factors (*e.g.,* SES) that contribute to an individual being disproportionately exposed to higher concentrations than the general population.[6] It should be noted that in some cases specific populations may be affected by multiple susceptibility factors. For example, a population that is characterized as having low SES may have less access to healthcare resulting in the manifestation of a disease, which increases their susceptibility to SO_2, while they may also reside in a location that results in disproportionately high exposure to SO_2.

To examine whether SO_2 differentially affects certain populations, stratified analyses are often conducted in epidemiologic investigations to identify the presence or absence of effect modification. A thorough evaluation of potential effect modifiers may help identify susceptible populations that are at increased risk to SO_2 exposure. These analyses are based on the proper identification of confounders and subsequent adjustment for them in statistical models, which helps separate a spurious from a true causal association. Although the design of toxicological and human clinical studies does not allow for an extensive examination of effect modifiers, the use of animal models of disease and the study of individuals with underlying disease or genetic polymorphisms do allow for comparisons between subgroups. Therefore, the results from these studies, combined with those results obtained through stratified analyses in epidemiologic studies, contribute to the overall weight of evidence for the increased susceptibility of specific populations to SO_2. Those populations identified in the ISA to be potentially at greater risk of experiencing an adverse health effect from SO_2 were described in detail in the proposal (section II.B.5) and include: (1) Those with pre-existing respiratory disease; (2) children and older adults; (3) persons who spend increased time outdoors or at elevated ventilation rates; (4) persons with lower SES; and (5) persons with certain genetic factors.

As discussed in the proposal (section II.B.5.g, 74 FR at 64821), large proportions of the U.S. population are likely to be at increased risk of experiencing SO_2-related health effects. In the United States, approximately 7% of adults and 9% of children have been diagnosed with asthma. Notably, the prevalence and severity of asthma is higher among certain ethnic or racial groups such as Puerto Ricans, American Indians, Alaskan Natives, and African Americans (EPA 2008b). Furthermore, a higher prevalence of asthma among persons of lower SES and an excess burden of asthma hospitalizations and mortality in minority and inner-city communities have been observed (EPA, 2008b). In addition, population groups based on age comprise substantial segments of individuals that may be potentially at risk for SO_2-related health impacts. Based on U.S. census data from 2000, about 72.3 million (26%) of the U.S. population are under 18 years of age, 18.3 million (7.4%) are under 5 years of age, and 35 million (12%) are 65 years of age or older. There is also concern for the large segment of the population that is potentially at risk to SO_2-related health effects because of increased time spent outdoors at elevated ventilation rates (those who work or play outdoors). Overall, the considerable size of the population groups at risk indicates that exposure to ambient SO_2 could have a significant impact on public health in the United States.

C. Human Exposure and Health Risk Characterization

To put judgments about SO_2-associated health effects into a broader public health context, EPA has drawn upon the results of the quantitative exposure and risk assessments. Judgments reflecting the nature of the evidence and the overall weight of the evidence are taken into consideration in these quantitative exposure and risk assessments. These assessments include estimates of the likelihood that asthmatic children at moderate or greater exertion (*e.g.* while exercising) in St. Louis or Greene County, Missouri would experience SO_2 exposures of potential concern. In addition, these analyses include an estimate of the number and percent of exposed asthmatic children in these locations likely to experience SO_2-induced lung function responses (*i.e.,* moderate or greater decrements in lung function defined in terms of sRaw or FEV_1) under varying air quality scenarios (*i.e.,* current air quality and air quality simulated to just meet the current or potential alternative standards). These assessments also characterize the kind and degree of uncertainties inherent in such estimates.

As previously mentioned, the ISA concluded that the evidence for an association between respiratory morbidity and short-term SO_2 exposure was "sufficient to infer a causal relationship" (ISA, section 5.2) and that the "definitive evidence" for this conclusion was from the results of 5–10 minute controlled human exposure studies demonstrating decrements in lung function and/or respiratory symptoms in exercising asthmatics (ISA, section 5.2). Accordingly, the air quality and exposure analyses and their associated risk characterizations focused on 5-minute concentrations of SO_2 in excess of potential health effect benchmark values derived from the controlled human exposure literature (*see* proposal section II.C.1, 74 FR at 64821, and REA, section 6.2). These benchmark levels are not potential standards, but rather are SO_2 exposure concentrations which represent "exposures of potential concern" which are used in these analyses to estimate potential exposures and risks associated with 5-minute concentrations of SO_2. The REA considered 5-minute benchmark levels of 100, 200, 300, and 400 ppb in these analyses, but especially noted exceedances or exposures with respect to the 200 and 400 ppb 5-minute benchmark levels. These benchmark levels were highlighted because (1) 400 ppb represents the lowest concentration in free-breathing controlled human exposure studies where moderate or greater lung function decrements occurred which were often statistically significant at the group mean level and were frequently accompanied by respiratory symptoms; and (2) 200 ppb is the lowest level at which moderate or greater decrements in lung function in free-breathing controlled human exposure studies were found in some individuals, although these lung function changes were not statistically significant at the group mean level. Notably, 200 ppb is also the lowest level that has been tested in free-breathing controlled human exposure studies (REA, section 4.2.2).[7]

[6] This aspect of susceptibility is referred to as vulnerability in the proposal and in the ISA.

[7] The ISA cites one chamber study with intermittent exercise where healthy and asthmatic

Continued

The REA utilized three approaches to characterize health risks. In the first approach, for each air quality scenario, statistically estimated 5-minute SO_2 concentrations [8] and measured ambient 5-minute SO_2 concentrations were compared to the 5-minute potential health effect benchmark levels discussed above (REA, chapter 7). This air quality analysis included all available ambient monitoring data as well as a more detailed analysis in 40 counties. The air quality analysis was considered a broad characterization of national air quality and human exposures that might be associated with these 5-minute SO_2 concentrations. An advantage of the air quality analysis is its relative simplicity; however, there is uncertainty associated with the assumption that SO_2 air quality can serve as an adequate surrogate for total exposure to ambient SO_2. Actual exposures might be influenced by factors not considered by this approach, including small-scale spatial variability in ambient SO_2 concentrations (which might not be represented by the current fixed-site ambient monitoring network) and spatial/temporal variability in human activity patterns. A more detailed overview of the air quality analysis and its associated limitations and uncertainties is provided in the proposal (*see* sections II.C.2, 74 FR at 64822 and II.C.3, 74 FR at 64823, respectively) and the air quality analysis is thoroughly described in the REA (chapter 7).

In the second approach, an inhalation exposure model was used to generate more realistic estimates of personal exposures in asthmatics (REA, chapter 8). This analysis estimated temporally and spatially variable microenvironmental 5-minute SO_2 concentrations and simulated asthmatics' contact with these pollutant concentrations while at moderate or greater exertion (*i.e.,* while at elevated ventilation rates). The approach was designed to estimate exposures that are not necessarily represented by the existing ambient monitoring data and to better represent the physiological conditions corresponding with the respiratory effects reported in controlled human exposure studies. AERMOD, an EPA dispersion model, was used to estimate 1-hour ambient SO_2 concentrations using emissions estimates from stationary, non-point, and where applicable, port sources. The Air Pollutants Exposure (APEX) model, an EPA human exposure model, was then used to estimate population exposures using the estimated hourly census block level SO_2 concentrations. From the 1-hour census block concentrations, 5-minute maximum SO_2 concentrations within each hour were estimated by APEX (REA, section 8.7.1) using the statistical relationship mentioned above in footnote 8. Estimated exposures to 5-minute SO_2 levels were then compared to the 5-minute potential health effect benchmark levels discussed above. This approach to assessing exposures was more resource intensive than using ambient levels as an indicator of exposure; therefore, the final REA included the analysis of two locations: St. Louis and Greene County, MO. Although the geographic scope of this analysis was limited, the approach provided estimates of SO_2 exposures in asthmatics and asthmatic children in St. Louis and Greene Counties, and thus served to complement the broader air quality characterization. A more detailed overview of this exposure analysis and its associated limitations and uncertainties is provided in the proposal (*see* sections II.C.2, 74 FR at 64822 and II.C.3, 74 FR at 64823, respectively) and the exposure analysis is thoroughly described in the REA (chapter 8).

The third approach was a quantitative risk assessment. This approach combined results from the exposure analysis (*i.e.,* the number of exposed total asthmatics or asthmatic children while at moderate or greater exertion) with exposure-response functions derived from individual level data from controlled human exposure studies (*see* ISA, Table 3–1 and Johns (2009) [9]) to estimate the percentage and number of exposed asthmatics and asthmatic children in St. Louis and Greene County likely to experience a moderate or greater lung function response (*i.e.,* decrements in lung function defined in terms of FEV_1 and sRaw) under the air quality scenarios mentioned above (REA, chapter 9). A more detailed overview of this analysis and its associated limitations and uncertainties is provided in the proposal (*see* sections II.C.2, 74 FR at 64822 and II.C.3, 74 FR at 64823, respectively) and the quantitative risk analysis is thoroughly described in the REA (chapter 9).

Notably, for the reasons described in the REA (REA, section 10.3.3) and the proposal (*see* section II.E.1.b, 74 FR at 64827), when considering the St. Louis and Greene County exposure and risk results as they relate to the adequacy of the current standards, the REA concluded that the St. Louis results were more informative in terms of ascertaining the extent to which the current standards protect against health effects linked to the various benchmarks (linked in turn to 5-minute SO_2 exposures). The results in fact suggested that the current standards may not adequately protect public health (REA, section 10.3.3, p. 364). Moreover, the REA judged that the exposure and risk estimates for the St. Louis study area provided useful insights into exposures and risks for other urban areas in the U.S. with similar population and SO_2 emissions densities (*id.*). For similar reasons, the St. Louis results were more informative for ascertaining the adequacy of the potential alternative standards under consideration.

Key results of the air quality, exposure, and risk analyses were presented in the policy assessment chapter of the REA (chapter 10) and summarized in the proposal (*see* Tables 2–4 in the preamble to the proposed rule). In considering these results, the proposal noted that these analyses support that 5-minute SO_2 exposures, reasonably judged important from a public health perspective, were associated with air quality adjusted upward to simulate just meeting the current standards (*see* proposal, section II.E.1.c, 74 FR at 64828). Moreover, these results indicated that 99th percentile 1-hour daily maximum standard levels in the range of 50–100 ppb could substantially limit exposures of asthmatic children at moderate or greater exertion from 5-minute SO_2 concentrations ≥400 ppb, and appreciably limit exposures of these children from 5-minute SO_2 concentrations ≥200 ppb (REA, p. 392–393). Results of these analyses also indicated that a 1-hour standard at 150

children were exposed to 100 ppb SO_2 in a mixture with ozone and sulfuric acid. The ISA notes that compared to exposure to filtered air, exposure to the pollutant mix did not result in statistically significant changes in lung function or respiratory symptoms (ISA, section 3.1.3.4).

8 Benchmark values derived from the controlled human exposure literature were associated with a 5-minute averaging time. However, as noted in footnote 3 above, only 98 ambient monitors located in 13 States from 1997–2007 reported measured 5-minute SO_2 concentrations since such monitoring is not required (*see* section II.A.2 and section IV). In contrast, 809 monitors in 48 States, DC, Puerto Rico, and the Virgin Islands reported 1-hour SO_2 concentrations over a similar time period. Therefore, to broaden analyses to areas where measured 5-minute SO_2 concentrations were not available, the REA utilized a statistical relationship to estimate the highest 5-minute level in an hour, given a reported 1-hour average SO_2 concentration (REA, section 6.4). Then, similar to measured 5-minute SO_2 concentrations, statistically estimated 5-minute SO_2 concentrations were compared to 5-minute potential health effect benchmark values (REA, chapters 7 and 8, respectively).

9 EPA recently conducted a complete quality assurance review of all individual subject data. The results of this review did not substantively change any of the entries in ISA, Table 3–1, and did not in any way affect the conclusions of the ISA (*see* Johns and Simmons, 2009).

ppb could still substantially limit exposures of asthmatic children at moderate or greater exertion from 5-minute SO_2 concentrations ≥400 ppb, but would provide these children appreciably less protection from exposure to 5-minute SO_2 concentrations ≥200 ppb (REA, p. 395–396).

D. Approach for Determining Whether To Retain or Revise the Current Standards

EPA notes that the final decision on retaining or revising the current primary SO_2 standards is a public health policy judgment to be made by the Administrator. This judgment has been informed by a recognition that the available health effects evidence reflects a continuum consisting of ambient levels of SO_2 at which scientists generally agree that health effects are likely to occur, through lower levels at which the likelihood and magnitude of the response become increasingly uncertain. The Administrator's final decisions draw upon scientific information and analyses related to health effects, population exposures and risks; judgments about the appropriate response to the range of uncertainties that are inherent in the scientific evidence and analyses; and comments received from CASAC and the public.

To evaluate whether the current primary SO_2 standards are adequate or whether revisions are appropriate, EPA has used an approach in this review described in chapter 10 of the REA which builds upon the approaches used in reviews of other criteria pollutants, including the most recent reviews of the NO_2, Pb, O_3, and PM NAAQS (EPA, 2008c; EPA, 2007c; EPA, 2007d; EPA, 2005), and reflects the latest body of evidence and information that is currently available, as reflected by the ISA. As in other recent reviews, EPA considered the implications of placing more or less weight or emphasis on different aspects of the scientific evidence and the exposure-/risk-based information, recognizing that the weight to be given to various elements of the evidence and exposure/risk information is part of the public health policy judgments that the Administrator will make in reaching decisions on the standard.

A series of general questions framed this approach to considering the scientific evidence and exposure-/risk-based information. First, EPA's consideration of the scientific evidence and exposure/risk information with regard to the adequacy of the current standards has been framed by the following questions:

- To what extent does evidence that has become available since the last review reinforce or call into question evidence for SO_2-associated effects that were identified in the last review?
- To what extent has evidence for different health effects and/or susceptible populations become available since the last review?
- To what extent have uncertainties identified in the last review been reduced and/or have new uncertainties emerged?
- To what extent does evidence and exposure-/risk-based information that has become available since the last review reinforce or call into question any of the basic elements (indicator, averaging time, form, and level) of the current standard?

To the extent that the available evidence and exposure-/risk-based information suggests it may be appropriate to consider revision of the current standards, EPA considers that evidence and information with regard to its support for consideration of a standard that is either more or less stringent than the current standards. This evaluation is framed by the following questions:

- Is there evidence that associations, especially causal or likely causal associations, extend to ambient SO_2 concentrations as low as, or lower than, the concentrations that have previously been associated with health effects? If so, what are the important uncertainties associated with that evidence?
- Are exposures above benchmark levels and/or health risks estimated to occur in areas that meet the current standard? If so, are the estimated exposures and health risks important from a public health perspective? What are the important uncertainties associated with the estimated risks?

To the extent that there is support for consideration of a revised standard, EPA then considers the specific elements of the standard (indicator, averaging time, form, and level) within the context of the currently available information. In so doing, the Agency addresses the following questions regarding the elements of the standard:

- Does the evidence provide support for considering a different indicator for gaseous SO_X?
- Does the evidence provide support for considering different, or additional averaging times?
- What ranges of levels and forms of alternative standards are supported by the evidence, and what are the associated uncertainties and limitations?
- To what extent do specific averaging times, levels, and forms of alternative standards reduce the estimated exposures above benchmark levels and risks attributable to exposure to ambient SO_2, and what are the uncertainties associated with the estimated exposure and risk reductions?

The questions outlined above have been addressed in the REA. The following sections present considerations regarding the adequacy of the current standards and conclusions on the elements of a new short-term standard in terms of indicator, averaging time, form, and level.

E. Adequacy of the Current Standards

This section discusses considerations related to the decision as to whether the current 24-hour and annual SO_2 primary NAAQS are requisite to protect public health with an adequate margin of safety. Specifically, section II.E.1 provides an overview of the rationale supporting the Administrator's proposal that the current standards do not provide adequate public health protection; section II.E.2 discusses public comments received on the adequacy of the current standards; and section II.E.3 discusses the Administrator's final decision on whether the current SO_2 primary NAAQS is requisite to protect public health with an adequate margin of safety, as required by sections 109(d) and (b) of the Act.

1. Rationale for Proposed Decision

In the proposal, the Administrator initially concluded that the current 24-hour and annual SO_2 NAAQS were not adequate to protect public health with an adequate margin of safety (*see* section II.E.4, 74 FR at 64829). In reaching this conclusion, she considered the: (1) Scientific evidence and conclusions in the ISA; (2) exposure and risk information presented in the REA; (3) conclusions of the policy assessment chapter of the REA; and (4) views expressed by CASAC. These considerations are discussed in detail in the proposal (*see* section II.E., 74 FR at 64826) and are summarized in this section.

In the proposal the Administrator noted the following in considering the adequacy of the current 24-hour and annual primary SO_2 standards:

- The conclusion of the ISA that the results of controlled human exposure and epidemiologic studies form a plausible and coherent data set that supports a causal relationship between short-term (5-minutes to 24-hours) SO_2 exposures and adverse respiratory effects, and that the epidemiologic evidence (buttressed by the clinical evidence) indicates that the effects seen in the epidemiologic studies are attributable to exposure to SO_2 (ISA, section 5.2).
- The conclusion of the ISA that "[i]n the epidemiologic studies, respiratory effects were observed in areas where the maximum ambient 24-h avg SO_2 concentration was below the current 24-

h avg NAAQS level * * *.” (ISA, section 5.2, p. 5–2.) and so would occur at ambient SO_2 concentrations that are present in locations meeting the current 24-hour NAAQS.

• These respiratory effects also occurred in areas with annual air quality levels considerably lower than those allowed by the current annual standard, indicating that the current annual standard is also not providing protection against short-term health effects reported in epidemiologic studies (ISA, section 5.2).

• Analyses in the REA supporting that 5-minute exposures, reasonably judged important from a public health perspective (*i.e.,* respiratory effects judged to be adverse to the health of asthmatics, *see* sections II.B.1.c above, and II.E.2.b below), were associated with air quality adjusted upward to simulate just meeting the current 24-hour and annual standards.

• CASAC advice “that the current 24-hour and annual standards are not adequate to protect public health, especially in relation to short term exposures to SO_2 (5–10 minutes) by exercising asthmatics” (Samet, 2009, p. 15).

Based on these considerations (discussed in more detail in the proposal, *see* sections II.E.1 and II.E.2), the Administrator proposed that the current 24-hour and annual SO_2 standards are not requisite to protect public health with an adequate margin of safety against adverse respiratory effects associated with short-term (5-minute to 24-hour) SO_2 exposures. In considering approaches to revising the current standards, the Administrator initially concluded it appropriate to consider setting a new 1-hour standard. The Administrator noted that a 1-hour standard would likely provide increased public health protection, especially for members of at-risk groups, from the respiratory effects described in both epidemiologic and controlled human exposure studies.

2. Comments on the Adequacy of the Current Standards

This section discusses public comments on the proposal that either supported or opposed the Administrator’s proposed decision to revise the current SO_2 primary NAAQS. Comments on the adequacy of the current standards that focused on the scientific and/or the exposure/risk basis for the Administrator’s proposed conclusions are discussed in sections II.E.2.a–II.E.2.c. Comments on the epidemiologic evidence are considered in section II.E.2.a. Comments on the controlled human exposure evidence are considered in section II.E.2.b. Comments on human exposure and health risk assessments are considered in section II.E.2.c. To the extent these comments on the evidence and information are also used to justify commenters’ conclusions on decisions related to indicator, averaging time, form, or level, they are noted as well in the appropriate sections below (II.F.1–II.F.4, respectively). The summaries of comments, and responses thereto, presented below are not exclusive: other comments and responses are being included in the Response to Comment (RTC) Document which is part of the record for this rulemaking (EPA, 2010).

Many public commenters agreed with the proposal that based on the available information, the current SO_2 standards are not requisite to protect public health with an adequate margin of safety and that revisions to the standards are therefore appropriate. Among those calling for revisions to the standards were environmental groups (*e.g.,* Sierra Club, WEACT for Environmental Justice, Center for Biological Diversity, (CBD) Environmental Defense Fund (EDF), Natural Resources Defense Council (NRDC)); medical/public health organizations (*e.g.,* American Lung Association (ALA), American Thoracic Society (ATS)); State environmental organizations (*e.g.,* National Association of Clean Air Agencies (NACAA), Northeast States for Coordinated Air Use Management (NESCAUM); State environmental agencies (*e.g.,* such agencies in DE, IA, IL, MI, NY, NM, OH, PA, TX, VT); the Fond du Lac Band of Lake Superior Chippewa (Fond du Lac) Tribe, local groups (*e.g.,* Houston-Galveston Area Council, Alexandria Department of Transportation and Environmental Services) and most individual commenters (~13,000). These commenters generally concluded that the current SO_2 standards need to be revised and that a more stringent standard is needed to protect the health of susceptible population groups. In supporting the need to adopt a more stringent NAAQS for SO_2, these commenters often referenced the conclusions of CASAC, as well as evidence and information presented in the proposal. As such, the rationale offered by these commenters was consistent with that presented in the proposal to support the Administrator’s proposed decision to revise the current SO_2 NAAQS.

Most industry commenters (*e.g.,* Utility Air Regulatory Group (UARG), American Petroleum Institute (API), Arizona Public Service, National Petrochemical & Refiners Association (NPRA), Montana-Dakota Utilities Co., Dominion Resources, Council of Industrial Boiler Owners (CIBO), Edison Electric Institute (EEI), Duke Energy, National Mining Association (NMA)); and some organizations (*e.g.,* Texas Association of Business, The Annapolis Center for Science-Based Public Policy (ACSBPP), South Carolina Chamber of Commerce) opposed the proposed revisions to the SO_2 primary NAAQS. In supporting their views, industry commenters generally concluded that EPA did not appropriately consider uncertainties associated with the epidemiologic and controlled human exposure evidence.

More specifically, with respect to the epidemiologic studies, many of these commenters concluded that results of these studies are confounded by co-pollutants and thus too uncertain to determine whether SO_2 is truly associated with the health outcomes being measured (*e.g.,* hospital admissions; **Federal Register** *see* below). With respect to the controlled human exposure studies, many commenters were critical of the 5-minute benchmark levels that were derived from these studies and subsequently used by EPA in the air quality, exposure, and risk analyses. These groups were particularly concerned about the Administrator’s reliance on the 200 ppb 5-minute benchmark level in assessing the adequacy of the current and potential alternative standards. In general, many industry groups maintained that adverse respiratory effects did not occur following 5–10 minute SO_2 exposures < 400 ppb (*e.g.,* API, EEI, CIBO) and some groups stated that even at SO_2 concentrations ≥ 400 ppb, reported effects may not be of clinical concern, and thus are likely not adverse (*e.g.,* UARG). Many industry groups (*e.g.,* API, UARG) also disagreed with EPA’s (and CASAC’s) conclusions that severe asthmatics were not included in these controlled human exposure studies, and that severe asthmatics would likely have a more pronounced response to SO_2 exposures at a given level, or would respond to even lower levels of SO_2.

In responding to these specific comments, we note that the Administrator relied in the proposal on the evidence, information, and judgments contained in the ISA and the REA (including the policy assessment chapter), as well as on the advice of CASAC. In considering the evidence, information, and judgments of the ISA and the REA, the Agency notes that these documents have been reviewed and discussed extensively by CASAC at multiple public meetings (*see* above, section I.D) and in their letters to the

EPA Administrator. Thus, it is important to note that CASAC generally accepted the key findings and conclusions presented in both the ISA and REA (*see* Henderson 2008a, Henderson 2008b, and Samet, 2009).

a. Comments on EPA's Interpretation of the Epidemiologic Evidence

Many industry groups (*e.g.,* API, UARG, American Chemistry Council (ACC), Dominion Resources, ExxonMobil, Progress Energy, CIBO, The Fertilizer Institute, EEI, Dow Chemical Company (Dow), MeadWestvaco Corporation (MWV), (NMA) and some organizations (*e.g.,* ACSBPP) commented that, given the presence of numerous co-pollutants in the air, the epidemiologic studies do not support the contention that SO_2 itself is causing health effects. For example, UARG stated: "The epidemiological evidence cannot determine that SO_2 is a cause of or a contributor to hospital admissions ("HA"), emergency department ("ED") visits or respiratory symptoms, the effects cited in the Proposed Rule."

Although EPA has recognized that multiple factors can contribute to the etiology of respiratory disease and that more than one air pollutant could independently impact respiratory health, we continue to judge, as discussed in the ISA, that the available evidence supports the conclusion that there is an independent effect of SO_2 on respiratory morbidity. In reaching this judgment, we recognize that a major methodological issue affecting SO_2 epidemiologic studies concerns the evaluation of the extent to which other air pollutants, particular $PM_{2.5}$,[10] may confound or modify SO_2-related effect estimates. The use of multi-pollutant regression models is a common approach for evaluating potential confounding by co-pollutants in epidemiologic studies. It is therefore important to note that when the ISA evaluated U.S. and international epidemiologic studies employing multi-pollutant models, SO_2 effect estimates generally remained positive and relatively unchanged when co-pollutants, including PM, were included (*see* ISA, p. 5–5). Therefore, although recognizing the uncertainties associated with separating the effects of SO_2 from those of co-occurring pollutants, the ISA concluded that the limited available evidence indicates that the effect of SO_2 on respiratory health outcomes appears to be generally robust and independent of the effects of gaseous co-pollutants, including NO_2 and O_3, as well as particulate co-pollutants, particularly $PM_{2.5}$ (ISA, section 5.2; p. 5–9).

In considering questions of confounding and causation, the epidemiologic studies should not be considered in a vacuum. As emphasized by the ISA, and endorsed by CASAC, controlled human exposure studies provide support for the plausibility of the associations reported in epidemiologic studies (ISA, section 5–5; Henderson 2008a; Henderson 2008b). These controlled human exposure studies exposed exercising asthmatics to 5–10 minute peaks of SO_2 and reported decrements in lung function and/or respiratory symptoms in up to 60% of these individuals (depending on exposure concentration; *see* ISA, Table 5–3; p. 5–11). Thus, these experimental study results provide strong support for an independent contribution of SO_2 to the respiratory health effects reported in epidemiologic studies: "The effects of SO_2 on respiratory symptoms, lung function, and airway inflammation observed in the human clinical studies using peak exposures further provides a basis for a progression of respiratory morbidity resulting in increased emergency department visits and hospital admissions. Collectively, these findings provide biological plausibility for the observed association between ambient SO_2 levels and emergency department visits and hospitalizations for all respiratory diseases and asthma, notably in children and older adults. * * *" (ISA, section 5.2 at p. 5–5). Thus, EPA is not relying solely on the epidemiologic studies to evaluate whether associations reported in these studies (*e.g.,* associations with emergency department visits) are likely the result of ambient SO_2 exposure.

b. Comments on EPA's Interpretation of the Controlled Human Exposure Evidence

Many industry groups (*e.g.,* API, ACC, Progress Energy, EEI, CIBO) commented that adverse health effects do not occur following 5–10 minute SO_2 exposures < 400 ppb. In addition, some groups (*e.g.,* UARG) commented that adverse respiratory effects do not occur in exercising asthmatics following SO_2 exposures below 600 ppb. The disagreement is not whether effects occur in exercising asthmatics at these exposure levels and exposure durations. Rather, the issue is whether the effects experienced can properly be regarded as adverse. In general, these groups conclude that EPA's judgment of adverse health effects at SO_2 exposure levels below 600 or 400 ppb is inappropriately based on an unsound interpretation of ATS guidelines. More specifically, these groups generally contend that decrements in lung function without accompanying respiratory symptoms are not adverse effects of SO_2 exposure, and that decrements in lung function in a percentage of exercising asthmatics does not represent a shift in lung function at the population level. Some of these groups also contend that EPA followed the advice of individual CASAC members, rather than consensus CASAC written comments on the ISA and REA when concluding respiratory effects associated with SO_2 exposures below 600 or 400 ppb are adverse. Furthermore, some groups contend that effects below 400 ppb should not be considered adverse because compared to the number of asthmatics experiencing decrements in lung function, there were similar numbers of asthmatics experiencing increases in lung function. EPA disagrees with these comments, and believes that the clinical evidence also supports the conclusion that the current standards are not requisite to protect public health with and adequate margin of safety.

The Agency disagrees that adverse respiratory effects do not occur in exercising asthmatics following 5–10 minute SO_2 exposures ranging from 400–600 ppb. As previously mentioned, at SO_2 concentrations ranging from 400–600 ppb, moderate or greater decrements in lung function occur in approximately 20–60% of exercising asthmatics (again, defined in terms of a ≥ 15% decline in FEV_1 or 100% increase in sRaw; ISA, Table 3–1). Moreover, at concentrations ≥ 400 ppb, decrements in lung function are often statistically significant at the group mean level, and are frequently accompanied by respiratory symptoms (ISA, Table 5–1). ATS guidelines on what constitutes an adverse health effect of air pollution clearly state that reversible loss of lung function in combination with the presence of symptoms should be considered adverse (ATS 1985, 2000). Moderate or greater decrements in lung function accompanied by respiratory symptoms fit this description. Thus, the Agency's conclusion of adverse health effects associated with SO_2 concentrations ≥ 400 ppb is consistent with ATS guidelines.

The Agency also disagrees with industry commenters regarding the adversity of the respiratory effects seen in exercising asthmatics following 5–10 minute SO_2 exposures ranging from 200–300 ppb. As mentioned above (section II.B.1), and discussed more

[10] As noted in the proposal (*see* sections II.D.1, 74 FR at 64824–64825 and II.F.4.a, 74 FR at 64835), there is special sensitivity in this review in disentangling SO_2-related effects from PM-related effects (especially sulfate PM).

fully in the proposal (*see* section II.B.3, 74 FR at 64819), the ISA reported that exposure to SO_2 concentrations as low as 200–300 ppb for 5–10 minutes results in approximately 5–30% of exercising asthmatics experiencing moderate or greater decrements in lung function. In 2000, the ATS updated its guidelines on "what constitutes an adverse health effect of air pollution." These guidelines indicated that exposure to air pollution that increases the risk of an adverse effect to the entire population is adverse, even though it may not increase the risk of any individual to an unacceptable level (ATS 2000). For example, ATS notes that a population of asthmatics could have a distribution of lung function such that no individual has a level associated with significant impairment. Exposure to air pollution could shift the distribution to lower levels that still do not bring any individual to a level that is associated with clinically relevant effects. However, this would be considered adverse because individuals within the population would have diminished reserve function, and therefore would be at increased risk if affected by another agent (ATS 2000).

Considering the 2000 ATS guidelines, the results of the clinical studies conducted at 200–300 ppb were reasonably interpreted by EPA to indicate an SO_2-induced shift in these lung function measurements for a subset of this population. That is, an appreciable percentage of this population of exercising asthmatics would be expected to experience moderate or greater decrements in lung function in response to SO_2 concentrations as low as 200 ppb, and thus would be expected to have diminished reserve lung function. As a result, this sub-population would be at greater risk of a more severe response if affected by another respiratory agent (*e.g.,* viral infection, or O_3).

EPA is also mindful of CASAC comments on this issue following the second draft ISA. The second draft ISA placed relatively little weight on health effects associated with SO_2 exposures at 200–300 ppb. CASAC strongly disagreed with this characterization of the health evidence. Their consensus letter following the second draft ISA states:

> Our major concern is the conclusions in the ISA regarding the weight of the evidence for health effects for short-term exposure to low levels of SO_2. Although the ISA presents evidence from both clinical and epidemiological studies that indicate health effects occur at 0.2 ppm or lower, the final chapter emphasizes health effects at 0.4 ppm and above * * * CASAC believes the clinical and epidemiological evidence warrants stronger conclusions in the ISA regarding the available evidence of health effects at 0.2 ppm or lower concentrations of SO_2. The selection of a lower bound concentration for health effects is very important because the ISA sets the stage for EPA's risk assessment decisions. In its draft Risk and Exposure Assessment (REA) to Support the Review of the SO2 Primary National Ambient Air Quality Standards (July 2008), EPA chose a range of 0.4 ppm–0.6 ppm SO_2 concentrations for its benchmark analysis. As CASAC will emphasize in a forthcoming letter on the REA, we recommend that a lower bound be set at least as low as 0.2 ppm. (Henderson 2008a)

EPA also notes the similar CASAC comments on the first draft of the REA. The consensus CASAC letter following the 1st draft REA states:

> The CASAC believes strongly that the weight of clinical and epidemiology evidence indicates there are detectable clinically relevant health effects in sensitive subpopulations down to a level at least as low as 0.2 ppm SO_2. These sensitive subpopulations represent a substantial segment of the at-risk population. (Henderson 2008b; p. 1)

See Coalition of Battery Recyclers Association v. *EPA,* No. 09–1011 (DC Cir., May 14, 2010), slip opinion at 9, holding that it was reasonable for EPA to conclude that a two IQ point mean population loss is an adverse effect based in part on CASAC advice that such a decrement is significant. CASAC's strong advice regarding the adversity of effects at the 200 ppb level similarly supports EPA's conclusion that the observed lung decrements are adverse.

In addition to the considerations described above, we also note the following key points:

- In the current SO_2 NAAQS review, clinicians on the CASAC Panel advised that moderate or greater decrements in lung function can be clinically significant in some individuals with respiratory disease.[11]
- In the last O_3 NAAQS review, CASAC indicated that moderate decrements in lung function can be clinically significant in some asthmatics (Henderson 2006), and that in the context of standard setting, a focus on the lower end of the range of moderate functional responses is most appropriate for estimating potentially adverse lung function decrements in people with lung disease (*e.g.,* asthma; *see* 73 FR at 16463).
- In the last O_3 NAAQS review, the Criteria Document and the Staff Paper indicated that for many people with lung disease (*e.g.,* asthma), even moderate decrements in lung function or respiratory symptoms would likely interfere with normal activities and result in additional and more frequent use of medication (EPA 2006, EPA 2007d).
- Subjects participating controlled human exposure studies do not include severe asthmatics, and it is reasonable to presume that persons with more severe asthma than the study participants would have a more serious health effect from short-term exposure to 200 ppb SO_2.

Considering these key points along with the ATS guidelines and consensus CASAC comments on the draft ISA and REA described above, we reasonably conclude that 5–10 minute exposures to SO_2 concentrations at least as low as 200 ppb can result in adverse health effects in exercising asthmatics.

In addition, as noted above some groups (*e.g.,* API) contend that effects below 400 ppb should not be considered adverse because compared to the number of asthmatics experiencing decrements in lung function, there were similar numbers of asthmatics experiencing increases in lung function.

The commenters correctly point out that at the lowest concentration tested in free-breathing chamber studies (200 ppb), there are a similar number of asthmatics experiencing a moderate or greater decrease in lung function (*i.e.,* $\geq$ 100 increase in sRaw or $\geq$ 15 decrease in FEV_1) and experiencing what might be called a moderate improvement in lung function (*i.e.,* $\geq$ 100 decrease in sRaw or $\geq$ 15 increase in FEV_1). This observation is consistent with data presented in Figures 4–2 and 4–3 of the ISA showing essentially no SO_2 -induced change in lung function at 200 ppb when averaged across asthmatics participating in the three Lin *et al.,* controlled human exposure studies. However, these figures also demonstrate that asthmatics who are sensitive to SO_2 at a higher concentration (600 ppb) experience, on average, a greater decrement in lung function at lower concentrations, including 200 ppb, when compared with all subjects combined. Therefore, while some asthmatics are relatively insensitive to SO_2-induced respiratory effects even at concentrations $\geq$ 600 ppb, there is clear empirical evidence that others experience significant bronchoconstriction following exposures to both relatively high (600 ppb) and low (200 ppb) SO_2 concentrations. Among these SO_2-sensitive asthmatics, Figures 4–2 and 4–3 of the ISA show a clear increase in

[11] *See* hearing transcripts from EPA Clean Air Scientific Advisory Committee (CASAC), July 30–31 2008, Sulfur Oxides-Health Criteria (part 3 of 4) pages 211–213). These transcripts can be found in Docket ID No. EPA–HQ–ORD–2006–0260. Available at *http://www.regulations.gov.*

bronchoconstriction with increasing SO_2 concentrations from 200–400 ppb. Given this clear relationship of exposure and effect at all levels in the sensitive asthmatics (*i.e.* those who experienced significant decrements in lung function at the highest exposure concentration used (600 ppb)), EPA does not accept the commenter's premise that controlled human exposure studies do not demonstrate adverse effects in some asthmatics at 5–10 minute levels below 400 ppb.

In addition to disagreeing with EPA's proposed finding of adverse health effects following 5– 10 minute SO_2 exposures as low as 200 ppb, many industry groups (*e.g.,* API, UARG, ACC, ExxonMobil) also disagreed with EPA that severe asthmatics were not included in controlled human exposure studies. That is, these groups contend that EPA is incorrect in assuming that severe asthmatics would likely have a more pronounced response to SO_2 exposures at a given level, or would respond to even lower levels of SO_2 and that this should be taken into account when judging the adequacy of the current standards. As support for their assertion, multiple industry groups cite controlled human exposure studies in the ISA stating that they included "severe asthmatics" and also cite a study by Linn *et al.* (1987) which concluded that among asthmatics, responses to SO_2 exposure are not dependent on the clinical severity of asthma and that "the subjects with the highest risk [of temporary respiratory disturbances from ambient SO_2] can be identified only by actually measuring their responses to SO_2".

We disagree with the assertion that severe asthmatics have been evaluated in 5–10 minute controlled human exposure studies. Although studies cited in the ISA referred to a group of subjects as "moderate/severe" asthmatics, these individuals had well-controlled asthma, were able to withhold medication, were not dependent on corticosteroids, and were able to engage in moderate to heavy levels of exercise. By today's standards, these individuals would clearly be classified as moderate asthmatics. EPA therefore concludes that persons with asthma that is more severe than moderate asthma, as that term is currently understood, were not included in the controlled human exposure studies (and understandably so, for ethical reasons).

In addition, EPA agrees with the commenters that there is little evidence from controlled human exposure studies to suggest that the respiratory effects of SO_2 differ between mild and moderate asthmatics (*see* Linn *et al.,* 1987). However, this may very well be due, at least in part, to persistence of medication among the moderate asthmatic subjects. More importantly, the moderate asthmatics began the exposure with compromised lung function relative to the mild asthmatics. Therefore, similar functional declines from different baselines between mild and moderate asthmatics would clearly not have the same physiological importance. CASAC specifically addressed the issue of asthma severity in a letter to the Administrator: "For ethical reasons severe asthmatics were not part of these clinical studies, but it is not unreasonable to presume that they would have responded to even a greater degree (Henderson 2008a; p. v)." It is also important to note that in addition to the strict health-specific inclusion and exclusion criteria for a given controlled human exposure study, many asthmatics who might otherwise be able to participate choose not to participate because of anxiety related to what they viewed as potential adverse health risks. EPA concludes that it is appropriate to assume, as CASAC suggested, that persons with more severe asthma would respond to an even greater degree than the moderate asthmatics in the clinical studies.

c. Comments on EPA's Characterization of SO_2-Associated Exposures and Health Risks

Several commenters discussed the analyses of SO_2-associated exposures and health risks presented in the REA. As in past reviews (EPA 2005, 2007c, 2007d), EPA has estimated risks associated with the current standards to inform judgments on the public health risks that could exist under different standard options. Some industry commenters (*e.g.,* API, UARG, Lignite Energy Council (LEC), Jackson Walker, ASARCO, the National Rural Electric Cooperative Association) concluded that when considering the adequacy of the current standards, the Administrator should consider exposures and risks associated with actual SO_2 air quality rather than air quality allowed by the current NAAQS. They consequently challenged the relevance and appropriateness of EPA's use of SO_2 concentrations that have been simulated to just meet the current standards in assessing the adequacy of the current standards.

In addition to the objections noted above, we note that UARG generally concluded that the results of EPA's quantitative risk assessment are fundamentally flawed in that they substantially overestimate risks associated with the various air quality scenarios. UARG contends that this is because EPA did not use proper exposure-response functions in estimating risks associated with SO_2 exposure. Moreover, UARG contends EPA further overestimates risk because of the use of 50 ppb exposure bins in estimating the number of occurrences of an adverse lung function response (*see* below).

With respect to comments that when considering the adequacy of the current standards, the Administrator should consider exposures and risks associated with actual SO_2 air quality rather than that simulated to just meet the current standards, these commenters generally concluded: (1) It is more relevant to assess exposures and risks associated with actual SO_2 air quality since adjusting air quality to just meet the current standards require large adjustments to air quality that are highly uncertain; and (2) NAAQS are intended to address actual, rather than highly improbable, risks to human health. In addition, these groups generally concluded that exposure and risk estimates presented in the REA suggest relatively little health risk associated with current levels of SO_2, and thus, there is no need to revise the current SO_2 standards.

We disagree with these commenters that exposure- and risk-related considerations in the NAAQS reviews should rely only on actual air quality, and that EPA therefore improperly adjusted air quality in its risk and exposure analyses to simulate air quality allowed by the current primary SO_2 NAAQS. EPA is required to review whether the present standards—not present air quality—are requisite to protect public health with an adequate margin of safety. Section 109(b)(1). In making this determination it is relevant to consider exposures and risks which could be permissible under the current standards. *See American Trucking Associations* v. *EPA,* 283 F.3d 355, 370 (DC Cir. 2002) (existence of evidence showing adverse effects occurring at levels allowed by the current standards justifies finding that it is appropriate to revise the existing NAAQS). Consequently, it is at the very least reasonable for EPA, in its REA, to make air quality adjustments to estimate SO_2-related exposures and health risks that could exist in areas that just meet the present standards. Thus, although we acknowledge that exposure and health risk estimates associated with current ambient concentrations are substantially smaller than those associated with air quality adjusted to just meet the current standards, we also note that this is irrelevant to the question of whether the current standards are requisite to protect public health with an margin of safety.

In both of these cases, EPA is not trying to evaluate whether areas would or would not be in attainment of the current standards. Those are issues that are addressed during the implementation of the NAAQS. Instead, in this rulemaking EPA is evaluating what NAAQS would be appropriate under section 109(b)(1), by evaluating the impact on or risks to public health from air quality that is at the level of the current standards, as well as evaluating air quality that is at the level of various alternative standards. EPA uses this information to inform the decision on what NAAQS would be requisite to protect public health with an adequate margin of safety.

If EPA determines that the current standards require revision, EPA is further required to determine what revisions are appropriate in light of the requirement that primary NAAQS be requisite to protect public health with an adequate margin of safety. Section 109(d)(1). It is thus similarly reasonable for EPA to make air quality adjustments to simulate different potential alternative standards to provide information on exposures and risks under these potential alternative standards.[12]

We agree that there are uncertainties inherent in making air quality adjustments. These uncertainties are discussed thoroughly in the REA (REA, sections 6.5 and 7.4.2.5). For example, the REA noted the following regarding adjustment of SO_2 concentrations:

> This procedure for adjusting either the ambient concentrations (*i.e.,* in the air quality characterization) or health effect benchmark levels (*i.e.,* in the exposure assessment) was necessary to provide insight into the degree of exposure and risk which would be associated with an increase in ambient SO_2 levels such that the levels were just at the current standards in the areas analyzed. Staff recognizes that it is extremely unlikely that SO_2 concentrations in any of the selected areas where concentrations have been adjusted would rise to meet the current NAAQS and that there is considerable uncertainty associated with the simulation of conditions that would just meet the current standards. Nevertheless, this procedure was necessary to assess the ability of the current standards, not current ambient SO_2 concentrations, to protect public health (REA, section 6.5; p. 64)

These air quality adjustments are not meant to imply an expectation that SO_2 concentrations will increase broadly across the United States or in any given area. Rather, as just noted above, they are meant to estimate SO_2-related exposures and health risks if air quality were at the level of the current and potential alternative standards. Such estimates can inform decisions on whether the current standards, or particular potential alternative standards, provide the requisite protection of public health.

As mentioned above, UARG generally concluded that under all air quality scenarios, the results of EPA's quantitative risk assessment (the third of the analyses conducted in the REA (chapter 9), *see* section II.C above) are substantially overestimated because EPA did not use proper methods to estimate the parameters of the exposure-response functions used in its analyses. UARG contends this is because many of the subjects in the controlled human exposure studies from which EPA's exposure-response functions were derived (*see* REA, Table 9–3) were exposed to more than one SO_2 concentration, yet EPA treated each exposure event as being independent (*e.g.,* if the same subject was exposed to 200 and 300 ppb SO_2, EPA considered these as representing two independent exposure events). UARG contends that observations from the same subject exposed to different SO_2 concentrations are not independent observations and should not be treated as such. Notably, when UARG derived their own exposure-response functions taking into account that observations from the same subject exposed to different SO_2 concentrations are not independent of each other, they estimated appreciably less risk than that estimated by EPA.

There are a variety of techniques and/or assumptions that can be used to fit individual subject data from the controlled human exposure studies (*see* REA, Table 9–3) to exposure-response curves. Moreover, any technique or assumption utilized will have inherent uncertainties. EPA discussed the uncertainties associated with our quantitative risk assessment in detail in the REA (REA, section 9.4); we also gave an overview of key uncertainties in the proposal (*see* section II.C.3, 74 FR at 64824). The approach used to estimate the exposure-response functions was not first introduced in the SO_2 risk assessment, it was previously recommended to EPA by an applied statistician serving on the O_3 CASAC Panel and used in the O_3 risk assessment (which had individual controlled human exposure data similar to that in the current SO_2 NAAQS review; *see* EPA 2007d and EPA 2007e). Importantly, this approach allowed EPA to use all the available individual subject data. Moreover, an inspection of the estimated exposure-response curve and the underlying data suggest that any biases in the parameter estimates are likely to be slight (*see* EPA 2010, section II.C). Consequently, EPA does not accept UARG's view that the methodology used in EPA's quantitative risk assessment was inappropriate.

We further note that UARG's exposure-response functions do not fit the underlying controlled human exposure data (the proportions of subjects who responded at each exposure level) nearly as well as the exposure-response functions estimated using EPA's approach. We believe this could be due to the methodology used in UARG's reanalysis of the individual-level data from the controlled human exposure studies used in the quantitative risk assessment. UARG attempted to estimate subject-specific exposure-response functions, and to use the results of these estimates to obtain estimates of the two parameters in the population-level exposure-response functions. As described in more detail in section II.C of the RTC document (EPA 2010), EPA does not believe there are sufficient data to properly estimate the parameters of subject-specific exposure-response functions. More specifically, UARG chose a three-parameter quadratic function for the subject-specific exposure-response functions. However, none of the subjects had more than three exposures, and many had only one or two. EPA believes that this information is particularly limited for estimating these subject-specific exposure-response functions, especially given that a large percentage of the total number of subjects had fewer exposures than the number of parameters UARG was attempting to estimate (*i.e.,* UARG estimated three parameters in its exposure-response functions, but over fifty percent of subjects only had one or two exposures). It appears that UARG's population-level exposure-response function estimates depended on these subject-specific exposure-response function estimates and thus could explain why UARG's estimated population-level exposure-response functions do not fit the underlying controlled human exposure data nearly as well as the approach used by EPA. A more detailed response to this comment can be found in section II.C of the RTC document (EPA 2010).

As mentioned above, UARG also concluded that EPA further overestimates the total number of occurrences of an adverse lung function response (*i.e.,* total number of

[12] In conducting these analyses, EPA is not trying to evaluate whether areas would or would not be in attainment of the current standards. Again, those issues are addressed during the implementation of the NAAQS.

occurrences of increases in sRaw ≥ 100 or 200% and/or declines in FEV_1 ≥ 15 or 20%) in its quantitative risk assessment. More specifically, UARG concluded that the use of 50 ppb bins, combined with assigning all exposures within a bin the probability of an adverse lung function response at the midpoint of that bin (*e.g.,* all exposures from 0–50 ppb were assigned the probability of an adverse lung function response occurring at 25 ppb), resulted in a substantial overestimate of the total number of occurrences of lung function responses in asthmatics at moderate or greater exertion. UARG generally concludes that this is because the vast majority of exposures of asthmatics at moderate or greater exertion are occurring below the midpoint of the 0–50 ppb exposure bin (*i.e.,* most exposures are occurring below 25 ppb), yet EPA is assigning these very low SO_2 exposures the higher probability of a lung function response associated with the midpoint of the 0–50 ppb exposure bin. UARG contends that this results in a substantial overestimation of the total number of occurrences of lung function response in asthmatics and asthmatic children at moderate or greater exertion. UARG further notes that this methodological concern was raised in its comments on the second draft REA, but EPA failed to address this issue and relied heavily on this metric in the proposal with respect to the adequacy of the current and potential alternative standards. EPA's response to this comment is discussed below and in more detail in section II.C of the RTC document (EPA 2010).

EPA generally agrees with UARG's technical comments that there is a substantial overestimation of the total occurrences of lung function responses because of the binning issues described above. However, we strongly disagree that: (1) This issue was not acknowledged in the final REA; and (2) the metric of total occurrences was relied on heavily in the policy assessment chapter of the REA (REA, chapter 10) and in the Administrator's rationale with respect to the adequacy of the current and potential alternative standards. First, EPA did respond to this concern in the final REA. More specifically, page 344 of the final REA states:

As noted in public comments on the 2nd draft SO_2 REA, the assignment of response probability to the midpoint of the exposure bin combined with the lack of more finely divided intervals in this range can lead to significant overestimation of risks based on total occurrences of a defined lung function response. This is because the distribution of population exposures for occurrences is not evenly distributed across the bin, but rather is more heavily weighted toward the lower range of the bin. Thus, combining all exposures estimated to occur in the lowest bin with a response probability assigned to the midpoint of the bin results in a significant overestimate of the risk. Therefore, staff places less weight on the estimated number of occurrences of lung function responses.

Thus, as noted in the final REA, less weight was placed on this metric in the quantitative risk assessment chapter (REA, chapter 9), and importantly, no weight was placed on this metric in either the policy assessment chapter of the REA (REA, chapter 10) or in the Administrator's rationale sections of the proposal preamble. Rather, the policy assessment chapter of the REA and the Administrator's rationale at the proposal considered the percent of exposed asthmatic children at moderate or greater exertion estimated to have at least one defined lung function response per year in St. Louis. Importantly, this metric is not appreciably affected by the binning issue raised in UARG's comments. As stated on page 344–345 of the final REA:

This overestimation of total occurrences does not impact the risk metric expressed as incidence or percent incidence of a defined lung function response 1 or more times per year because the bulk of the exposures contributing to these risk metrics are not skewed toward the lower range of the reported exposure bins.[13]

Finally, it is important to note that the Administrator's rationale in the proposal regarding the adequacy of the current and potential alternative standards in general placed only limited reliance on the results of the quantitative risk assessment in St. Louis, with no reliance on the estimates of total occurrences. Rather, in addition to the substantial weight that she placed on the scientific evidence as described in the ISA, the Administrator placed relatively more weight on the results of the St. Louis exposure analysis. For example, in discussing the adequacy of the current standards, the proposal states: "The Administrator especially notes the results of the St. Louis exposure analysis which, as summarized above, indicates that substantial percentages of asthmatic children at moderate or greater exertion would be exposed, at least once annually, to air quality exceeding the 400 and 200 ppb benchmarks" (*see* 74 FR at 64829). We note that results of the quantitative risk assessment in St. Louis, with respect to the percent of asthmatic children estimated to have at least one lung function response per year (using EPA's exposure-response functions), supports the Administrator's overall conclusions in the proposal regarding the adequacy of the current and potential alternative standards.

3. Conclusions Regarding the Adequacy of the Current 24-Hour and Annual Standards

In reviewing the adequacy of the current standards, the Administrator has considered the scientific evidence assessed in the ISA, the exposure and risk results presented in the REA, the conclusions of the policy assessment chapter of the REA, and comments from CASAC and the public. These considerations are described below.

As in the proposal, the Administrator accepts and agrees with the ISA's conclusion that the results of controlled human exposure and epidemiologic studies form a plausible and coherent data set that supports a causal relationship between short-term (5 minutes to 24 hours) SO_2 exposures and adverse respiratory effects. The Administrator acknowledges that there are uncertainties associated with the epidemiologic evidence (*e.g.,* potential confounding by co-pollutants). However, she agrees that the epidemiologic evidence, supported by the controlled human exposure evidence, generally indicates that the effects seen in these studies are attributable to exposure to SO_2, rather than co-pollutants, most notably $PM_{2.5}$. She also accepts and agrees with the conclusion of the ISA that "[i]n the epidemiologic studies, respiratory effects were observed in areas where the maximum ambient 24-h avg SO_2 concentration was below the current 24-h avg NAAQS level. * * *" (ISA, section 5.2, p. 5–2) and so would occur at ambient SO_2 concentrations that are present in locations meeting the current 24-hour NAAQS. The Administrator also notes that these effects occurred in areas with annual air quality levels considerably lower than those allowed by the current annual standard, indicating that the annual standard also

[13] Although in St. Louis, the percent of exposed asthmatic children at moderate or greater exertion estimated to have at least one defined lung function response per year was not appreciably affected, it was found that for this same metric, the already very low risk estimates in Greene County became appreciably lower when the binning issue discussed above was considered. However, as noted above in section II.C and discussed in more detail in the REA (REA, section 10.3.3) and the proposal (*see* section II.E.b, 74 FR at 64827), the St. Louis exposure and risk results were found to be more informative in addressing the adequacy of the current and potential alternative standards. Moreover, while the Administrator's rationale in the proposal relied minimally on the St. Louis quantitative risk results (*see* above), she importantly placed no weight on any metric from the Greene County quantitative risk assessment.

is not providing protection against such effects. Existence of epidemiologic studies showing adverse effects occurring at levels allowed by the current standards is an accepted justification for finding that it is appropriate to revise the existing standards. *See, e.g. American Trucking Associations* v. *EPA,* 283 F. 3d at 370*; see also American Farm Bureau* v. *EPA,* 559 F. 3d.512, 521–23 (DC Cir. 2009) (effects associated with short-term exposure seen in areas with ambient concentrations lower than long-term standard, so that without further explanation, standard does not adequately protect against short-term exposures).

With respect to the controlled human exposure studies, the Administrator judges that effects following 5–10 minute SO_2 exposures ≥ 400 ppb and ≥ 200 ppb can result in adverse health effects to asthmatics. This judgment is based on ATS guidelines, explicit CASAC consensus written advice and recommendations, and judgments made by EPA in previous NAAQS reviews. Thus, similar to the proposal, she notes analyses in the REA supporting that 5-minute exposures ≥ 400 ppb and ≥ 200 ppb were associated with air quality adjusted upward to simulate just meeting the current standards. The Administrator especially notes the results of the St. Louis exposure analysis which, as summarized in the proposal (*see* section II.E.1.b and Table 3, *see* 74 FR at 64841), indicates that substantial percentages of asthmatic children at moderate or greater exertion would be exposed, at least once annually, to air quality exceeding the 400 and 200 ppb 5-minute benchmarks given air quality simulated to just meet the current standards. The Administrator judged these 5-minute exposures to be significant from a public health perspective due to their estimated frequency: Approximately 24% of child asthmatics at moderate or greater exertion in St. Louis are estimated to be exposed at least once per year to air quality exceeding the 5-minute 400 ppb benchmark, a level associated with lung function decrements in the presence of respiratory symptoms. Additionally, approximately 73% of child asthmatics in St. Louis at moderate or greater exertion would be expected to be exposed at least once per year to air quality exceeding the 5-minute 200 ppb benchmark. This health evidence and risk-based information underlie CASAC's conclusion that the current SO_2 standards do not adequately protect public health. As discussed in the proposal, CASAC stated: "the current 24-hour and annual standards are not adequate to protect public health, especially in relation to short-term exposures to SO_2 (5–10 minutes) by exercising asthmatics" (Samet, 2009, p. 15). The Administrator agrees with this conclusion.

In considering approaches to revising the current standards, the Administrator concludes that it is appropriate to set a new standard, that such standard must provide requisite protection with an adequate margin of safety to a susceptible population (*i.e.,* asthmatics at elevated ventilation), and that the standard must afford protection from short-term exposures to SO_2 in order to prevent the adverse health effects reported in both the controlled human exposure and epidemiologic studies. The Administrator notes that a 1-hour standard could provide increased public health protection, especially for members of at-risk groups, from health effects described in both controlled human exposure and epidemiologic studies, and hence, health effects associated with 5-minute to 24-hour exposures to SO_2.[14] As discussed in section II.F.5 below, given the degree of protection afforded by such a standard, it may be appropriate to replace, and not retain, the current 24-hour and annual standards in conjunction with setting a new short-term standard.

F. Conclusions on the Elements of a New Short-Term Standard

In considering a revised SO_2 primary NAAQS, the Administrator notes the need to protect at-risk populations from: (1) 1-hour daily maximum and 24-hour average exposures to SO_2 that could cause the types of respiratory morbidity effects reported in epidemiologic studies; and (2) 5–10 minute SO_2 exposure concentrations reported in controlled human exposure studies to result in moderate or greater decrements in lung function and/or respiratory symptoms. Considerations with regard to potential alternative standards and the specific conclusions of the Administrator are discussed in the following sections in terms of indicator, averaging time, form, and level (sections II.F.1 to II.F.4 below).

[14] We also note that such a standard would, among other things, address the deficiency in the current NAAQS which occasioned the remand of that standard for failing to adequately explain the absence of protection from short-term SO_2 bursts which could cause adverse health effects in hundreds of thousands of heavily breathing asthmatics. *American Lung Ass'n* v. *EPA,* 134 F. 3d at 392–93.

1. Indicator

a. Rationale for Proposed Decision

In the last review, EPA focused on SO_2 as the most appropriate indicator for ambient SO_X. In making a decision in the current review on the most appropriate indicator, the Administrator has considered the conclusions of the ISA and REA as well as the views expressed by CASAC and the public. The REA noted that, although the presence of gaseous SO_X species other than SO_2 has been recognized, no alternative to SO_2 has been advanced as being a more appropriate surrogate for ambient gaseous SO_X. Controlled human exposure studies and animal toxicology studies provide specific evidence for health effects following exposure to SO_2. Epidemiologic studies also typically report levels of SO_2, as opposed to other gaseous SO_X. Because emissions that lead to the formation of SO_2 generally also lead to the formation of other SO_X oxidation products, measures leading to reductions in population exposures to SO_2 can generally be expected to lead to reductions in population exposures to other gaseous SO_X. Therefore, as noted in the proposal, meeting an SO_2 standard that protects the public health can also be expected to provide protection against potential health effects that may be independently associated with other gaseous SO_X even though such effects are not discernable from currently available studies indexed by SO_2 alone. *See American Petroleum Institute* v. *EPA,* 665 F, 2d 1176, 1186 (DC Cir. 1981) (reasonable for EPA to use ozone as the indicator for all photochemical oxidants even though health information on the other photochemical oxidants is unknown; regulating ozone alone is reasonable since it presents a "predictable danger" and in doing so EPA did not abandon its responsibility to regulate other photochemical oxidants encompassed by the determination that photochemical oxidants as a class may be reasonably anticipated to endanger public health or welfare). Given these key points, the REA concluded that the available evidence supports the retention of SO_2 as the indicator in the current review (REA, section 10.5.1). Consistent with this conclusion, CASAC stated in a letter to the EPA Administrator that: "for indicator, SO_2 is clearly the preferred choice" (Samet 2009, p. 14).

b. Comments on Indicator

A small number of commenters directly addressed the issue of the indicator for the standard. These commenters generally endorsed the proposal to continue to use SO_2 as the indicator for ambient SO_X.

c. Conclusions on Indicator

Based on the available information discussed above, and consistent with the views of CASAC and other commenters, the Administrator concludes that it is appropriate to continue to use SO_2 as the indicator for a standard that is intended to address effects associated with exposure to SO_2, alone or in combination with other gaseous SO_X. In so doing, the Administrator recognizes that measures leading to reductions in population exposures to SO_2 will also reduce population exposures to other oxides of sulfur.

2. Averaging Time

This section discusses considerations related to the averaging time of the SO_2 primary NAAQS. Specifically, this section summarizes the rationale for the Administrator's proposed decision regarding averaging time (II.F.2.a below; *see* section II.F.2 of the proposal for more detail at 74 FR 64832–64833), discusses public comments and EPA responses related to averaging time (II.F.2.b), and presents the Administrator's final conclusions regarding averaging time (II.F.2.c). Notably, public comments and the Administrator's conclusions on whether to retain or revoke the current 24-hour and/or annual standards given a new 1-hour standard are discussed in section II.F.5.

a. Rationale for Proposed Decision

In considering the most appropriate averaging time for the SO_2 primary NAAQS, the Administrator noted in the proposal the conclusions and judgments made in the ISA about the available scientific evidence, air quality correlations discussed in the REA, conclusions of the policy assessment chapter of the REA, and CASAC recommendations (section II.F.2 in the proposal). Specifically, she noted the following:

- The REA conclusion that an appropriate averaging time should focus protection on SO_2 exposures from 5-minutes to 24-hours (REA, section, 10.5.2).
- Air quality, exposure, and risk analyses from the REA indicating it is likely a 1-hour standard—with the appropriate form and level—can substantially reduce 5–10 minute peaks of SO_2 shown in controlled human exposure studies to result in respiratory symptoms and/or decrements in lung function in exercising asthmatics (*i.e.* 5-minute SO_2 concentrations ≥ 200 and 400 ppb).
- Air quality analyses indicating that a 1-hour standard—with the appropriate form and level—can substantially reduce the upper end of the distribution of SO_2 levels more likely to be associated with adverse respiratory effects (*see* section II.F.3 below); that is: (1) 99th percentile 1-hour daily maximum air quality concentrations in U.S. cities where positive effect estimates in epidemiologic studies of hospital admissions and emergency department visits for all respiratory causes and asthma were observed; and (2) 99th percentile 24-hour average air quality concentrations found in U.S. cities where emergency department visit and hospitalization studies (for all respiratory causes and asthma) reported statistically significant associations in multi-pollutant models with PM.
- The REA conclusion that a 5-minute averaging time is undesirable because it would result in significant and unnecessary instability due to the likelihood that locations would frequently shift in and out of attainment—thereby reducing public health protection by disrupting an area's ongoing implementation plans and associated control programs.
- CASAC statement addressing whether a 1-hour averaging time can adequately control 5–10 minute peak exposures and whether there should be a 5-minute averaging time. CASAC stated that the REA's rationale for a one-hour standard was "convincing" (Samet 2009, p. 16), and that "a one-hour standard is the preferred averaging time" (Samet 2009, p. 15).
- CASAC's statement that they were "in agreement with having a short-term standard and finds that the REA supports a 1-hour standard as protective of public health" (Samet 2009, p. 1).

b. Comments on Averaging Time

A large number of public commenters also endorsed the establishment of a new standard with a 1-hour averaging time (although some groups' support hinged on the accompanying level). These included a number of State organizations (*e.g.,* NACAA, NESCAUM); State environmental agencies (*e.g.,* such agencies in IA, IL, NY, MI, NM, OH, PA, TX, VT); public health and environmental organizations (*e.g.,* ALA, ATS, New York Department of Health (NYDOH), Sierra Club, EDF); the Fond du Lac Tribe; local groups (*e.g.,* Houston-Galveston Area Council, New York City); and almost all of the individual commenters (13,000). The supporting rationales offered by these commenters often acknowledged the recommendations of CASAC and the Administrator's rationale as discussed in the proposal.

Though many industry commenters did not support the proposed revisions to the SO_2 primary NAAQS (as discussed above in section II.E.2), a few of these groups did express that if a short-term standard were to be set, a 1-hour averaging time could be appropriate, depending on the level and form selected (*e.g.,* ExxonMobil, Kean Miller). Other industry commenters (*e.g.,* ASARCO, RIO Tinto Alcan, Association of Battery Recyclers (ABR)) and the South Dakota Department of Environment and Natural Resources (SD DENR) expressed that EPA should have considered longer averaging times (*e.g.,* 3 hours). In addition, although health and environmental groups were supportive of setting a new 1-hour standard to protect against short-term exposures to SO_2 (again, depending on the level of the 1-hour standard selected), these groups also commented that a 5-minute standard to protect susceptible populations from health effects associated with 5-minute peaks of SO_2 would be optimal (*e.g.,* ALA, ATS, Sierra Club, EDF). These comments, and EPA's responses, are discussed in more detail below.

As discussed above, industry commenters who disagreed with setting a new 1-hour standard generally based this conclusion on their interpretation of the scientific evidence and their conclusion that this evidence does not support the proposed revisions to the current SO_2 NAAQS. EPA's responses to these commenters were presented above in section II.E.2.a and II.E.2.b.

Also noted above, some industry commenters (*e.g.,* ASARCO, RIO Tinto Alcan, ABR) and the SD DENR expressed that EPA should have considered longer averaging times (*e.g.,* 3-hour, 8-hour, 24-hour). In general, these groups concluded that a standard with a longer averaging time could potentially provide the same public health protection as a 1-hour standard, while also providing a more stable regulatory target. For example, in its comments, the SD DENR states: "DENR recommends EPA evaluate a 3-hour or 8-hour standard to determine if these averaging periods are also protective of the public health. If they are, EPA should propose a 3-hour or 8-hour sulfur dioxide standard instead of a 1-hour standard. A longer averaging period would smooth out the variability of the upper range measurements and provide a more stable standard." Similarly, Rio Tinto Alcan stated in its comments: "the short-term averaging period defined by EPA (*i.e.,* 5 minutes to 24 hours) is not limited to only 5-minute, 1-hour and 24-hour averaging periods. EPA could explain in more detail why these three averaging periods were examined when considering appropriate averaging periods to limit short-term peaks of SO_2 * * * a longer term average could provide additional stability to the standard while at the same time effectively protecting public health.''

Although we agree that alternative averaging times could potentially provide similar public health protection (assuming an appropriate form and level), we believe that a 1-hour averaging time is reasonably justified by the scientific evidence presented in the ISA and by the air quality information presented in the REA. As described in detail in the proposal (*see* section II.F.2), the controlled human exposure evidence presented in the ISA provided support for an averaging time that protects against 5–10 minute peak SO_2 exposures (REA, section 10.5.2, pp. 371–372), and results from epidemiologic studies most directly provided support for both 1-hour and 24-hour averaging times (REA, section 10.5.2, p. 372). Thus, we found it most reasonable to consider these averaging times for a revised SO_2 NAAQS given that there is very little basis in the health evidence presented in the ISA to consider other averaging times (*e.g.,* 3-hour or 8-hour). In so doing, we first noted the likelihood that averaging times of 1 and 24 hours could provide protection against 5-minute peak SO_2 exposures. As described in detail in the proposal (*see* section II.F.2, 74 FR at 64830–64833), it was initially concluded that a 1-hour averaging time, rather than a 24-hour averaging time, would be more appropriate for limiting 5-minute peaks of SO_2. Similarly, we concluded that a 1-hour standard, given the appropriate form and level, could likely limit 99th percentile 24-hour average air quality concentrations found in U.S. locations where emergency department visit and hospitalization studies (for all respiratory causes and asthma) observed statistically significant associations in multi-pollutant models with PM (*i.e.,* 99th percentile 24-hour average SO_2 concentration ≥ 36 ppb). Taken together, we reasonably concluded that a 1-hour standard, with an appropriate form and level, can provide adequate protection against the range of health outcomes associated with averaging times from 5 minutes to 24 hours (proposal section II.F.2 and REA, section 10.5.2.3). We also note that our conclusion is in agreement with CASAC comments on the second draft REA. CASAC stated that they were ''in agreement with having a short-term standard and finds that the REA supports a one-hour standard as protective of public health'' (Samet 2009, p. 1). In addition, as discussed in more detail below in section II.F.3, we found that a 1-hour standard in combination with the selected form, will provide a stable regulatory target.

As noted above, although health and environmental groups were supportive of setting a new 1-hour standard to protect against short-term exposures to SO_2 (again, depending on the level of the 1-hour standard selected), these groups generally commented that a 5-minute standard to protect against health effects associated with 5-minute peaks would be optimal (*e.g.,* ALA, Sierra Club, EDF). For example, in their combined comments ALA, EDF, NRDC, and Sierra Club (ALA *et al.,*) stated: ''We need a short-term SO_2 standard, optimally a 5-minute standard, to protect against bursts of pollution that can result from start-up, shutdown, upset, malfunction, downwash, complex terrain, atmospheric inversion conditions, and other situations'' and that ''EPA has over emphasized a concern about the stability of a 5-minute standard * * * The record does not show that any alleged instability of a 5-minute standard has any relevance to whether such a standard is requisite to protect public health.''

We agree that there needs to be a short-term standard to protect against 5-minute peaks of SO_2. However, we do not believe setting a 5-minute standard to be the best way of accomplishing that objective. As in past NAAQS reviews, EPA properly considered the stability of the design of pollution control programs in its review of the elements of a NAAQS, since more stable programs are more effective, and hence result in enhanced public safety. *American Trucking Associations* v. *EPA,* 283 F. 3d at 375 (choice of 98th percentile form for 24-hour PM NAAQS, which allows a number of high exposure days per year to escape regulation under the NAAQS, justifiable as ''promot[ing] development of more 'effective [pollution] control programs' '', since such programs would otherwise be ''less 'stable'—and hence * * * less effective—than programs designed to address longer-term average conditions'', and there are other means (viz. emergency episode plans) to control those high exposure days). In this review, there were legitimate concerns about the stability of a standard using a 5-minute averaging time. Specifically, there was concern that compared to longer averaging times (*e.g.,* 1-hour, 24-hour), year-to-year variation in 5-minute SO_2 concentrations were likely to be substantially more temporally and spatially diverse. Thus, it is more likely that locations would frequently shift in and out of attainment thereby reducing public health protection by disrupting an area's ongoing implementation plans and associated control programs. Consequently, the REA concluded that a 5-minute averaging time would not provide a stable regulatory target and therefore would not be the preferred approach to provide adequate public health protection. A 1-hour averaging time does not have these drawbacks. As noted in the REA and the proposal (*see* proposal sections II.F.2.a and II.F.2.c), air quality, exposure, and risk analyses support that a 1-hour averaging time, given an appropriate form and level can adequately limit 5-minute SO_2 exposures and provide a more stable regulatory target than setting a 5-minute standard. More specifically, based on the air quality and exposure analyses presented in chapters 7 and 8 of the REA, there is also a strong likelihood that a 99th percentile 1-hour daily maximum standard will limit 5–10 minute peaks of SO_2 shown in controlled human exposure studies to result in decrements in lung function and/or respiratory symptoms in exercising asthmatics (*see* especially REA Tables 7–11 to 7–14 and Figure 8–19).

We also note that a 1-hour standard to protect against 5-minute exposures is in agreement with CASAC advice and recommendations. That is, CASAC stated that they were ''in agreement with having a short-term standard and finds that the REA supports a 1-hour standard as protective of public health'' (Samet 2009, p. 1). Similarly, in a CASAC statement addressing whether a 1-hour averaging time can adequately control 5–10 minute peak exposures and whether there should be a 5-minute averaging time, CASAC stated that the REA had presented a ''convincing rationale'' (Samet 2009, p. 16) for a 1-hour standard, and that ''a one-hour standard is the preferred averaging time'' (Samet 2009, p. 15).

c. Conclusions on Averaging Time

In considering the most appropriate averaging time(s) for the SO_2 primary NAAQS, the Administrator notes the conclusions and judgments made in the ISA about the available scientific evidence, air quality considerations from the REA, CASAC advice and recommendations, and public comments received. Based on these considerations, the Administrator concludes that a new standard based on

1-hour daily maximum SO_2 concentrations will provide increased protection against effects associated with short-term (5 minutes to 24 hours) exposures. The rationale for this decision is described below.

Similar to the proposal (*see* section II.F.2.c), the Administrator first agrees with the REA's conclusion that the standard should focus protection on short-term SO_2 exposures from 5 minutes to 24 hours. As noted above, CASAC's strong recommendation supports this approach as well.[15] The Administrator further agrees that the standard must provide requisite protection from 5–10 minute exposure events, but believes that this can be provided without having a standard with a 5-minute averaging time. The Administrator agrees with the REA conclusion that it is likely a 1-hour standard—with the appropriate form and level—can substantially reduce 5–10 minute peaks of SO_2 shown in controlled human exposure studies to result in respiratory symptoms and/or decrements in lung function in exercising asthmatics. The Administrator further believes that a 5-minute averaging time would result in significant and unnecessary instability and is undesirable for that reason. The Administrator also notes the statements from CASAC mentioned above addressing whether a 1-hour averaging time can adequately control 5–10 minute peak exposures and whether there should be a 5-minute averaging time. As noted above, addressing this question, CASAC stated that the REA had presented a "convincing rationale" (Samet 2009, p. 16) for a 1-hour standard, and that "a one-hour standard is the preferred averaging time" (Samet 2009, p. 15).

Second, as in the proposal the Administrator agrees that a 1-hour averaging time (again, with the appropriate form and level) would provide protection against the range of health outcomes associated with averaging times of 1 hour to 24 hours. Specifically, the Administrator finds that a 1-hour standard can substantially reduce the upper end of the distribution of SO_2 levels more likely to be associated with adverse respiratory effects (*see* discussion on Form, section II.F.3); that is: (1) 99th percentile 1-hour daily maximum SO_2 air quality concentrations in U.S. locations where positive SO_2 effect estimates were reported in epidemiologic studies of emergency department visits and hospital admissions for all respiratory causes and asthma; and (2) 99th percentile 24-hour average SO_2 air quality concentrations found in U.S. locations where emergency department visit and hospital admission studies using multi-pollutant models with PM reported statistically significant associations (for all respiratory causes or asthma) with ambient SO_2 (*see* REA, section 10.5.2.2 and proposal section II.F.2, 74 FR at 64831). Finally, the Administrator again notes that establishing a new 1-hour averaging time is in agreement with CASAC recommendations. As noted above, CASAC stated that they were "in agreement with having a short-term standard and finds that the REA supports a one-hour standard as protective of public health" (Samet 2009, p. 1). Moreover, CASAC agreed with the REA that a "one-hour standard is the preferred averaging time" (Samet 2009, p.15).

[15] As noted above, such a standard also satisfactorily addresses the issue raised by the reviewing court in the litigation that followed the last review of the SO_2 NAAQS: Why was no protection afforded in the standard for a susceptible subpopulation known to experience repeated adverse effects from exposure to 5–10 minute SO_2 bursts. American Lung Ass'n, 134 F. 3d at 392–93.

3. Form

This section discusses considerations related to the form of the 1-hour SO_2 primary NAAQS. Specifically, this section summarizes the rationale for the Administrator's proposed decision regarding form (II.F.3.a; *see* proposal section II.F.3, 74 FR at 64833–64834 of the proposal for more detail), discusses comments related to form (II.F.3.b), and presents the Administrator's final conclusions regarding form (II.F.3.c).

a. Rationale for Proposed Decision

In considering the most appropriate form for the SO_2 primary NAAQS, the Administrator noted in the proposal the conclusions and judgments made in the ISA about available scientific evidence, air quality information discussed in the REA, conclusions of the policy assessment chapter of the REA, and CASAC recommendations (*see* section II.F.3, 74 FR at 64833–64834 in the proposal). Specifically, the proposal referenced the following:

- Information in the ISA that suggested that adverse respiratory effects are more likely to occur at the upper end of the distribution of ambient SO_2 concentrations. That is, the ISA describes a few studies that reported an increase in SO_2-related respiratory health effects at the upper end of the distribution of SO_2 concentrations (ISA, section 5.3, p. 5–9).
- The REA conclusion that a concentration-based form averaged over three years would better reflect the continuum of health risks posed by increasing SO_2 concentrations (*i.e.* the percentage of asthmatics affected and the severity of the response increases with increasing SO_2 concentrations; REA, section 10.5.3) by giving proportionally greater weight to years when 1-hour daily maximum SO_2 concentrations are well above the level of the standard, than just above the level of the standard.
- Analyses in the REA that suggested for a given SO_2 standard level, a 99th percentile form is appreciably more effective at limiting 5-minute peak SO_2 concentrations than a 98th percentile form (REA, section 10.5.3 and REA, Figures 7–27 and 7–28).
- Analyses in the REA indicating that over the last 10 years and for the vast majority of the sites examined, there appears to be little difference in 98th and 99th percentile design value stability (REA, section 10.5.3).
- The REA conclusion that taken together, the evidence and air quality information indicate that consideration should be given primarily to a 1-hour daily maximum standard with a 99th percentile or 4th highest daily maximum form (REA, section 10.5.3.3).
- CASAC indications that: "there is adequate information to justify the use of a concentration-based form averaged over 3 years" (Samet 2009, p. 16).
- CASAC recommendations that when evaluating 98th vs. 99th percentile forms, EPA should consider the number of days per year 98th vs. 99th percentile forms would allow SO_2 concentrations to exceed the selected standard level. Similarly, CASAC recommendations to consider the number of exceedences of 5-minute benchmarks given 98th vs. 99th percentile forms at a given standard level (Samet 2009).

b. Comments on Form

Most all State organizations and agencies (*e.g.,* NAACA, NESCAUM and agencies in FL, NM, PA, SC, TX, VT) supported a 99th percentile or 4th highest form. Similarly, public health (*e.g.,* ALA, ATS) and environmental organizations (*e.g.,* CBD, WEACT for Environmental Justice) and the Alexandria Department of Transportation and Environmental Services preferred either a 99th percentile or a more stringent form (*e.g.,* no exceedence) to further limit the occurrence of SO_2 concentrations that exceed the standard level in locations that attain the standard. In contrast, many industry groups (*e.g.,* UARG, NAM, LEC, RRI Energy, AirQuality Research & Logistics (AQRL)), and the SD DENR conditionally supported a

98th percentile form if EPA were to set a 1-hour standard.[16] EPA responses to specific comments on the form of the standard can be found below and in the RTC document (EPA 2010).

As mentioned above, a number of industry groups and the SD DENR preferred a 98th percentile form. In general, their preference for a 98th percentile form was based on their conclusion that a form based on the 98th percentile would be more stable than a form based on the 99th percentile, and that a 98th percentile form is consistent with the forms selected in recent NAAQS reviews (*i.e.* $PM_{2.5}$ and NO_2). For example AQRL stated: "The Administrator should reconsider her proposal and choose instead the 98th percentile (or equivalent nth highest value) *form* of the standard for the added reliability and stability it offers in determining compliance or progress towards attainment. This approach has been promulgated for recent revisions of the $PM_{2.5}$ and NO_2 standards and this consistency should be maintained with SO_2."

We agree with the commenters that it is important that a 1-hour standard have a form that is reasonably stable, but we disagree that a 98th percentile form is significantly more stable than a 99th percentile form. We note that the REA discussed analyses (also briefly described in the proposal; *see* section II.F.3, 74 FR at 64834) comparing trends in 98th and 99th percentile design values from 54 sites located in the 40 counties selected for the detailed air quality analysis (REA section 10.5.3 and Thompson, 2009). These results suggested that at the vast majority of sites, there would have been similar changes in 98th and 99th percentile design values over the last ten years (*i.e.* based on evaluating overlapping three year intervals over the last ten years; *see* REA, Figure 10–1 and Thompson, 2009). As part of this analysis, all of the design values over this ten year period for all 54 sites were aggregated and the standard deviation calculated (REA, Figure 10–2 and Thompson, 2009). Results demonstrated similar standard deviations—*i.e.* similar stability—based on aggregated 98th or aggregated 99th percentile design values over the ten year period (*see* REA, Figure 10–2 and Thompson 2009). Thus, we believe that in most locations, there will not be a substantial difference in stability between 98th and 99th percentile forms.

We also disagree with the commenters that the forms of NAAQS standards should be consistent across different NAAQS pollutants. This is almost like advocating consistent levels or averaging times for different NAAQS pollutants. Each pollutant is manifestly different from another, and the decision as to an appropriate standard for each, and appropriate elements (including form) of each standard and the interaction of these elements, necessarily is fact-specific. Cf. *Sierra Club* v. *EPA,* 353 F. 3d 976, 986 (DC Cir. 2004) ("This court has adopted an 'every tub on its own bottom' approach to EPA's setting of standards pursuant to the CAA, under which the adequacy of the underlying justification offered by the agency is the pertinent factor—not what the agency did on a different record concerning a different industry") (Roberts J.). There is thus no basis to say *a priori* that any element of one NAAQS should be consistent with another, although if all other things are equal, selecting stable forms for each NAAQS is a legitimate objective.

A 99th percentile form, rather than a 98th percentile form, is also needed for the standard to provide requisite public health protection. In this review of the primary SO_2 NAAQS, we considered information in the ISA suggesting that adverse respiratory effects are more likely to occur at the upper end of the distribution of ambient SO_2 concentrations. That is, the ISA described a few studies that reported an increase in SO_2-related respiratory health effects at the upper end of the distribution of SO_2 concentrations (*i.e.,* above 90th percentile SO_2 concentrations; ISA, section 5.3, p. 5–9). Moreover, we considered the extent to which different percentile forms, given the same standard level, limit 5-minute concentrations of SO_2 above benchmark levels. As noted above in section II.F.3.a, and in more detail in the proposal (*see* section II.F.3.a, 74 FR at 64834), air quality analyses presented in the REA suggested that at a given SO_2 standard level, a 99th percentile form is appreciably more effective at limiting 5-minute peak SO_2 concentrations than a 98th percentile form (REA, section 10.5.3, and REA, Figures 7–27 and 7–28). Taken together with the analyses suggesting that 98th and 99th percentile forms have similar stabilities, we reasonably concluded that a 99th percentile form was most appropriate for a 1-hour SO_2 standard.

As mentioned above, a number of health and environmental groups supported a 99th percentile form, but expressed that they would prefer a more restrictive form, such as a no-exceedence based form. In addition, the Alexandria Department of Transportation and Environmental Services only recommended a no, or one exceedence based form. In general, these groups concluded that a more restrictive form would further limit the: (1) Number of days an area could exceed the standard level and still attain the standard; and (2) the occurrence of 5-minute peaks of SO_2 above benchmark levels.

It is important that the particular form selected for a 1-hour daily maximum standard reflect the nature of the health risks posed by increasing SO_2 concentrations. The REA and proposal (*see* section II.F.3, 74 FR at 64833) noted that the form of the standard should reflect results from controlled human exposure studies demonstrating that the percentage of asthmatics affected, and the severity of the respiratory response (*i.e.* decrements in lung function, respiratory symptoms) increases as SO_2 concentrations increase. Taking this into consideration, EPA staff concluded that a concentration-based form, averaged over three years, is more appropriate than an exceedance-based form (REA, section 10.5.3). This is because a concentration-based form averaged over three years gives proportionally greater weight to years when 1-hour daily maximum SO_2 concentrations are well above the level of the standard, as it gives to years when 1-hour daily maximum SO_2 concentrations are just above the level of the standard. In contrast, an expected exceedance form gives the same weight to years when 1-hour daily maximum SO_2 concentrations are just above the level of the standard as it gives to years when 1-hour daily maximum SO_2 concentrations are well above the level of the standard. Therefore, we concluded that a concentration-based form, averaged over three years (which also increases the stability of the standard) better reflects the continuum of health risks posed by increasing SO_2 concentrations (*i.e.* the percentage of asthmatics affected and the severity of the response increases with increasing SO_2 concentrations; REA, section 10.5.3). Moreover, we note that analyses in the REA indicate that in most locations analyzed, a 99th percentile form would correspond to the 4th highest daily maximum concentration in a year, and that the 99th percentile, combined with the standard level

[16] EPA did not propose or seek comment on a 98th percentile form or a more restrictive form (*e.g.,* an exceedence based form). EPA also considered a 4th highest form, which is generally equivalent to the 99th percentile. However, a percentile based form is preferred since it results in a sampling from the same part of the annual distribution of 1-hour daily maximum SO_2 concentrations regardless of the number of 1-hour daily maximum concentrations reported in a given year for a particular location.

selected, will substantially limit 5-minute peaks of SO_2 above the 200 ppb and higher benchmark levels (*see* below, section II.F.4). Finally, we note that a concentration based form is in agreement with CASAC advice that: "there is adequate information to justify the use of a concentration-based form averaged over 3 years" (Samet 2009, p. 16).

c. Conclusions on Form

The Administrator agrees that the form of the standard should reflect the health evidence presented in the ISA indicating that the percentage of asthmatics affected and the severity of the response increases with increasing SO_2 concentrations. The Administrator also agrees that it is reasonable to consider the standard's stability as part of consideration of the form of the standard. Thus, the Administrator agrees that the standard should use a concentration-based form averaged over three years in order to give due weight to years when 1-hour SO_2 concentrations are well above the level of the standard, than to years when 1-hour SO_2 concentrations are just above the level of the standard. She also notes that a concentration-based form averaged over 3 years would likely be appreciably more stable than a no-exceedence based form.

In selecting a specific concentration based form, the Administrator first notes that a few epidemiologic studies described in the ISA reported an increase in SO_2-related respiratory health effects at the upper end of the distribution of ambient SO_2 concentrations (*i.e.,* above 90th percentile SO_2 concentrations; *see* ISA, section 5.3, p. 5–9). The Administrator notes further that numerous controlled human exposure studies have reported decrements in lung function and/or respiratory symptoms in exercising asthmatics exposed to peak 5–10 minute SO_2 concentrations. The Administrator therefore concludes that the form of a new 1-hour standard should be especially focused on limiting the upper end of the distribution of ambient SO_2 concentrations (*i.e.,* above 90th percentile SO_2 concentrations) in order to provide protection with an adequate margin of safety against effects reported in both epidemiologic and controlled human exposure studies.

In further considering specific concentration based forms, the Administrator notes as outlined above in section II.F.3.b, and discussed in more detail in the REA (REA, section 10.5.3) and proposal (*see* section II.F.3, 74 FR at 64834), that a 99th percentile form is likely to be appreciably more effective at limiting 5-minute benchmark exposures of concern compared to a 98th percentile form. Taken together with the considerations just discussed above, the Administrator has selected a 99th percentile form, averaged over 3 years. The Administrator concludes that a 99th percentile form, given the level selected (*see* section II.F.4 immediately below), will limit both the upper end of the distribution of ambient SO_2 concentrations reported in some epidemiologic studies to be associated with increased risk of SO_2-related respiratory morbidity effects (*e.g.,* emergency department visits), as well as 5-minute peak SO_2 concentrations resulting in decrements in lung function and/or respiratory symptoms in exercising asthmatics participating in controlled human exposure studies.

4. Level

As discussed below and in more detail in the proposal (section II.F.4, 74 FR at 64834), the Administrator proposed to set a 1-hour standard with a 99th percentile form (averaged over three years), with a level in the range of 50 to 100 ppb. The Administrator also solicited comment on standard levels greater than 100 ppb up to 150 ppb. This section summarizes the rationale for the Administrator's proposed range of standard levels (II.F.3.a), discusses comments related to the range of standard levels (II.F.3.b), and presents the Administrator's final conclusions regarding the level of a new 1-hour SO_2 standard (II.F.3.c).

a. Rationale for Proposed Decision

In assessing the level of a 1-hour standard with a 99th percentile form (averaged over three years), the Administrator considered the broad range of scientific evidence assessed in the ISA, including the epidemiologic studies and controlled human exposure studies, as well as the results of air quality, exposure, and risk analyses presented in the REA. In light of this body of evidence and analyses, the Administrator found it is necessary to provide increased public health protection for at-risk populations against an array of adverse respiratory health effects related to short-term (*i.e.,* 5 minutes to 24 hours) exposures to ambient SO_2. In considering the most appropriate way to provide this protection, the Administrator was mindful of the extent to which the available evidence and analyses could inform a decision on the level of a standard. The Administrator's proposed decisions on level, as discussed in detail in the proposal (*see* section II.F.4.e), are outlined below.

Given the above considerations, the Administrator proposed to set a level for a new 99th percentile 1-hour daily maximum primary SO_2 standard within the range from 50 to 100 ppb and took comment on levels above 100 ppb, up to 150 ppb. In reaching this proposed decision, the Administrator considered: (1) The evidence-based considerations from the final ISA and the final REA; (2) the results of the air quality, exposure, and risk assessments discussed above and in the final REA; (3) CASAC advice and recommendations on both the ISA and REA discussed above and provided in CASAC's letters to the Administrator; and (4) public comments received on the first and second drafts of the ISA and REA. In considering what level of a 1-hour SO_2 standard is requisite to protect public health with an adequate margin of safety, the Administrator was mindful that this choice requires judgments based on an interpretation of the evidence and other information that neither overstates nor understates the strength and limitations of that evidence and information.

As noted above, the Administrator selected an upper end of a range of levels to propose at 100 ppb. The selection of this level focused on the results of the controlled human exposure studies and is primarily based on the results of the air quality and exposure analyses which suggest that a 1-hour standard should be at or below 100 ppb to appreciably limit 5-minute SO_2 benchmark concentrations $\geq$ 200 ppb (*see* proposal Tables 2–4, and proposal sections II.F.4.a and II.F.4.b). That is, as described in the proposal (*see* section II.F.4.e), the 40-county air quality analysis estimates that a 100 ppb 1-hour standard would allow at most 2 days per year on average when estimated 5-minute daily maximum SO_2 concentrations exceed the 400 ppb benchmark, and at most 13 days per year on average when 5-minute daily maximum SO_2 concentrations exceed the 200 ppb benchmark (*see* proposal Table 2). Furthermore, given a simulated 1-hour 100 ppb standard level, most counties in the air quality analysis were estimated to experience 0 days per year on average when 5-minute daily maximum SO_2 concentrations exceed the 400 ppb benchmark and $\leq$ 3 days per year on average when 5-minute daily maximum SO_2 concentrations were estimated to exceed the 200 ppb benchmark (*see* REA, Tables 7–14 and 7–12). The Administrator also noted that the St. Louis exposure analysis indicated that a 1-hour standard at

100 ppb would still be estimated to protect > 99% of asthmatic children at moderate or greater exertion from experiencing at least one 5-minute SO_2 exposure ≥ 400 ppb per year, and about 97% of these children from exposures ≥ 200 ppb. In contrast, as described in the proposal (*see* section II.F.4.b), the St. Louis exposure analysis estimated that a 1-hour standard at 150 ppb would likely only protect about 88% of asthmatic children at moderate or greater exertion from experiencing at least one 5-minute SO_2 exposure ≥ 200 ppb per year.

As noted above and described in detail in the proposal (*see* section II.F.4.e), the Administrator selected 50 ppb as the lower end of a range of levels to propose, which is consistent with CASAC's advice. The selection of this level focused in part on the U.S. epidemiologic evidence described in detail in the proposal (*see* sections II.B.2, II.F.4.a, and II.F.4.e). With respect to these epidemiologic studies, seven of ten U.S. emergency department visit and hospital admission studies reporting generally positive associations with ambient SO_2 were conducted in locations where 99th percentile 1-hour daily maximum SO_2 levels were about 75–150 ppb, and three of these studies observed statistically significant positive associations between ambient SO_2 and respiratory-related emergency department visits and hospitalizations in multi-pollutant models with PM (NYDOH (2006), Ito *et al.,* (2007), and Schwartz et. al, (1995)). Thus, the Administrator noted that a 99th percentile 1-hour daily maximum standard set at a level of 50 ppb is well below the 99th percentile 1-hour daily maximum SO_2 concentrations reported in locations where these three studies were conducted (*i.e.* well below 99th percentile 1-hour daily maximum SO_2 levels of 78–150 ppb seen in NYDOH (2006), Ito *et al.,* (2007), and Schwartz et. al, (1995)). Finally, the Administrator noted that two epidemiologic studies reported generally positive associations between ambient SO_2 and emergency department visits in cities when 99th percentile 1-hour daily maximum SO_2 concentrations were approximately 50 ppb, but did not consider that evidence strong enough to propose setting a standard level lower than 50 ppb.

In considering the results of the air quality and exposure analyses, the Administrator also noted that the 40-county air quality analysis estimates that a 99th percentile 1-hour daily maximum standard set at a level of 50 ppb would result in zero days per year when estimated 5-minute SO_2 concentrations exceed the 400 ppb 5-minute benchmark level and at most 2 days per year when modeled 5-minute SO_2 concentrations exceed the 200 ppb 5-minute benchmark level (*see* proposal section II.F.4.b and proposal Table 2). In addition, the St. Louis exposure analysis estimates that a 99th percentile 1-hour daily maximum standard set at a level of 50 ppb would likely protect > 99% of asthmatic children at moderate or greater exertion from experiencing at least one 5-minute exposure both ≥ 400 and > 200 ppb per year (*see* proposal section II.F.4.b and Table 3). In addition, although not directly analyzed in the REA, the proposal (section II.F.4.b) noted that a 1-hour daily maximum standard at a level of 75 ppb would be bound by the exposure estimates from air quality adjusted to just meet 99th percentile 1-hour daily maximum standards at 50 and 100 ppb. Thus, a 1-hour daily maximum standard at a level of 75 ppb would be estimated to protect > 99% of asthmatic children at moderate or greater exertion in St. Louis from experiencing at least one exposure ≥ 400 ppb per year, and about 97% to > 99% of these children from experiencing at least one exposure ≥ 200 ppb per year.

The Administrator thus proposed to set the level of a new 1-hour standard that would protect public health with an adequate margin of safety between 50 ppb and 100 ppb. In so doing, the Administrator relied on reported findings from both epidemiologic and controlled human exposure studies, as well as the results of air quality and exposure analyses. The Administrator noted that the lower end of the proposed range was consistent with CASAC advice that there is clearly sufficient evidence for consideration of standard levels starting at 50 ppb (Samet 2009, p. 16). With respect to the upper end of the proposed range, the Administrator noted that CASAC concluded that standards up to 150 ppb "could be justified under some interpretations of weight of evidence, uncertainties, and policy choices regarding margin of safety" (*id.*), although the letter did not provide any indication of what interpretations, uncertainties, or policy choices might support selection of a level as high as 150 ppb.

In light of the range of levels included in CASAC's advice, the Administrator also solicited comment on setting a standard level above 100 ppb and up to 150 ppb. In so doing, the Administrator recognized that there are uncertainties with the scientific evidence, such as attributing effects reported in epidemiologic studies specifically to SO_2 given the presence of co-occurring pollutants, especially PM, and the uncertainties associated with using ambient SO_2 concentrations as a surrogate for exposure. However, the Administrator noted that compared to the proposed range of 50–100 ppb, a standard level as high as 150 ppb would not comparably limit 5-minute SO_2 exposures ≥ 200 ppb. That is, she noted that the St. Louis exposure analysis estimated that a 150 ppb standard would protect approximately 88% of asthmatic children at moderate or greater exertion from experiencing at least one SO_2 exposure ≥ 200 ppb per year (compared to > 99% and approximately 97% given standards at 50 and 100 ppb respectively; *see* proposal Table 3 at 74FR at 64841).

b. Comments on Level

Most State and local agencies and organizations that commented on this issue expressed support for setting the level of a 1-hour SO_2 standard somewhere within the proposed range of 50 to 100 ppb. More specifically, State environmental organizations (*i.e.,* NACAA and NESCAUM); State environmental agencies (*e.g.,* such agencies in DE, IL, MI, NY, NM, PA, VT), the Fond du Lac Tribe, and local groups (*e.g.,* NYDOH, City of Houston, New York City, Houston-Galveston Area Council) supported a level of a 1-hour SO_2 standard in the range of 50 to 100 ppb. In addition, State environmental agencies in IA and TX specifically supported a standard level of 100 ppb. In general, these groups cited the conclusions of CASAC and the Administrator's rationale as stated in the proposal as a basis for their recommendations, though State environmental agencies in IA and TX generally recommended placing more weight on the controlled human exposure evidence rather than on the epidemiology.

A number of environmental and medical/public health organizations (*e.g.,* ALA, ATS, EDF, Sierra Club, WEACT for Environmental Justice, NRDC, CBD) and some local organizations (*e.g.,* Alexandria Department of Transportation and Environmental Services, and Harris County (TX) Public Health & Environmental Services) supported setting a standard level at or near 50 ppb. This recommendation was typically based on the commenters' interpretation of the controlled human exposure and epidemiologic evidence, as described below.

With regard to the controlled human exposure evidence, health and environmental groups generally concluded that a 1-hour SO_2 standard no higher than 50 ppb is needed to protect against 5-minute SO_2 benchmark exposures as low as 100 ppb identified from mouthpiece exposure studies, rather than the 200 ppb 5-minute SO_2 benchmark identified from "free breathing" controlled human exposure studies. More specifically, ALA *et al.,* stated:

In its analysis of data from chamber studies in the ISA and in the REA, EPA focuses on studies of "free breathing" exposure. In doing so, EPA improperly and arbitrarily downplays important evidence that reported increased airway resistance, a measure of bronchoconstriction, in subjects with mild asthma at concentrations of 100 ppb. Regrettably, EPA does not rely on the mouthpiece studies in formulating its proposed standards * * * In downplaying the mouthpiece studies, EPA ignores the large segment of people who rely on oral or oronasal breathing some or all of the time.

The Administrator disagrees with the assertion that results from mouthpiece studies were improperly downplayed. These studies are discussed in the ISA, REA, and proposed rule as demonstrating respiratory effects of SO_2 at concentrations of 100 ppb, the lowest concentration tested using a mouthpiece exposure system. Nonetheless, these mouthpiece studies are not a reasonable proxy for actual exposure. In these studies, SO_2 is delivered directly through the mouth, typically in conjunction with nasal occlusion. This allows a greater fraction of the inhaled SO_2 to reach the tracheobronchial airways. Although we agree with commenters that some individuals do breathe oronasally both while at rest and during exercise, nasal ventilation still constitutes a significant percentage of total ventilation. The consequence is that individuals exposed to SO_2 through a mouthpiece are likely to experience greater respiratory effects from a given SO_2 exposure than they would in real life. Thus, as noted in the REA (REA, section 6.2) and in the proposal preamble (*see* section II.B.1.b), these mouthpiece studies only provide very limited evidence of decrements in lung function following exposure to 100 ppb SO_2. Therefore, the Administrator did not place great weight on these mouthpiece studies when considering the appropriate level of a 1-hour SO_2 standard.

In addition to their interpretation of the controlled human exposure evidence, health and environmental groups (*e.g.,* ALA, ATS, EDF, NRDC, Sierra Club, CBD) and the Alexandria Department of Transportation and Environmental Services generally concluded that the epidemiologic evidence indicates that a standard no higher than 50 ppb is required to protect public health. For example, it its comments the CBD stated:

Epidemiologic studies referenced in the Proposed Rule showed positive, and in many cases statistically significant, relationships between ambient SO_2 concentrations and hospital admissions where 99th percentile 1-hour concentrations ranged from 50–460 ppb. Of these studies, two showed positive and sometimes statistically significant relationships in single-pollutant models at 50 ppb, and three studies showed statistically significant correlations at 78–150 ppb in multi-pollutant models. These three multipollutant studies, moreover, "lend[] strong support * * * to the conclusion that SO_2 effects are generally independent" of those of co-pollutants like particulate matter. Giving these studies their proper weight, and allowing for an adequate margin of safety, EPA should set a one-hour NAAQS at a level no higher than the lowest concentration at which positive, adverse relationships have been demonstrated: 50 ppb (note that footnotes were omitted).

The Administrator agrees that the epidemiologic studies referenced in the proposal need to be considered in judging the appropriate level for a new 99th percentile 1-hour SO_2 standard. However, she disagrees that when considered in total, these studies strongly support an SO_2 standard no higher than 50 ppb. The Administrator notes that selecting a standard level of 50 ppb would place considerable weight on the two U.S. emergency department visit studies conducted in locations where 99th percentile 1-hour SO_2 concentrations were approximately 50 ppb (*i.e.,* Wilson *et al.,* (2005) in Portland, ME and Jaffe *et al.,* (2003) in Columbus, OH). However, the Administrator does not find this appropriate given that, importantly, neither of these studies evaluated the potential for confounding by co-pollutants through the use of multipollutant models and thus, left unaddressed the issue of whether the effects seen in the studies were partially or totally attributable to exposure to sulfate PM. In addition, the Administrator notes that the overall results reported in these studies are mixed. It is important to note that mixed results do not automatically disqualify studies from being used as part of the evidence base for setting levels in NAAQS reviews. However, in this review the Administrator judges that the lack of mutipollutant model evaluation for potential confounding by PM in two locations with the lowest SO_2 levels combined with the presence of mixed emergency department visit results renders these two studies inappropriate to serve as the primary basis for the selection of the level of the SO_2 NAAQS. As an additional matter, the suggestion in some of the comments that EPA should necessarily base the level of a NAAQS on the lowest level seen in epidemiologic studies has been rejected repeatedly. *See, e.g. American Petroleum Inst.* v. *EPA,* 665 F. 2d at 1187 ("In so arguing NRDC essentially ignores the mixed results of the medical studies evident in the record, choosing instead to rely only on the studies that favor its position. The Administrator, however, was required to take into account all the relevant studies revealed in the record. Because he did so in a rational manner, we will not overrule his judgment as to the margin of safety.") Thus, although the Administrator finds that these two studies provide limited evidence of emergency department visits in cities where 99th percentile 1-hour daily maximum SO_2 concentrations are approximately 50 ppb, she also concludes that these studies do not provide enough evidence to warrant a standard at this level.

As discussed above in section, II.E.2, a number of industry groups (*e.g.,* ACC, UARG) did not support setting a new 1-hour SO_2 standard. However, several of these groups (*e.g.,* UARG, API) and the SC Chamber of Commerce concluded that, if EPA does choose to set a new 1-hour standard, the level of that standard should be ≥ 150 ppb. In addition, State environmental agencies in SD (SD DENR) and OH recommended standard levels at 150 ppb. As a basis for this recommendation, these groups generally emphasized uncertainties in the scientific evidence. Specifically, as discussed in more detail above (section II.E.2.a), these commenters typically concluded that the available epidemiologic studies do not support the conclusion that SO_2 causes the reported health effects. This was based on their assertion that the presence of co-pollutants in the ambient air precludes the identification of a specific SO_2 contribution to reported effects. Thus, these groups generally concluded that weight should not be placed on the cluster of three epidemiologic studies reporting statistically significant effects in multipollutant models with PM (*i.e.,* NYDOH 2006; Ito 2007; and Schwartz 1995). That is, these groups contend that these studies do not demonstrate an independent effect of SO_2. In addition, as noted in section II.E.2.b, many of these groups also disagreed with the Agency's judgment that adverse respiratory effects occur following 5-minute exposures to SO_2 concentrations as low as 200 ppb. These comments and EPA's responses are discussed below and in section II of the RTC document (EPA 2010).

As described in more detail in section II.E.2.a, we agree that the interpretation of SO_2 epidemiologic studies is complicated by the fact that SO_2 is but one component of a complex mixture of pollutants present in the ambient air. However, the ISA concluded that when U.S. and international epidemiologic literature is evaluated as a whole, SO_2 effect estimates generally remained positive and relatively unchanged in multi-pollutant models with gaseous or particulate co-pollutants. Thus, although recognizing the uncertainties associated with separating the effects of SO_2 from those of co-occurring pollutants, the ISA concluded that the limited available evidence from studies employing multi-pollutant models indicates that the effect of SO_2 on respiratory health outcomes appears to be generally robust and independent of the effects of gaseous co-pollutants, including NO_2 and O_3, as well as particulate co-pollutants, particularly $PM_{2.5}$ (ISA, section 5.2; p. 5–9).

In addition, as described in detail above in section II.E.2.a, the ISA emphasized that controlled human exposure studies provide support for the plausibility of the associations reported in epidemiologic studies. The ISA noted that the results of controlled human exposure and epidemiologic studies form a plausible and coherent data set that supports a causal relationship between short-term (5-minutes to 24-hours) SO_2 exposures and adverse respiratory effects, and that the epidemiologic evidence (buttressed by the clinical evidence) indicates that the effects seen in the epidemiologic studies are attributable to exposure to SO_2 (ISA, section 5.2). The ISA in fact made the strongest finding possible regarding causality: "[e]valuation of the health evidence, with consideration of issues related to atmospheric sciences, exposure assessment, and dosimetry, led to the conclusion that there is *a causal relationship between respiratory morbidity and short-term exposure to* SO_2. This conclusion is supported by the consistency, coherence, and plausibility of findings observed in the human clinical, epidemiologic, and animal toxicological studies." ISA p. 5–2 (emphasis original).

As mentioned above, many groups dispute the ISA conclusion that taken together, results from U.S. and international epidemiologic studies employing multipollutant models indicate that SO_2 has an independent effect on the respiratory health outcomes reported in these studies. Thus, these groups contend that the Administrator should not place weight on epidemiologic studies and their associated air quality information in general, and more specifically, the Administrator should not place weight on air quality information from the three U.S. epidemiologic studies reporting statistically significant effects in multipollutant models with PM (*i.e.,* NYDOH 2006; Ito 2007; and Schwartz 1995). Specific comments on these three epidemiologic studies reporting statistically significant effects in multi-pollutant models with PM, and EPA responses are presented below and in the RTC document (EPA 2010).

Industry groups (*e.g.,* API) had several comments with respect to the study conducted by the NYDOH (NYDOH, 2006). First, these groups generally concluded that the results of this study are mixed. That is, while SO_2 effect estimates were positive and statistically significant even in multipollutant models with $PM_{2.5}$ or NO_2 in the Bronx, SO_2 effect estimates were actually negative in Manhattan in both single and multipollutant models. These groups also contend that this report was not peer-reviewed and that the authors of this study indicated that high correlations among pollutants in the Bronx made it difficult to confidently identify which pollutants are actually increasing risks. For these reasons, industry groups generally concluded that this study should not be relied upon by the Administrator.

We acknowledge that the results of the NYDOH analysis are mixed when comparing the Bronx and Manhattan study areas. However, we disagree that the presence of mixed results renders this study unreliable. We note that the mixed results reported in this study are likely to reflect greater statistical power for identifying effects in the Bronx, where the average daily emergency department visits differed substantially from those in Manhattan. Specifically, daily asthma emergency department visits were six times higher in the Bronx study area (43 per day) than in the Manhattan study area (7.2 per day). Thus, the more prominent effects in the Bronx likely at least partially reflect greater statistical power for identifying effects there. To put these numbers in perspective, the crude daily rates of asthma emergency department visits can be estimated by dividing the daily asthma counts by the population. The mean daily crude rates of asthma emergency department visits were over eight-fold higher in the Bronx study area (16.9 per 100,000 persons) than in the Manhattan area (2.02 per 100,000 persons). Population age structures were quite different in the two communities, with larger proportions of younger persons in the Bronx versus Manhattan. There are likely additional differences in population structures of the two communities, including differences in SES, race/ethnicity, and access to primary asthma care. These differences in the two communities may explain the differences in the results, and do not prevent EPA from legitimately relying on this study.

As mentioned above, these groups also contend that the NYDOH epidemiologic study should not be relied upon because it was not peer-reviewed. We disagree with this assertion. The NYDOH study was subject to multiple peer-review processes. This included reviews by the Agency for Toxic Substances and Disease Registry (ATSDR), EPA, and CASAC.

Finally, as also mentioned above, these groups contend that the NYDOH epidemiologic study is unreliable because the study authors indicated that high correlations among pollutants in the Bronx make it difficult to confidently identify which pollutants are actually increasing risks. In response, we note that high correlations among ambient air pollutant concentrations are not specific to the NYDOH study, and may contribute to uncertainty in the interpretation of many epidemiologic studies of air pollution. The approach most commonly utilized to disentangle the effects of correlated pollutants in air pollution epidemiology is the copollutant model. The NYDOH uses copollutant models and finds that the results for SO_2 remain significant in models considering the simultaneous effects of NO_2, O_3, and $PM_{2.5}$. This indicates an independent effect of SO_2 on the asthma emergency department visits reported in this study.

With respect to Ito *et al.,* (2007), industry groups generally commented that since the SO_2 effect estimate did not remain statistically significant in multipollutant models with NO_2, this study does not indicate an independent effect of SO_2 on emergency department visits in the NYC study area. API specifically commented:

> The RR for an increase of 6 ppb SO_2 was statistically significant (1.20; 95% CI: 1.13, 1.28) and remained so when $PM_{2.5}$, O_3, or CO was included in the model, but became nonsignificant when NO_2 was included in the model (RR not provided, 95% CI: 0.9, 1.1). Because associations with SO_2 could be attributable to NO_2, this study cannot be used to assess the effects of SO_2 on health effects with small incremental increases in exposure.

We disagree with the commenters. We believe that this study does demonstrate an independent effect of SO_2 on emergency department visits in NYC. We note that evidence from controlled human exposure studies has demonstrated effects of NO_2 (EPA, 2008b) and SO_2 independently on respiratory morbidity. Since each of these criteria pollutants has an independent effect on the respiratory system, it is logical that each may be responsible for an increase in emergency department visits for asthma in epidemiologic studies. In addition, the authors note that the attenuation of the SO_2 effect estimate when NO_2 is included in the model is "consistent with the result of monitor-to-monitor correlations, suggesting that NO_2 has less exposure error than CO or SO_2 in this data set." Thus, it appears as though the high spatial heterogeneity of SO_2 compared to NO_2, leading to increased exposure error, may be causing the attenuation of the SO_2 effect estimate when NO_2 is included in the model in this study—not that the effects seen in the study are attributable to NO_2. Overall, the results from this study are consistent with the SO_2 effect on respiratory emergency department visits and hospital admissions across studies and are coherent with the respiratory effects observed in controlled human exposure studies. This study thus provides persuasive evidence of an independent effect of short-term SO_2 exposure on respiratory morbidity.

With respect to Schwartz *et al.,* (1995), industry groups generally commented that the results of this study are mixed, and therefore should not be considered by the Administrator. More specifically, these commenters noted that although the results in New Haven remained statistically significant in the presence of PM_{10}, the SO_2 effect estimate in Tacoma was reduced and no longer statistically significant in the presence of PM_{10}. Commenters also noted that in both cities, the SO_2 effect estimate was reduced and no longer statistically significant in the presence of O_3.

We disagree that the results of this study of hospital admissions should not be considered by the Administrator. As noted by the commenters, this study was conducted in two cities, New Haven, CT and Tacoma, WA. These cities were chosen because they differ in several important aspects and the author expected the results from the two cities to be different due to the inherent nature of the study design and study locations. "New Haven has almost twice the mean SO_2 concentration of Tacoma, almost two and a half times the SO_2 concentration in the peak winter season, and a much larger summer ozone peak than Tacoma (Schwartz 1995)." Since the study was designed to examine the differences in these two cities, the fact that the results differed in the two cities does not invalidate those results. In addition, EPA considers the SO_2 effect to be robust to inclusion of O_3 in New Haven. The central effect estimate for SO_2 changed from 1.03 to 1.02 after the addition of O_3 as a copollutant and likely lost statistical significance due to a greater than 40% reduction in the number of days included because O_3 was only measured during the warm months. This reduction likely led to model instability and a loss of statistical significance. To be consistent with how results of other studies were interpreted in the ISA, and as supported by the CASAC, the effect of SO_2 is considered robust to the inclusion of O_3 in New Haven.

In addition to generally concluding that the epidemiology is too uncertain to demonstrate that SO_2 has an independent effect on the respiratory effects reported in those studies, many industry groups (*e.g.,* API, ACC, Progress Energy, EEI, CIBO) also commented that adverse health effects do not occur following 5–10 minute SO_2 exposures < 400 ppb in controlled human exposure studies (an issue also discussed above in section II.E.2.b). Thus, these groups generally maintained that the level of a 1-hour standard should not take into account limiting 5-minute peaks as low as 200 ppb. From this argument, many of these groups further maintained that 1-hour standard levels ≥ 150 ppb are requisite to protect public health with an adequate margin of safety.

As first discussed in section II.E.2.b above, we disagree with the commenters that adverse respiratory effects do not occur following 5-minute SO_2 exposures as low as 200 ppb. The ISA reported that exposure to SO_2 concentrations as low as 200–300 ppb for 5–10 minutes results in approximately 5–30% of exercising asthmatics experiencing moderate or greater decrements in lung function (defined in terms of a ≥ 15% decline in FEV_1 or 100% increase in sRaw; ISA, Table 3–1). Considering the 2000 ATS guidelines described in section II.E.2.b, we determined that these results could reasonably indicate an SO_2-induced shift in these lung function measurements for this sub-population. Under this scenario, an appreciable percentage of exercising asthmatics exposed to SO_2 concentrations as low as 200 ppb would likely have diminished reserve lung function and thus would likely be at greater risk if affected by another respiratory agent (*e.g.,* viral infection). Importantly, diminished reserve lung function in a population that is attributable to air pollution is considered an adverse effect under ATS guidance.[17] Also noted in section II.E.2.b, we were mindful of CASAC's pointed comments. The second draft ISA placed relatively little weight on health effects associated with SO_2 exposures at 200–300 ppb. CASAC strongly disagreed with this characterization of the health evidence. Their consensus letter following the second draft ISA states:

> Our major concern is the conclusions in the ISA regarding the weight of the evidence for health effects for short-term exposure to low levels of SO_2. Although the ISA presents evidence from both clinical and epidemiological studies that indicate health effects occur at 0.2 ppm or lower, the final chapter emphasizes health effects at 0.4 ppm and above * * * CASAC believes the clinical and epidemiological evidence warrants stronger conclusions in the ISA regarding the available evidence of health effects at 0.2 ppm or lower concentrations of SO_2. The selection of a lower bound concentration for health effects is very important because the ISA sets the stage for EPA's risk assessment decisions. In its draft Risk and Exposure Assessment (REA) to Support the Review of the SO_2 Primary National Ambient Air Quality Standards (July 2008), EPA chose a range of 0.4 ppm—0.6 ppm SO_2 concentrations for its benchmark analysis. As CASAC will emphasize in a forthcoming letter on the REA, we recommend that a lower bound be set at least as low as 0.2 ppm (Henderson 2008a).

Similarly, we were also mindful of CASAC comments on the first draft of the REA. The consensus CASAC letter following the 1st draft REA states:

> The CASAC believes strongly that the weight of clinical and epidemiology evidence indicates there are detectable clinically relevant health effects in sensitive subpopulations down to a level at least as low as 0.2 ppm SO_2. These sensitive subpopulations represent a substantial segment of the at-risk population (Henderson 2008b).

As noted in section II.E.2.b, we were also mindful of: (1) Previous CASAC recommendations (Henderson 2006) and NAAQS review conclusions (EPA 2006, EPA 2007d) indicating that moderate decrements in lung function can be clinically significant in some asthmatics (*see* section II.E.2.b for more detail) and

[17] *See Coalition of Battery Recyclers Association* v. *EPA,* No. 09–1011 (DC Cir., May 14, 2010), slip opinion at 9, holding that it was reasonable for EPA to conclude that a two IQ point mean population loss is an adverse effect based in part on consideration of comments from the American Academy of Pediatrics that such a loss should be prevented.

(2) controlled human exposure studies not including severe asthmatics and thus, that it is reasonable to assume that persons with more severe asthma than the study participants would have a more serious health effect from short-term exposure to 200 ppb SO_2. CASAC echoed this concern in its comments on the policy assessment chapter of the REA:

Chapter 10 should better address uncertainty in identifying alternative NAAQS for SO_2. In particular, the uncertainties discussed in the health risk characterization should be considered in specifying a NAAQS that provides adequate margin of safety. One particular source of uncertainty needing acknowledgment is the characteristics of persons included in the clinical studies. The draft REA acknowledges that clinical studies are unlikely to have included severe asthmatics that are likely to be potentially at greater risk than those persons included in the clinical studies (Samet 2009; p. 15).

Taken together, the Administrator concluded that exposure to SO_2 concentrations as low as 200 ppb can result in adverse health effects in asthmatics. Consequently the Administrator also concluded that a 1-hour standard of 150 ppb is not requisite to protect public health with an adequate margin of safety, even with a 99th percentile form. This conclusion takes into account the St. Louis exposure analysis estimating that only 88% of asthmatic children at moderate or greater exertion would be protected from at least one 5-minute SO_2 exposure ≥ 200 ppb per year at a 1-hour standard level of 150 ppb, and appropriate weight placed on the epidemiologic evidence (*see* section II.F.4.c for a discussion of the epidemiologic evidence with respect to level).

c. Conclusions on Standard Level

Having carefully considered the public comments on the appropriate level for a 1-hour SO_2 standard, as discussed above, the Administrator believes the fundamental conclusions reached in the ISA and REA remain valid. In considering the level at which the 1-hour primary SO_2 standard should be set, the Administrator continues to place primary emphasis on the body of controlled human exposure and epidemiologic evidence assessed in the ISA, as summarized above in section II.B. In addition, the Administrator continues to view the results of exposure and risk analyses, discussed above in section II.C, as providing supporting information for her decision.

In considering the level of a 1-hour SO_2 standard, the Administrator notes that there is no bright line clearly mandating the choice of level within the reasonable range proposed. Rather, the choice of what is appropriate within this reasonable range is a public health policy judgment entrusted to the Administrator. This judgment must include consideration of the strengths and limitations of the evidence and the appropriate inferences to be drawn from the evidence and the exposure and risk assessments. These considerations and the Administrator's final decision with regard to the level of a new 1-hour SO_2 standard are discussed below.

In considering the controlled human exposure studies, the Administrator notes that these studies provide the most direct evidence of respiratory effects from exposure to SO_2. These studies exposed groups of exercising asthmatics to defined concentrations of SO_2 for 5–10 minutes and found adverse respiratory effects. As noted above (*see* section II.C), SO_2 exposure levels which resulted in respiratory effects in these studies were considered 5-minute benchmark exposures of potential concern in the analyses found in the REA. With respect to this evidence, the Administrator notes the following key points:

- Exposure of exercising asthmatics to 5–10 minute SO_2 concentrations ≥ 400 ppb results in moderate or greater decrements in lung function (in terms of FEV_1 or sRaw) in 20–60% of tested individuals in these studies. Moreover, these decrements in lung function are often statistically significant at the group mean level and are frequently accompanied by respiratory symptoms.[18] Based on ATS guidelines, exposure to SO_2 concentrations ≥ 400 ppb clearly result in adverse respiratory effects (*i.e.,* decrements in lung function in the presence of respiratory symptoms). Therefore, the Administrator has concluded it appropriate to place weight on the 400 ppb 5-minute SO_2 benchmark concentration of concern.
- Exposure of exercising asthmatics to 5–10 minute SO_2 concentrations at 200–300 ppb results in moderate or greater decrements in lung function in 5–30% of the tested individuals in these studies. The Administrator notes that although these decrements in lung function have not been shown to be statistically significant at the group mean level, or to be frequently accompanied by respiratory symptoms, she considers effects associated with exposures as low as 200 ppb to be adverse in light of CASAC advice, similar conclusions in prior NAAQS reviews, and the ATS guidelines described in detail above (*see* section II.E.2.b and II.F.4.b). Therefore, she has concluded it appropriate to place weight on the 200 ppb 5-minute benchmark concentration.
- There is very limited evidence from two mouthpiece exposure studies suggesting respiratory effects in exercising asthmatics following SO_2 exposures at 100 ppb. However, given the uncertainties and potential unrepresentativeness associated with mouthpiece studies (*see* section II.F.4.b above), the Administrator found it appropriate not to place weight on this 5-minute SO_2 benchmark concentration.

The Administrator also considered the results of the air quality, exposure, and risk analyses, as they serve to estimate the extent to which a given 1-hour standard limits the 5-minute benchmark concentrations of concern identified from controlled human exposure studies (*see* REA chapters 7–9, proposal section II.F.4.b, and proposal Tables 2–4). In considering these results as they relate to limiting 5-minute SO_2 benchmark concentrations ≥ 200 and 400 ppb, the Administrator notes the following key points:

- The 40-county air quality analysis estimates that a 100 ppb 1-hour daily maximum standard would allow at most 2 days per year on average in any county when estimated 5-minute daily maximum SO_2 concentrations exceed the 400 ppb benchmark, and at most 13 days per year on average when 5-minute daily maximum SO_2 concentrations exceed the 200 ppb benchmark (*see* proposal, Table 2, 74 FR at 64840). Furthermore, given a simulated 1-hour 100 ppb standard level, most of the counties in that air quality analysis were estimated to experience 0 days per year on average when 5-minute daily maximum SO_2 concentrations exceed the 400 ppb benchmark and ≤ 3 days per year on average when 5-minute daily maximum SO_2 concentrations were estimated to exceed the 200 ppb benchmark (*see* REA, Tables 7–14 and 7–12).
- The St. Louis exposure analysis estimates that a 99th percentile 1-hour daily maximum standard at a level of 100 ppb would likely protect > 99% of asthmatic children in that city at moderate or greater exertion from experiencing at least one 5-minute exposure ≥ 400 ppb per year, and

[18] The ISA concluded that collective evidence from key controlled human exposure studies considered in the previous review, along with a limited number of new controlled human exposure studies, consistently indicates that with elevated ventilation rates a large percentage of asthmatic individuals tested in a given chamber study (up to 60%, depending on the study) experience moderate or greater decrements in lung function, frequently accompanied by respiratory symptoms, following peak exposures to SO_2 at concentrations of 0.4–0.6 ppm. (ISA, p. 3–9).

approximately 97% of those asthmatic children at moderate or greater exertion from experiencing at least one exposure ≥ 200 ppb per year (*see* proposal, section II.F.4.b).

• The St. Louis risk assessment estimates that a 99th percentile 1-hour standard level at 100 ppb would likely protect about 97–98% of exposed asthmatic children in that city at moderate or greater exertion from experiencing at least one moderate or greater lung function response (defined as a ≥ 100% increase in sRaw; *see* proposal, section II.F.4.b).

Given the above considerations, the Administrator concludes that a 1-hour standard at a level of 100 ppb would appropriately limit 5-minute SO_2 benchmark concentrations ≥ 200 or 400 ppb. Moreover, although the Administrator acknowledges that the air quality and exposure analyses mentioned above suggest that a 50 ppb standard may somewhat further limit 5-minute SO_2 concentrations/exposures in excess of the 200 ppb benchmark (*see* proposal section II.F.4.b), she does not believe this information alone warrants a standard level lower than 100 ppb. More specifically, although she considers the health effects resulting from 5-minute SO_2 exposures as low as 200 ppb to be adverse, she also recognizes that such effects are appreciably less severe than those at SO_2 concentrations ≥ 400 ppb. Thus, she concludes that there is little difference in limiting 5-minute concentrations/exposures ≥ 400 ppb given 1-hour standard levels in the range of 50 to 100 ppb.

In considering the epidemiologic evidence with regard to level, the Administrator notes that there have been more than 50 peer reviewed epidemiologic studies published worldwide evaluating SO_2 (ISA, Tables 5–4 and 5–5). These studies have generally reported positive, although not always statistically significant associations between more serious health outcomes (*i.e.* respiratory-related emergency department visits and hospitalizations) and ambient SO_2 concentrations and have generally included populations potentially at increased risk for SO_2-related respiratory effects (e.g, children, older adults, and those with pre-existing respiratory disease). The Administrator finds that in assessing the extent to which these studies and their associated air quality information can inform the level of a new 99th percentile 1-hour daily maximum standard for the U.S., air quality information from the U.S. and Canada is most relevant since these areas have similar monitor network designs and patterns of air quality. However, as described in proposal section II.F.4.a, SO_2 concentrations reported for Canadian studies were not directly comparable to those reported for U.S. studies due to use of different monitoring protocols in those studies. Thus, the Administrator focused on 99th percentile air quality information from U.S. studies for informing potential 1-hour standard levels. She concludes that this information provides evidence of associations between ambient SO_2 and emergency department visits and hospital admissions in U.S. cities with particular 99th percentile 1-hour SO_2 levels, and thus provides information that is particularly relevant for setting the level of a 1-hour SO_2 standard. With regard to these studies she notes the following key points:

• Ten studies (some conducted in multiple locations) reported mostly positive, and sometimes statistically significant, associations between ambient SO_2 concentrations and emergency department visit and hospital admissions in locations where 99th percentile 1-hour daily maximum SO_2 levels ranged from approximately 50–460 ppb.

• Within this broader range of SO_2 concentrations, there is a cluster of three epidemiologic studies between 78–150 ppb (for the 99th percentile of the 1-hour SO_2 concentrations) where the SO_2 effect estimate remained positive and statistically significant in multi-pollutant models with PM (NYDOH (2006), Ito *et al.,* (2007), and Schwartz *et al.,* (1995)). Notably, although statistical significance in multi-pollutant models is an important consideration, it is not the only consideration when relying on such epidemiologic evidence.[19] However, as noted earlier, there is special sensitivity in this review in disentangling PM-related effects (especially sulfate PM) from SO_2-related effects in interpreting the epidemiologic studies; thus, these studies are of particular relevance here, lending strong support both to the conclusion that SO_2 effects are generally independent of PM (ISA, section 5.2) and that these independent adverse effects of SO_2 have occurred in cities with 1-hour daily maximum, 99th percentile concentrations in the range of 78–150 ppb. Nor did EPA find the comments criticizing these studies persuasive, as explained above in section II.F.4.b and in the RTC document (EPA 2010). The Administrator therefore judges it appropriate to place substantial weight on this cluster of three U.S. epidemiologic studies in selecting a standard level, as they are a group of studies that reported positive and statistically significant associations between ambient SO_2 and emergency department visits or hospital admissions even when potential confounding by PM was considered.

• The Administrator agrees with the finding in the ISA that the controlled human exposure evidence lends biological plausibility to the effects reported in epidemiologic studies (ISA, p. 5–9).

• There is limited evidence from two epidemiologic studies employing single pollutant models that found generally positive associations between ambient SO_2 and emergency department visits in locations where 99th percentile 1-hour SO_2 concentrations were approximately 50 ppb (*see* proposal, Figures 1 and 2). However, considering that the results of these studies were mixed, and importantly, that neither of these two studies evaluated the potential for confounding by co-pollutants through the use of multipollutant models (particularly with PM), the Administrator judges it appropriate to place limited weight on these studies.

• With regard to the cluster of three studies conducted in the Bronx (NYDOH 2006), NYC (Ito *et al.,* 2007), and New Haven (Scwartz *et al.,* 1995), there is a degree of uncertainty as to whether the 99th percentile 1-hour daily maximum SO_2 concentrations reported from monitors in these three study areas reflect the highest 99th percentile 1-hour daily maximum SO_2 concentration. Our limited qualitative analysis suggests that 99th percentile 1-hour daily maximum SO_2 concentrations reported by monitors in these study areas are reasonable approximations for the absolute highest 99th percentile 1-hour daily maximum SO_2 concentration that can occur across the entire area in these studies (including the areas where monitors were not located) (*see* Brode, 2010). However, although a reasonable approximation, it is still likely that these monitored concentrations are somewhat lower than the absolute highest 99th percentile 1-hour daily maximum SO_2 concentrations occurring across these epidemiologic study areas.

[19] For example, as noted in the proposal (proposal, section II.F.4, 74 FR at 64835) evidence of a pattern of results from a group of studies that find effect estimates similar in direction and magnitude would warrant consideration of and reliance on such studies even if the studies did not all report statistically significant associations in single- or multi-pollutant models. The SO_2 epidemiologic studies fit this pattern, and are buttressed further by the results of the clinical studies. ISA, section 5.2.

Weighing all of this evidence, the Administrator concludes that the epidemiologic studies provide strong support for setting a standard that limits the 99th percentile of the distribution of 1-hour daily maximum SO_2 concentrations to 75 ppb. This judgment takes into account the strong determinations in the ISA (and endorsed by CASAC), based on a much broader body of evidence, that there is a causal association between exposure to SO_2 and the types of respiratory morbidity effects reported in these studies. The Administrator further judges that it is not necessary based on existing epidemiologic evidence, to set a standard below 75 ppb. That is, the Administrator concludes that a standard level of 75 ppb is sufficiently below the SO_2 levels in three cities where epidemiologic studies found statistically significant effects in multipollutant models with PM (*i.e.,* 78, 82, and 150 ppb) to provide an adequate margin of safety given the uncertainty as to whether monitors in these study locations reflected the highest 1-hour daily maximum SO_2 concentration across the entire study area. Thus, a standard set at a level of 75 ppb is likely further below the 99th percentile 1-hour daily maximum concentrations in these three study areas than the bare comparison of levels would otherwise indicate. Finally, the Administrator again notes that epidemiologic evidence below 75 ppb is more uncertain because studies below 75 ppb did not evaluate potential confounding of results in multipollutant models, and because these studies reported mixed results.

Given the above considerations and the comments received on the proposal, the Administrator determines that the appropriate judgment, based on the entire body of evidence and information available in this review, and the related uncertainties, is a standard level of 75 ppb. She concludes that such a standard, with a 1-hour averaging time and 99th percentile form, will provide a significant increase in public health protection compared to the current standards and would be expected to protect against the respiratory effects that have been linked with SO_2 exposures in both controlled human exposure and epidemiologic studies. Specifically, she concludes that such a standard will limit 1-hour exposures at and above 75 ppb for those in susceptible populations that are at-risk of experiencing adverse health effects from short-term exposure to SO_2. Such a standard will also maintain SO_2 concentrations below those in locations where key U.S. epidemiologic studies have reported that ambient SO_2 is associated with clearly adverse respiratory health effects, as indicated by increased hospital admissions and emergency department visits. She also notes that a 1-hour standard at a level of 75 ppb is expected to substantially limit asthmatics' exposure to 5–10 minute SO_2 concentrations ≥ 200 ppb, thereby substantially limiting the adverse health effects associated with such exposures. Finally, the Administrator notes that a standard level of 75 ppb is consistent with the consensus recommendation of CASAC.

In setting the standard level at 75 ppb rather than at a lower level, the Administrator notes that a 1-hour standard with a level lower than 75 ppb would only result in significant further public health protection if, in fact, there is a continuum of serious, adverse health risks caused by exposure to SO_2 concentrations below 75 ppb. Based on the available evidence, the Administrator does not believe that such assumptions are warranted. Taking into account the uncertainties that remain in interpreting the evidence from available controlled human exposure and epidemiologic studies, the Administrator notes that the likelihood of obtaining benefits to public health with a standard set below 75 ppb decreases, while the likelihood of requiring reductions in ambient concentrations that go beyond those that are needed to protect public health increases.

Therefore, the Administrator judges that a 1-hour SO_2 standard at 75 ppb is sufficient to protect public health with an adequate margin of safety. This includes protection with an adequate margin of safety for susceptible populations at increased risk for adverse respiratory effects from short-term exposures to SO_2 for which the evidence supports a causal relationship with SO_2 exposures. The Administrator does not believe that a lower standard level is needed to provide this degree of protection. These conclusions by the Administrator appropriately consider the requirement for a standard that is neither more nor less stringent than necessary for this purpose and recognizes that the CAA does not require that primary NAAQS be set at a zero-risk level or to protect the most susceptible individual, but rather at a level that reduces risk sufficiently so as to protect the public health with an adequate margin of safety.

5. Retaining or Revoking the Current 24-Hour and Annual Standards

This section discusses considerations related to retaining or revoking the current 24-hour and annual SO_2 primary NAAQS. Specifically, this section summarizes the rationale for the Administrator's proposed decision regarding whether to retain or revoke the current standards (section II.F.5.a), discusses public comments related to whether to retain or revoke the current standards (II.F.5.b), and presents the Administrator's final conclusions regarding whether to retain or revoke the current standards (II.F.5.c).

a. Rationale for Proposed Decision

As noted in the proposal (*see* section II.F.5), the REA recognized that the particular level selected for a new 99th percentile 1-hour daily maximum standard would have implications for deciding whether to retain or revoke the current 24-hour and annual standards. That is, with respect to SO_2-induced respiratory morbidity, the lower the level selected for a 99th percentile 1-hour daily maximum standard, the less additional public health protection the current standards would be expected to provide. CASAC expressed a similar view following their review of the 2nd draft REA: "Assuming that EPA adopts a one hour standard in the range suggested, and if there is evidence showing that the short-term standard provides equivalent protection of public health in the long-term as the annual standard, the panel is supportive of the REA discussion of discontinuing the annual standard" (Samet 2009, p. 15). With regard to the current 24-hour standard, CASAC was generally supportive of using the air quality analyses in the REA as a means of determining whether the current 24-hour standard was needed in addition to a new 1-hour standard to protect public health. CASAC stated: "The evidence presented [in REA Table 10–3] was convincing that some of the alternative one-hour standards could also adequately protect against exceedances of the current 24-hour standard" (Samet 2009, p. 15).

In accordance with the REA findings and CASAC recommendations mentioned above, the Administrator noted that 1-hour standards in the range of 50–100 ppb would have the effect of maintaining 24-hour and annual SO_2 concentrations generally well below the levels of the current 24-hour and annual NAAQS (*see* REA Tables 10–3 and 10–4 and REA Appendix Tables D–3 to D–6). Thus, if a new 99th percentile 1-hour daily maximum standard was set in the proposed range of 50–100 ppb, then the Administrator proposed to revoke the current 24-hour and annual standards. However, as noted in the proposal, if a standard was set at a level >100 ppb and up to 150 ppb, then the Administrator indicated that she would retain the existing 24-hour standard, recognizing that a 99th percentile 1-hour daily maximum standard at 150 ppb would not have the effect of maintaining 24-hour average SO_2 concentrations below the level of the current 24-hour standard in all locations analyzed (*see* REA Appendix Table D–4). Under this scenario, the Administrator would still revoke the current annual standard recognizing: (1) 99th percentile 1-hour daily maximum standards in the range of 50–150 ppb would maintain annual average SO_2 concentrations below the level of the current annual standard (*see* REA Table 10–4 and REA Appendix tables D–5 and D–6); and (2) the lack of sufficient evidence linking long-term SO_2 exposure to adverse health effects.

b. Comments on Retaining or Revoking the Current 24-Hour and Annual Standards

As noted above, most industry groups were opposed to the proposed revisions to the SO_2 NAAQS. However, some of these groups noted that if a 1-hour standard was adopted, then they would support revoking the current 24-hour and annual standards. State agencies generally supported revoking the current standards if a 1-hour standard was set in the proposed range, although NAACA, NESCAUM, and VT, while supportive of revoking the existing standards, also suggested that EPA explore setting a new 24-hour standard to minimize the potential that multiple hours within a day would exceed a 1-hour standard (*see* RTC document (EPA 2010), section IV). Groups which supported revoking the current 24-hour and annual standards (if a 1-hour standard was set in the proposed ranged) generally referenced the Administrator's rationale and CASAC advice described in the proposal (*see* section II.F.5).

Public health (*e.g.,* ALA, ATS) and environmental organizations (*e.g.,* CBD, WEACT for Environmental Justice) were generally opposed to revoking the current 24-hour and annual standards. These groups generally concluded that the 24-hour standard should be revised while the annual standard should be retained. In support of this position, ALA *et al.,* cited air quality information from the REA indicating that if air quality was simulated to just meet a 99th percentile 1-hour daily maximum standard in the proposed range of 50–100 ppb, then in some locations analyzed, 99th percentile 24-hour average SO_2 concentrations would be above concentrations (*i.e.,* above 99th percentile 24-hour average concentrations) in cities where U.S. emergency department visit and hospital admission studies reported positive associations with SO_2. In addition, many of these groups were opposed to revoking the current annual standard. In general, these groups concluded that given the uncertainties associated with SO_2 exposure and long-term health effects, EPA should err on the side of being health protective and retain the existing annual standard. EPA responses to comments on whether the current standards should be retained or revoked are presented below as well as in section IV of the RTC document (EPA 2010).

As stated in the REA and proposal, 99th percentile 24-hour average SO_2 concentrations in cities where U.S. emergency department visit and hospital admission studies (for all respiratory causes and asthma; identified from Table 5–5 of the ISA) were conducted ranged from 16 ppb to 115 ppb (Thompson and Stewart, 2009). Moreover, as stated in the REA and proposal (*see* section II.F.2), effect estimates that remained statistically significant in multi-pollutant models with PM were found in cities with 99th percentile 24-hour average SO_2 concentrations ranging from approximately 36 ppb to 64 ppb. In its comments, ALA *et al.,* stated (based on the air quality information in REA Appendix Table D–2) "with a 1-hour 50 ppb 99th percentile standard, 7 counties would experience a 99th percentile 24-hour concentration of 16 ppb or greater, the range found to be harmful in epidemiological studies. With an hourly standard of 100 ppb, 24 of 30 counties would have 99th percentile 24-hour concentrations above 16 ppb, with 1 county exceeding 36 ppb." Thus, these commenters generally maintained that a lowered 24-hour standard is needed to protect against these 24-hour SO_2 concentrations.

We disagree that a lowered 24-hour standard is needed to protect against 24-hour average SO_2 concentrations of concern identified from cities where U.S. emergency department visit and hospital admission studies were conducted. As noted in detail in the REA, there is uncertainty as to whether the health effects reported in epidemiologic studies using 24-hour average SO_2 concentrations are in fact due to 24-hour average SO_2 exposures (REA, section 10.5.2). That is, when describing epidemiologic studies observing positive associations between ambient SO_2 and respiratory symptoms, the ISA stated "that it is possible that these associations are determined in large part by peak exposures within a 24-hour period" (ISA, section 5.2 at p. 5–5). Similarly, the ISA stated that: "The effects of SO_2 on respiratory symptoms, lung function, and airway inflammation observed in the human clinical studies using peak exposures further provides a basis for a progression of respiratory morbidity resulting in increased emergency department visits and hospital admissions" and makes the associations observed in the epidemiologic studies "biologica[lly] plausib[le]" (*id.*). In contrast, evidence from controlled human exposure studies of 5–10 minutes and epidemiologic studies using 1-hour daily maximum SO_2 concentrations provided appreciably stronger evidence of respiratory morbidity effects following SO_2 exposures ≤ 1-hour.

Given that respiratory morbidity effects following SO_2 exposure may be most related to averaging times ≤1-hour, EPA found it most reasonable to consider the extent to which a 1-hour averaging time, given an appropriate form and level (which as discussed above, also substantially limits 5-minute benchmark exposures of concern; *see* sections II.F.2 and II.F.4), limited 99th percentile 24-hour average concentrations of SO_2 in locations where emergency department visit/hospitalization studies reported that the SO_2 effect estimate remained statistically significant in multi-pollutant models with PM (*i.e.,* locations with 99th percentile 24-hour average SO_2 concentrations ≥36 ppb). Considering this, we note that ALA *et al.,* identified only one county with 99th percentile 24-hour average SO_2 concentrations ≥36 ppb given a 99th percentile 1-hour daily maximum standard at 100 ppb, and no counties ≥36 ppb given a 99th percentile 1-hour daily maximum standard at 50 ppb. Thus, given a 99th percentile 1-hour daily maximum standard level at 75 ppb (*i.e.,* the form and level selected for a new 1-hour SO_2 standard), it is possible that no county in the ALA *et al.,* analysis would have had a 99th percentile 24-hour average SO_2 concentration ≥36 ppb.

With regard to the annual standard, we also disagree that this standard needs to be retained. First, the ISA found that "[t]he evidence linking short-term SO_2 exposure and cardiovascular effects, and morbidity and mortality with long-term exposures to SO_2 is inadequate to infer a causal relationship." ISA, p. 5–10. Thus, an annual standard is unnecessary to prevent long-term health effects. The remaining issue is whether such a standard provides further protection against short-term effects, given the new one hour standard. We conclude that it does not. As noted in the proposal, our air quality information indicates that 1-hour standard levels in the range of 50–100 ppb are estimated to generally keep annual SO_2 concentrations well below the level of the current annual standard. CASAC agreed. The panel stated: "Assuming that EPA adopts a one hour standard in the range suggested, and if there is evidence showing that the short-term standard provides equivalent protection of public health in the long-term as the annual standard, the panel is supportive of the REA discussion of discontinuing the annual standard" (Samet 2009, p. 15). Taken together, this information indicates that retaining the annual standard would add no additional public health protection.

c. Administrator's Conclusions on Retaining or Revoking the Current 24-Hour and Annual Standards

In accordance with the REA findings and CASAC recommendations mentioned above, the Administrator concludes that a 1-hour standard at level of 75 ppb would have the effect of maintaining 24-hour and annual SO_2 concentrations generally well below the levels of the current 24-hour and annual NAAQS (*see* REA Tables 10–3 and 10–4 and REA Appendix Tables D–3 to D–6). She also concludes that, as noted above in section II.F.2, a 1-hour standard at 75 ppb will likely limit 99th percentile 24-hour SO_2 concentrations in U.S. locations where emergency department visit and hospital admission studies reported statistically significant associations in multi-pollutant models with PM. Finally, she notes the lack of sufficient health evidence to support an annual standard to protect against health effects associated with long-term SO_2 exposure. Taken together, the Administrator concludes it appropriate to revoke the current 24-hour and annual standards.

G. Summary of Decisions on the Primary Standards

For the reasons discussed above, and taking into account information and assessments presented in the ISA and REA as well as the advice and recommendations of CASAC, the Administrator concludes that the current 24-hour and annual primary standards are not requisite to protect public health with an adequate margin of safety. The Administrator also concludes that establishing a new 1-hour standard will appropriately protect public health with an adequate margin of safety, and specifically will afford requisite increased protection for asthmatics and other at-risk populations against an array of adverse respiratory health effects related to short-term (5 minutes to 24 hours) SO_2 exposure. These effects include decrements in lung function (defined in terms of sRaw and FEV_1), increases in respiratory symptoms, and related serious indicators of respiratory morbidity including emergency department visits and hospital admissions for respiratory causes.

Specifically, the Administrator is establishing a new short-term primary SO_2 standard with a 1-hour (daily maximum) averaging time and a form defined as the 3-year average of the 99th percentile of the yearly distribution of 1-hour daily maximum SO_2 concentrations, and a level of 75 ppb. In addition to setting a new 1-hour standard at 75 ppb, the Administrator is revoking the current 24-hour and annual standards recognizing that a 1-hour standard set at 75 ppb will have the effect of generally maintaining 24-hour and annual SO_2 concentrations well below the levels of the current 24-hour and annual standards.

III. Overview of the Approach for Monitoring and Implementation

We received several comments regarding the approaches discussed in the proposal for monitoring and modeling for comparison to the proposed new 1-hour SO_2 NAAQS, designations of areas as either attaining or not attaining the NAAQS, and implementation of the new NAAQS in State implementation plans (SIPs) that would ensure ultimate attainment of the new NAAQS in transitioning from the annual and 24-hour NAAQS in a timely manner. These comments raised fundamental questions regarding our contemplated approaches in all three areas, and caused us to re-examine them and review their consistency with past practice under the SO_2 NAAQS implementation program. After conducting that review, and in response to the public comments we are revising our general anticipated approach toward implementation of the new 1-hour NAAQS. This revised approach would better address: (1) The unique source-specific impacts of SO_2 emissions; (2) the special challenges SO_2 emissions present in terms of monitoring short-term SO_2 levels for comparison with the NAAQS in many situations; (3) the superior utility that modeling offers for assessing SO_2 concentrations; and (4) the most appropriate method for ensuring that areas attain and maintain the new 1-hour SO_2 NAAQS in a manner that is as expeditious as practicable, taking into account the potential for substantial SO_2 emissions reductions from forthcoming national and regional rules that are currently underway.

Below, we provide an overview of our revised approach to monitoring, and of our expected approaches to designations of areas, and implementation of the NAAQS. Due to the unique challenges presented by SO_2, we do not expect that the anticipated approaches discussed below would be necessarily transferable to other NAAQS pollutant situations. For NAAQS pollutants other than SO_2, air quality monitoring is more appropriate for determining whether all areas are attaining the NAAQS, and there is comparatively less dependence upon conducting refined modeling. Each of these subjects (*i.e.,* our revised approach to monitoring, and our expected approaches to designations of areas, and implementation of the NAAQS) is further addressed later in the preamble, in sections IV, V and VI, respectively. Where specific public comments on the proposal are addressed and responded to, further details of the specific revised approaches are explained. In many respects, both the overview discussion below and the subsequent more detailed discussions explain our expected and intended future action in implementing the new 1-hour NAAQS—in other words, they constitute guidance, rather than final agency action—and it is possible that our approaches may continue to evolve as we, States, and other stakeholders proceed with actual implementation. In other respects, such as in the final regulatory provisions regarding the promulgated monitoring network, we are explaining EPA's final conclusions regarding what is required by this rule. We expect to issue further guidance regarding implementation, particularly concerning issues that may arise regarding the application of refined dispersion modeling under this revised approach for monitoring and implementation, and issues that States and other stakeholders may also ask us to address as we proceed toward various stages of ensuring attainment. EPA intends to solicit public comment prior to finalizing this guidance.

The main necessary elements of implementing the new 1-hour NAAQS are: (1) An approach for assessing ambient concentrations to determine compliance with the NAAQS; (2) a process for using these assessments to designate areas relative to the new standard; and (3) the development of State plans that include control measures sufficient for ensuring the NAAQS is attained everywhere as expeditiously as possible, which we believe should be no later than 2017. EPA's revised anticipated approach to determining compliance with the new SO_2 NAAQS is consistent with our historical approach to SO_2 designations and implementation through permits and emissions limitations, which involves the combined use of monitoring and modeling. The emphasis we would place on monitoring and modeling, compared with each other, under the revised expected approach is therefore significantly different than that in the approach discussed in the proposal, which was less in line with our historical practice for SO_2, as the public comments highlighted.

In the SO_2 NAAQS proposal, we recommended a monitoring-focused approach for comparison to the new NAAQS, featuring a two-pronged monitoring network design. This included monitors in certain CBSAs based on a combination of population and SO_2 emissions coupled with additional monitors within a State based on that State's contribution to national SO_2 emissions. The resulting proposed network would have required approximately 348 monitors nationwide to be sited at the locations of maximum concentration. Numerous State and local government commenters expressed concerns regarding the burdens of implementing the proposed monitoring network and the sufficiency of its scope for purposes of identifying violations. These commenters contended that our proposed monitoring network was too small and insufficient to cover the range of SO_2 sources, and yet too burdensome and expensive to expand to an adequate scale. Some of these commenters (the City of Alexandria, and the States of Delaware, North Carolina and Pennsylvania) suggested using modeling to determine the scope of monitoring requirements, or favored modeling over monitoring to determine compliance with the NAAQS.

Partly in response to these comments, and after reconsidering the proposal's monitoring-focused approach in light of EPA's historical approach to SO_2 NAAQS implementation and area designations decisions, we intend to use a hybrid analytic approach that would combine the use of monitoring and modeling to assess compliance with the new 1-hour SO_2 NAAQS. We believe that some type of hybrid approach is more consistent with our historical approach and longstanding guidance toward SO_2 than what we originally proposed. In addition, we believe that for a short-term 1-hour standard it is more technically appropriate, efficient, and effective to use modeling as the principle means of assessing compliance for medium to larger sources, and to rely more on monitoring for groups of smaller sources and sources not as conducive to modeling. We discuss the details of the final revised monitoring network requirements in section IV later in the preamble, but note here the relationship that the revised approach toward monitoring and modeling—taken partly in response to the public comments mentioned above—has to the other two general subject areas in implementation for which we are providing guidance, namely initial area designations and development of substantive implementation plans that ensure timely attainment and maintenance of the NAAQS. Our ultimate intention is to place greater emphasis on modeling than did the proposed rule as the most technically appropriate, efficient, and readily available method for assessing short-term ambient SO_2 concentrations in areas with large point sources. This projected change in approach would necessarily result in a lesser emphasis on the less appropriate, more expensive, and slower to establish monitoring tool than did the proposed rule. Therefore, the minimum requirements for the SO_2 monitoring network in this final rule are of a smaller scale than proposed, and we do not expect monitoring to become the primary method by which ambient concentrations are compared to the new 1-hour SO_2 NAAQS.

Instead, in areas without currently operating monitors but with sources that might have the potential to cause or contribute to violations of the NAAQS, we anticipate that the identification of NAAQS violations and compliance with the 1-hour SO_2 NAAQS would primarily be done through refined, source-oriented air quality dispersion modeling analyses, supplemented with a new, limited network of ambient air quality monitors. Historically, we have favored dispersion modeling to support SO_2 NAAQS compliance determinations for areas with sources that have the potential to cause an SO_2 NAAQS violation, and we have explained that for an area to be designated as "attainment," dispersion modeling regarding such sources needs to show the absence of violations even if monitoring does not show a violation. This has been our general position throughout the history of implementation of the SO_2 NAAQS program. *See, e.g.,* "Air Quality Control Regions, Criteria, and Control techniques; Attainment Status Designations," 43 FR 40412, 40415–16 (Sept. 11, 1978); "Air Quality Control Regions, Criteria, and Control Techniques," 43 FR 45993, 46000–02 (Oct. 5, 1978); "Air Quality Implementation Plans: State Implementation Plans; General Preamble," 57 FR 13498, 13545, 13547–48 (Apr. 16, 1992); "Approval and Promulgation of State Implementation Plans; Call for Sulfur Dioxide SIP Revisions for Billings/Laurel, MT," 58 FR 41430 (Aug. 4, 1993); "Designation of Areas for Air Quality Planning Purposes; Ohio," 59 FR 12886, 12887 (Mar. 18, 1994); "Ambient Air Quality Standards, National and Implementation Plans for Sulfur Oxides (Sulfur Dioxide)," 60 FR 12492, 12494–95 (Mar. 7, 1995); "Air Quality Implementation Plans; Approval and Promulgation: Various States: Montana," 67 FR 22167, 22170–71, 22183–887 (May 2, 2002).

Compared to other NAAQS pollutants, we would not consider ambient air quality monitoring alone to be the most appropriate means of determining whether all areas are attaining a short-term SO_2 NAAQS. Due to the generally localized impacts of SO_2, we have not historically considered monitoring alone to be an adequate, nor the most appropriate, tool to identify all maximum concentrations of SO_2. In the case of SO_2, we further believe that monitoring is not the most cost-efficient method for identifying all areas of maximum concentrations. However, for some situations monitoring is well suited, and we therefore will require it to some extent, as further explained in section IV of the preamble. For example, monitoring may appropriately be relied upon to assess compliance with the NAAQS by groups of smaller sources and sources that may not be as conducive to modeling as are larger SO_2 sources.

States will need to make any adjustments to the existing monitoring network to ensure that monitors meeting today's network design regulations for the new 1-hour NAAQS are sited and operational by January 1, 2013. We also expect to provide additional guidance regarding the application of refined dispersion modeling under this revised expected approach for implementation of the new SO_2 standard. Appendix A to the *Guideline on Air Quality Models* (Appendix W of 40 CFR part 51), Summaries of Preferred Air Quality Models, provides "key features of refined air quality models preferred for specific regulatory applications" (*see* Appendix A to Appendix W of Part 51 at A.0(1)). Refined dispersion modeling, following our current *Guideline on Air Quality Models* with appropriate flexibility for use in implementation, is anticipated to better reflect and account for source-specific SO_2 impacts than the more limited monitoring-focused proposal. As noted above, EPA intends to solicit public comment prior to finalizing this guidance.

Based on a revised, hybrid approach, we expect to implement the new SO_2 standard in the following manner. In accordance with CAA section 107(d), EPA must designate areas as "attainment," "nonattainment" or "unclassifiable" for the new 1-hour SO_2 NAAQS by June 2012 (*i.e.,* two years following promulgation of the new NAAQS).[20] State Governors are required to submit their initial area designation recommendations to EPA no later than June 2011. We expect that EPA's final area designation decisions in 2012 would be based principally on data reported from SO_2 monitors currently in place today, and any refined modeling the State chooses to conduct specifically for initial area designations.[21] For these initial designations, we would expect to designate an area "nonattainment" if either monitoring data or appropriate refined modeling results show a violation. Any area that has monitoring and appropriate modeling data showing no violations we would expect to designate as "attainment."[22] All other areas, absent monitoring data and air quality modeling results showing no violations, we would expect to initially designate as "unclassifiable," as required by the Clean Air Act. The expected presumptive boundary for any area designated "nonattainment" would be the county boundary associated with the violation unless additional information provided to EPA demonstrates otherwise, as has been our general approach for other NAAQS pollutants. Any area initially designated "nonattainment" or "unclassifiable" could request redesignation to "attainment" after an assessment based on air quality modeling, conducted in accordance with the new guidance, and available monitoring data indicates that the standard has been met, as well as meeting all other requirements of the CAA for redesignation to attainment.

This anticipated approach toward initial area designations is a change from the approach discussed in the proposal, and logically follows from our general change in approach to the use and utility of monitoring versus modeling for determining short-term SO_2 ambient concentrations. As public commenters pointed out, establishment and implementation of the proposed monitoring network would have been both too limited and too late to inform initial area designations, and the expense and burden of accelerating it and expanding it would have been severe for State implementing agencies. Given the time needed to establish monitors, it is not realistic to expect either such an expanded monitoring network or even the more reasonable limited network of the final rule to be the chief tool for informing initial designations.

That means that some other approach is needed to inform initial designations of areas and other implementation decisions under the new SO_2 NAAQS. In addition to using any valid data generated by existing monitors, refined dispersion modeling may inform designation and implementation decisions regarding sources that may have the potential to cause or contribute to a NAAQS violation. In order for modeling to be done on the scale sufficient to identify all areas that might violate the new 1-hour standard, EPA anticipates issuing guidance that addresses a variety of issues, such as how to identify and appropriately assess the air quality impacts of small SO_2 sources (*e.g.,* those emitting less than 100 tons of SO_2 per year) that may potentially cause or contribute to a violation of the new SO_2 NAAQS. EPA expects that it will take more time for EPA to issue that guidance than is available in order to use it for the initial round of attainment designations. In addition to any smaller sources that might cause or contribute to NAAQS violations, States would need to model approximately 2000 larger sources across the country (*i.e.,* sources that emit greater than 100 tons per year and are collectively responsible for about 99% of all SO_2 emissions from point sources in the U.S.) to determine whether areas are attaining or not attaining the 1-hour standard. While these sources emitting 100 or more tons of SO_2 per year represent the significant fraction of the total emissions from point sources in the U.S., smaller sources also have the potential to violate the new SO_2 NAAQS.

After receiving EPA's forthcoming modeling guidance, States might initially focus modeling assessments on these larger sources that have been subject to permitting requirements and are generally better characterized than smaller sources. But even this effort would entail a substantial burden on States, under a compressed timeline following EPA's issuance of further modeling guidance. Consequently, EPA does not believe that for this new 1-hour SO_2 NAAQS it would be realistic or appropriate to expect States to complete such modeling and incorporate the results in initial designation recommendations, which under CAA section 107(d)(1)(A) must be submitted to EPA within 1 year of the promulgation of the 1-hour standard.

The remaining issue, then, is how to most appropriately use a modified hybrid approach, and its constituent modeling and monitoring tools, in the implementation plan development process in order to ensure expeditious attainment and maintenance of the NAAQS. Under the CAA, all States must develop and submit to EPA State implementation plans (SIPs) to attain and maintain the new 1-hour SO_2 NAAQS. CAA section 110(a)(1) requires States, regardless of designation status, to adopt SIPs that provide for implementation, maintenance and enforcement of each primary NAAQS. Traditionally, for areas that were designated "attainment" or "unclassifiable", we accepted State submissions of prevention of significant deterioration (PSD) permitting programs and other "infrastructure" SIP elements contained in CAA section 110(a)(2) as being sufficient to satisfy the section 110(a)(1) SIP submission requirement. However, due to our recognition here that monitoring is not generally the most appropriate or effective tool for assessing compliance with the new 1-hour SO_2 NAAQS, that additional guidance from EPA on conducting refined modeling for the new 1-hour NAAQS is anticipated to support our expected implementation approach, and that considerable time and resources may be needed to fully identify and properly characterize all SO_2 sources (including those emitting less than 100 tons of SO_2 per year) that may potentially cause or contribute to a violation of the new SO_2 NAAQS, we also had to assess how and when to best use modeling as the primary method in implementation.

[20] EPA is authorized by the Clean Air Act to take up to 3 years to complete the initial area designations in the event that insufficient information is available to complete the designations within 2 years.

[21] Since three complete years of data from any newly sited monitors meeting the new monitoring network design criteria are not expected to be obtained until the end of 2015, any newly sited monitors will not play a role in EPA's initial area designations.

[22] EPA anticipates making the determination of when monitoring alone is "appropriate" for a specific area on a case-by-case basis, informed by that area's factual record, as part of the designations process. EPA would expect to address this issue for such areas by examining the historic treatment of the area with respect to prior SO_2 designations as well as whether the area is one in which monitoring would be the more technically appropriate tool for determining compliance with the new SO_2 NAAQS. An example of a situation in which monitoring may be the more preferred approach is a shipping port (non-point source or "area" source) that is not in close proximity to other significant stationary SO_2 sources.

The approach that EPA expects to take, which is described in sections V and VI of the preamble, is consistent with the language of the Clean Air Act and would accommodate the time needed for an accurate assessment of ambient air quality levels for the 1-hour SO_2 standard. Section 107(d)(1) requires areas to be designated "attainment" if they meet the standard, "nonattainment" if they do not meet the standard or contribute to a nearby violation, or "unclassifiable" if they cannot be designated on the basis of available information. EPA's expected approach would enable us to make the appropriate designation decision required by the CAA, based on the record of information that will be before EPA regarding each area. Areas would be designated "nonattainment" if either available monitoring data or modeling shows that a violation exists, or "attainment" if both available monitoring data and modeling indicate the area is attaining. All other areas would be designated "unclassifiable," as required by section 107(d)(1)(A).

We currently anticipate that our projected post-designation implementation approach would look to robust CAA section 110(a)(1) SIPs, which have sometimes been previously referred to as "maintenance" or "infrastructure" SIPs but for the new SO_2 NAAQS would serve as substantive "attainment" SIPs. Our current thinking is that, to be approved by EPA, such plans would need to provide for attainment and maintenance of the new 1-hour SO_2 NAAQS as expeditiously as practicable, which we expect to be no later than five years after initial designation (or approximately August 2017) in all areas of the State, including any area initially designated "nonattainment," and also including any area designated "unclassifiable" that has SO_2 sources with the potential to cause or contribute to a violation of the NAAQS. The CAA establishes deadlines for States to submit these plans to EPA.[23] State plans that address areas designated as "nonattainment" (*i.e.,* "nonattainment area SIPs") are due within 18 months from the effective date of the designation, under CAA section 192. EPA anticipates that this deadline would be February 2014. State plans addressing all other areas (*i.e.,* "maintenance SIPs") are due within 3 years following the promulgation of the new NAAQS, or June 2013, under CAA section 110(a)(1).

Section 110(a)(1), unlike section 192, does not specify a maximum deadline by which States are required to show they have met the requirements to implement, maintain, and enforce a NAAQS. EPA believes, however, that August 2017 is the latest date by which areas should show they have achieved attainment and maintenance of the standard because this deadline is the same as would be required for areas designated nonattainment in June 2012. It is therefore presumptively reasonable as it is identical to the period Congress provided for nonattainment areas to reach attainment. Moreover, EPA notes that the maintenance SIPs will be due in June 2013, rather than in February 2014, giving States and sources at least as much time between SIP development and submission and the date by which attainment should be achieved as they would have had the area been designated nonattainment in 2012. These section 110(a)(1) SIPs would be able to rely on modeling reflecting any SO_2 reductions that we expect to result before the attainment date from compliance with the rules EPA expects to promulgate before 2013, (including technology-based standards under CAA section 112(d) for certain source categories emitting large amounts of SO_2 such as Electric Generating Units and industrial boilers, and revised rules establishing further limits on SO_2 emitted by sources in upwind States which contribute significantly to downstream States' inability to attain or maintain the $PM_{2.5}$ NAAS (the so-called Clean Air Interstate Replacement rule)). Thus, we intend that a State's section 110(a)(1) SIP may account for projected emissions reductions, including any from national and regional rules that are promulgated before these SIP submissions, provided that those reductions occur under a schedule that ensures attainment as expeditiously as practicable. We expect that date to be no later than 5 years from the date of initial designation or August 2017.

Under this anticipated approach, attainment SIPs for nonattainment areas would have to include enforceable emissions limitations, timetables for compliance, and appropriate testing/reporting to assure compliance, and demonstrate attainment through air quality modeling for all sources contributing to monitored and modeled violations, or that have the potential to cause or contribute to a violation of the NAAQS. The SIPs under section 110(a)(1) would need to demonstrate through refined air quality modeling that any source or group of sources that have the potential to cause or contribute to a violation of the NAAQS are, or will be, sufficiently controlled to ensure timely attainment and maintenance of the NAAQS. We would expect this to include any individual sources with the potential to emit 100 or more tons per year of SO_2, and other sources that may also cause or contribute to violations of the new SO_2 NAAQS. We expect to develop guidance for the States' use on how best to identify and assess the impact of sources that may have this potential. As mentioned previously, we intend to provide an opportunity for notice and comment on this guidance before finalizing it.

EPA again notes that it anticipates several forthcoming national and regional rules, such as the pending Industrial Boilers MACT standard under CAA section 112(d), that are likely to require significant reductions in SO_2 emissions over the next several years. A limited qualitative assessment based on the results of preliminary modeling of some sample facilities indicates that well controlled sources should meet the new SO_2 NAAQS (*see* Brode 2010b). Exceptions could include unique sources with specific characteristics that contribute to higher ambient impacts (short stack heights, complex terrain, *etc.*). These national and regional rules are expected to lead to SO_2 reductions that will help achieve compliance with the new SO_2 NAAQS prior to 2017. If, upon EPA review of submitted SIPs that rely upon those reductions or other local controls, it appears that States will nevertheless fail to attain the NAAQS as expeditiously as practicable (and no later than August 2017), the Clean Air Act provides authorities for EPA to solve such failure, including, as appropriate, disapproving submitted SIPs, re-designating unclassifiable areas to nonattainment, issuing SIP calls, and promulgating FIPs.

For the reasons discussed above, EPA has determined that it is appropriate and efficient to principally use modeling to assess compliance for medium to larger sources, and to rely more on monitoring for groups of smaller sources and sources not as conducive to modeling. EPA's revised monitoring network requirements have been developed to be consistent with this approach. However, EPA is still considering how monitoring and modeling data would be used together in specific situations to define attainment and nonattainment boundaries and under what circumstances it may be appropriate to rely on monitoring data alone to make attainment determinations. EPA intends

[23] The schedule for State plans addressing areas designated "nonattainment" is governed by CAA section 191. The schedule for State plans for all other areas, including areas designated "unclassifiable" and "attainment," is governed by CAA section 110(a)(1).

to address these issues as it develops implementation guidance.

In light of the new approach that EPA intends to take with respect to implementation of the SO_2 NAAQS, EPA intends to solicit public comment on guidance regarding modeling, and also solicit public comment on additional implementation planning guidance, including the content of the maintenance plans required under section 110(a)(1) of the Clean Air Act. EPA also notes that State monitoring plans and the SIP submissions that States will make will also be subject to public notice and comment.

IV. Amendments to Ambient Monitoring and Reporting Requirements

In this section of the preamble, we describe the proposal, the public comments that we received on the proposed monitoring and reporting requirements, and the final requirements for the SO_2 monitoring network. We are modifying our proposed approach to the amount of monitoring to require following consideration of public comments and a review of our historic practice in assessing compliance with the SO_2 NAAQS. As we explain above in section III, we will use a hybrid approach that combines monitoring and modeling, using each of these analytic tools where they are most appropriate and effective. This approach and its requirements are intended to support the revised SO_2 NAAQS, described in section II above. For a short-term 1-hour standard, dispersion modeling of stationary sources will generally be more technically appropriate, efficient, and effective because it takes into account fairly infrequent combinations of meteorological and source operating conditions that can contribute to peak ground-level concentrations of SO_2. Even an expansive monitoring network could fail to identify all such locations. Consequently, we have revised the scope of the monitoring network, reflecting a modified and expanded set of objectives. This section also describes and explains the final requirements for the new SO_2 Federal Reference Method (FRM), and the SO_2 network design, monitoring objectives, data reporting, and data quality objectives that support the revised primary SO_2 NAAQS.

A. Monitoring Methods

1. Requirements for SO_2 Federal Reference Method (FRM)

The proposal to promulgate an automated SO_2 FRM was based on a need to update the cumbersome existing manual wet-chemistry (pararosaniline) method to a continuous-type automated method that can readily provide 1-hour SO_2 measurement capability. *See* 74 FR at 64846–849. The following paragraphs provide background, rationale, and the final changes to the automated SO_2 Federal Reference Method (FRM) and to the associated performance specifications for automated SO_2 analyzers.

a. Proposed Ultraviolet Fluorescence SO_2 FRM and Its Implementation

FRMs, set forth in several appendices to 40 CFR Part 50, serve (1) To provide a specified methodology for definitively measuring concentrations of ambient air pollutants for comparison to the NAAQS in Part 50, and (2) to provide a standard of comparison for determining equivalency of alternative pollutant measurement methods that can be used in lieu of the FRM for such monitoring.

The FRM for measuring SO_2 in the ambient air was promulgated on April 30, 1971 in conjunction with the first primary SO_2 NAAQS (36 FR 8196). This SO_2 FRM is specified in Appendix A of Part 50 and identified as the pararosaniline manual method. *See* generally 74 FR at 64846. In the interim, EPA has designated many SO_2 methods as equivalent methods (FEMs), most of which are based on the ultraviolet fluorescence (UVF) measuring technique. *Id.* In fact, virtually all SO_2 monitoring data are now obtained with FEMs that use the UVF technique.

In light of this, EPA proposed to establish a new automated SO_2 FRM based on UVF—the same measurement technique employed by FEM analyzers now in widespread use by most State and local monitoring agencies and having the measurement capability needed to implement the proposed 1-hour SO_2 NAAQS. FRM analyzers using this UVF technique can provide the needed detection limits, precision, and accuracy and fulfill other purposes of an FRM, including use as an appropriate standard of reference for testing and designation of new FEM analyzers. At proposal, EPA specified the new method in performance-based form, describing a generic reference measurement principle and associated calibration procedure in a new Appendix A–1 to 40 CFR Part 50. Associated performance requirements applicable to candidate automated SO_2 analyzers (both FRMs and FEMs) were proposed in 40 CFR Part 53.

EPA also proposed retaining the existing manual pararosaniline FRM for SO_2. Although EPA recognized that the existing method is cumbersome for one-hour measurements, it is capable of making measurements of 1 hour or even 30 minute periods. 74 FR at 64846; *see also* Part 50 Appendix A at 1.1 ("[t]he method is applicable to the measurement of ambient SO_2 concentrations using sampling periods ranging from 30 minutes to 24 hours"). Supersession of the existing manual FRM, as defined in § 53.16, would require not only withdrawal of that existing FRM but also the cancellation of the designations of all existing SO_2 FEMs. Loss of the use of these FEM analyzers would leave State and local monitoring agencies with no approved SO_2 monitors until new FRM and FEM analyzers could be designated under the new FRM. The resulting costs and disruptions to monitoring agencies is unnecessary because the current SO_2 FEMs readily and accurately measure (and report) one-hour ambient measurements. *See* 74 FR at 64847. Accordingly, EPA concluded that supersession of the existing FRM was not warranted, given the costs and disruptions which would occur to State monitoring programs and the limited benefits from such an action given the suitability of the in-use FEMs. *Id.* at 68646; *see also* section 53.16(b)(1) stating that in exercising its discretion as to whether to proceed with supersession of an FRM, EPA will consider the benefits (in terms of requirements and purposes of the Act) from specifying a new reference method, potential economic consequences of such supersession for State and local monitoring agencies, and disruption to State and local air quality monitoring programs. Instead, EPA proposed to add the new UVF FRM while retaining the existing FRM for some period of time to support the continued approval of existing SO_2 FEM analyzers.

b. Public Comments on the Proposed FRM and Implementation

EPA received comments from State and local groups (*e.g.,* City of Houston, Houston-Galveston Area Council, KY, NC, NY, PA, SC, SD, and WI) and industry (*e.g.,* AirQuality Research and Logistics (AQRL), Consumers Energy, ExxonMobil, Montana Sulfur and Chemical Company, Inc. (MSCC), and the Utility Air Regulatory Group (UARG)), all generally supporting EPA's proposal to adopt the proposed automated UVF as an FRM. For example, South Dakota supported adding the UVF SO_2 method as an additional FRM and stated that this method is currently being used in the network and will reduce the cost of implementing the new monitoring requirements for this rule. The UARG stated that the proposal to specify a different FRM to judge compliance is entirely reasonable, and UARG generally supported the proposed specifications for a new FRM but maintained that the current FRM could not be used along with a new FRM. ExxonMobil stated that it supports "* * * EPA allowing monitoring agencies to choose mobile monitoring that meets monitoring quality requirements." AQRL stated that "EPA is correct in choosing to designate [promulgate] a new (automated) FRM for measurement of SO_2."

EPA did not receive any public comments opposing the proposed automated UVF SO_2 FRM but did receive a few technical comments on specific provisions of the method. EPA proposed use of an inlet line particle filter as a requirement for new UVF SO_2 FRM analyzers, believing that use of a particle filter is advantageous to prevent interference, malfunction, or damage to the analyzer from particles in the sampled air. The State of Missouri questioned this requirement, noting that such a filter can sometimes cause problems and that filter requirements for other FRM and FEM analyzers have been analyzer-specific depending on the manufacturer's stipulation. EPA believes, however, that for new SO_2 FRM analyzers, the benefits and uniformity provided by a mandatory filter requirement outweigh possible disadvantages of such a filter.

Missouri also suggested that the language of proposed Sections 4.1.1 and 4.1.2 regarding calibration system flow rate requirements were somewhat confusing, and that the high (50–100 ppm) concentration requirement for the calibration standard specified in Section 4.1.6.1 is sometimes a problem. In response to these comments, the language of Sections 4.1.1 and 4.1.2 has been clarified, and the concentration of the standard specified in Section 4.1.6.1 has been reduced to 10 ppm.

EPA received a number of comments from States (*e.g.,* NC, NYSDEC, PA, SC, and SD) that supported the EPA proposed plan of temporary retention of the existing wet-chemistry pararosaniline FRM and for FEMs approved based on that method. For example, Pennsylvania stated "[t]his methodology should enable State and local agencies to continue using their existing monitoring equipment and [thereby] avoid large capital fund outlays for samplers and ultimately avoid any delays in collecting data that would be comparable to the proposed new primary sulfur dioxide NAAQS." North Carolina requested "* * * that the EPA maintain the current reference method for at least an additional 10 years." Wisconsin and the Center for Biological Diversity (CBD) suggested expeditiously phasing out the existing manual SO_2 FRM.

In contrast, however, EPA also received comments from industry that opposed the retention of the existing pararosaniline FRM while promulgating a new automated UVF FRM. In particular, UARG stated "* * * having two FRMs specified for a given NAAQS—is not viable," pointing out that there is only one FRM for each NAAQS under the present standards, a result UARG appears to believe is legally mandated.

EPA disagrees with this comment. First, there is nothing in the Act that mandates a single FRM for each NAAQS. Section 109 of the Act, in fact, does not address this issue at all. Second, as noted previously, there are sound policy reasons for not withdrawing the existing FRM at this time. Therefore, EPA sees no legal or other obstacle in adding a new automated UVF FRM while retaining the existing manual FRM.

UARG further maintained that EPA provided no support for its statement that the existing FEMs, which constitute the bulk of the existing SO_2 monitoring network, are adequate for the current and proposed new SO_2 NAAQS. UARG also stated that "although the FEMs may be adequate for many other purposes, they may only be used to judge compliance with the 1-hour NAAQS if they are shown to qualify as FRMs or FEMs under the new FRM definition."

EPA disagrees with this comment also. In answer to UARG's second point, it is not necessary that these existing FEMs be re-designated as FRMs pursuant to the new automated FRM to continue their approved use. There is no legal impediment to such continued use, since they are (and will continue to be) FEMs approved based on an FRM that adequately measures one-hour ambient SO_2 concentrations. Nor is there any technical impediment to the continued use of these FEMs, given that they are automated continuous monitoring methods capable of measuring SO_2 concentrations ranging from a few minutes to a 1-hour period. The existing FEMs in the network use the same UVF technology as the proposed (and now final) automated FRM and have been reporting 1-hour monitoring data for decades. These FRMs have been tested against the test and performance requirements of Part 53, which are designed specifically to test such continuous methods. Further, the proposed SO_2 method performance specifications for the standard measurement range were derived from data submitted in FEM applications for analyzers that were subsequently designated as FEMs. Therefore, these FEMs are technically and legally sound to judge compliance with the one-hour NAAQS.

EPA has clarified the regulatory text so that the rules state unambiguously that both SO_2 FRMs apply to the new one-hour standard (as well as to the 24-hour and annual standards so long as they are retained), as do all presently-designated FEMs.

c. Conclusions on Ultraviolet Fluorescence SO_2 FRM and Implementation

We are finalizing the proposed new automated SO_2 FRM, which is based on UVF technology, with the following minor technical changes: The language of Sections 4.1.1 and 4.1.2 has been clarified, and the minimum concentration of the calibration standard specified in Section 4.1.6.1 has been reduced to 10 ppm. The new FRM is codified as Appendix A–1 to 40 CFR Part 50 and titled "Reference Measurement Principle and Calibration Procedure for the Measurement of Sulfur Dioxide in the Atmosphere (Ultraviolet Fluorescence Method)." EPA is retaining the previously existing manual pararosaniline SO_2 FRM for the time being and re-codifying it as Appendix A–2 to 40 CFR Part 50. However, EPA plans to rescind this manual FRM at a future time when new SO_2 FRM analyzers have adequately permeated State monitoring networks.

2. Requirements for Automated SO_2 Methods

a. Performance Specifications for Automated Methods

In association with the proposal to adopt a new automated FRM, EPA proposed to update the performance-based designation requirements for FEM SO_2 analyzers currently specified in 40 CFR Part 53. As noted in the proposal preamble (74 at 64846), these requirements were established in the 1970's, based primarily on the wet-chemical measurement technology available at that time. Those initial requirements have become significantly outdated and need to be modified to match current technology, particularly because they would apply to new SO_2 FRM analyzers under the proposed new FRM. The better instrumental performance available with the proposed new UVF FRM technique allows the performance requirements in Part 53 to be made more stringent for both FRM and FEM SO_2 analyzers. Updating these performance requirements is needed to ensure that, going forward, all new SO_2 monitors will have improved performance.

EPA solicited comments on the proposed new performance requirements for automated SO_2 methods that were included in Table B–1 (Performance Specifications for Automated Methods) of Part 53. We proposed revised performance specifications for noise, lower detectable limit, interference equivalent, zero drift, span drift, lag time, rise time, fall time, and precision. EPA proposed to reduce the allowable noise limit from 5 to 1 ppb, the lower detectable limit from 10 to 2 ppb, the interference equivalent limits from ±20 ppb to ±5 ppb for each interferent, and from 60 ppb to 20 ppb for the total of all interferents, the zero drift limit from ±20 to ±4 ppb, the lag time limit from 20 to 2 minutes, both rise and fall time limits from 15 to 2 minutes, and the precision limits from 15 ppb to 2 percent of the upper range limit. EPA further proposed to eliminate the requirements for span drift at 20% of the upper range limit. In addition, to address the need for more sensitive, lower measurement ranges for SO_2 analyzers, EPA proposed a separate set of performance requirements that would apply specifically to narrower measurement ranges, *i.e.* ranges extending from zero to concentrations less than 0.5 ppm. Other minor changes were proposed in the wording of a few sections of Part 53 Subparts A and B, including provision for alternate data recording devices in § 53.21 to supplement the older language relating specifically to strip chart recorders.

b. Public Comments

EPA received a number of comments from industry (AQRL and UARG) and from the multi-State organization NESCAUM regarding the proposed interferent limit requirements listed in Table B–1. UARG submitted comments supportive of all the proposed requirements for the new UVF SO_2 FRM, except for the proposed total interferent limits of 20 ppb. UARG acknowledged that EPA proposed to reduce the total interferent level substantially from 60 ppb to 20 ppb, but maintained that the proposed level of 20 ppb is still too high because it amounts to 20%–40% of the levels being considered for the NAAQS (50–150 ppb). AQRL recommended limiting "* * * each interferent to no more than ±3 ppb and total interference to no more than 12 ppb." NESCAUM recommended tightening the nitric oxide (NO) interference limit from 100:1 to 300:1 (*i.e.,* one third of the proposed value of ±5 ppb). NESCAUM states that the proposed interferent value of ±5 ppb results in substantial NO interference at sites with low SO_2 levels in urban areas.

EPA revisited the issue of the interferent equivalent limit for SO_2 analyzers in context of the above comments and reconsidered what is reasonably feasible with current technology. We reviewed the current instrument specifications and test data submitted for numerous SO_2 FEM applications. We also took into account that the test concentrations of most of these interferents are substantially higher than the concentrations normally observed in ambient air. EPA considered lowering the testing concentrations of these interferents, which would have correspondingly lowered the interferent equivalent for each analyte. However, EPA took a more conservative approach and retained the existing test concentrations for H_2S, NO_2, NO, O_3, m-xylene, and water vapor. Based on this review, we found that it is not feasible to further lower the limit requirement for these interferents below ±5 ppb. However, in response to the NESCAUM comment, EPA determined that the interferent equivalent limit requirement for NO interference could be reduced to ±3 ppb (166:1) for the new, lower measurement range to reduce possible NO interference at sites with low SO_2 levels in urban area.

In regard to the total limit for all interferent equivalents for SO_2 analyzers, EPA notes that many of the interferents for which testing is required (specified in Table B–3 of Part 53) would likely react with each other and would thus not co-exist in ambient air at the specified test concentrations. Therefore, EPA determined that the limit requirement for total interference equivalent can be eliminated, and Table B–1 now reflects this change.

EPA received comment from AQRL on the existing span drift requirement for SO_2 analyzers specified in Table B-1. AQRL recommended lowering the span drift requirement at 80% URL to 2.5%, stating that "ambient air monitors in the 21st century should be able to hold span drift to no more than ±2.5% under the conditions specified in EPA testing * * *." Based on information from FEM testing laboratories and manufacturers' data (EPA, 2009c), EPA largely agrees with this comment and concludes that the span drift requirement at 80% can be lowered to ±3%. Table B–1 has been changed to include this revised limit.

EPA received comment from the State of Wisconsin suggesting that the proposed revised provisions of section 53.21 (Test conditions) be further changed to more specifically recognize use of digital recorders for obtaining test results rather than maintaining the tie to analog strip chart recorder technology. EPA acknowledges that industry has moved away from strip chart recording technology to digital data recording. However, the proposed language of § 53.21 calls for a graphic representation of analyzer responses to test concentrations to facilitate visual examination of test results and allows any "alternative measurement data recording device" as long as it can provide such a graphic representation. Describing the analog strip chart recorder in this section provides an appropriate model to help define the type of graphic representation needed for the Part 53 tests. EPA believes that the proposed language of § 53.21 is adequately broad to permit digital or other types of data recording devices.

c. Conclusions for Performance Specifications for SO_2 Automated Methods

Based on typical performance capabilities of current UVF analyzers and manufacturers' actual testing data, we are keeping the limit for each interference equivalent for SO_2 analyzers at ±5 ppb. However, we are lowering the interference equivalent requirement for NO to ±3 ppb for the lower measurement range. A footnote denoting this specific requirement is being added to Table B–1. We are eliminating the total interference equivalent requirement for SO_2 analyzers, and Table B–1 is being revised to incorporate this change.

The 24-hour span drift at 80% of the upper range limit for SO_2 analyzers is being lowered to ±3% in Table B–1 to be in line with current technology. Also, unrelated to SO_2, a typographical error for the noise requirement for CO analyzers is being corrected to 0.5 ppm in Table B–1.

Finally, information on generation and verification of test concentrations for naphthalene was inadvertently omitted from Table B–2, Test Atmospheres, even though it was added as a required interferent test in our proposal. Therefore, we are adding that information for naphthalene. Also in Table B–2, we are correcting the verification information for nitric oxide.

B. Network Design

Ambient SO_2 monitoring data are collected by State, local, and Tribal monitoring agencies ("monitoring agencies") in accordance with the monitoring requirements contained in

40 CFR parts 50, 53, and 58. A monitoring network is generally designed to measure, report, and provide related information on air quality data as described in 40 CFR Part 58. To ensure that the data from the network is accurate and reliable, the monitors in the network must meet a number of requirements including the use of monitoring methods that EPA has approved as Federal Reference Methods (FRMs) or Federal Equivalent Methods (FEMs) (discussed in some detail above in section IV.A), focusing on particular monitoring objectives, and following specific siting criteria, data reporting, quality assurance and data handling rules or procedures.

With the revision to the SO_2 NAAQS, which establishes a new 1-hour averaging period intended to limit short-term exposures that may occur anywhere in an area, EPA evaluated the existing network to determine if it was adequate to support the revised SO_2 NAAQS. A significant fact for ambient SO_2 concentrations is that stationary sources are the predominant emission sources of SO_2 and the peak, maximum SO_2 concentrations that may occur are most likely to occur nearer the parent stationary source, as noted in the ISA (ISA, 2–1), section II.A.1 above, and in section IV.B.1 below. According to the 2005 National Emissions Inventory, there are 32,288 sources (facilities) emitting SO_2, of which 1,928 are emitting 100 tons per year (tpy) or more. In the proposal (74 FR 64851), EPA had anticipated requiring 348 source-oriented monitors in the network design based on a population and emissions metric and a State's emissions contribution to the National Emissions Inventory (NEI). In response to this proposal, EPA received numerous comments arguing that the required number of monitors in the network would be too small. Other commenters argued that expanding the monitoring to an adequate scale would impose a large burden and expense on the States. Some commenters referred to SO_2 modeling in their submissions as an addition or alternative to monitoring. Consequently, as part of developing a balanced response to these comments, we revisited how we had historically dealt with SO_2 for various purposes including designations and implementation through permitting and emissions limitations. As explained in section III, this has been realized through a combined monitoring and modeling approach. As set out below, and in sections III, VI, and VII, our ultimate intention is to utilize a combined monitoring and modeling approach, a hybrid analytic approach, to assess compliance with the revised SO_2 NAAQS.

As a result of this contemplated hybrid analytic approach, the minimum number of monitors required in the network through this rulemaking is reduced to approximately 163 monitors from the approximated 348 monitors that were proposed. This section of the preamble includes a discussion of the proposal, the comments received, and the details of and the rationale for the final changes to the SO_2 network design requirements.

1. Approach for Network Design

a. Proposed Approach for Network Design

To fully support the proposed revision to the SO_2 NAAQS, EPA indicated the need to identify where short-term, peak ground-level concentrations—*i.e.*, concentrations from 5 minutes to one hour (or potentially up to 24 hours)—may occur. Given that large stationary sources are the predominant source of emissions, monitoring short-term, peak ground-level concentrations would require monitors to be sited to assess impacts of individual or groups of sources and therefore be source-oriented in nature. As a result, under a monitoring-focused approach, EPA proposed a two-pronged monitoring network of all source-oriented monitors. However, due to the multiple variables that affect ground level SO_2 concentrations from individual or groups of sources, including stack heights, emission velocities, stack diameters, terrain, and meteorology, EPA could not specify a source specific threshold, algorithm, or metric by which to require monitoring. The design of the proposed network represented a primarily monitoring-focused approach to assess compliance with the primary SO_2 NAAQS.

In preparation for the SO_2 NAAQS proposal, EPA conducted an analysis of the approximately 488 SO_2 monitoring sites operating during calendar year 2008 (Watkins and Thompson, 2009). This analysis indicated that approximately ~ 35% of the monitoring network was addressing locations of maximum (highest) concentrations, likely linked to a specific source or group of sources. Meanwhile, just under half (~ 46%) of the sites were reported to be for the assessment of concentrations for general population exposure. These data allowed EPA to conclude that the network [24] was not properly focused to support the revised NAAQS (under the assumption that source-oriented monitoring data would be the primary tool for assessing compliance with the NAAQS). As a result, EPA proposed a two-pronged monitoring network (74 FR 64850), based on the premise of a monitoring-focused approach, with minimum requirements for: (1) Monitors in urban areas where there is a higher coincidence of population and emissions, utilizing a Population Weighted Emissions Index (PWEI), and (2) monitors in States based on each State's contributions to the national SO_2 emissions inventory. In addition, all the monitors in the network would be sited at locations of expected maximum hourly concentrations and therefore likely be source-oriented. This two-pronged network would have resulted in a minimum of approximately 348 monitors nationwide [25] providing data for comparison with the 1-hour standard and supporting its implementation.

Under the first prong of the network design, EPA proposed that the ambient SO_2 monitoring network account for SO_2 exposure by requiring monitors in locations where population and emissions may lead to higher potential for population exposure to peak hourly SO_2 concentrations. In order to do this, EPA developed a Population Weighted Emissions Index (PWEI) that uses population and emissions inventory data at the CBSA [26] level to assign required monitoring for a given CBSA (with population and emissions being obvious relevant factors in prioritizing numbers of required monitors). The PWEI for a particular CBSA was proposed to be calculated by multiplying the population (using the latest Census Bureau estimates) of a CBSA by the total amount of SO_2 emissions in that CBSA. The CBSA SO_2 emission value would be in tons per year, and calculated by aggregating the county level emissions for each county in a CBSA. We would then divide the resulting product of CBSA population and CBSA SO_2 emissions by 1,000,000 to provide a PWEI value, the units of

[24] Prior to this rulemaking there were no minimum monitoring requirements, except for those required at the multi-pollutant National Core (NCore) monitoring sites. The monitoring rule promulgated in 2006 (71 FR 61236) removed minimum monitoring requirements (except for those NCore stations). This change was largely driven by the fact that there was no longer an SO_2 nonattainment problem under the then-existing standards. However, this logic does not apply to the revised primary SO_2 NAAQS.

[25] Required monitor estimates were based on 2008 Census estimates and the 2005 National Emissions Inventory.

[26] CBSAs are defined by the U.S. Census Bureau, and are comprised of both Metropolitan Statistical Areas and Micropolitan Statistical Areas (*http://www.census.gov*).

which would be millions of people-tons per year.

We proposed that the first prong of the SO_2 network design require monitors in CBSAs, according to the following criteria. For any CBSA with a calculated PWEI value equal to or greater than 1,000,000, a minimum of three SO_2 monitors would be required within that CBSA. For any CBSA with a calculated PWEI value equal to or greater than 10,000, but less than 1,000,000, a minimum of two SO_2 monitors would be required within that CBSA. For any CBSA with a calculated PWEI value equal to or greater than 5,000, but less than 10,000, a minimum of one SO_2 monitor would be required within that CBSA. EPA estimated that the proposed criteria would have resulted in 231 required sites in 131 CBSAs.

Under the second prong of the network design, EPA proposed to require a monitor or monitors in each State, allocated by State-level SO_2 emissions. This prong of the network design was intended to allow a portion of the overall required monitors to be placed where needed, independent of the first prong of the network design, inside or outside of CBSAs. EPA proposed to require monitors, using State boundaries as the geographic unit for allocation purposes, in proportion to a State's SO_2 emissions, *i.e.,* a State with higher emissions would have been required to have a proportionally higher number of monitors. The proposed percent contribution of individual States would have been based on the most recent NEI, with SO_2 emissions being aggregated by State. The number of required monitors per State would correspond to every one percent (after rounding) of each State's contribution to the national SO_2 inventory. EPA also proposed that each State have at least one monitor required as part of this second prong, even if a particular State contributes less than 0.5% of the total anthropogenic national emissions inventory. As a result, the proposed second prong would have required approximately 117 monitoring sites based on State-level SO_2 emissions in the most recent NEI, which at the time of the proposal, was the 2005 NEI.

EPA also stated in the proposal that the multi-pollutant National Core (NCore) monitoring sites would not have counted towards meeting the proposed monitoring requirements. However, data from the NCore would be compared to the NAAQS even though NAAQS comparisons are not the sole objective of NCore monitors. The monitoring rule promulgated in 2006 (71 FR 61236) and codified at 40 CFR Part 58 and its Appendices established the NCore multi-pollutant network requirement to support integrated air quality management data needs. In particular, NCore sites are intended to provide long-term data for air quality trends analysis, model evaluation, and, for urban sites, tracking metropolitan air quality statistics. To do this, NCore sites are required to measure various pollutants, including SO_2, but they are not source oriented monitoring sites, and therefore are not likely to be the location of maximum expected concentration in an area. NCore sites are intended to provide data representing concentrations at the broader neighborhood and urban spatial scales. These reasons were the rationale justifying why SO_2 monitors at NCore stations would not have been part of the minimum monitors required under the proposed network.

b. Alternative Network Design

EPA also solicited comment on an alternative network design, including alternative methods to determine the minimum number of monitors per State (74 FR 64854). EPA requested comment on whether a screening approach for assessing the likelihood of a NAAQS exceedance could be developed and serve as a basis for determining the number and location of required monitors. In particular, EPA requested comment on whether it should utilize existing screening tools such as AERSCREEN or SCREEN3, which use parameters such as effective stack height and emissions levels to identify facilities with the potential to cause an exceedance of the proposed standard. For that set of sources, EPA could then require States to conduct more refined modeling (using the American Meteorological Society (AMS)/EPA Regulatory Model (AERMOD)) to determine locations where monitoring should be conducted. Any screening or refined modeling would likely be carried out by States by using EPA recommended models and techniques referenced by 40 CFR Part 51, Appendix W, which provides guidance on air quality modeling. Such screening or refined modeling uses facility emission tonnage, stack heights, stack diameters, emission temperatures, emission velocities, and accounts for local terrain and meteorology in determining where expected maximum hourly concentrations may occur. In using this approach, EPA would then require States to locate monitors at the point of maximum concentration around sources identified as likely causing NAAQS exceedances. EPA also noted that this alternative approach would not distinctly use population as a factor for where monitors should be placed.

c. Public Comments

EPA received many comments on the proposed network design and the alternative network design approaches. Based on comments that were clear enough on the issue, EPA believes the commenters' positions on the network design approach generally fell into one of three categories: (1) Those who supported the two-prong approach, but suggested some modification to it, (2) those who supported the alternative network design, and (3) those who suggested other concepts for the network instead of the two approaches EPA presented in the proposal.

The commenters who generally supported the two-prong network design, but suggested some modification included some State and local air agencies (*e.g.* NACAA and nine other State groups or agency commenters) and industry groups (*e.g.* AQRL, ACC, and eight other commenters). Of this group, some of the State and local air agencies specifically commented on how EPA should modify one or both of the prongs of the proposed network design. Some particular individual suggestions will be addressed here and those comments not addressed here will be addressed in the response to comment document. However, one recurring suggestion from the State and local agency commenters in this group was that the network design leads to some duplicative and/or unneeded monitoring, and therefore they requested that EPA include a provision to "waive" the monitoring network design requirements in situations where minimum monitoring requirements appear duplicative or unnecessary. In particular, NACAA stated that it "* * * is concerned that the two pronged approach in the proposed regulation will lead to duplicative monitoring in some areas and require monitors in areas where monitors are not needed. EPA recognizes the potential for duplicative monitoring, but the proposal does not permit the removal of duplicative monitors." This NACAA comment was echoed by some of the other States who commented on the proposed approach (*e.g.* AK, FL, IL, NC, SC, and WI). The industry commenters were also generally supportive of the two-prong approach, with some making general suggestions to modify the network design. For example, AQRL stated that the "* * * network design proposal seems to provide the flexibility for States and the EPA regions to work together to arrive at the adequate monitoring network." AQRL also suggests that "a State/local area should have the option to shutdown or relocate any site mandated [by monitoring requirements] if measured design values at the site are less than 75% of the selected standard level." Multiple industry commenters (*e.g.* API, LEC, and RRI Energy) expressed concern that the proposed network design had no monitoring required specifically to measure background concentrations of SO_2. Dow Chemical suggested that EPA maintain some of the existing monitors that characterize population exposure and other non-source oriented sites for trends analysis.

Those commenters who did not support the proposed network design, and instead generally supported the concepts of the alternative network design, include public health and environmental groups (*e.g.* ALA, CBD, EDF, EJ, NRDC, and SC) and the States of Delaware and Iowa. In particular, ALA, EDF, NRDC, and SC stated "* * * the proposed 348 monitors are a grossly inadequate number to detect peak concentrations from the nearly 2,000 major sources that emit more than 100 tons per year of sulfur dioxide * * *" and that "it is most appropriate to use screening tools to site all the monitors in the areas of highest expected concentration * * *" The Center for Biological Diversity, with regard to the proposed network design, stated that "* * * a number of communities with very significant SO_2 emissions will not have any monitoring stations at all * * *" Further, the State of Iowa claimed that "the proposed design of the SO_2 ambient monitoring network provides insufficient assurances that the public is protected from the health effects of SO_2 exposure," and suggested that "* * * the final rule contain provisions that require monitors to be sited only at locations where dispersion modeling indicates that the NAAQS is violated."

Commenters also suggested other concepts for the monitoring network design in lieu of the approaches discussed in the proposal. NESCAUM, NYSDEC, and PADEP, all suggested using an emissions-only approach to trigger required monitoring instead of using the PWEI to require monitors in an area. For example, NYSDEC suggests that the proposed approach, using the PWEI, is "* * * not more predictive than using emissions data alone." NYSDEC went on to recommend that monitors be required in CBSAs with aggregated emissions of 50,000 tons per year or more and that ambient monitoring be considered for point sources with 20,000 tons per year. PADEP made several suggestions on network design, including monitoring in any CBSA "where there is a sulfur dioxide source or combination of sources within 50 miles emitting a total of at least 20,000 tons of SO_2 per year * * *"

Among all three groups of commenters discussed above, there was a subset of commenters who specifically mentioned using modeling in some form. Modeling was a component of the alternative network design, where monitors would be required based on screening models and possibly refined modeling of individual sources. EPA also expected that under the proposed approach, many States would use modeling as a quantitative analysis tool to site required monitors. Finally, source modeling is a critical element for PSD and facility permitting. In their comments, NESCAUM recommended that EPA allow modeling to be used in conjunction with monitoring data to better determine nonattainment areas. North Carolina advocated that EPA require SO_2 sources, without specifying a threshold size for sources, to perform modeling to demonstrate that fence-line (ambient) air does not exceed the NAAQS due to that particular source's emissions. North Carolina went on to suggest that if a source's modeling showed an exceedance of the NAAQS, the source could "then be required to reduce emissions from the stack, install continuous emissions monitoring (CEM) in the stack itself, or require a fence-line monitor at the target facility." North Carolina also stated, in the context of discussing its own PSD program, that "the costs for modeling are small compared to the costs for monitoring." Sierra Club stated that EPA should "* * * employ modern computer models to determine whether areas should be designated nonattainment because they do not meet the NAAQS in areas where there is no monitor." From these comments, EPA gathers that some public commenters find modeling a useful tool and support the use of modeling to ascertain ambient concentrations of SO_2.

2. Modeling Ambient SO_2 Concentrations

EPA considered the various and sometimes competing concerns raised by the commenters including duplicative monitoring, lack of adequate number of monitors, insufficient flexibility, the monitoring burden, and the modeling suggestions. EPA considered its historic practice and the analytic tools available to arrive at a balanced approach that took into account these concerns. In the past, EPA used a combination of modeling and monitoring for SO_2 during permitting, designations, and re-designations in recognition of the fact that a single monitoring site is generally not adequate to fully characterize ambient concentrations, including the maximum ground level concentrations, which exist around stationary SO_2 sources. With representative and appropriate meteorological and other input data, refined dispersion models are able to characterize air quality impacts from the modeled sources across the domain of interest on an hourly basis with a high degree of spatial resolution, overcoming the limitations of an approach based solely on monitoring. By simulating plume dispersion on an hourly basis across a grid of receptor locations, dispersion models are able to estimate the detailed spatial gradients of ambient concentrations resulting from SO_2 emission sources across a full range of meteorological and source operating conditions. The 1-hour NAAQS is intended to provide protection against short-term (5 minute to 24 hour) peak exposures, whether they result from typical meteorological conditions or not. Because ambient monitors are in fixed locations and a single monitor can only represent impacts which occur at the location of the monitor, a single monitor cannot identify all instances of peak ground-level concentrations if, for example, different wind directions on various days cause peak ground-level concentrations in different areas that do not overlap. The uncertainty associated with this limitation is much higher for an hourly standard than a long-term standard due to the higher degree of spatial and temporal variability associated with peak hourly impacts (discussed in ISA chapters 2.4 and 2.5). This limitation of ambient monitoring may be true even if the source-oriented ambient monitor was sited with the aid of modeling data, since the model is less reliable at predicting the precise location of maximum impacts than at predicting the distribution of impacts across the full modeling domain, and no single monitor can be sited in a way to always measure the peak ground-level SO_2 concentrations that may be occurring in the area around a source.

EPA's *Guideline on Air Quality Models,* Appendix W to 40 CFR Part 51, provides recommendations on modeling techniques and guidance for estimating pollutant concentrations in order to assess control strategies and determine emission limits. These recommendations were originally published in April 1978 and were incorporated by reference in the PSD regulations, 40 CFR sections 51.166 and

52.21 in June 1978 (43 FR 26382). The purpose of Appendix is to promote consistency in the use of modeling within the air quality management process. Appendix W is periodically revised to ensure that new model developments or expanded regulatory requirements are incorporated. The most recent revision to Appendix W was published on November 9, 2005 (70 FR 68218), wherein EPA adopted AERMOD as the preferred dispersion model for a wide range of regulatory applications in all types of terrain. AERMOD is a steady-state plume dispersion model that employs hourly sequential preprocessed meteorological data to simulate transport and dispersion from multiple point, area, or volume sources for averaging times from one hour to multiple years, based on an advanced characterization of the atmospheric boundary layer. AERMOD also accounts for building wake effects (*i.e.,* downwash) on plume dispersion. To support the promulgation of AERMOD as the preferred model for near-field dispersion (50 km or less), EPA evaluated the performance of the model across a total of 17 field study data bases (Perry, *et al.,* 2005; EPA, 2003), including several field studies based on model-to-monitor comparisons of SO_2 concentrations from operating power plants.

EPA anticipates that additional guidance for States may be needed to clarify how to conduct dispersion modeling under Appendix W to support the implementation of the new 1-hour SO_2 NAAQS. Although AERMOD is identified as the preferred model under Appendix W for a wide range of applications and will be appropriate for most modeling applications to support the new SO_2 NAAQS, Appendix W allows flexibility to consider the use of alternative models on a case-by-case basis when an adequate demonstration can be made that the alternative model performs better than, or is more appropriate than, the preferred model for a particular application.

In conclusion, EPA believes that a hybrid analytic approach that uses a combination of modeling and monitoring information addresses the varying and competing concerns expressed by the commenters. Modeling large emission sources, along with smaller sources with the potential to violate the NAAQS, deals effectively with the concern that the monitoring network is not large enough to account for all sources that could have high ambient SO_2 concentrations. EPA believes that more SO_2 sources will ultimately be directly addressed through modeling alone versus the number of sources which would have been monitored under the proposed network design (which proposed a minimum of 348 monitors). Because modeling provides a technically appropriate and efficient method to identify locations of maximum concentrations attributable to the major stationary SO_2 sources, in the final network design (discussed below in section IV.B.4), EPA is not requiring that monitors must be in locations of expected maximum concentration, and thus, typically source-oriented. Instead, monitors required under the final network design now can address multiple monitoring objectives (discussed in IV.B.3 below), with fewer number of monitors required overall than the number estimated in the proposal. The flexibility that States now have, where relatively fewer required monitors may be sited to meet multiple objectives, effectively addresses concerns about duplicative monitoring and the need for waivers, the need for measuring background concentrations, and that emissions data rather than the PWEI could be more predictive of high ambient SO_2 concentrations as a basis on which to require monitoring. The comments that suggested the use of modeling, along with an examination of past practice, resulted in the change to a hybrid approach where we use both modeling and monitoring to assess ambient SO_2 concentrations.

3. Monitoring Objectives

Because EPA contemplates an ultimate approach that combines both monitoring and modeling, the monitor objectives of the final network design are now broadened to include assessment of source impacts, highest concentration, population exposure, general background concentrations, SO_2 transport, and long-term trends. The following paragraphs provide background, rationale, and details for the final changes to monitoring objectives.

a. Proposed Monitoring Objectives

EPA proposed that all minimally required monitoring sites in the proposed two-prong network design be sited at locations of expected maximum 1-hour concentrations, which would also likely discern 5-minute peaks. EPA noted that in general, such locations would be close to larger emitting sources (in tons per year) and/or areas of relatively high emissions densities where multiple sources may be contributing to peak ground-level concentrations. As a result, the proposed monitoring network would have been comprised primarily of source-oriented monitors. EPA also proposed that when selecting monitoring sites from among a pool of candidate locations (which would be source-oriented under the proposed network design), States prioritize these sites based on where the maximum expected hourly concentrations would occur in greater proximity to populations. EPA solicited general comments on the role of population exposure in the site selection process.

b. Public Comments

Commenters discussed a variety of issues on the subject of monitoring objectives including the importance of considering population exposure, the need for flexibility in monitor placement, monitoring for background concentrations, monitoring for long term trends analysis, and characterizing potential long-range transport of SO_2.

EPA received many comments from States (*e.g.,* NACAA, DE, IL, IN, MO, SD, WI), the public health group ATS, and industry (*e.g.,* AQRL, Consumers Energy, Dominion, Dow, EPRI, ExxonMobil, Montana Sulfur and Chemical, NPRA, Portland Cement, Rio Tinto, and UARG) suggesting that required monitors account for, or be focused on, population exposure. EPA also received many comments from States (*e.g.,* NACAA, NESCAUM, FL, IL, IN, IA, MI, OH, SC, and WI) and industry (*e.g.,* API, Dow, and TxOGA) asking for more flexibility in (source-oriented) monitor placement with regard to both the target source and the physical location of a monitor relative to that source. For example NACAA stated that "for source oriented monitors, placement at the point of 1-hour maximum concentration must be realistic and flexible. EPA must allow agencies to determine the most scientifically defensible location, while taking into account potential exposures and access to locations with adequate siting." Wisconsin stated that "* * * monitor siting should be balanced toward population-based monitors with a preference toward maximum exposure." Wisconsin added that "* * * placing monitors at the maximum downwind location does not necessarily result in effective protection of public health."

EPA received a number of comments on background monitoring [27] from industry (API, LEC, and RRI Energy) and from the State of South Carolina. API stated that "because the monitors provide background concentrations

[27] Background monitoring can be considered to be representative of ambient concentrations upwind of (and therefore not typically influenced by) a geographic area such as an urban area, or of an individual or group of emission sources.

needed to model impacts of new sources or sources undergoing major modification in addition to providing data for judging compliance with the NAAQS, it is important that some monitors be sited in a manner suitable for assessing this background." API went on to state that "* * * EPA should encourage States to site an appropriate number of area-wide monitors for use in establishing ambient background levels of SO_2." South Carolina states that "to better support the monitoring objectives, in particular those improving our understanding and context for the source oriented monitoring data, the monitoring requirements must include the ability for States to address the needs for area and regional background concentration measurements."

A number of commenters, including States (*e.g.,* Missouri, NESCAUM, Ohio, and South Carolina), citizens (Valley Watch at the Atlanta public hearing), the CBD, and Dow, commented on SO_2 transport and related cross-boundary monitoring. Dow stated that "SO_2 distribution has long been known as an interstate issue with the vast majority of SO_2 sources being power plants and other fossil fuel combustion facilities. These facilities are more likely to impact distant areas than local areas and the resultant ground-level concentrations are often minimal." Ohio stated that, under the proposed approach, "* * * it is likely that OH, WV, KY, and IN will find sources along the Ohio River which could result in monitors being located across the river from each other." In such situations, Ohio asserts that "States are capable of working with our neighbors to determine which State would be in the best position to site and operate a monitor."

c. Conclusions on Monitoring Objectives

A hybrid analytical approach, as noted above in section III and IV.B.1 would ultimately make the most appropriate use of available tools such as modeling and monitoring. Thus, unlike under the proposal, the monitoring network will not have to be focused solely at locations of expected maximum concentration relative to an SO_2 source given the anticipated adoption of a hybrid analytical approach. The final network design is intended to be flexible to meet multiple monitoring objectives, most of which were identified in the public comments. Ambient monitoring networks are generally designed to meet three primary monitoring objectives, as listed in 40 CFR Part 58 Appendix D, Section 1, including: (1) Providing air pollution data to the general public in a timely manner, (2) support compliance with ambient air quality standards and emissions strategy development, and (3) support air pollution research studies (which includes health studies and research). In order to support these air quality management objectives, monitoring networks can have a variety of monitoring sites that can be sited, as necessary, to characterize (a) emission sources (*i.e.,* source-oriented monitoring), (b) the highest concentration in an area, (c) population exposure, (d) general background concentrations, (e) regional transport, and (f) welfare-based impact.

In light of the approach described in section III and further in IV.B.1 above, EPA is finalizing an SO_2 network design, with broadened objectives, which EPA believes will address the concerns noted in the public comments above, particularly those regarding siting flexibility, population exposure, cross-boundary impacts, and the need for the network to address multiple monitoring objectives. The final network design requires that any SO_2 monitors required in a particular CBSA as determined based on PWEI values, discussed below in section IV.B.4, shall satisfy the minimum monitoring requirements if they are sited at locations where they can meet any one or more of the following objectives (*see* Part 58 Appendix D section 4.4.2 as added by today's final rule):

(1) *Source-Oriented Monitoring:* This is accomplished with a monitor sited to determine the impact of significant sources or source categories on air quality. In some situations, such monitoring sites may also be classified as high concentration sites (discussed below). Examples of source-oriented monitors include those sited to capture or assess peak ground-level concentrations from one or more major SO_2 sources, or those sited in an area with multiple smaller sources with overlapping plumes.

(2) *Highest Concentration:* This is assessed by a monitor sited to measure the highest concentrations expected to occur in the area covered by the network. Such a location may, or may not, also be considered a source-oriented location (discussed above). Depending on the case, this location is representative of the highest concentration occurring across a relatively homogeneous area with spatial scales typically ranging from tens of meters up to four kilometers.[28]

[28] Spatial scales are defined in 40 CFR Part 58 Appendix D, section 1. Each scale is a description of the physical dimensions of an air parcel nearest a monitoring site throughout which pollutant concentrations are reasonably similar.

(3) *Population Exposure:* This is assessed by a monitor sited to measure typical concentrations in areas of (relatively) high population density. Some examples are a monitor placed in an area of elevated or high SO_2 concentrations that also has a high population density, an area that might be included in public health studies, or in areas with vulnerable and susceptible populations.

(4) *General Background:* This is assessed by placing a monitor in an area to determine general background concentrations. Such locations might be considered to be representative of ambient concentrations upwind of (and therefore not typically influenced by) a geographic area such as an urban area, or of an individual or group of emission sources. EPA notes that although a required monitor is allowed to be sited to assess background concentrations, the required monitor is not allowed to be sited outside of the parent CBSA (whose PWEI value triggered required monitoring, discussed in section IV.B.4 and IV.B.5). If a State believes that there is a need to conduct background monitoring outside of CBSAs with required monitoring, EPA notes that States always have the prerogative to conduct monitoring above the minimum requirements in any location the State believes is appropriate.

(5) *Regional Transport:* This is assessed by placing a monitor in a location to determine the extent of regional pollutant transport. Such locations could be either upwind or downwind of urban areas, characterizing the entry or exit of the pollutant in a region, respectively. EPA notes that although a required monitor is allowed to be sited to assess regional transport, the required monitor is not allowed to be sited outside of the parent CBSA (whose PWEI value triggered required monitoring, discussed in section IV.B.4 and IV.B.5). If a State believes that there is a need to conduct background monitoring outside of CBSAs with required monitoring, EPA notes that States always have the prerogative to conduct monitoring above the minimum requirements in any location the State believes is appropriate.

In regard to the public comments expressing concerns on the issue of cross-boundary transport, *i.e.,* a source on one side of a political boundary contributes to peak ground-level concentrations on the other side of that boundary, EPA will allow a required monitor to be placed outside of the parent CBSA (whose PWEI value triggered monitoring, discussed in section IV.B.4 and IV.B.5) under one particular condition. A source-oriented monitor may be sited outside of the parent CBSA, whose PWEI value triggered required monitoring, if that monitor is characterizing the location of expected maximum concentration of a source inside that parent CBSA. If a State chooses to exercise this flexibility in source-oriented monitor siting, the State must provide clear rationale for their choice in their annual monitoring plan, which is subject to EPA regional approval. If the source-oriented monitor is to be placed in another State, such as the example provided by the State of Ohio in the public comments above, the two States are responsible for collaboration on the location and operation of that monitoring site.

Further, due to the broadened objectives of the final network design, EPA also is finalizing the provision that an NCore SO_2 monitor within a CBSA (where a CBSAs PWEI value triggered required monitoring) can be counted towards meeting the minimum monitoring requirements in this rulemaking (discussed in section IV.B.4) because they can meet some of the expanded objectives of the network. NCore sites are intended to provide long-term data for air quality trends analysis, model evaluation, and, for urban sites, tracking metropolitan air quality statistics, and therefore are appropriate to allow to count towards minimum monitoring requirements under the revised monitoring scheme.

Finally, EPA strongly encourages State and local air agencies to consider using required monitoring, as appropriate, to characterize those sources which are not as conducive to dispersion modeling and to assess population exposure. Sources that are not conducive to dispersion modeling include (1) sources classified as non-point sources (a.k.a. "area-sources") such as shipping ports, (2) a source situated in an area of complex terrain and/or situated in a complex meteorological regime, and (3) locations that have multiple, relatively small sources with overlapping plumes.

4. Final Monitoring Network Design

The use of a hybrid analytic approach (discussed above in section III and IV.B.1) makes it unnecessary for the final monitoring network design to be distinctly focused on monitoring locations of expected maximum concentration (and thus be primarily source-oriented), as discussed in section IV.B.3 above. Instead, with the dual use of modeling and monitoring for designations, the final monitoring network is designed to provide flexibility for required monitors to address the multiple monitoring objectives just discussed in the preceding section. This flexibility in monitoring objectives is in response, in part, to the many public comments received from States (*e.g.,* NACAA and six other States), industry (API, EPRI, UARG, and eight other groups), and from the American Thoracic Society (ATS), urging EPA to ensure that some or all of the required monitors be sited and suited to characterize population exposure and, from many of these same commenters, to allow flexibility in implementing the siting requirements for the monitors. Under a hybrid approach, and the different monitoring objectives resulting thereof, the final monitoring network design also does not need to be a two-prong approach like the one proposed. Therefore, EPA is adopting a modified version of the first prong of the proposed network design, which will use PWEI values to require monitors in certain CBSAs where there is increased coincidence of population and SO_2 emissions. There is no second prong in the final network design by which monitors are required based on a State's individual contribution to the national anthropogenic SO_2 inventory, as was proposed.

The final monitoring network design requires monitoring in CBSAs based on calculated PWEI values, where a PWEI shall be calculated (as discussed in section IV.B.5 below) for each CBSA. For any CBSA with a calculated PWEI value equal to or greater than 1,000,000, a minimum of three SO_2 monitors are required within that CBSA. This requirement remains the same as proposed. For any CBSA with a calculated PWEI value equal to or greater than 100,000, but less than 1,000,000, a minimum of two SO_2 monitors are required within that CBSA. For any CBSA with a calculated PWEI value equal to or greater than 5,000, but less than 100,000, a minimum of one SO_2 monitor is required within that CBSA. EPA has adjusted the thresholds for requiring one or two monitors in a CBSA and the rationale for this adjustment is explained more fully below in section IV.B.5. As just explained in section III.B.3, these monitors shall be sited to meet one or more of a number of monitoring site objectives, including the assessment of source impacts, highest concentrations, population exposure, general background, and regional transport. EPA believes that the monitors required within these PWEI breakpoints provide a reasonable minimum number of monitors in a CBSA, where there is a relatively increased coincidence of population and SO_2 emissions and therefore increased potential for exposures, because we are directly accounting for both population and emissions that exist in individual CBSAs.[29] EPA estimates that these minimum monitoring criteria (based on 2008 population and 2005 NEI data) require 163 monitors within 131 CBSAs. EPA also intends for SO_2 monitors at NCore stations to satisfy these minimum monitoring requirements. Based on analysis of proposed and approved NCore sites (as of April 2010), all of which are scheduled to be operational no later than January 1, 2011, EPA estimates that 52 of the total 80 SO_2 monitors at NCore stations are within the 131 CBSAs that have required monitors based on their PWEI values. As a result, EPA estimates that between these minimum monitoring requirements and the NCore network, there will be at least 191 SO_2 monitors operating across the country.

5. Population Weighted Emissions Index

In the proposal, EPA had introduced a metric based on population and emissions as a basis for locating monitors in the network. EPA anticipated that this metric would characterize the potential for exposure based on the proximity of source emissions to populations. The following paragraphs provide background, rationale, and details for the final changes of the calculation and use of the Population Weighted Emissions Index in determining minimum monitoring requirements.

a. Proposed Use of the Population Weighted Emissions Index

In the proposed network design approach, which utilized a two-prong network design, EPA created the Population Weighted Emissions Index (PWEI) in an attempt to focus monitoring resource where there was a higher proximity of population and SO_2 emissions. In effect, areas with higher PWEI values have higher potential for population exposure to short-term SO_2 emissions. EPA proposed that the PWEI be calculated using population and emissions inventory data at the Core Based Statistical Area (CBSA)[30] level to assign required monitoring for a given CBSA, with population and emissions being the relevant factors. To calculate the PWEI for a particular CBSA, using

[29] The rationale for finalizing the use of the PWEI and the number of monitors required through its application are discussed in section III.B.4.

[30] CBSAs are defined by the U.S. Census Bureau, and are comprised of both Metropolitan Statistical Areas and Micropolitan Statistical Areas (*http://www.census.gov*).

the latest Census Bureau estimates, the population of a CBSA must be multiplied by the total amount of SO_2 emissions in that CBSA. The CBSA emission value is in tons per year (using the latest available National Emissions Inventory [NEI] data), and is calculated by aggregating the county level emissions for each county in a CBSA. We then divide the resulting product of CBSA population and CBSA SO_2 emissions by 1,000,000 to provide a PWEI value in more manageable units of millions of people-tons per year.

With the change in the approach discussed in section III and section IV.B.1 above, and considering the final monitoring network design discussed in IV.B.4 above, the use of the PWEI from that which was proposed also changes. The following paragraphs discuss some of the public comments received on the general use and calculation of the PWEI; other comments that focused on the detailed application of the PWEI as proposed will be addressed in the response to comments document since our approach in applying the PWEI has changed.

b. Public Comments

EPA received a number of comments from State and local groups (*e.g.,* NACAA and eight others) and industry (*e.g.,* AQRL, ACC, and eight others) who generally agreed with the two-pronged network design concept which had the PWEI as a component. More specifically, some State commenters (*e.g.* NACAA, AK, FL, IL, NC, SC, and WI) expressed concern that the PWEI (along with the second prong of the proposed network design) created monitoring requirements that were "duplicative" and also called for monitors in areas where they were not needed. Even amongst some of the commenters who generally agreed with the PWEI concept, some provided examples of where the PWEI appeared to be duplicative in its proposed application. One example was provided by the State of Florida, "in the case of Homosassa Springs, the [proposed network design] requires two monitors [in that CBSA as a result of the proposed use of the PWEI]. The driving source is the Crystal River Power Plant, with emissions in 2008 of over 85,000 tons per year of SO_2. The next largest source in the CBSA has emissions of roughly two tons per year." EPA believes that Florida is asserting that the one large source disproportionately drove the PWEI too high for that particular CBSA and only one monitor was actually needed. EPA notes that these particular comments on duplicative monitoring were made under the premise that all proposed required monitors would be sited in locations of expected maximum concentration, and therefore would be source-oriented in nature. As a result, these commenters believed it was necessary that a waiver provision be included if they could show that the required number of monitors was too many, as in Florida's example.

As discussed in section IV.B.4 above, a hybrid approach results in a final network design with a reduced number of required monitors from the number proposed, a different application of the PWEI, and provides flexibility in meeting additional monitoring objectives for the required monitors, making the need for a waiver from the minimally required monitors unnecessary. If a CBSA is required to have multiple monitors now, those monitors are not specifically required to be located near sources where maximum concentrations of SO_2 are expected to occur. Instead, they can be sited at different locations to fulfill a variety of objectives, although, as noted in secion IV.B.3 above, EPA is strongly encouraging States to consider monitoring near sources not conducive to dispersion modeling and for characterization of population exposures.

EPA received comments from Michigan, South Carolina, and CBD requesting clarification on the logic behind the proposed PWEI thresholds, or breakpoints, by which three, two, one, or no monitors would be required in a given CBSA. In addition, some States (*e.g.,* MI, MO, SC, and WI) and industry (*e.g.,* LCA, LMOGA, and LPPA) suggested specific adjustments to the proposed application of the PWEI. For example, Michigan suggested that the required monitor breakpoint values be adjusted to the "natural breakpoints in the overall distribution". South Carolina suggested EPA identify a way to normalize the PWEI stating the PWEI would be more appropriate "* * * if it used a value that better addressed difference in area, population distribution, land use, number, types of sources, *etc.*"

In the proposed network design, EPA selected the PWEI values, or breakpoints, to require one or more monitors based on the overall distribution of PWEI values across all CBSAs. Based on U.S. Census Bureau data (*http://www.census.gov*), there are approximately 939 CBSAs in the country. EPA proposed and now requires that a PWEI value be calculated for each of these CBSAs to determine if monitoring is required in that CBSA. Based on 2008 census estimates and the 2005 NEI, the average CBSA PWEI value is 21,900 while the median value is only 121. This indicates that a relatively small number of CBSAs with high PWEI values are driving the very upper end of the PWEI distribution. The proposed breakpoint where one monitor was required in a CBSA was a PWEI value of 5,000. EPA estimated that 131 out of 939 CBSAs (~14%) have a PWEI value of 5,000 or more. Further, these 131 CBSAs occupy ~98% of the sum of PWEI values across all 939 CBSAs, where high PWEI values indicate increased coincidence in population and SO_2 emissions. Within this group of CBSAs with PWEI values of 5,000 or more, EPA considered the relative amounts of population, emissions, and general frequency of occurrence of relatively larger SO_2 sources (such as those that emit 100 tons per year or more) in selecting the breakpoints to require two and three monitors in a CBSA for the proposed network design. These considerations were made in an effort to apply a nationally applicable process by which to require a minimum number of monitors for an area, which all were to be sited in locations of expected maximum concentration, and therefore likely source-oriented monitors. In regard to the comments suggesting modification to the calculation or to normalize the PWEI, EPA believes that the proposed calculation, under a hybrid analytical approach, is still most appropriate. Under a hybrid analytical approach, States have the flexibility to move monitoring resources where needed within CBSAs that have a high coincidence of population and emissions instead of only being able to site monitors to characterize sources. States have the option to consider additional factors such as those listed in South Carolina's comments above in further identifying where required monitoring may be most appropriate in their areas with required monitoring.

Several States (*e.g.* NESCAUM, NYSDEC, and PADEP) suggested abandoning the PWEI concept altogether and instead using some form of emissions-only approach to require monitors. For example, NESCAUM, who generally supported a "hot-spot" monitoring approach, suggested that the PWEI be abandoned and EPA instead "* * * adopt an emissions-only approach, resulting in fewer CBSA monitors. We [NESCAUM] suggest a threshold of 50,000 tpy CBSA SO_2 emissions to trigger the first CBSA monitor and a second CBSA monitor required when emissions exceed 200,000 tpy." NESCAUM states that the proposed use of the PWEI "* * * can result in multiple monitors in large cities that have relatively small CBSA SO_2 emissions, or no monitor in a CBSA with large emissions." NYSDEC suggests that the proposed approach, using the PWEI, is "* * * not more predictive than using emissions data alone." NYSDEC went on to suggest that monitors be required in CBSAs with aggregated emissions of 50,000 tons per year or more and that ambient monitoring be considered for point sources with 20,000 tons per year. PADEP made several suggestions on network design, with one that suggested monitoring in any CBSA "where there is a sulfur dioxide source or combination of sources within 50 miles emitting a total of at least 20,000 tons of SO_2 per year * * *"

EPA reviewed emissions and 2005 NEI data and compared the suggestions provided by NESCAUM and NYSDEC to the requirement of the final network design. Under NESCAUM's suggested design, EPA estimates there would be 75 required monitors in 65 CBSAs. Of these 65 CBSAs, 6 CBSAs that are not covered by the final network design would be included; however, 72 CBSAs that will have monitors under the final network design would otherwise not have monitors under NESCAUM's design. EPA believes that the exclusion of those 72 CBSAs would lead to too sparse a network to adequately meet the monitoring objectives of the network. Under NYSDEC's suggested network design, EPA estimates that there would be a minimum of 65 monitors in the same 65 CBSAs of the NESCAUM suggested design. Further, if States ensured that monitors were placed near all sources emitting 20,000 tons per year (as NYSDEC suggested should be "considered" for monitoring), there could be an additional 69 monitors.[31] EPA believes that the final network design as discussed above in section IV.B.4, with the increased flexibility for monitors to meet multiple monitoring objectives (discussed in IV.B.3 above) including, among others, characterization of source impacts or population exposure, is better served using PWEI values to require monitors because it explicitly accounts for population to require and distribute monitors as compared to an emissions-only approach. If there is reason for concern that other CBSAs or areas not included in the final network design, such as the six CBSAs that were included in the NESCAUM and NYSDEC suggested network designs noted above, warrant monitoring resources, States or the EPA Regional Administrator may take action to require monitoring in such areas. The authority of an EPA Regional Administrator to require additional monitoring above the minimum requirements is discussed in section IV.B.6 below.

EPA received a number of comments from States (*e.g.,* IA, NESCAUM, NC, NYSDEC, SC, and WI) and industry (*e.g.,* CE, Dominion, EEI, LCA, LMOGA, LPPA, and UARG) raising concern over the way the PWEI is calculated. Specifically, many commenters in this group indicated that they believed that the 2005 NEI would be used in an exclusive or permanent fashion to calculate the PWEI, and that updated NEI data would not be used. For example, NESCAUM states that "EPA should not require States to rely solely on EPA's inventories [for calculating the PWEI], such as the National Emissions Inventory (NEI), as they do not always have the updated information that is necessary for such regulatory decisions." Wisconsin "* * * believes that States should be allowed to use their own annual point source inventories instead of EPA's National Emissions Inventory (NEI) for evaluating emission sources. Wisconsin's point inventory is updated annually and has a reporting threshold of five tons per year for SO_2, making it more sensitive to changes in facility operations than the NEI, which is updated triennially." UARG stated that their "primary concern with this network design is its reliance on old emissions data. For electric utilities which report their SO_2 emissions to EPA annually, the use of more recent data would be appropriate."

EPA does not intend for relatively old emissions data to be used in calculating the PWEI values for individual CBSAs. As was detailed in the proposed regulatory text for 40 CFR Part 58 Appendix D (74 FR 64880), EPA stated that "The PWEI shall be calculated by multiplying the population of each CBSA, using the most current census data, by the total amount of SO_2 in tons per year emitted within the CBSA area, using an aggregate of the most recent county level emissions data available in the National Emissions Inventory for each county in each CBSA." Although commenters suggested that there may be other resources from which emissions data may be obtained, particularly at the individual State level, the NEI is comprised of emissions data which is collected by EPA from the States themselves. The Air Emissions Reporting Requirements (40 CFR Part 51), by which EPA sets out how States are to report their emission inventories, was recently revised in December of 2008. That rulemaking was intended to provide enhanced options to States for emissions data collection and exchange and unify reporting dates for various categories of inventories. EPA notes that the NEI is updated in full every three years and the 2008 NEI is scheduled to be available by January 2011. States will have submitted their data by May 31, 2010, before this rule is promulgated and published, and EPA will provide comment on these submittals during the summer of 2010. States will have an opportunity to revise their 2008 data submissions in the fall of 2010. In the triennial update, both point and nonpoint data are required to be submitted by States and are included in the inventory. Further, States are required to submit emissions data annually for all sources emitting 2,500 tons per year or more of SO_2 as well as for sources emitting other pollutants in excess of thresholds set for those pollutants. In all point source submittals to the NEI, States are also allowed to submit emissions data for sources of any emissions level, but are not required to do so. Starting with the 2009 NEI, the annual and triennial State NEI submittals will be due one year after the end of the emissions year. States have an additional opportunity to revise their submittals based on EPA comment in the spring of the following year, with EPA publishing the inventory no later than 6 months after the inventory submittal dates (18 months after the end of the emissions year). This approach and schedule is accelerated over past NEI schedules and has been designed as part of the development of the new Emission Inventory System (EIS). Rather than representing old emissions data, the NEI available through EIS represents a timely and appropriate source of emissions data.

EPA believes that the process by which the NEI will be updated (through use of the EIS) will be adjusted in a manner that will allow for more frequent insertion of State supplied emissions data, allowing for a more up-to-date inventory. EPA takes this opportunity to encourage States to supply all of their available emissions information to the NEI as soon as practicable. Therefore, EPA believes that the NEI is an appropriate and nationally representative source of emissions data by which PWEI calculations may be

[31] In simulating NYSDEC's suggested network design, EPA assumed that no CBSA would have more than one monitor. According to the 2005 NEI, there are 162 sources emitting 20,000 tpy or more a year. 93 of those sources are estimated to be inside CBSAs that have emissions of 50,000 tpy, leaving approximately 62 sources that would need a monitor to satisfy NYSDEC's suggested network design.

made. PWEI calculations for all CBSAs will use the same year of data at any given time, and States, local agencies, and Tribes will have uniform opportunity for revising their emissions data for this purpose. EPA again encourages States to view the NEI submittals as their opportunity to submit their best available SO_2 and other inventory data with the knowledge that it will be used for the purpose of PWEI values.

c. Conclusions on the Use of the Population Weighted Emissions Index

In the final network design, EPA has determined that it is appropriate to use PWEI values as the mechanism by which to require monitors in certain CBSAs, similar to its use in the first prong of the proposed two-prong network design. EPA believes that using the PWEI metric to inform where monitoring is required is more appropriate for the SO_2 network design than utilizing a population-only or emissions-only type of approach, because it takes into account not just one factor, *i.e.,* only population or only emissions, but instead takes into account the exposure from SO_2 emissions to groups of people who are in greater proximity to such emissions.

In the final rule, EPA is retaining the requirement to calculate the PWEI by multiplying the population of each CBSA, using the most current census data/estimates from the U.S. Census bureau, by the total amount of SO_2 in tons per year emitted within the CBSA area, using an aggregate of county level emissions data available in the most recent published version of the National Emissions Inventory for each county in each CBSA. The resulting product shall be divided by one million, providing a PWEI value, the units of which are million persons-tons per year. For any CBSA with a calculated PWEI value equal to or greater than 1,000,000, a minimum of three SO_2 monitors are required within that CBSA. For any CBSA with a calculated PWEI value equal to or greater than 100,000, but less than 1,000,000, a minimum of two SO_2 monitors are required within that CBSA. For any CBSA with a calculated PWEI value equal to or greater than 5,000, but less than 100,000, a minimum of one SO_2 monitor is required within that CBSA. EPA believes that the monitors required within these breakpoints provide a reasonable minimum number of monitors in a CBSA that considers the combination of population and emissions that exist in a CBSA. These criteria (based on 2008 population and 2005 NEI data) are estimated to require 163 monitors within 131 CBSAs.

EPA has changed the PWEI breakpoint in the final rule at which two monitors are required in a CBSA to 100,000 from the breakpoint of 10,000 in the proposed network design based on multiple considerations. First, EPA changed the breakpoint because of a hybrid analytic approach and attendant changes in monitoring objectives (*see* section IV.B.3), with the result being that the monitoring network is no longer intended to be comprised primarily of source-oriented monitors that are sited at locations of expected maximum concentration. This change in objective of the network design allows fewer monitors to provide the necessary amount of ambient monitoring data EPA to meet the multiple monitoring objectives. Second, the breakpoint of 100,000 occurs near a "natural" breakpoint in the PWEI distribution, a consideration that Michigan suggested, where the estimated 28 CBSAs with PWEI values of 100,000 or more occupy ~87% of the sum of PWEI values across all 939 CBSAs. Finally, EPA considered commenters' assertion that the first prong of the proposed network design created duplicative monitoring in certain CBSAs. This duplicative monitoring is especially recognized in some CBSAs with relatively small populations and somewhat large emissions which are dominated by a single source (such as the Homosassa Springs, FL example discussed above). Raising the second breakpoint helps to alleviate some of the duplicative monitoring that many of the State commenters noted.

EPA therefore is keeping the first and third breakpoints, which require one monitor in a CBSA having a PWEI value of 5,000 and three monitors in a CBSA having a PWEI value of 1,000,000. EPA believes maintaining these breakpoints along with the revised 100,000 PWEI breakpoint, will (1) ensure that highly populated areas will be monitored for ambient SO_2 concentrations even if the emissions in that area are moderate, which is appropriate given the fact that the greater population creates increased potential for exposure to those moderate emissions, and (2) that those areas with higher emissions or emission densities, with moderate or modest populations will be monitored because those increased emissions are likely to have a significant impact on nearby populations.

6. Regional Administrator Authority

The following paragraphs provide background, rationale, and details for the final changes to Regional Administrator authority to use discretion in requiring additional SO_2 monitors beyond the minimum network requirements.

a. Proposed Regional Administrator Authority

EPA proposed that the Regional Administrators will have discretion to require monitoring above the minimum requirements, as necessary, to address situations where the minimum monitoring requirements are not sufficient to meet monitoring objectives. EPA recognized that the minimum required monitors in the proposed two-pronged network design were based on indicators that may not have always provided spatial coverage for all the areas that have SO_2 sources. Although the network design and the objectives of the network design have changed from those that were proposed because of our contemplated use of a hybrid analytical approach, EPA believes it is still important for Regional Administrators to have the discretion, and authority, to require monitoring above the minimum requirements. Providing the RAs with this discretion will allow them to fill any identified gaps in meeting the monitoring objectives of the network.

b. Public Comments

Some commenters (*e.g.,* LCA, LMOGA, LPPA, and South Carolina) expressed concerns with the proposed provision authorizing the Regional Administrator to require additional monitoring above the minimum requirements. The LCA, LMOGA, and LPPA stated that "the EPA's proposal to allow the Regional Administrator discretion to require a State to add additional monitors is flawed in that it provides unfettered discretion. Criteria should be added * * * that limit such discretion and require the Regional Administrator to consider certain objective factors when determining whether to require any additional ambient SO_2 monitors to the network." South Carolina stated that "the Regional Administrators should not have the discretion to require monitoring above the requirements described in [the proposal for] Part 58 and its Appendices. State monitoring organizations must be given discretion to decide the appropriate use of resources to meet uniform monitoring requirements. Additional monitoring requirements should not be imposed without concurrence of the monitoring organization and additional funding that completely supports the additional costs."

c. Conclusions on Regional Administrator Authority

The authority of Regional Administrators to require additional monitoring above the minimum required is not unique to the SO_2 NAAQS. For example, Regional Administrators have the authority to use their discretion to require additional NO_2 or Pb monitors (40 CFR Part 58 Appendix D section 4.3.4 and 4.5, respectively) and to work with State and local air agencies in designing and/or maintaining an appropriate ozone monitoring network (40 CFR Part 58 Appendix D section 4.1). EPA believes that the nationally applicable final network design, although somewhat dictated by local factors (population and emissions), may not account for all locations where monitors should be sited, including where potentially high concentrations of SO_2 may be occurring. Examples include locations that have the potential to violate or contribute to violations of the NAAQS, areas that might have high concentrations of SO_2 that are not characterized by modeling or have sources that are not conducive to modeling, and locations with susceptible and vulnerable populations. As a result, EPA believes it is important for Regional Administrators to have the authority to address possible gaps in the minimally required monitoring network, especially near sources or areas that are not conducive to modeling by granting them authority to require monitoring above the minimum requirements. However, in response to public comments, EPA notes that Regional Administrators would use this authority in collaboration with State agencies to design and/or maintain the most appropriate SO_2 monitoring network to meet the needs of a given area. For all the situations where the Regional Administrators may require additional monitoring, it is expected that the Regional Administrators will work on a case-by-case basis with State or local air agencies. Further, any monitor required through the Regional Administrator and selected by the State agency, or any new monitor proposed by the State itself, is not done so with unfettered discretion, since any such action would be included in the Annual Monitoring Network Plan per § 58.10, which must be made available for public inspection or comment, and approval by the EPA Regional Administrator.

Therefore, EPA is finalizing the proposal that Regional Administrators may use their authority to require monitoring above the minimum requirements, as necessary, in any area, to address situations where the minimally required monitoring network is not sufficient to meet monitoring objectives. In all cases in which a Regional Administrator may consider the need for additional monitoring, it is expected that the Regional Administrators will work with the State or local air agencies to evaluate evidence or needs to determine if a particular area may warrant additional monitoring.

7. Monitoring Network Implementation

The following paragraphs provide background, rationale, and details for the final approach for the monitoring network implementation.

a. Proposed Monitoring Network Implementation

EPA proposed that State and, where appropriate, local air monitoring agencies submit a plan for deploying SO_2 monitors in accordance with the proposed requirements discussed above by July 1, 2011. EPA also proposed that the SO_2 network be physically established no later than January 1, 2013. EPA also proposed that the number of sites required to operate as a result of the Population Weighted Emissions Index (PWEI) values calculated for each CBSA be reviewed and revised for each CBSA through the 5-year network assessment cycle required in § 58.10.

b. Public Comments

EPA received comments from the ALA, EDF, NRDC, and SC that supported "* * * a more accelerated deployment of new monitoring than the 2013 target date proposed by EPA. The sooner monitors are in place, the sooner the public will experience the health benefits of the new standard." However, EPA received comment from States (*e.g.,* IA, MI, NC, SC and WI), industry (*e.g.,* LCA, LMOGA, and LPPA) and public health and environmental groups (*e.g.,* ALA, EDF, NRDC, and SC) expressing concern with the proposed deployment schedule of the proposed SO_2 network in that it was too fast or needed to be phased in. The States of Iowa, South Carolina, and Wisconsin suggested that EPA allow the proposed network to deploy on a phased schedule. For example, South Carolina recommended a "phased implementation with largest source/highest probability population exposure areas designated for implementation in 2013 (some proportion of the highest PWEI monitors) and establishment of the remaining PWEI and the State level emissions triggered monitoring required the following year." Meanwhile, the States of Michigan and North Carolina, along with the industry commenters LCA, LMOGA, and LPPA, suggested EPA reconsider implementation dates in light of the multiple rulemakings that impose mandates on States that have and will be occurring in the future. For example, North Carolina stated that "EPA must keep in mind that it is simultaneously revising numerous ambient standards and associated monitoring requirements. EPA seems to view each of these proposals as independent actions; but the State and local agencies must consider the cumulative impact of EPA's various regulatory actions on their ability to comply." North Carolina goes on to say that "EPA must allow States the flexibility to prioritize among the new requirements to get community based monitors in place first and to establish the others as funding and personnel resources allow."

EPA believes that with the use of a hybrid analytical approach, the concerns raised by States and industry commenters suggesting a phased or delayed implementation are addressed because the final network minimum design requirements result in fewer monitors being required than in the proposed network design. EPA's analysis of the existing network had indicated that a substantial number of monitors were not sited at locations of maximum concentrations. These monitors would have had to be re-located to count towards minimum monitoring requirements under the proposed monitoring-focused approach. Under a combined modeling and monitoring approach, the required monitors can be used to satisfy multiple monitoring objectives and therefore, many of the monitors in the existing network will satisfy the requirements in the final network design, eliminating any need for a phased or delayed network implementation. In regard to the suggestion by public health and environmental groups to speed up implementation, EPA notes that under a hybrid analytical approach much of the existing network will fulfill minimum monitoring requirements, and an accelerated schedule is not necessary; the network implementation date provides a balance between ensuring the minimally required network is fully in place in a reasonable amount of time and providing States adequate time to fulfill all the requirements in this rulemaking.[32]

EPA received comment on the frequency by which the minimally

[32] Moreover, as explained in section IV.A, the existing FEM monitors in operation may continue to be used to monitor compliance with the NAAQS.

required network will be reviewed and possibly adjusted based on updated population and emissions inventories. The State commenters listed above, and some others including NACAA, indicated that they believed that the proposal for reviewing the SO_2 network every five years was intended to be a separate review from the required 5-year network assessments required in § 58.10(d). NACAA stated "EPA proposes that the SO_2 monitoring network be evaluated every five years. This is an unnecessary duplication of effort in light of the current requirements for the annual network plan and five year network review." NACAA went on to say that "the current requirements [in § 58.10] should be regarded as the primary source of monitoring network information for all NAAQS pollutant monitoring, regardless of the pollutant."

EPA concurs with NACAA's statements that the existing requirements for network assessment are an appropriate primary source of monitoring network information. In the proposal, EPA did not intend for a required 5-year review of the SO_2 network to be an additional effort on top of the existing required network assessments but instead to be included as part of the 5-year assessment in § 58.10(d). EPA notes that CBSA populations and emissions inventories change over time, suggesting a need for periodic review of the monitoring network. At the same time, EPA recognizes the advantages of a stable monitoring network. However, after considering comments, EPA is not finalizing the proposed language for 40 CFR Part 58 Appendix D, section 4.4.3(2) which simply referenced back to § 58.10. This proposed text it is not needed and appears to simply cause confusion. EPA asserts that the existing requirements in § 58.10 provide a sufficient and appropriate mechanism for network updates and assessment.

c. Conclusions on Monitoring Network Implementation

Based on the public comments, and due to the contemplated use of a hybrid analytical approach, EPA is finalizing, as was proposed, that State and, where appropriate, local air monitoring agencies submit a plan for deploying SO_2 monitors in accordance with the proposed requirements presented below by July 1, 2011. Minimally required SO_2 monitors shall be physically established no later than January 1, 2013.

C. Data Reporting

The following paragraphs provide background, rationale, and details for monitor data reporting requirements.

a. Proposed Data Reporting

Controlled human exposure studies indicate that exposures to peaks of SO_2 on the order of 5 to 10 minutes result in moderate or greater decrements in lung function and/or respiratory symptoms in exercising asthmatics (section II.B.1 above, ISA section 5.2, REA section 7.2.3, and REA section 10.3.3.2). As a result, the 1-hour standard is intended to protect against short term exposures, including exposures on the order of 5 minutes up to 24 hours, as is discussed in section II.F.2 above. Therefore, in support of the revised NAAQS and its intent, EPA proposed that State and local agencies shall report to AQS the maximum 5-minute block average of the twelve 5-minute block averages of SO_2 for each hour. This 5-minute block reporting requirement is in addition to the existing requirement to report the 1-hour average. In addition, EPA solicited comment on the advantages and disadvantages (including associated resource burdens) of alternatively requiring State and local agencies to report all twelve 5-minute SO_2 values for each hour or the maximum 5-minute concentration in an hour based on a moving 5-minute averaging period rather than time block averaging.

EPA also proposed Data Quality Objectives (DQOs) for the SO_2 network. DQOs generally specify the tolerable levels for potential decision error used as a basis for establishing the quality and quantity of data needed to support the objectives of the monitors. EPA proposed the goal for acceptable measurement uncertainty for SO_2 methods to be defined as an upper 90 percent confidence limit for the coefficient of variation (CV) of 15 percent for precision and as an upper 95 percent confidence limit for the absolute bias of 15 percent for bias.

b. Public Comments

EPA received many comments on the reporting of 5-minute data values. The comments generally fell into one of the following categories:[33] (1) Those State, public health, and environmental groups who supported the proposed requirement to report the maximum 5-minute block average of the twelve 5-minute block averages of SO_2 for each hour (*e.g.,* Missouri, NESCAUM, North Carolina, ALA, EJ, EDF, NRDC, and SC), (2) those State, public health, and environmental groups who supported the reporting of all twelve 5-minute averages of each hour (*e.g.,* Kentucky, NYSDEC, AQRL, ALA, ATS, CBD, EJ, EDF, NRDC, and SC), (3) those State, public health, and environmental groups who supported reporting the maximum 5-minute concentration in an hour based on a moving 5-minute average (*e.g.,* South Dakota, ALA, CBD, EJ, EDF, NRDC, and SC), and (4) those State and industry groups who did not support the reporting of any 5-minute data (*e.g.,* Iowa, South Carolina, LEC, and RRI Energy).

Public health and environmental groups (*e.g.* ALA, CBD, EJ, EDF, NRDC, and SC) supported an approach where 5-minute data must be reported. However, these commenters were flexible in their position and supported multiple forms or types of 5-minute data reporting. The ALA, EJ, EDF, NRDC, and SC stated that "we support the proposed requirement for State and local monitoring agencies to report both hourly average and maximum 5-minute averages out of the twelve 5-minute block averages of SO_2 for each hour." They also expressed a preference for alternative 5-minute data reporting stating that they "strongly prefer that States be required to report the peak 5-minute concentrations of SO_2 based on a rolling average." Similarly, CBD stated that "* * * EPA should require that State and local agencies report all 12 five-minute SO_2 values for each hour in addition to 1-hour averages. Where possible, EPA also should require reporting of rolling five-minute averages rather than block data * * *"

Missouri generally supported the proposed requirement to report the maximum 5-minute average in the hour, saying "it is not a problem to report both the hourly average and the maximum 5-minute block average." Nevertheless, Missouri went on to note constraints, stating that "* * * [their] data logger and associated software do not have the capability to report all twelve 5-minute SO_2 values for each hour" and that they "* * * could not do this without software being developed for this purpose and it could be time intensive to validate this data."

Kentucky did not support the proposal to report the maximum 5-minute data block in the hour because of the limitations in their data acquisition systems. They explained that "the data acquisition system used by the [State] does not have the capability to automatically report the maximum 5-minute block of data from an hour concentration. [State] personnel would have to manually determine that

[33] *Note* that some commenters supported more than one form of reported 5-minute data.

value and then manually enter that data into AQS." Kentucky goes on to suggest that "the only feasible option for the [State] to submit 5-minute data to AQS would be to submit all twelve 5-minute blocks of data for each hour to AQS."

South Dakota stated that its "* * * preference would be to report the maximum 5-minute average for each hour calculated using a 5-minute rolling average." South Dakota goes on to state that "* * * while doubling the work required to validate data and load the data into AQS, the additional data should help determine if the selected standard concentration level has achieved the necessary reduction in high concentration 5-minute levels and provide the necessary data for further study of health impacts * * *"

South Carolina stated that it "* * * does not support mandatory reporting of 5-minute averages in addition to the 1-hour average required for comparison to the standard. The validation and reporting of 5-minute averages imposes a significant additional burden on the reporting organization and its Quality System." Iowa, who also did not support any form of 5-minute data reporting stated that "the five-minute data is not used to determine compliance with the NAAQS, and represents ancillary data," and that "validating and uploading the five-minute data will take at least as much staff time as generating the hourly data used for compliance." As a result, Iowa states that "if EPA determines that five-minute data is needed, we recommend that EPA require the maximum five-minute average in each hour, rather than all twelve five-minute averages, in order to reduce the burden associated with generation of the ancillary data set."

With regard to the proposed DQOs, EPA received comments from some States (*e.g.,* Kentucky, North Carolina, NYSDEC, and South Carolina) providing general support for the goals for acceptable measurement uncertainty for precision and bias. North Carolina stated that the "* * * precision and bias measurement uncertainty criteria should emulate those that have been established for other recent NAAQS and NCore pollutants." NYSDEC stated that "the proposal does not seem unreasonable, however these statistics are now expressed in terms of confidence limits: Precision—90% confidence of a CV of 15% and Bias—95% confidence of a CV of 15%." NYSDEC raises concern that "* * * the results are now dependent on the number of audits performed. This is highly variable because some agencies run automatic audits every night, [while] others use the old standard of once every 2 weeks."

In regard to comments on the proposed DQOs, EPA notes that the precision and bias estimation technique on which NYSDEC comments were focused were proposed and adopted in the monitoring rule promulgated on October 6, 2006 and EPA did not intend to reopen those requirements for comment. Moreover, SO_2 precision and bias estimates have been performed in this manner for the past four years and there have been no adverse effects on data quality at the minimum required level of performance checks every two weeks. The statistics for the precision and bias estimates and the DQO goals are based on the accumulation of the one-point precision checks aggregated at the frequencies required in CFR which is every two weeks. Any organization performing more frequent checks (such as every night) would accumulate more data for the precision and bias estimates, have higher confidence in the data, and would have less potential for outliers or higher than normal values effecting the precision and bias estimate. In addition, monitoring organizations running precision checks every 24 hours would be more able to control data quality to meet the DQO goals than organizations running the check every two weeks.

c. Conclusions on Data Reporting

EPA received a fairly diverse set of comments on the appropriateness of reporting 5-minute data and in what particular format it may be provided in. EPA has considered the comments by the States regarding validation of potentially 13 data values per hour (instead of 1 or 2) and some States' lack of data acquisition capacity or processing capability to report any particular type of 5-minute value. EPA believes that in light of these comments, adopting a requirement for continuous SO_2 analyzers to report all twelve 5-minute values or a rolling 5-minute value does not appear to provide enough added value for the potential increased burden on States, such as increased staff time dedicated to data processing and QA, or in improving or adjusting data acquisition capabilities. However, EPA also believes that obtaining some form of 5-minute data is appropriate because such data have been critical to this NAAQS review, and are anticipated to be of high value to inform future health studies and, subsequently, future SO_2 NAAQS reviews.[34] Indeed, as noted earlier, it was EPA's failure to adequately explain the absence of protection from elevated short-term (5- to 10-minute exposure) SO_2 concentrations for heavily breathing asthmatics that occasioned the remand of the 1996 SO_2 primary NAAQS (American Lung Association, 134 F.3d at 392). This belief is supported further by the expectation that a significant portion of the monitors operating to satisfy the final monitoring network design will likely be sited for population exposures, which have traditionally provided ambient data that is often utilized by epidemiologic health studies. Therefore, EPA is finalizing the requirement that State and local air agencies operating continuous SO_2 analyzers shall report the maximum 5-minute block average out of the twelve 5-minute block averages in each hour, for each hour of the day, and that State and local air agencies operating any type of SO_2 analyzer shall report the integrated 1-hour average value, as was proposed. EPA encourages States capable of reporting all twelve 5-minute data blocks in an hour to report such data to AQS. AQS is currently set-up to take the 5-minute maximum value in an hour under parameter code 42406 and can take all twelve 5-minute values under parameter code 42401 (with a duration code of H). EPA notes that if a State were to choose to submit all twelve 5-minute blocks in the hour, by default, they would be submitting the maximum 5-minute data block within that hour, although they have not singled out that particular value. Since the 5-minute data is not directly being used for comparison to the NAAQS, EPA believes that any State electing to submit all twelve 5-minute values is still satisfying the intent of having the maximum 5-minute value reported. Therefore, if a State chooses to submit all twelve 5-minute values in an hour, they will be considered to be satisfying the data reporting requirement of submitting the maximum 5-minute value in an hour, and they do not have to separately report the maximum 5-minute value from within that set of data values to AQS under parameter code 42406.

EPA proposed new regulation text for 40 CFR Part 58 Appendix C, which would have added section 2.1.2 that would have required any SO_2 FRM or

[34] The REA assessed exposure and risks associated with 5-minute SO_2 concentrations above 5-minute health effect benchmark levels derived from controlled human exposure studies. In the analyses, the REA noted that very few State and local agencies report ambient 5-minute SO_2 data (REA, section 10.3.3.2) and that the lack of 5-minute data necessitated the use of statistically estimated 5-minute SO_2 data in order to expand the geographic scope of the exposure and risk analyses (REA, section 7.2.3).

FEM used for making NAAQS decisions to be capable of providing both 1-hour and 5-minute averaged concentration data. EPA is not finalizing this proposed language, as the manual wet-chemistry pararosaniline reference method cannot provide 5-minute data. Therefore, the proposed language is inappropriate. However, both the UVF FEM and the new UVF FRM continuous methods are capable of providing 5-minute averaged data. As a result, the language in 58.12(g) and 58.16(g) requiring 5-minute SO_2 data has been adjusted to appropriately specify that only those States operating continuous FRM or FEMs are required to report the maximum 5-minute data value for each hour.

With regard to acceptable measurement uncertainties, EPA reviewed summary data for each Primary Quality Assurance Organization (PQAO) in the 2008 Data Quality Indicator Report on SO_2 data within the 2008 Criteria Pollutant Quality Indicator Summary Report for AQS Data (*http://www.epa.gov/ttn/amtic/qareport.html*). Of the 100 PQAOs in the report, none of those organizations had summary CV or bias values exceeding 10 percent. Thus, EPA believes that the SO_2 network can and does easily attain measurement uncertainty criteria more stringent than the finalized goal values and the monitoring required under the final network design should be able to maintain this level of performance. Therefore, in consideration of comments and existing quality assurance data, EPA is changing the final goals from those which were proposed for acceptable measurement uncertainty for SO_2 methods to be defined for precision as an upper 90 percent confidence limit for the coefficient of variation (CV) of 10 percent and for bias as an upper 95 percent confidence limit for the absolute bias of 10 percent.

V. Initial Designation of Areas for the 1-Hour SO_2 NAAQS

This section of the preamble further addresses the process under which EPA intends to identify whether areas of the country attain or do not attain or are “unclassifiable” regarding the new 1-hour SO_2 NAAQS. After EPA establishes a new NAAQS, the CAA directs States and EPA to take this first step, known as the “initial area designations,” in ensuring that the NAAQS is ultimately attained.

We are revising our discussion of an expected approach toward issuing initial area designations in response to comments we received on the proposed rule’s treatment of monitoring and modeling (both generally and in the specific context of designations), and to make the expected process more consistent with our historical approach to implementing the SO_2 NAAQS. A revised anticipated approach for issuing designations logically follows from our revised hybrid approach to monitoring and modeling as discussed above in sections III and IV. It would also affect a revised expected implementation approach that we later discuss in section VI. 1. Designations.

a. Clean Air Act Requirements

The CAA requires EPA and the States to take steps to ensure that the new NAAQS are met following promulgation. The first step is for EPA to identify whether areas of the country meet, do not meet, or cannot yet be classified as either meeting or not meeting the new NAAQS. Section 107(d)(1)(A) provides that, “By such date as the Administrator may reasonably require, but not later than 1 year after promulgation of a new or revised NAAQS for any pollutant under section 109, the Governor of each State shall * * * submit to the Administrator a list of all areas (or portions thereof) in the State” that should be designated as nonattainment, attainment, or unclassifiable for the new NAAQS. 42 U.S.C. 7407(d)(1)(A)(i)–(iii). Section 107(d)(1)(B)(i) further provides, “Upon promulgation or revision of a NAAQS, the Administrator shall promulgate the designations of all areas (or portions thereof) * * * as expeditiously as practicable, but in no case later than 2 years from the date of promulgation. Such period may be extended for up to one year in the event the Administrator has insufficient information to promulgate the designations within 2 years.” 42 U.S.C. 7407(d)(1)(B)(i).

Under CAA section 107(d)(1)(B)(ii), no later than 120 days prior to promulgating designations, EPA is required to notify States of any intended modifications to their boundaries as EPA may deem necessary, and States will have an opportunity to comment on EPA’s tentative decision. Whether or not a State provides a recommendation, the EPA must promulgate the designation that it deems appropriate. 42 U.S.C. 7407(d)(1)(B)(ii).

Accordingly, since the new 1-hour SO_2 NAAQS is being promulgated today, Governors should submit their initial SO_2 designation recommendations to EPA no later than June 2, 2011. If the Administrator intends to modify any State’s boundary recommendation, the EPA will notify the Governor no later than 120 days prior to designations or, February 2012. States that believe the Administrator’s modification is inappropriate will have an opportunity to demonstrate why they believe their recommendation is more appropriate before designations are finalized in June 2012.

For initial designations that will be finalized in June 2012, States should use monitoring data from the existing SO_2 network for the years 2008–2010, as well as any refined SO_2 dispersion modeling (*see* Appendix W to 40 CFR Part 51) for sources that may have the potential to cause or contribute to a NAAQS violation, provided that it is recent and available. EPA will then issue designations based on the record of information for that area. Under our anticipated approach, an area that has monitoring data or refined modeling results showing a violation of the NAAQS would be designated as “nonattainment.” An area that has both monitoring data and appropriate modeling results showing no violations would be designated as “attainment.” All other areas, including those with SO_2 monitors showing no violations but without modeling showing no violations, would be designated as “unclassifiable.” Areas with no SO_2 monitors at all *i.e.,* “rest of State,” would be designated as “unclassifiable” as well.

b. Approach Described in Proposal

In the proposed rule’s preamble, we explained that we had proposed a new SO_2 ambient monitoring network, with new monitors expected to be deployed no later than January 2013. We also explained that we expected compliance with the new NAAQS to be determined based on 3 years of complete, quality assured, certified monitoring data. We further explained that we did not expect newly-cited monitors for the proposed network to generate sufficient monitoring data for us to use in determining whether areas complied with the new NAAQS by the statutory deadline to complete initial designations. Therefore, we explained, we intended to complete designations by June 2012 based on 3 years of complete, quality assured, certified air quality monitoring data as generated from the current monitoring network.

Consequently, we discussed our expectations to base initial designations on air quality data from the years 2008–2010 or 2009–2011, from SO_2 monitors operating at current locations, which we expected to continue through 2011. While those monitors are generally sited to measure 24-hour and annual average SO_2 concentrations, we noted that they all report hourly data, and we estimated that at least one third of those monitors might meet the proposed network design requirements and not need to be moved. We explained that if any monitor in the current network indicated a violation of the new 1-hour NAAQS, we would intend to designate the area as "nonattainment." We further explained that if a monitor did not indicate a violation, our designation decision for the area would be made on a case-by-case basis, with one possibility being a designation of "unclassifiable."

We also explained that while the CAA section 107 designation provisions specifically address States, we intended to follow the same process for Tribes to the extent practicable, pursuant to CAA section 301(d), 42 U.S.C. 7601(d), and the Tribal Authority Rule, 40 CFR part 49.

c. Comments

Several commenters stated that the EPA did not provide nonattainment boundary guidance in the proposed rule and argued that guidance should be developed. Commenters also stated that EPA should consider boundaries that are less than the Core Based Statistical Area (CBSA), and perhaps even smaller than the county boundary (State of Michigan, Sierra Club).

In response, we note that the CAA requires that the EPA designate as "nonattainment" any area that does not meet (or contributes to an area that does not meet) the NAAQS. 42 U.S.C. 7407(d)(1)(A)(i). States with monitored or modeled SO_2 violations will need to recommend an appropriate nonattainment boundary that both includes sources contributing to that violation, as well as informs the public of the extent of the violation. For purposes of determining nonattainment boundaries, the EPA expects to consider the county line as the presumptive boundary for SO_2. This would be consistent with our approach under other NAAQS. States recommending less-than-countywide nonattainment boundaries should provide additional information along with their recommendation, demonstrating why a smaller area is more appropriate, as we have advised for other NAAQS. If States request it, EPA may develop additional guidance on the factors that States should consider when determining nonattainment boundaries.

In addition, as further discussed in section IV.B above, in the SO_2 NAAQS proposal, we proposed a monitoring-focused approach for comparison to the new NAAQS. The proposed network would have required approximately 348 monitors nationwide to be sited at the locations of maximum concentration. Numerous State and local government commenters expressed concerns regarding the perceived burdens of implementing the proposed monitoring network and the sufficiency of its scope for purposes of identifying violations. Some of these commenters (the City of Alexandria, and the States of Delaware, North Carolina and Pennsylvania) suggested using modeling to determine the scope of monitoring requirements, or favored modeling over monitoring to determine compliance with the NAAQS. Partly in response to these comments, and after reconsidering the proposal's monitoring-focused approach, specifically regarding how we have historically implemented SO_2 designations, we now anticipate taking a revised approach toward designations, using a hybrid analytic approach that combines the use of monitoring and available modeling to assess compliance with the new 1-hour SO_2 NAAQS. We discuss a revised expected approach toward designations below, and further discuss in section VI how we expect a hybrid approach to affect other implementation activities.

d. Expected Designations Process

As discussed in sections III and IV of this preamble, in response to the comments and after reviewing our historical SO_2 implementation practice, we intend to use a hybrid analytic approach for assessing compliance with the new 1-hour SO_2 NAAQS for initial designations. We also believe that a hybrid approach is more consistent with our historical approach and longstanding guidance toward SO_2 NAAQS designations and implementation than what we originally proposed. Technically, for a short-term 1-hour standard, it is more appropriate and efficient to principally use modeling to assess compliance for medium to larger sources, and to rely more on monitoring for groups of smaller sources and sources not as conducive to modeling.

In cases where there is complete air quality data from FRM and FEM SO_2 monitors, that data would be considered by EPA in designating areas as either "attainment" or "nonattainment" for the new SO_2 NAAQS. *See* Appendix T to Part 50 section 3b. In addition, in cases where a State submits air quality modeling data that are consistent with our current guidance or our expected revisions thereto, and which indicates that an area is attaining the standard or violating the standard, these data may support recommendations of "attainment" or "nonattainment." As explained in section IV above, we would not consider monitoring alone to be an adequate, nor the most accurate, tool to identify all areas of maximum concentrations of SO_2. In the case of SO_2, we further believe that monitoring is not the most cost-efficient method for identifying all areas of maximum concentrations.

Due to the necessarily limited spatial coverage provided by any monitoring regime, and the strong source-oriented nature of SO_2 ambient impacts, we recognize that using this more traditional approach in designations, would be more likely to identify a greater number of potential instances of nonattainment, if areas were to immediately conduct modeling of current source emissions, as compared to the approach we discussed in the proposed rule. As discussed in section III, forthcoming national and regional rules, such as the pending Industrial Boilers "Maximum Achievable Control Technology" (MACT) standard under CAA section 112(d), are likely to result in significant SO_2 emissions reductions in the next three to four years. A limited qualitative assessment of preliminary modeling of some sample facilities that would be covered by those rules indicates that well-controlled facilities should meet the new SO_2 NAAQS. However, there are some exceptions. These exceptions include unique sources with specific source characteristics that contribute to higher ambient impacts (short stack heights, complex terrain, *etc.*).

Again as described in section III, in order for States to conduct modeling on a large scale for the new 1-hour NAAQS, EPA expects additional guidance would be needed to clarify how to conduct dispersion modeling under Appendix W to support the implementation of the new 1-hour SO_2 NAAQS, and how to identify and appropriately assess the air quality impacts of sources that potentially may cause or contribute to violations of the NAAQS. Our anticipated modeling guidance will provide for refined modeling that will better reflect and account for source-specific impacts by following our current *Guideline on Air Quality Models,* Appendix W to 40 CFR Part 51, with appropriate flexibility for use in implementation. EPA intends to solicit public comment on this modeling guidance. We expect it will take some time for EPA to issue this guidance, and believe that given the timing and substantial burden of having to model several hundred sources, it would not be realistic or appropriate to expect States to complete such modeling and incorporate the results in designation recommendations for the new 1-hour SO_2 NAAQS that, under CAA section

107(d), are due to EPA within 1 year of the promulgation of the NAAQS.

Consequently, we expect that in most instances, Governors will submit designation recommendations of "unclassifiable" rather than conduct large-scale refined modeling of sources in advance of receiving our anticipated guidance. The absence of monitoring data showing violations for most areas, combined with the paucity of refined modeling of sources that have the potential to cause or contribute to violations of the NAAQS, will likely result in informational records that are insufficient to support initial designations of either "attainment" or "nonattainment." Under the Clean Air Act, in such a situation EPA is required to issue a designation for the area as "unclassifiable." However, we do not expect this result to delay expeditious attainment and maintenance of the new NAAQS, or to cause inappropriate, indefinite uncertainty regarding whether or not sources cause or contribute to NAAQS violations.

As described more fully in section III above and in section VI below, EPA's expected implementation approach would rely on the CAA section 110(a)(1) SIP obligation to ensure that all areas of the country attain and maintain the NAAQS on a timely basis even if they are designated "unclassifiable" initially. This SIP is due under CAA section 110(a)(1) within 3 years after promulgation of the new NAAQS, and does not depend upon EPA designating an area "nonattainment" based on recently monitored or modeled SO_2 levels. This period of time would allow States to use EPA's anticipated guidance on modeling for the new 1-hour SO_2 NAAQS, as well as account for SO_2 reduction levels at individual sources that are anticipated to result from promulgated national and regional rules to show attainment.

Once areas have both appropriate monitoring data (if required) and modeling data as appropriate, consistent with the new guidance, showing no violations of the SO_2 NAAQS, and have met other applicable requirements of CAA section 107(d)(3), the Agency would consider re-designating them from "unclassifiable" or "nonattainment" to "attainment" under CAA section 107(d)(3).

VI. Clean Air Act Implementation Requirements

This section of the preamble discusses the CAA requirements that States and emissions sources would need to address when implementing the new 1-hour SO_2 NAAQS based on the structure outlined in the CAA and existing rules. The EPA believes that existing guidance documents and regulations will be useful in helping States and sources to implement the new SO_2 NAAQS, but we also expect to develop additional guidance on modeling for the new one-hour standard and on developing SIPs under Section 110(a)(1) of the CAA.[35] In light of the new approach that EPA intends to take with respect to implementation of the SO_2 NAAQS, EPA intends to solicit public comment on guidance regarding modeling, and also solicit public comment on additional implementation planning guidance, including the content of the maintenance plans required under section 110(a)(1) of the Clean Air Act. EPA also notes that State monitoring plans and the SIP submissions that States will make will also be subject to public notice and comment."

In this section, we also further discuss how EPA's modified expected approaches toward monitoring and modeling and toward initial designations under the new SO_2 NAAQS (compared to how the proposed rule discussed addressing these issues) are anticipated to affect the types of SIP submissions States will need to provide to EPA and the timing of EPA's actions on those submissions leading up to attainment and maintenance of the new SO_2 NAAQS. In section IV above, we discuss the final amendments to the ambient monitoring and reporting requirements, and explain how in response to comments received on the proposal and after revisiting our historical practice in assessing compliance with prior SO_2 NAAQS, we have revised both the scope of the revised monitoring network and our expectations on how monitoring will be used in conjunction with modeling in assessing compliance and designating areas. In section V above, we discuss how we have revised our expected approach for issuing designations for the new 1-hour SO_2 NAAQS, and similarly explain how, in response to comments and after reviewing our historical approach, we have modified our expectations as discussed in the proposal for how and when monitoring and modeling will be used for designations. In this section VI, we describe in more detail how and when we expect States to demonstrate attainment, implementation, maintenance and enforcement of the new one-hour SO_2 NAAQS.

The CAA assigns important roles to EPA, States and Tribal governments to achieve the NAAQS. States have the primary responsibility for developing and implementing State implementation plans (SIPs) that contain State measures necessary to achieve the air quality standards in each area once EPA has established the NAAQS. EPA provides assistance to States and Tribes by providing technical tools, assistance, and guidance, including information on the potential control measures that may assist in helping areas attain the standards.

Under section 110 of the CAA, 42 U.S.C. 7410, and related provisions, States are directed to submit, for EPA approval, SIPs that provide for the attainment, implementation, maintenance, and enforcement of such standards through control programs directed at sources of SO_2 emissions. *See* CAA sections 110(a), and 191–192, 42 U.S.C. 7410(a) and 7514–7514a. If a State fails to adopt and implement the required SIPs by the time periods provided in the CAA, EPA has the responsibility under the CAA to adopt a Federal implementation plan (FIP) to ensure that areas attain the NAAQS in an expeditious manner. The States, in conjunction with EPA, also administer the prevention of significant deterioration (PSD) program for SO_2. *See* sections 160–169 of the CAA, 42 U.S.C. 7470–7479. In addition, Federal programs provide for nationwide reductions in emissions of SO_2 and other air pollutants under Title II of the Act, 42 U.S.C. 7521–7574. These programs involve limits on the sulfur content of the fuel used by automobiles, trucks, buses, motorcycles, non-road engines and equipment, marine vessels and locomotives. Emissions reductions for SO_2 are also obtained from implementation of the new source performance standards (NSPS) for stationary sources under sections 111 and 129 of the CAA, 42 U.S.C. 7411 and 7429; and the national emission standards for hazardous air pollutants (NESHAP) for stationary sources under section 112 of the CAA, 42 U.S.C. 7412 (such reductions resulting due to control of hazardous air pollutants (HAP) such as hydrogen chloride (HCl) under those rules). Title IV of the CAA, sections 402–416, 42 U.S.C. 7651a–7651o, specifically provides for major reductions in SO_2 emissions. EPA has also promulgated the Clean Air Interstate Rule (CAIR) to define additional SO_2 emission reductions needed in the Eastern United States to eliminate significant contribution of upwind States to downwind States'

[35] *See* SO_2 Guideline Document, Office of Air Quality Planning and Standards, Research Triangle Park, NC 27711, EPA–452/R–94–008, February 1994.

nonattainment, or inability to maintain, the $PM_{2.5}$ NAAQS pursuant to CAA section 110(a)(2)(D), 42 U.S.C. 7410(a)(2)(D), a rule which EPA is reevaluating pursuant to court remand.

A. How This Rule Applies to Tribes

CAA section 301(d) authorizes EPA to treat eligible Indian Tribes in the same manner as States under the CAA and requires EPA to promulgate regulations specifying the provisions of the statute for which such treatment is appropriate. EPA has promulgated these regulations—known as the Tribal Authority Rule or TAR—at 40 CFR Part 49. *See* 63 FR 7254 (February 12, 1998). The TAR establishes the process for Indian Tribes to seek treatment-as-a-State eligibility and sets forth the CAA functions for which such treatment will be available. Under the TAR, eligible Tribes may seek approval for all CAA and regulatory purposes other than a small number of functions enumerated at section 49.4. Implementation plans under section 110 are included within the scope of CAA functions for which eligible Tribes may obtain approval. Section 110(o) also specifically describes Tribal roles in submitting implementation plans. Eligible Indian Tribes may thus submit implementation plans covering their reservations and other areas under their jurisdiction.

The CAA and TAR do not, however, direct Tribes to apply for treatment as a State or implement any CAA program. In promulgating the TAR EPA explicitly determined that it was not appropriate to treat Tribes similarly to States for purposes of, among other things, specific plan submittal and implementation deadlines for NAAQS-related requirements. 40 CFR 49.4(a). In addition, where Tribes do seek approval of CAA programs, including section 110 implementation plans, the TAR provides flexibility and allows them to submit partial program elements, so long as such elements are reasonably severable—*i.e.,* "not integrally related to program elements that are not included in the plan submittal, and are consistent with applicable statutory and regulatory requirements." 40 CFR 49.7.

To date, very few Tribes have sought treatment as a State for purposes of section 110 implementation plans. However, some Tribes may be interested in pursuing such plans to implement today's proposed standard, once it is promulgated.

1. Approach Described in the Proposal

In the proposed rule preamble, EPA described the various roles and requirements States would address in implementing the proposed NAAQS. Such references to States generally included eligible Indian Tribes to the extent consistent with the flexibility provided to Tribes under the TAR. Where Tribes do not seek treatment as a State for section 110 implementation plans, we explained that EPA under its discretionary authority will promulgate FIPs as "necessary or appropriate to protect air quality." 40 CFR 49.11(a). EPA also noted that some Tribes operate air quality monitoring networks in their areas. We explained that for such monitors to be used to measure attainment with the proposed revised primary NAAQS for SO_2, the criteria and procedures identified in the proposed rule would apply.

2. Current Approach

EPA did not receive any comments on this issue. However, as discussed elsewhere in this preamble, the final rule reflects in several respects modified expected approaches regarding the use of monitoring and modeling, the manner in which we expect to issue designations under the new SO_2 NAAQS, and the types of SIP submissions we expect would be needed to show attainment, implementation, maintenance and enforcement of the new NAAQS. Those changes in expected approach would, as appropriate, also apply to how we address data and any other submissions from Tribes for purposes of the new SO_2 NAAQS.

B. Nonattainment Area Attainment Dates

The latest date by which an area designated as nonattainment is required to attain the SO_2 NAAQS is determined from the effective date of the nonattainment designation for the affected area. For areas designated nonattainment for the revised SO_2 NAAQS, SIPs must provide for attainment of the NAAQS as expeditiously as practicable, but no later than 5 years from the effective date of the nonattainment designation for the area. *See* section 192(a) of the CAA, 42 U.S.C. 7651a(a). The EPA expects to determine whether an area has demonstrated attainment of the new SO_2 NAAQS by evaluating air quality monitoring and modeling data consistent with 40 CFR part 50, Appendix T and 40 CFR part 51, Appendix W. (*Note* that this differs from how we explained we would expect to make such determinations in the proposed rule, where we only mentioned monitoring as supplying the data we would evaluate. This expanded and changed discussion reflects the contemplated changes in our overall approaches to using monitoring and modeling, expectations for issuing designations, and expectations for reviewing SIP submissions showing attainment, implementation, maintenance, and enforcement of the new SO_2 NAAQS.)

1. Attaining the NAAQS

a. Approach Described in the Proposal

In the proposal preamble, we set forth the basic five conditions provided under section 107(d)(3)(E) of the CAA, 42 U.S.C. 7407(d)(3)(E) that a nonattainment area must meet in order to be redesignated as attainment:

- EPA must have determined that the area has met the SO_2 NAAQS;
- EPA has fully approved the State's implementation plan;
- The improvement in air quality in the affected area is due to permanent and enforceable reductions in emissions;
- EPA has fully approved a maintenance plan for the area; and
- The State(s) containing the area have met all applicable requirements under section 110 and part D.

b. Current Approach

EPA did not receive any comments on this aspect of the preamble of the proposal. However, in light of the fact that in the final rule, in response to other comments and consistent with historic practice, we are revising our proposed anticipated approaches to the overall use of monitoring and modeling and our expected approaches to issuing initial designations and reviewing SIP submissions, it follows that the way in which a nonattainment area seeks redesignation as an attainment area would also be affected by the final rule's overall changed approaches. For example, for EPA to determine that a nonattainment area has met the SO_2 NAAQS, we anticipate that the area would need to not only provide any monitoring data showing such compliance (and there would need to be an absence of monitoring data showing otherwise), but modeling where appropriate, consistent with modeling guidance that we plan to issue, would also need to show that the area is attaining and maintaining the NAAQS.

2. Consequences of a Nonattainment Area Failing To Attain by the Statutory Attainment Date

a. Approach Described in the Proposal

We explained in the proposal that any SO_2 nonattainment area that fails to attain by its statutory attainment date would be subject to the requirements of sections 179(c) and (d) of the CAA, 42

U.S.C. 7509(c) and (d). EPA is required to make a finding of failure to attain no later than 6 months after the specified attainment date and publish a notice in the **Federal Register**. The State would then need to submit an implementation plan revision no later than one year following the effective date of the **Federal Register** notice making the determination of the area's failure to attain. This submission must demonstrate that the standard will be attained as expeditiously as practicable, but no later than 5 years from the effective date of EPA's finding that the area failed to attain. In addition, section 179(d)(2) provides that the SIP revision must include any specific additional measures as may be reasonably prescribed by EPA, including "all measures that can be feasibly implemented in the area in light of technological achievability, costs, and any nonair quality and other air quality-related health and environmental impacts."

b. Current Approach

EPA did not receive any comments on this aspect of the discussion in the preamble to the proposal. However, due to the changes in the final rule's discussion of the overall expected approaches to monitoring and modeling, designations and EPA review of SIP submissions, it follows that the implementation of CAA sections 179(c) and (d) would also be affected by those changes. For example, under the anticipated approach, a nonattainment area's initial demonstration of attainment would need to show through modeling consistent with modeling guidance that we plan to issue, that the area attains and maintains the new SO_2 NAAQS. If the area fails to attain on time, any remedial implementation plan submission would also need to show, where appropriate, through modeling consistent with modeling guidance that we plan to issue, that the area attains and maintains the new SO_2 NAAQS.

C. Section 110(a)(1) and (2) NAAQS Maintenance/Infrastructure Requirements

We are significantly revising our expected approaches to the use of monitoring and modeling, expected issuance of initial designations, and EPA review of SIP submissions. This change in anticipated approach has particular relevance for how States would meet their statutory obligations under CAA section 110(a) to implement, maintain and enforce the new SO_2 NAAQS. In short, under such an approach, all areas, whether designated as attainment, nonattainment, or unclassifiable, would need to submit SIPs under CAA section 110(a) that show that they are attaining and maintaining the 1-hour SO_2 NAAQS as expeditiously as practicable through permanent and enforceable measures. In other words, the duty to show maintenance of the SO_2 NAAQS would not be limited to areas that are initially designated as nonattainment, but instead would apply regardless of designation. As has been expected historically, areas initially designated attainment for SO_2 are expected to submit to EPA the infrastructure elements of the 110(a) SIP, including the PSD program. Historically, EPA has determined this to be sufficient to demonstrate maintenance absent other available information to suggest the area would have difficulty maintaining the NAAQS.

As required by CAA section 192, nonattainment areas must demonstrate attainment as expeditiously as practicable, and no later than 5 years after designation (which would be August 2017). Under a hybrid approach as we have discussed earlier in sections III, IV, and V of this preamble, EPA believes that August 2017 would be the latest point that could be as expeditiously as practicable for attainment and unclassifiable areas as well, and EPA anticipates establishing this date through future rulemaking actions on individual SIPs.

As noted in earlier sections of this preamble, in the SO_2 NAAQS proposal, we recommended a monitoring-focused approach for comparison to the NAAQS. We received public comments that contended our proposed monitoring network was too small and insufficient to assess the hundreds of areas that might violate the new SO_2 NAAQS and yet too burdensome and expensive to expand to an adequate scale. Some commenters, especially State air agencies, recommended the use of modeling either to determine potential nonattainment areas or to identify areas subject to monitoring requirements. Because SO_2 is primarily a localized pollutant, modeling is the the most appropriate tool to accurately predict SO_2 impacts from large sources, EPA has used it in the past to determine SO_2 attainment status, and it can be performed more quickly and less costly than monitoring. Consequently, as part of developing a balanced response to the numerous comments we received on modeling and monitoring, we expect to use a hybrid analytic approach that combines the use of monitoring and modeling to assess compliance with respect to the new SO_2 NAAQS.

A hybrid analytic approach for assessing compliance with the new SO_2 NAAQS would make the most appropriate use of available tools and be more consistent with our historical approach than was what we originally proposed. For a short-term 1-hour standard, it is more accurate and efficient to use modeling to assess medium to larger sources and to rely on monitoring for groups of smaller sources and sources not as conducive to modeling.

We expect that States would initially focus performance of attainment demonstration modeling on larger sources (*e.g.,* those ≥ 100 tons per year (tpy) of SO_2), and that States would also identify and eventually conduct refined modeling of any other sources that may be anticipated to cause or contribute to a violation to determine compliance with the new SO_2 NAAQS. As discussed in Section III, EPA anticipates providing additional guidance to States to clarify how to conduct dispersion modeling under Appendix W to support the implementation of the new 1-hour SO_2 NAAQS. Prior to issuing this guidance, EPA intends to solicit public comment.

Since determining compliance with the SO_2 NAAQS will likely be a uniquely source-driven analysis, EPA explored options to ensure that the SO_2 designations process realistically accounts for anticipated SO_2 reductions at those sources that we expect will be achieved by current and pending national and regional rules. To ensure that all areas of the country attain the NAAQS on a timely basis, while accommodating modeling that is both informed by anticipated modeling guidance and accounts for those anticipated SO_2 reductions, EPA's intention is to emphasize the CAA section 110(a)(1) requirement that all States submit a SIP that shows implementation, maintenance and enforcement of the NAAQS. This SIP would be due under CAA section 110(a)(1) within 3 years after promulgation of the new NAAQS, and would not depend upon EPA designating an area nonattainment based on recently monitored or modeled SO_2 levels. In addition, like an attainment SIP required for a designated nonattainment area under CAA section 192, to show attainment this SIP can account for controlled SO_2 levels at individual sources that will be achieved after submission of the SIP but before the demonstrated attainment date. EPA intends to implement this approach in a way that ensures expeditious attainment of the NAAQS, under a schedule that we explain more fully below.

1. Section 110(a)(1)–(2) Submission

a. Approach Described in the Proposal

In the preamble to the proposal, we explained that section 110(a)(2) of the CAA directs all States to develop and maintain a solid air quality management infrastructure, including enforceable emission limitations, an ambient monitoring program, an enforcement program, air quality modeling capabilities, and adequate personnel, resources, and legal authority. Section 110(a)(2)(D) also requires State plans to prohibit emissions from within the State which contribute significantly to nonattainment or maintenance areas in any other State, or which interfere with programs under part C of the CAA to prevent significant deterioration of air quality or to achieve reasonable progress toward the national visibility goal for Federal class I areas (national parks and wilderness areas).

Under sections 110(a)(1) and (2) of the CAA, all States are directed to submit SIPs to EPA which demonstrate that basic program elements have been addressed within 3 years of the promulgation of any new or revised NAAQS. Subsections (A) through (M) of section 110(a)(2) set forth the elements that a State's program must contain in the SIP.[36] The proposed rule listed section 110(a)(2) NAAQS implementation requirements as the following:

- *Ambient air quality monitoring/data system:* Section 110(a)(2)(B) requires SIPs to provide for setting up and operating ambient air quality monitors, collecting and analyzing data and making these data available to EPA upon request.
- *Program for enforcement of control measures:* Section 110(a)(2)(C) requires SIPs to include a program providing for enforcement of SIP measures and the regulation and permitting of new/modified sources.
- *Interstate transport:* Section 110(a)(2)(D) requires SIPs to include provisions prohibiting any source or other type of emissions activity in the State from contributing significantly to nonattainment or interfering with maintenance of the NAAQS in another State, or from interfering with measures required to prevent significant deterioration of air quality or to protect visibility.
- *Adequate resources:* Section 110(a)(2)(E) directs States to provide assurances of adequate funding, personnel and legal authority to implement their SIPs.
- *Stationary source monitoring system:* Section 110(a)(2)(F) directs States to establish a system to monitor emissions from stationary sources and to submit periodic emissions reports to EPA.
- *Emergency power:* Section 110(a)(2)(G) directs States to include contingency plans, and adequate authority to implement them, for emergency episodes in their SIPs.
- *Provisions for SIP revision due to NAAQS changes or findings of inadequacies:* Section 110(a)(2)(H) directs States to provide for revisions of their SIPs in response to changes in the NAAQS, availability of improved methods for attaining the NAAQS, or in response to an EPA finding that the SIP is inadequate.
- *Consultation with local and Federal government officials:* Section 110(a)(2)(J) directs States to meet applicable local and Federal government consultation requirements when developing SIPs and reviewing preconstruction permits.
- *Public notification of NAAQS exceedances:* Section 110(a)(2)(J) directs States to adopt measures to notify the public of instances or areas in which a NAAQS is exceeded.
- *PSD and visibility protection:* Section 110(a)(2)(J) also directs States to adopt emissions imitations, and such other measures, as may be necessary to prevent significant deterioration of air quality in attainment areas and protect visibility in Federal Class I areas in accordance with the requirements of CAA Title I, part C.
- *Air quality modeling/data:* Section 110(a)(2)(K) requires that SIPs provide for performing air quality modeling for predicting effects on air quality of emissions of any NAAQS pollutant and submission of data to EPA upon request.
- *Permitting fees:* Section 110(a)(2)(L) requires the SIP to include requirements for each major stationary source to pay permitting fees to cover the cost of reviewing, approving, implementing and enforcing a permit.
- *Consultation/participation by affected local government:* Section 110(a)(2)(M) directs States to provide for consultation and participation by local political subdivisions affected by the SIP.

b. Final

EPA did not receive any comments on this aspect of the approached explained in the proposal preamble. However, in light of the modified approach discussed above, EPA is providing additional guidance concerning the CAA section 110(a)(1) maintenance plan requirement as a part of this discussion so that States will have sufficient information to meet this requirement with a SIP submittal three years after promulgation of the NAAQS. Section 110(a)(1) of the CAA states that each State, after reasonable notice and public hearing, is required to adopt and to submit to EPA, within 3 years after promulgation of any new or revised NAAQS for any pollutant, a SIP which provides for the implementation, maintenance, and enforcement of any new or revised NAAQS in each area of the State. As stated previously, in light of the new approach that EPA intends to take with respect to implementation of the SO_2 NAAQS, EPA intends to solicit public comment on guidance regarding modeling, and also solicit public comment on additional implementation planning guidance, including the content of the maintenance plans required under section 110(a)(1) of the Clean Air Act.

EPA expects that most areas of the country would be designated as unclassifiable for the 1-hour NAAQS for SO_2, due to a lack of both monitoring and modeling information concerning the attainment status of areas, in advance of States conducting further refined modeling according to our anticipated guidance. For areas that are designated unclassifiable, States are required to submit section 110(a)(1) plans to demonstrate implementation, maintenance and enforcement of the new SO_2 NAAQS. As previously explained in section III of the preamble, in order to meet the requirements of section 110(a)(1) and to ensure timely attainment of the NAAQS on a schedule that is as expeditious as would be required if an area had been designated nonattainment, EPA's current expectation is that States would submit SIPs which provide for attainment, implementation, maintenance, and enforcement of the 1-hour SO_2 NAAQS in all areas as expeditiously as practicable, which EPA believes in these cases would be no later than 5 years from the effective date of the area's designation. The section 110(a)(1) maintenance plan would also need to contain the following elements: (1) An

[36] In the proposed rule preamble, we explained that two elements identified in section 110(a)(2) were not listed in our summary because, as EPA interprets the CAA, SIPs incorporating any necessary local nonattainment area controls would not be due within 3 years, but rather are generally due at the time the nonattainment area planning requirements are due. *See* 74 FR 64860 at n. 39. These elements are: (1) Emission limits and other control measures, section 110(a)(2)(A), and (2) Provisions for meeting part D, section 110(a)(2)(I), which requires areas designated as nonattainment to meet the applicable nonattainment planning requirements of part D, title I of the CAA. To implement our revised intended approach in the final rule, however, it would be necessary for States to include, if relied upon to show attainment and maintenance of the new SO_2 NAAQS, any necessary emission limits and other control measures under section 110(a)(2)(A).

attainment emissions inventory, (2) a control strategy, as appropriate, (3) a maintenance demonstration, using an EPA approved air quality model as appropriate, (4) a contingency plan, and (5) a plan for verification of continued attainment of the standard. Attainment areas that appear to have difficulty maintaining attainment may also have to submit some of these elements. These elements are now explained in detail.

(1) Attainment Emissions Inventory

The State should develop an accurate attainment emissions inventory to identify the level of emissions in the area which is sufficient to attain the 1-hour SO_2 NAAQS. This inventory should be consistent with EPA's most recent guidance on emissions inventories currently available, and should include the emissions for the time period associated with the modeling and monitoring data showing attainment. Major source size thresholds for SO_2 are currently listed as 100 ton/yr, however, in cases where sources, individually, or collectively, that are below this level may potentially cause or contribute to a violation of the standard, these sources should also be included in the emissions inventory for the affected area. EPA notes that, unlike any monitoring or modeling data used in the initial designations context, which would be limited to current emissions levels, this estimate under a hybrid approach we expect to use for the new SO_2 NAAQS would be able to rely on modeled controlled emissions levels at sources achieved by enforceable national, regional or local rules that will be in place within the timeframe for demonstrating attainment. This is because demonstrations of attainment and maintenance of a NAAQS, unlike designations, are necessarily projections regarding future and continuing levels of ambient air pollution concentrations given that the statutory deadlines for their submission are in advance of the required achievement of attainment and maintenance. *See, e.g.,* CAA sections 191(a) and 192(a).

(2) Maintenance Demonstration

The key element of a section 110(a)(1) maintenance plan is a demonstration using, as appropriate, refined SO_2 dispersion modeling (*see* Appendix W to 40 CFR Part 51) which provides an indication of how the area will attain and maintain the 1-hour SO_2 NAAQS as expeditiously as practicable, which EPA believes would be within the 5 year period following the designation of the area. For SO_2 the State may generally demonstrate maintenance of the NAAQS by using refined dispersion modeling to show that the future mix of sources and emission rates in an area will not cause a violation of the 1-hour SO_2 NAAQS. As a result of applying the control strategy, EPA anticipates that additional guidance for States may be needed to clarify how to conduct dispersion modeling under Appendix W to support the implementation of the new 1-hour SO_2 NAAQS.

As explained above in IV.B, EPA believes that for SO_2 attainment and maintenance demonstrations, monitoring data alone is generally not adequate to characterize fully short-term ambient concentrations around major stationary sources of SO_2, and as a result may not capture the maximum SO_2 impacts. With representative and appropriate meteorological and other input data, refined dispersion models are able to characterize air quality impacts from the modeled sources across the domain of interest on an hourly basis with a high degree of spatial resolution, overcoming the limitations of an approach based solely on monitoring. By simulating plume dispersion on an hourly basis across a grid of receptor locations, dispersion models are able to estimate the detailed spatial gradients of ambient concentrations resulting from SO_2 emission sources across a full range of meteorological and source operating conditions. To capture such results on a monitor would normally require a prohibitively expansive air quality monitoring network. Further, as we have observed in prior actions (*see., e.g.,* 43 FR 45993, 45997, 46000–03 (Oct. 5, 1978)), monitoring data would not be adequate to demonstrate attainment if sources are using stacks with heights that are greater than good engineering practice (GEP), or other prohibited dispersion techniques, as section 123 prohibits credit in an attainment demonstration for any such practices.

Refined dispersion modeling for the section 110(a)(1) maintenance plan is expected to follow EPA's *Guideline on Air Quality Models,* Appendix W to 40 CFR Part 51, which provides recommendations on modeling techniques and guidance for estimating pollutant concentrations in order to assess control strategies and determine emission limits. These recommendations were originally published in April 1978 and were incorporated by reference in the PSD regulations, 40 CFR sections 51.166 and 52.21 in June 1978 (43 FR 26382–26388). The purpose of Appendix W is to promote consistency in the use of modeling within the air quality management process. Appendix W is periodically revised to ensure that new model developments or expanded regulatory requirements are incorporated. The most recent revision to Appendix W was published on November 9, 2005 (70 FR 68218), wherein EPA adopted AERMOD as the preferred dispersion model for a wide range of regulatory applications in all types of terrain. To support the promulgation of AERMOD as the preferred model, EPA evaluated the performance of the model across a total of 17 field study data bases (Perry, *et al.,* 2005; EPA, 2003), including several field studies based on model-to-monitor comparisons of SO_2 concentrations from operating power plants. AERMOD is a steady-state plume dispersion model that employs hourly sequential preprocessed meteorological data to simulate transport and dispersion from multiple point, area, or volume sources for averaging times from one hour to multiple years, based on an advanced characterization of the atmospheric boundary layer. AERMOD also accounts for building wake effects (*i.e.,* downwash) on plume dispersion.

As stated previously, EPA anticipates that additional guidance for States, Tribal, and local governments is needed to clarify how to conduct refined dispersion modeling under Appendix W to support the implementation of the new 1-hour SO_2 NAAQS. EPA intends to solicit public comment on guidance regarding modeling. Although AERMOD is identified as the preferred model under Appendix W for a wide range of applications and will be appropriate for most modeling applications to support the new SO_2 NAAQS, Appendix W allows flexibility to consider the use of alternative models on a case-by-case basis when an adequate demonstration can be made that the alternative model performs better than, or is more appropriate than, the preferred model for a particular application.

(3) Control Strategy

The EPA believes that in order to meet the implementation, maintenance and enforcement plan requirements of section 110(a)(1) for the new SO_2 NAAQS, States should consider all control measures that are reasonable to implement in light of the attainment and maintenance needs for the affected area(s). The EPA believes that where additional controls are necessary it would be appropriate for the level of controls in these areas to be similar to that required in areas that are designated as nonattainment for SO_2. These controls would provide for the attainment and maintenance of the SO_2 1-hour standard as expeditiously as practicable. EPA believes that expeditious attainment in these areas will be within 5 years of the effective date of designation of an area. This approach would allow States to take into consideration emission reductions that we expect to be achieved from the implementation of future controls from national control measures as well as regional and local control measures that will be in place by the anticipated attainment date and are projected to help achieve attainment and maintenance of the standard. It would also reduce the risk of such areas failing to meet the NAAQS as expeditiously as nonattainment areas must meet it.

(4) Contingency Plan

The contingency plan is considered to be an enforceable part of the section 110(a)(1) plan and should ensure that there are appropriate contingency measures which can be implemented as expeditiously as practicable once they are triggered. The contingency plan should clearly identify the measures to be adopted, provide a schedule and procedures for adoption and implementation, and provide a specific time limit for actions by the State.

The EPA believes that in this case the contingency measures implemented under the contingency plan requirement for the section 110(a)(1) plan in unclassifiable areas under a revised approach for SO_2 should closely resemble the contingency measures required under section 172(c)(9) of the CAA. Section 172(c)(9) of the CAA defines contingency measures as measures in the SIP which are to be implemented in the event that an area fails to attain the NAAQS, or fails to meet the reasonable further progress (RFP) requirement, by the applicable attainment date for the area. Contingency measures become effective without further action by the State or EPA, upon determination by EPA that the area (1) failed to attain the NAAQS by the applicable attainment date, or (2) fail to meet RFP. These contingency measures should consist of other available control measures that are not included in the control strategy for the SIP.

The EPA interprets the contingency measure provision as primarily directed at general control programs which can be undertaken on an area-wide basis. Since SO_2 control measures are based on what is directly and quantifiably necessary to attain the SO_2 NAAQS, it would be unlikely for an area to implement the necessary emissions control yet fail to attain the NAAQS. Therefore, for SO_2 programs, EPA believes that State agencies should have a comprehensive program to identify sources of violations of the SO_2 NAAQS and undertake an aggressive follow-up for compliance and enforcement, including expedited procedures for establishing enforceable consent agreements pending the adoption of revised SIPs.

Such an approach toward minimum contingency measures for SO_2 would not preclude a State from requiring additional contingency measures that are enforceable and appropriate for a particular source or source category. A contingency measure for an SO_2 SIP might be a consent agreement between the State and EPA to reduce emissions from a source further in the event that the contingency measures are triggered. Alternatively, a source might adopt a contingency measure such as switching to low sulfur coal or reducing load until more permanent measures can be put into place to correct the problem. In either case, the contingency measure should be a fully adopted provision in the SIP in order for it to become effective at the time that EPA determines that the area either fails to attain the NAAQS or fails to meet RFP.

As a necessary part of the section 110(a)(1) plan, the State should also identify specific indicators, or triggers, which will be used to determine when the contingency measures need to be implemented. The identification of triggers would allow a State an opportunity to take early action to address potential violations of the NAAQS before they occur. By taking early action, States may be able to prevent any actual violations of the NAAQS, and therefore, reduce the need on the part of EPA to start the process to re-designate the areas as nonattainment. An example of a trigger would be monitored or modeled violations of the NAAQS. The EPA will review what constitutes an approvable contingency plan on a case-by-case basis.

(5) Verification of Continued Attainment

The submittal should provide an indication of how the State will track the progress of the section 110(a)(1) plan. This is necessary due to the fact that the emissions projections made for the attainment and maintenance demonstrations depend on assumptions of point, area, and mobile source growth. One option for tracking the progress of the attainment and maintenance demonstrations, provided here as an example, would be for the State to update periodically the emissions inventory. The attainment and maintenance demonstration should project maintenance during the five year period following the designations for the 1-hour SO_2 NAAQS, not simply that the area will be in attainment in the fifth year.

States should develop interim emission projection years to show a trend analysis for attainment and maintenance of the standard. These emission projections can also be used as triggers for implementing contingency measures. The EPA recognizes that it would be difficult and time consuming to develop projections for each year of the 5 year period. Therefore, the number of interim projection years should reflect whatever information exists regarding the potential for increases in emissions in the intervening years. For instance, if there is a high probability that emissions will increase to such an extent as to jeopardize continued maintenance of the standard even temporarily over the intervening years, the number of interim projection periods should be sufficient to document that such increases will not interfere with maintenance of the 1-hour SO_2 NAAQS.

When modeling for the attainment and maintenance demonstrations, one option for tracking progress would also be for the State to reevaluate periodically the modeling assumptions and data input. Such reevaluation, for example, could address any delays in source compliance with national, regional or local rules for which the State had previously modeled timely SO_2 reductions. In any event, the State should monitor the indicators for triggering the contingency measures on a regular basis.

EPA recognizes that the approach discussed above for SO_2 SIPs submitted under CAA section 110(a)(1)–(2) is significantly different from the one outlined in the proposal, and from what we have applied in the context of other criteria pollutants. However, EPA anticipates using a revised approach under section 110(a)(1)–(2) as part of an overall revised hybrid monitoring and modeling approach in response to comments on the proposed monitoring-focused approach to implementation of the new SO_2 NAAQS. We believe that such an approach would best account for the unique source-specific and localized impacts inherent to SO_2, and would be the most reasonable way to ensure that all areas of the United States timely attain and maintain the new NAAQS, while at the same time avoiding inappropriately requiring immediate refined modeling of all sources without appropriate EPA guidance. This would also allow attainment demonstrations to account for expected substantial SO_2 reductions that will occur well in advance of the attainment deadline. Of course, for such a unique SO_2 approach to work, it would be imperative for all areas to timely submit, and for EPA to able to approve, adequate attainment, implementation, maintenance and enforcement SIPs that show attainment as expeditiously as practicable, and no later than 5 years following initial designations. Only by applying such a timeframe to the section 110(a)(1) SIP approach we are adopting for SO_2 could the approach be a reasonable one. To that end, EPA would not intend to approve SIPs that do not meet this schedule, and would take necessary and appropriate actions in response to any submission that would result in unacceptable delay of attainment. Such actions may include, but are not limited to, any combination of SIP disapproval, redesignation to nonattainment, and promulgation of a Federal implementation plan (FIP). Any future action establishing an attainment deadline will be completed through notice-and-comment rulemaking on individual SIP submissions.

The timeline below shows how we expect the several steps from promulgation of the new NAAQS through attainment should proceed, whether areas are designated nonattainment or unclassifiable, assuming timely action at each step:

- *June 2010:* EPA issues new SO_2 NAAQS, which starts periods within which CAA section 107 initial area designations must occur and CAA section 110(a)(1)–(2) SIPs must be submitted.
- *June 2011:* States submit initial area designations recommendations, based on available monitoring data, and on any refined modeling performed in advance of submitting CAA section 110(a)(1)–(2) SIPs.
- *June 2012:* EPA issues initial area designations. Any monitored or modeled violations would trigger nonattainment designations. (Per below, States designated nonattainment would submit nonattainment SIPs by February 2014, relying on refined modeling that demonstrates attainment by no later than August 2017.) States would be designated attainment if they submit both monitoring and modeling showing adequate evidence of no violations. All other cases would be initially designated as unclassifiable.
- *June 2013:* States submit CAA section 110(a)(1)–(2) SIPs. SIPs would rely on refined modeling and any required monitoring that demonstrates attainment and maintenance of the new SO_2 NAAQS as expeditiously as practicable, and no later than August 2017. For areas within the State designated attainment and unclassifiable, the section 110(a) SIP must contain any additional Federally enforceable control measures necessary to ensure attainment and maintenance of the NAAQS. (Control measures to be implemented in designated nonattainment areas are due later as part of the nonattainment SIP in February 2014.)
- *February 2014:* Any initially designated nonattainment areas submit CAA section 191–192 SIPs showing attainment no later than August 2017.
- *June 2014:* EPA approves or disapproves submitted CAA section 110(a)(1)–(2) SIPs. For attainment and unclassifiable areas, EPA's action would be based on adequacy of States' modeling (and any required monitoring) showing attainment as expeditiously as practicable, and no later than August 2017, in partial reliance on SO_2 reductions from national and regional standards that are achieved by the attainment date. EPA would also have discretion to re-designate areas based on these SIPs, including to nonattainment if SIPs are inadequate, as well as promulgate FIPs.
- *February 2015:* EPA approves or disapproves CAA section 191–192 attainment SIPs submitted by areas initially designated as nonattainment, with similar remedies as discussed above if SIPs are deficient.
- *June 2016:* CAA section 110(c) deadline by which EPA must issue a FIP for any area whose section 110(a)(1) SIP is disapproved in June 2014.
- *February 2017:* CAA section 110(c) deadline by which EPA must issue a FIP for a nonattainment area whose section 192 SIP is disapproved in February 2015.

August 2017: Expected date by which all areas, regardless of classification, achieve attainment, implementation, maintenance and enforcement of the new SO_2 NAAQS.

D. Attainment Planning Requirements

1. SO_2 Nonattainment Area SIP Requirements

a. Approach Described in the Proposal

We explained in the preamble to the proposal that any State containing an area designated as nonattainment with respect to the SO_2 NAAQS would need to develop for submission to EPA a SIP meeting the requirements of part D, Title I, of the CAA, providing for attainment by the applicable statutory attainment date. *See* sections 191(a) and 192(a) of the CAA. As indicated in section 191(a), all components of the SO_2 part D SIP must be submitted within 18 months of the effective date of an area's designation as nonattainment.

Section 172 of the CAA addresses the general requirements for areas designated as nonattainment. Section 172(c) directs States with nonattainment areas to submit a SIP which contains an attainment demonstration showing that the affected area will attain the standard by the applicable statutory attainment date. The SIP must show that the area will attain the standard as expeditiously as practicable, and must "provide for the implementation of all Reasonably Available Control Measures (RACM) as expeditiously as practicable (including such reductions in emissions from existing sources in the area as may be obtained through the adoption, at a minimum, of Reasonably Available Control Technology (RACT))."

SIPs required under Part D of the CAA must also provide for reasonable further progress (RFP). *See* section 172(c)(2) of the CAA. The CAA defines RFP as "such annual incremental reductions in emissions of the relevant air pollution as are required by part D, or may reasonably be required by the Administrator for the purpose of ensuring attainment of the applicable NAAQS by the applicable attainment date." *See* section 171 of the CAA. Historically, for some pollutants, RFP has been met by showing annual incremental emission reductions sufficient to maintain generally linear progress toward attainment by the applicable attainment date.

All SO_2 nonattainment area SIPs must include contingency measures which must be implemented in the event that an area fails to meet RFP or fails to attain the standards by its attainment date. *See* section 172(c)(9) of the CAA. These contingency measures must be fully adopted rules or control measures that take effect without further action by the State or the Administrator. The EPA interprets this requirement to mean that the contingency measures must be implemented with only minimal further action by the State or the affected sources with no additional rulemaking actions such as public hearings or legislative review.

Emission inventories are also critical for the efforts of State, local, and Federal agencies to attain and maintain the NAAQS that EPA has established for criteria pollutants including SO_2. Section 191(a) in conjunction with section 172(c) requires that areas designated as nonattainment for SO_2 submit an emission inventory to EPA no later than 18 months after designation as nonattainment. In the case of SO_2, sections 191(a) and 172(c) also direct States to submit periodic emission inventories for nonattainment areas. The periodic inventory must include emissions of SO_2 for point, nonpoint, mobile, and area sources.

b. Current Approach

EPA did not receive any comments on this issue. Thus, EPA has no changes to make to this discussion.

2. New Source Review and Prevention of Significant Deterioration Requirements

a. Approach Described in the Proposal

We provided a discussion of the new source review and prevention of significant deterioration programs in the preamble to the proposed rule. The Prevention of Significant Deterioration (PSD) and nonattainment New Source Review (NSR) programs contained in parts C and D of Title I of the CAA govern preconstruction review of any new or modified major stationary sources of air pollutants regulated under the CAA as well as any precursors to the formation of that pollutant when identified for regulation by the Administrator.[37] The EPA rules addressing these programs can be found at 40 CFR 51.165, 51.166, 52.21, 52.24, and Part 51, appendix S.

The PSD program applies when a major source located in an area that is designated as attainment or unclassifiable for any criteria pollutant is constructed or undergoes a major modification.[38] The nonattainment NSR program applies on a pollutant-specific basis when a major source constructs or modifies in an area that is designated as nonattainment for that pollutant. The minor NSR program addresses major and minor sources that undergo construction or modification activities that do not qualify as major, and it applies, as necessary to assure attainment, regardless of the designation of the area in which a source is located.

The PSD requirements include but are not limited to the following:

- Installation of Best Available Control Technology (BACT);
- Air quality monitoring and modeling analyses to ensure that a project's emissions will not cause or contribute to a violation of any NAAQS or maximum allowable pollutant increase (PSD increment);
- Notification of Federal Land Manager of nearby Class I areas; and public comment on the permit.

To the extent necessary to address these PSD requirements for the new 1-hour SO_2 NAAQS, SIPs are due no later than 3 years after the promulgation date. Generally, however, the owner or operator of any major stationary source or major modification obtaining a final PSD permit on or after the effective date of the new 1-hour SO_2 NAAQS will be required, as a prerequisite for the PSD permit, to demonstrate that the emissions increases from the new or modified source will not cause or contribute to a violation of that new NAAQS. The EPA anticipates that individual sources will be able to complete this demonstration under the PSD regulations based on current guidance in EPA's Guideline on Air Quality Models, Appendix W of 40 CFR Part 51.

The owner or operator of a new or modified source will still be required to demonstrate compliance with the annual and 24-hour SO_2 increments, even when their counterpart NAAQS are revoked. The annual and 24-hour increments are established in the CAA and will need to remain in the PSD regulations because EPA does not interpret the CAA to authorize EPA to remove them. It appears necessary for Congress to amend the CAA to make appropriate changes to the statutory SO_2 increments. In 1990, the CAA was amended to accommodate PM_{10} increments in lieu of the statutory TSP increments.

In association with the requirement to demonstrate compliance with the NAAQS and increments, the owner or operator of a new or modified source must submit for review and approval a source impact analysis and an air quality analysis. The source impact analysis, primarily a modeling analysis, must demonstrate that allowable emissions increases from the proposed source or modification, in conjunction with emissions from other existing sources will not cause or contribute to either a NAAQS or increment violation. The air quality analysis must assess the ambient air quality in the area that the proposed source or modification would affect.

For the air quality analysis, the owner or operator must submit in its permit application air quality monitoring data that shall have been gathered over a period of one year and is representative of air quality in the area of the proposed project. If existing data representative of the area of the proposed project is not available, new data may need to be collected by the owner or operator of the source or modification. Where data is already available, it might be necessary to evaluate the location of the monitoring sites from which the SO_2 data were collected in comparison to any new siting requirements associated with the 1-hour SO_2 NAAQS. If existing sites are inappropriate for providing the necessary representative data, then new monitoring data will need to be collected by the owner or operator of the proposed project.

Historically, EPA has allowed the use of several screening tools to help facilitate the implementation of the new source review program by reducing the permit applicant's burden, and streamlining the permitting process for de minimis circumstances. These screening tools include a significant emissions rate (SER), significant impact levels (SILs), and a significant monitoring concentration (SMC). The SER, as defined in tons per year for each regulated pollutant, is used to determine whether any proposed source or modification will emit sufficient amounts of a particular pollutant to require the review of that pollutant under the NSR permit program. EPA will consider whether to evaluate the existing SER for SO_2 to see if it would change substantially based on the NAAQS levels for the 1-hour averaging period. Historically, for purposes of defining the SER, we have defined a de minimis pollutant impact as one that results in a modeled ambient impact of less than approximately 4% of the short-term NAAQS. The current SER for SO_2 (40 tpy) is based on the impact on the 24-hour SO_2 NAAQS. *See* 45 FR 52676, 52707 (August 7, 1980). We have typically used the most sensitive averaging period to calculate the SER, and we may want to evaluate the new 1-hour period for SO_2 because it is likely to represent the most sensitive averaging period for SO_2.

The SIL, expressed as an ambient pollutant concentration (ug/m3), is used to determine whether the impact of a particular pollutant is significant enough to warrant a complete air quality impact analysis for any applicable NAAQS and increments. EPA has promulgated regulations under 40 CFR 51.165(b) which include SILs for SO_2 to determine whether a source's impact would be considered to cause or contribute to a NAAQS violation for the 3-hour (the secondary NAAQS), 24-hour or annual averaging periods. These SILs were originally developed in 1978 to limit the application of air quality dispersion models to a downwind

[37] The terms "major" and "minor" define the size of a stationary source, for applicability purposes, in terms of an annual emissions rate (tons per year, tpy) for a pollutant. Generally, a minor source is any source that is not "major." "Major" is defined by the applicable regulations—PSD or nonattainment NSR.

[38] In addition, the PSD program applies to non-criteria pollutants subject to regulation under the Act, except those pollutants regulated under section 112 and pollutants subject to regulation only under section 211(o).

distance of no more than 50 kilometers or to "insignificant levels." *See* 43 FR 26398, June 19, 1978. Through guidance, EPA has also allowed the use of SILs to determine whether or not it is necessary for a source to carry out a comprehensive source impact analysis and to determine the extent of the impact area in which the analysis will be carried out. The existing SILs for SO_2 were not developed on the basis of specific SO_2 NAAQS levels, so there may be no need to revise the existing SILs. Even upon revocation of the annual and 24-hour NAAQS, the corresponding SIL should still be useful for increment assessment. A SIL for the 1-hour averaging period does not exist, and would need to be developed for use with modeling for 1-hour SO_2 NAAQS and any 1-hour increments.

Finally, the SMC, also measured as an ambient pollutant concentration ($\mu g/m^3$), is used to determine whether it may be appropriate to exempt a proposed project from the requirement to collect ambient monitoring data for a particular pollutant as part of a complete permit application. EPA first defined SMCs for regulated pollutants under the PSD program in 1980. *See* 45 FR 52676, 52709–10 (August 7, 1980). The existing SMC for SO_2, based on a 24-hour averaging period, may need to be re-evaluated to consider the effect of basing the SMC on the 1-hour averaging period, especially in light of revocation of the NAAQS for the 24-hour averaging period. Third, even if the 1-hour averaging period does not indicate the need for a revised SMC for SO_2, the fact that the original SMC for SO_2 is based on 1980 monitoring data (Lowest Detectable Level, correction factor of "5"), could be a basis for revising the existing value. More up-to-date monitoring data and statistical analyses of monitoring accuracy may yield a different—possibly lower—correction factor today. The new 1-hour NAAQS will not necessarily cause this result, but may provide a "window of opportunity" to re-evaluate the SMC for SO_2.

States which have areas designated as nonattainment for the SO_2 NAAQS are directed to submit, as a part of the SIP due 18 months after an area is designated as nonattainment, provisions requiring permits for the construction and operation of new or modified stationary sources anywhere in the nonattainment area. Prior to adoption of the SIP revision addressing major source nonattainment NSR for SO_2 nonattainment areas, the requirements of 40 CFR part 51, appendix S will apply. Nonattainment NSR requirements include but are not limited to:

- Installation of Lowest Achievable Emissions Rate (LAER) control technology;
- Offsetting new emissions with creditable emissions reductions;
- A certification that all major sources owned and operated in the State by the same owner are in compliance with all applicable requirements under the CAA;
- An alternatives and siting analysis demonstrating that the benefits of a proposed source significantly outweigh the environmental and social costs imposed as a result of its location, construction, or modification; and
- Public comment on the permit.

Minor NSR programs must meet the statutory requirements in section 110(a)(2)(C) of the CAA which requires "* * * regulation of the modification and construction of any stationary source * * * as necessary to assure that the [NAAQS] are achieved." These programs must be established in each State within 3 years of the promulgation of a new or revised NAAQS.

b. Comments and Responses

Several commenters stated that in order to avoid confusion and lag time as it relates to PSD/NSR and permitting activities, which must be taken by States following the promulgation of the revised NAAQS, EPA must provide guidance as soon as possible related to these issues. Commenters also stated that EPA must develop guidance as soon as possible to address the screening tools for PSD/NSR such as SILs, SERs, SMCs, and the development of increments. Several commenters also stated that guidance should be provided as it relates to the use of AERMOD to address PSD issues.

The EPA acknowledges that a decision to promulgate a new short-term SO_2 NAAQS will have implications for the air permitting process. The full extent of how a new short-term SO_2 NAAQS will affect the NSR process will need to be carefully evaluated. First, major new and modified sources applying for NSR/PSD permits will initially be required to demonstrate that their proposed emissions increases of SO_2 will not cause or contribute to a violation of any NAAQS or PSD increments for SO_2, including the new 1-hour SO_2 NAAQS. In addition, we believe that section 166(c) of the CAA authorizes EPA to consider the need to promulgate a new 1-hour increment. Historically, EPA has developed increments for each applicable averaging period for which a NAAQS has been promulgated. However, increments for a particular pollutant do not necessarily need to match the averaging periods that have been established for NAAQS for the same pollutant. *Environmental Defense Fund, Inc.* v. *EPA,* 898 F.2d 183, 189–190 (DC Cir. 1990) ("* * * the 'goals and purposes' of the PSD program, set forth in § 160, are not identical to the criteria on which the ambient standards are based.") Thus, we would need to evaluate the need for a new 1-hour SO_2 increment in association with the goals and purposes of the statutory PSD program requirements.

We agree with the commenters that there may be a need for EPA to provide additional screening tools or to revise existing screening tools that are frequently used under the NSR/PSD program for reducing the burden of completing SO_2 ambient air impact analyses. These screening tools include the SILs, as mentioned by the commenter, but also include the SER for emissions of SO_2 and the SMC for SO_2. The existing sceening tools apply to the averaging periods used to define the existing NAAQS for SO_2, including the annual, 24-hour, and 3-hour averaging periods. EPA intends to evaluate the need for possible changes or additions to each of these useful screening tools for SO_2 due to the revision of the SO_2 NAAQS to provide for a 1-hour standard. We believe it is highly likely that in order to be most useful for implementing the new 1-hour averaging period for NSR purposes, new 1-hour screening values will be appropriate.

Finally, in response to the comment concerning the need for additional guidance as it relates to the use of AERMOD to address PSD issues, EPA anticipates providing additional technical guidance on modeling and analysis as a part of the SIP demonstration process. As stated previously, EPA intends to solicit public comment on guidance regarding modeling, and also solicit public comment on additional implementation planning guidance. However, EPA believes that the air quality models currently required for NSR/PSD permitting as provided in the EPA's *Guideline on Air Quality Models,* Appendix W of CFR 40 Part 51 would be appropriate for demonstrating compliance with the revised SO_2 NAAQS under these programs. At this time, EPA is not considering modifying the AERMOD dispersion model and its underlying science for predicting SO_2 concentrations to accommodate the revised NAAQS for SO_2.

c. Current Approach

In the preamble to the proposed regulation, EPA noted that "PSD permit requirements are effective on the promulgation date of a new or revised standard." However, this statement did not reflect an important distinction that needs to be clarified here. Under section 51.166(b)(49)(i) and 52.21(b)(50)(i) of EPA's regulations, a pollutant that has not been regulated previously would become a "regulated NSR pollutant" upon promulgation of a NAAQS. *See,* 75 FR 17004, 17018–19. However, in the case of pollutants that are already "regulated NSR pollutants," at the time a new NAAQS is promulgated or an existing NAAQS is revised, EPA interprets the CAA and EPA regulations to require implementation of the new or revised standard in the Federal PSD permitting process upon the effective date of any new or revised standards. Section 165(a)(3) of the CAA and section 52.21(k) of EPA's regulations require that a permit applicant demonstrate that it will not cause or contribute to a violation of "any" NAAQS. *See,* Memorandum from Stephen D. Page, Director of EPA Office of Air Quality Planning and Standards, "Applicability of the Federal Prevention of Significant Deterioration Permit Requirements to New and Revised National Ambient Air Quality Standards" (April 1, 2010).

Amendments to the existing PSD requirements set forth in EPA regulations concerning SILs, SERs and SMCs may involve notice and comment rulemaking which could take at least one year to complete. For $PM_{2.5}$, EPA developed SERs under the initial NSR implementation requirements for $PM_{2.5}$. *See* 73 FR 28321, May 16, 2008. The SILs and SMC for $PM_{2.5}$ are being developed under a subsequent rulemaking simultaneously with the promulgation of $PM_{2.5}$ increments, pursuant to a CAA schedule that allows EPA 2 years from the promulgation of new and revised NAAQS to promulgate increments. Under such an approach, SILs and SMC are not available until the increments are promulgated. States and industry have criticized that approach because it has left State permitting authorities without an EPA-approved de minimis value that could be used in determining the level of analysis that individual PSD sources must undergo, and could result in more detailed analyses for sources that will have only have de miminis impacts on the NAAQS.

To address this concern, we believe it is appropriate to proceed with development of the PSD screening tools in advance of an increment rulemaking to hasten their availability. In addition, we are assessing the possibility of developing interim screening tools that can be used by States prior to the completion of the SIP-development process if the States establish an appropriate record for individual permitting actions based on the supporting technical information provided by EPA. It is our expectation, that if such interim screening tools are appropriate, we would make the interim SIL and the supporting record for EPA's assessment available before the effective date of the new 1-hour SO_2 NAAQS to facilitate more efficient PSD permit reviews once the new standard becomes effective.

3. General Conformity

a. Approach Described in the Proposal

Section 176(c) of the CAA requires that all Federal actions conform to an applicable implementation plan developed pursuant to section 110 and part D of the CAA. The EPA rules developed under section 176(c) prescribe the criteria and procedures for demonstrating and assuring conformity of Federal actions to a SIP. Each Federal agency must determine that any actions covered by the general conformity rule conform to the applicable SIP before the action is taken. The criteria and procedures for conformity apply only in nonattainment areas and those nonattainment areas redesignated to attainment since 1990 ("maintenance areas") with respect to the criteria pollutants under the CAA: [39] carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO_2), ozone (O3), particulate matter ($PM_{2.5}$ and PM_{10}), and sulfur dioxide (SO_2). The general conformity rules apply one year following the effective date of designations for any new or revised NAAQS.[40]

The general conformity determination examines the impacts of direct and indirect emissions related to Federal actions. The general conformity rule provides several options to satisfy air quality criteria, such as modeling or offsets, and requires the Federal action to also meet any applicable SIP requirements and emissions milestones. The general conformity rule also requires that notices of draft and final general conformity determinations be provided directly to air quality regulatory agencies and to the public by publication in a local newspaper.

b. Current Approach

EPA did not receive any comments on this aspect of the discussion in the proposal and expects to follow that approach.

E. Transition From the Existing SO_2 NAAQS to a Revised SO_2 NAAQS

a. Proposal

In addition to proposing a short-term 1-hour SO_2 NAAQS, EPA proposed to revoke the annual and 24-hour standards (annual 0.03 ppm and 24-hour 0.14 ppm). Specifically, EPA proposed that the level for the 1-hour standard for SO_2 be a range between 50–100 ppb, and took comment on setting the level of the standard up to 150 ppb. We explained that if the Administrator sets the 1-hour standard at 100 ppb or lower, EPA proposed to revoke the 24-hour standard. If the Administrator set the level of the 1-hour standard between a range of 100–150 ppb, then EPA proposed to retain the 24-hour standard.

We explained that if EPA revised the SO_2 NAAQS and revoked either the annual or 24-hour standard, EPA would need to promulgate adequate anti-backsliding provisions. The CAA establishes anti-backsliding requirements where EPA relaxes a NAAQS. Here, in EPA replacing the annual and 24-hour standards with a short term 1-hour standard, EPA must address the section 172(e) anti-backsliding provision of the CAA and determine whether it applies on its face or by analogy, and what provisions are appropriate to provide for transition to the new standard. States will need to insure that the health protection provided under the prior SO_2 NAAQS continues to be achieved as well as maintained as States begin to implement the new NAAQS. This means that States are directed to continue implementing attainment and maintenance SIPs associated with the prior SO_2 NAAQS until such time as they are subsumed by any new planning and control requirements associated with the new NAAQS.

Whether or not section 172(e) directly applies to EPA's final action on the SO_2 NAAQS, EPA has previously looked to other provisions of the CAA to determine how to address anti-

[39] Criteria pollutants are those pollutants for which EPA has established a NAAQS under section 109 of the CAA.

[40] Transportation conformity is required under CAA section 176(c) (42 U.S.C. 7506(c) to ensure that Federally supported highway and transit project activities are consistent with ("conform to") the purpose of the SIP. Transportation conformity applies to areas that are designated nonattainment, and those areas redesignated to attainment after 1990 ("maintenance areas" with plans developed under CAA section 175A) for transportation-related criteria pollutants. Due to the relatively small amounts of sulfur in gasoline and on-road diesel fuel, transportation conformity does not apply to the SO_2 NAAQS. 40 CFR 93.102(b)(1).

backsliding. The CAA contains a number of provisions that indicate Congress's intent to not allow provisions from implementation plans to be altered or removed if the plan revision would jeopardize the air quality protection being provided by the existing plan when EPA revises a NAAQS to make it more stringent. For example, section 110(l) provides that EPA may not approve a SIP revision if it interferes with any applicable requirement concerning attainment and RFP, or any other applicable requirement under the CAA. In addition, section 193 of the CAA prohibits the modification of a control, or a control requirement, in effect or required to be adopted as of November 15, 1990 (*i.e.,* prior to the promulgation of the Clean Air Act Amendments of 1990), unless such a modification would ensure equivalent or greater emissions reductions. Further, section 172(e) of the CAA specifies that if EPA revises a NAAQS to make it less stringent than a previous NAAQS, control obligations no less stringent than those that apply in nonattainment area SIPs may not be relaxed, and adopting those controls that have not yet been adopted as needed may not be avoided. The intent of Congress, concerning the aforementioned sections of the CAA, was confirmed in a recent DC Circuit Court opinion on the Phase I ozone implementation rule. *See South Coast Air Quality Management Dist.* v. *EPA,* 472 F.3d 882 (DC Cir. 2006).

To ensure that the anti-backsliding provisions and principles of section 172(e) are met and applied upon EPA revocation of the annual and 24-hour standards, EPA is providing that those SO_2 NAAQS will remain in effect for one year following the effective date of the initial designations under section 107(d)(1) for the new SO_2 NAAQS before the current NAAQS are revoked in most attainment areas. However, any existing SIP provisions under CAA sections 110, 191 and 192 associated with the annual and 24-hour SO_2 NAAQS will remain in effect, including all currently implemented planning and emissions control obligations, including both those in the State's SIP and that have been promulgated by EPA in FIPs. This will ensure that both the new nonattainment NSR requirements and the general conformity requirements for a revised standard are in place so that there will be no gap in the public health protections provided by these two programs. It will also ensure that all nonattainment areas under the annual and/or 24-hour NAAQS and all areas for which SIP calls have been issued will continue to be protected by currently required control measures.

EPA is also providing that the annual and 24-hour NAAQS remain in place for any current nonattainment area, or any area for which a State has not fulfilled the requirements of a SIP call, until the affected area submits, and EPA approves, a SIP with an attainment, implementation, maintenance and enforcement SIP which fully addresses the attainment and maintenance requirements of the new SO_2 NAAQS. This, in combination with the CAA mechanisms provided in sections 110(l), 193, and 172(e) will help to ensure that continued progress is made toward timely attainment of the SO_2 NAAQS. Also, in light of the nature of the new SO_2 NAAQS, the lack of classifications (and mandatory controls associated with such classifications pursuant to the CAA), and the small number of current nonattainment areas, and areas subject to SIP calls, EPA believes that retaining the current standard for a limited period of time until attainment and maintenance SIPs are approved for the new standard in current nonattainment areas and SIP call areas, and one year after designations in other areas, will adequately serve the anti-backsliding requirements and goals of the CAA.[41]

b. Comments and Responses

Several commenters stated that they support EPA's proposal stating that the annual and 24-hour SO_2 NAAQS EPA would remain in effect for one year following the effective date of the initial designations under section 107(d)(1) for the revised SO_2 NAAQS before the current NAAQS are revoked in most attainment areas. The commenters also support EPA's proposal that any existing SIP provisions under CAA sections 110, 191 and 192 associated with the annual and 24-hour SO_2 NAAQS would remain in effect, including all currently implemented planning and emissions control obligations, including both those in the State's SIP and that have been promulgated by EPA in FIPs. Several commenters also stated that they support EPA's proposal that an area's nonattainment designation and the subsequent CAA requirements under the current SO_2 NAAQS will remain in effect until the affected State submits, and EPA approves a SIP which meets all of the relevant CAA requirements for the affected nonattainment area. EPA appreciates the support of the commenters on its strategy for addressing the anti-backsliding requirements related to the current and revised SO_2 standard, pursuant to section 172(e) of the CAA.

One commenter, however, stated that while they support EPA's proposal to address the anti-backsliding provisions of section 172(e) of the CAA, they believe that EPA's proposal is deficient in several respects. The commenter stated that EPA's proposal to not terminate the annual and 24-hour standards for SO_2 in any nonattainment area, or any area for which a State has not fulfilled the requirements of a SIP call, until after the affected area submits and EPA approves a SIP with an attainment demonstration which fully "addresses" the attainment requirements of the revised SO_2 NAAQS is flawed. The commenter states that EPA's use of the term "addresses" is impermissibly and arbitrarily ambiguous and that the agency needs to clarify that "fully addressing" the attainment requirements of the revised NAAQS actually means providing for timely attainment of the NAAQS, and the submittal of a SIP that fully meets all of the requirements of section 110 and part D of Title I of the CAA, including sections 172, 173, and 191–193 of the CAA.

Another commenter stated that the 24-hour SO_2 standard should not be revoked in attainment areas until EPA approves section 110(a)(2) "infrastructure" SIPs under the new 1-hour standard for such areas, in order to avoid delays in between attainment designation and such SIP approvals resulting in leaving the public unprotected or creating inter-state conflict that triggers section 126 petitions. This commenter further stated that the annual SO_2 standard should not be revoked until EPA approves SIPs in attainment areas under the future SO_2 secondary standard, which may also be based on an annual averaging time.

EPA agrees with the comment made by the commenter regarding the need to approve SIPs in nonattainment areas (and in SIP call areas) before revoking the 24-hour and annual NAAQS for such areas. EPA clarifies that for those areas designated as nonattainment for the current NAAQS, or areas which have not met the requirements of a SIP call, that the State must submit a SIP that meets all of the applicable CAA requirements as they relate to section 110 and part D of Title I of the CAA, including sections 110(a), 172, 173, and 191–193 of the CAA. In addition to the

[41] The areas that are currently designated as nonattainment for the pre-existing SO_2 primary NAAQS are Hayden, AZ; Armstrong, PA; Laurel, MT; Piti, GU; and Tanguisson, GU. The areas that are designated nonattainment for both the primary and the secondary standards are East Helena, MT, Salt Lake Co, MT, Toole Co, UT, and Warren Co, NJ. (*See http://www.epa.gov/oar/oaqps/greenbk/lnc.html*). The Billings/Laurel, MT, area is the only area currently subject to a SIP call.

submittal of the SIP related to these requirements, EPA must approve the submittal for the area before the current standard can be revoked for the affected area.

EPA disagrees with the comment. This rulemaking concerns only the primary standards for SO_2. 74 FR at 64812 n. 2. The annual SO_2 standard is a primary standard, not a secondary standard. *See* 40 CFR section 50.4 (a). The exclusive secondary standard for SO_2 is the 3-hour standard codified in 40 CFR section 50.5. EPA is not determining the adequacy of this secondary standard in this review or this rulemaking, as just noted. The commenter's request to retain the annual primary standard until SIPs reflecting a new secondary standard are approved is effectively a request to amend the present secondary standard, and is therefore inappropriate given the scope of this review. In any case, in the event that any substantive responsive to this comment is required, air quality information indicates that a 1-hour standard of 75 ppb is estimated to generally keep annual SO_2 concentrations well below the level of the current annual standard. 74 FR at 64845. Thus, there would be no loss of protection to public welfare due to revocation of the annual primary standard.

EPA further disagrees with the commenter's request that we not revoke the 24-hour standard in attainment areas before section 110(a)(2) "infrastructure" SIPs are approved under the new 1-hour SO_2 standard. An area that has shown it has attained the 24-hour standard and that is not the subject of a SIP call, even after revocation of the 24-hour standard, will still have in its SIP its prior "infrastucture" SIP elements. There is no need to delay revocation when that will not cause the area to become subject to a new SIP under the new 1-hour NAAQS any faster than the statute already requires (*i.e.,* three years from the date of promulgation of the new NAAQS). Furthermore, as we have explained in sections III, IV, V and VI of this preamble, all areas are required by section 110(a)(1) of the Clean Air Act to submit such SIPs by June 2013, and we expect that to be approved they will all need to show attainment, implementation, maintenance and enforcement of the new NAAQS as expeditiously as practicable, which we believe is no later than August 2017. EPA believes this anticipated approach would more than sufficiently address the backsliding concerns raised by the commenter.

c. Final

EPA is making no changes to the proposed rule's discussion of the transition strategy discussion for SO_2 with the exception of the clarifications noted above.

VII. Appendix T—Interpretation of the Primary NAAQS for Oxides of Sulfur and Revisions to the Exceptional Events Rule

EPA proposed to add Appendix T, Interpretation of the Primary National Ambient Air Quality Standards for Oxides of Sulfur, to 40 CFR Part 50 in order to provide monitoring data handling procedures for the proposed SO_2 1-hour primary standard. The proposed section 50.17 which sets the averaging period, level, indicator, and form of the NAAQS referred to this Appendix T. The proposed Appendix T detailed the computations necessary for determining when the proposed 1-hour primary SO_2 NAAQS is met based on data from ambient monitoring and also addressed monitoring data reporting, data completeness considerations, and rounding conventions.

EPA proposed two versions of Appendix T. The first applied to a 1-hour primary standard based on the annual 4th high value form, while the second applied to a 1-hour primary standard based on the 99th percentile daily value form. The final version of the Appendix reflects our choice to adopt the 99th percentile daily form (*see* section II. E.3 above).

For the 1-hour primary standard, EPA proposed monitoring data handling procedures, a cross-reference to the Exceptional Events Rule, a grant of discretion for the Administrator to consider otherwise incomplete monitoring data to be complete, and a provision addressing the possibility of there being multiple SO_2 monitors at one site. EPA is finalizing these proposals, with one change from the proposal with regard to the multiple monitor provision.

EPA is also making certain drafting changes to the proposed regulatory text to clarify certain points and to assure that the regulatory text conforms with EPA's intentions as stated in the preamble. Specifically, EPA has slightly edited the text of the rule from that proposed by adding the phrase "at an ambient air monitoring site" to section 50.17 (b) and to section 1.1 of Appendix T to part 50, and also by adding a section 50.17 (c) stating that the level of the standard is to be measured by an FRM found in Appendix A or A–1 to Part 50, or by a properly designated FEM. Both of these provisions are being added to conform the text of the new 1-hour standard to the language of other NAAQS. *See. e.g.* the text of the 8-hour primary standard for ozone in section 50.10 (a) and (b). The reference to "at an ambient monitoring site" makes clear that the regulatory text refers to situations where compliance with a NAAQS is measured by means of monitoring. This text does not restrict or otherwise address approaches which EPA or States may use to implement the new 1-hour NAAQS, which may include, for example, use of modeling (*see* sections III—VI above). *See* CAA sections 107 (d) (3) (A) (any "air quality data" may be used for redesignations); 110 (a) (1) (which does not address the issue of the types of data States may use in devising plans for implementation, maintenance, and enforcement of a primary NAAQS); 192 (a) (which does not specify the types of data that may support a demonstration that a non-attainment area has attained a NAAQS). Similarly, EPA notes that Appendix T applies when ambient monitoring data is gathered and utilized in support of the new 1-hour SO_2 NAAQS. As noted in sections III, IV, V, and VI above, there are circumstances when EPA is considering use of modeling in the SO_2 NAAQS implementation effort, and other considerations would apply if and to the extent modeling is utilized.

The EPA is also making SO_2-specific changes to the deadlines in 40 CFR 50.14, by which States must flag ambient air data that they believe have been affected by exceptional events and submit initial descriptions of those events, and to the deadlines by which States must submit detailed justifications to support the exclusion of those data from EPA monitoring-based determinations of attainment or nonattainment with the NAAQS.

A. Interpretation of the Primary NAAQS for Oxides of Sulfur

The purpose of a monitoring data interpretation rule for the SO_2 NAAQS is to give effect to the form, level, averaging time, and indicator specified in the regulatory text at 40 CFR 50.17, anticipating and resolving in advance various future ambiguities that could otherwise occur regarding use of ambient monitoring data. The new Appendix T provides definitions and requirements that apply to the new 1-hour primary standard for SO_2. The requirements concern how ambient monitoring data are to be reported, what ambient monitoring data are to be considered (including the issue of which of multiple monitors' data sets will be used when more than one monitor has operated at a site), and the applicability of the Exceptional Events Rule to the primary SO_2 NAAQS.

1. Proposed Interpretation of the Standard Based on Data From Ambient Monitoring

With regard to monitoring data completeness for the proposed 1-hour primary standard, the proposed Appendix T followed past EPA practice for other NAAQS pollutants by requiring that in general at least 75% of the monitoring data that should have resulted from following the planned monitoring schedule in a period must be available for the key air quality statistic from that period to be considered valid. For the 1-hour primary SO_2 NAAQS, the key air quality statistics are the daily maximum 1-hour concentrations in three successive years. It is important that sampling within a day encompass the period when concentrations are likely to be highest and that all seasons of the year are well represented. Hence, the 75% requirement was proposed to be applied at the daily and quarterly levels.

Recognizing that there may be years with incomplete data, the proposed Appendix T for the 99th percentile form provided that a design value derived from incomplete monitoring data will nevertheless be considered valid if the relevant one of two diagnostic substitution tests validated such a design value as being either above the NAAQS level or equal to or below the NAAQS level.

The first proposed diagnostic data substitution test, relevant when the design value derived from incomplete data was equal to or below the NAAQS level, was intended to identify those cases with incomplete monitoring data in which it nevertheless is very likely, if not virtually certain, that the daily 1-hour design value would have been observed to be less than or equal to the level of the NAAQS if monitoring data had been minimally complete. This test involved the substitution of a high historical concentration for any missing data. The second proposed diagnostic data substitution test, relevant when the design value derived from incomplete data was above the NAAQS level, was intended to identify those cases with incomplete monitoring data in which it nevertheless is very likely, if not virtually certain, that the daily 1-hour design value would have been observed to be above the level of the NAAQS if monitoring data had been minimally complete. This test involved the substitution of a low historical concentration for any missing data.

It should be noted that one possible outcome of applying the relevant proposed substitution test is that a 3-year period with incomplete monitoring data may nevertheless be determined to not have a valid design value and thus to be unusable in making 1-hour primary NAAQS compliance determinations based on monitoring for that 3-year period.

Also, we proposed that the Administrator have general discretion to use incomplete monitoring data based on case specific factors, either at the request of a State or at her own initiative. Similar provisions existed already for some other NAAQS.

The 99th percentile version of the proposed Appendix T provided a table for determining which day's maximum 1-hour concentration will be used as the 99th percentile concentration for the year. The proposed table is similar to one used now for the 24-hour $PM_{2.5}$ NAAQS and the new 1-hour NO_2 NAAQS, which are both based on a 98th percentile form, but adjusted to reflect a 99th percentile form for the 1-hour primary SO_2 standard. The proposed Appendix T also provided instructions for rounding (not truncating) the average of three annual 99th percentile hourly concentrations before comparison to the level of the primary NAAQS.

2. Comments on Interpretation of the Standard

Several commenters expressed support for EPA's proposed 75% completeness requirement for daily and quarterly monitoring data. A comment was received that the substitution test should not be used to make attainment or non-attainment designations. This commenter also said that the same completeness requirement as used for nonattainment should be used for attainment. Another commenter agreed that there should be completeness criteria, but thought that monitoring data should be substituted to make the set only 75% complete. We received one comment that the computation of design values where multiple monitors are present at a site should be averaged and not taken from a designated primary monitor. We received no comment on the provision which would afford the Administrator (or her delegee) discretion to use incomplete monitoring data based on specified factors and accordingly are adopting that provision as proposed.

3. Conclusions on Interpretation of the Standard

Consistent with the Administrator's decision to adopt a 99th percentile form for the 1-hour NAAQS, the final version of Appendix T is based on that form.

We agree with the three comments expressing the view that the requirement for 75% monitoring data completeness per quarter should apply with respect to the 1-hour standard. The final rule includes this requirement.

We agree that nonattainment based on data from ambient monitoring should not be declared without a very high confidence that actual air quality did not meet the NAAQS, but we believe the proposed (and final) substitution test provides this irrefutable proof. In the relevant substitution test (Appendix T section 3.c.iii), the lowest daily maximum concentration observed in the same calendar quarter within the 3-year period is the value used in the substitution. Moreover, to guard against the possibility that even this lowest observed value is unrepresentative because only a small number of days that happened to have had poor air quality have valid monitoring data, substitution is permitted only if there are at least 200 days across the three matching quarters of the three years under consideration for which 75 percent of the hours in the day have reported concentrations. (If less than 200 days are available, the outcome is that no conclusion can be reached based on data from monitoring as to whether the NAAQS is met, an outcome which satisfies the concern expressed by the commenter.) While it is conceivable that the actual daily maximum concentration on the day(s) without sufficiently complete data could have been even lower than the value selected as the substitute value, the value that is selected for substitution will be quite low, and therefore it is extremely unlikely to be a candidate for selection as the annual 99th percentile daily maximum concentration. The actual effect of the data substitution, if any, is to change which of the actually observed and ranked daily maximum concentrations during the year is identified as the 99th percentile; the direction of the change, if any, will always be towards a lower design value. For example, if the substitution test of section 3.c.iii is used because there is one quarter of 92 days is missing 70 of its 92 daily maximum concentration values; causing there to be only 295 days with valid daily values for the whole year, it would be necessary to substitute 47 values to make that quarter 75 percent complete. This would result in 343 days of actual or substituted monitoring data for the year. The increase from 292 days to 342 days would cause the annual 99th percentile value to shift from the 3rd highest value to the 4th highest. Since a low concentration is being used for the substitution, it is impossible for the 4th highest value to itself be a substituted value. If this shift results in the 3-year design value remaining above the NAAQS, the failure to meet the NAAQS is confirmed. If this shift results in the 3-year design value changing to be equal to or below the NAAQS, under the terms of the substitution test the outcome is that no conclusion could be reached based on this ambient monitoring data as to whether the NAAQS is met. Since either the same or a lower ranking actually measured concentration will always be identified, it is impossible for the outcome of the substitution test of section 3.c.iii to be that an area truly meeting the NAAQS based on ambient monitoring data is determined to not meet it based on ambient monitoring data.

The commenter who said that the same completeness requirement should be used for nonattainment as for attainment appears to have been referring to a particular feature of the proposed diagnostic substitution test rather than to the basic completeness requirement of 75%, which in both the proposal and the final rule applies equally to both attainment and nonattainment situations. This particular feature is discussed in the next paragraph.

The commenter who said that it is appropriate to substitute data to make the set only 75% complete appears to have taken note that in the proposed substitution test relevant in the case of an incomplete design value equal to or below the NAAQS (section 3.c.ii), data are substituted until 100% completeness is reached for the affected quarter, while in the test relevant in the case of an incomplete design value above the NAAQS (section 3.c.iii) data are substituted only until 75% completeness is reached. EPA believes this distinction is appropriate, and we have retained the 100% substitution limit in the final rule. In the case of an incomplete design value that is equal to or below the NAAQS, the concern is that the actual concentrations on the days without a valid daily maximum 1-hour concentration may have been quite high such that the concentration on one of those days would have been selected as the annual 99th percentile value. To be selected as the annual 99th percentile value, a daily maximum must be ranked no lower than the 4th highest daily value for the year. If substitution stopped when 75% of the days in a quarter had an actual or substituted value, there could be a situation in which only one, two, or three historical high values would need to be substituted to reach the 75% limit. It would therefore be possible for one of the actually measured concentrations (for the same or another quarter) to be identified as the annual 99th percentile value even if the substitution value is higher than any value actually measured, defeating the very purpose of the diagnostic test for an incomplete design value below the NAAQS, which is to essentially rule out the possibility of not meeting the NAAQS (when making monitoring-based determinations). The simplest way to ensure that at least four values are substituted (when there are at least four missing daily values) is to require substitution up to the 100% limit.

With regard to situations with multiple monitors operating at one site, we note that there are few cases of this situation for SO_2 monitoring. Of over 500 SO_2 monitoring sites in operation any time during 2007–2009, for example, only seven stations reported 1-hour data to the Air Quality System under two or more distinct Pollutant Occurrence Codes (POC). In the same period, collocated monitors reported data to AQS under distinct POCs for only one of over 400 nitrogen dioxide sites, for only two of almost 400 carbon monoxide sites, and for only eight of almost 1300 ozone sites. Even so, we believe is it important to have a well defined monitor data handling procedure for such situations. Also, there is a practical advantage in implementation if the same or similar procedure is used across NAAQS pollutants especially for these four gaseous pollutants that are measured on a 1-hour basis. A procedure that is simple to implement also has advantages in implementation. Finally, the procedure should not introduce any upward or downward bias in the determination of the design value for the monitoring site.[42]

The proposed procedure for multiple SO_2 monitors was the same as EPA recently proposed and finalized for the new 1-hour NAAQS for nitrogen dioxide, where there were no adverse comments received on the proposal (75 FR 6474, February 9, 2010). It is also the same as recently proposed in the reconsideration of the 8-hour ozone NAAQS (75 FR 2938, January 19, 2010). In the proposed procedure, in general, data from two monitors would never be mixed within a year but data from different monitors in different years could be used to calculate the 3-year design value. As noted above, one commenter on the SO_2 proposal suggested that instead of designating a primary monitor when there are two monitors at a site, the measurements for an hour from multiple monitors should be averaged instead. EPA has also received at least one comment disagreeing with the recent proposal regarding multiple ozone monitors. The comment in the ozone rulemaking favored hour-by-hour substitution of data from a secondary monitor when the designated primary monitor has not given a value measurement, as opposed to the proposed restriction against mixing data within a year. These comments have caused us to rethink the direction set in the final NO_2 rule and in the proposals for SO_2 and ozone. We now believe that substitution of monitoring data hour-by-hour is an acceptable and in some ways superior approach to the other possible approaches, while averaging hour-by-hour would be unduly complex. Also, averaging hour-by-hour might not be transparent depending on whether the averaging is done at the monitoring agency before submission to EPA or by EPA as part of calculating a design value. However, in light of the rarity of collocated monitors, it would be an unwarranted demand on limited EPA resources to develop and maintain software for hour-by-hour data substitution. Also, an hour-by-hour data substitution approach depends on the advance designation of a primary monitor, which itself could introduce confusion and would require software changes to EPA's data system. Therefore, EPA believes that the most practical, and still a technically valid approach, is to allow monitoring agencies the option of hour-by-hour substitution between secondary and primary monitors before submission of data to EPA, and for EPA to select for use in calculating design values the one monitoring data record which has the highest degree of completeness for a given year. The final rule is based on this approach. EPA will also consider this approach when finalizing the ozone NAAQS reconsideration rule, and when proposing data interpretation provisions for a planned rulemaking to review the carbon monoxide NAAQS. The already finalized procedures for nitrogen dioxide data interpretation will be

[42] Selecting the maximum or minimum observed concentration for an hour, the maximum or minimum annual 99th percentile, or the maximum or minimum three-year design value would introduce such a bias. Averaging multiple 1-hour measurements when available, designating one monitor as primary and using a second monitor's measurement only when the primary monitor fails to give a valid measurement, or simply choosing to use the data record from only one of the monitors (on some basis that is independent of the concentration values obtained) would not introduce such a bias.

implemented as promulgated, but will affect only an extremely small number of collocated SO_2 monitoring situations.

Finally, as proposed, the final version of Appendix T has a cross reference to the Exceptional Events Rule (40 CFR 50.14) with regard to the exclusion of monitoring data affected by exceptional events. In addition, the specific steps for including such data in completeness calculations while excluding such data from actual design value calculations is clarified in Appendix T.

B. Exceptional Events Information Submission Schedule

The Exceptional Events Rule at 40 CFR 50.14 contains generic deadlines for a State to submit to EPA specified information about exceptional events and associated air pollutant concentration data. A State must initially notify EPA that data have been affected by an event by July 1 of the calendar year following the year in which the event occurred; this is done by flagging the data in AQS and providing an initial event description. The State must also, after notice and opportunity for public comment, submit a demonstration to justify any claim within 3 years after the quarter in which the data were collected. However, if a regulatory decision based on the data (for example, a designation action) is anticipated, the schedule to flag data in AQS and submit complete documentation to EPA for review is shortened, and all information must be submitted to EPA no later than one year before the decision is to be made.

These generic deadlines are suitable for the period after initial designations have been made under a NAAQS, when the decision that may depend on data exclusion is a redesignation from attainment to nonattainment or from nonattainment to attainment. However, these deadlines present problems with respect to initial designations under a newly revised NAAQS. One problem is that some of the deadlines, especially the deadlines for flagging some relevant data, may have already passed by the time the revised NAAQS is promulgated. Until the level and form of the NAAQS have been promulgated a State does not know whether the criteria for excluding data (which are tied to the level and form of the NAAQS) were met on a given day. Another problem is that it may not be feasible for information on some exceptional events that may affect final designations to be collected and submitted to EPA at least one year in advance of the final designation decision. This could have the unintended consequence of EPA designating an area nonattainment because of uncontrollable natural or other qualified exceptional events.

The Exceptional Events Rule at section 50.14(c)(2)(v) indicates "when EPA sets a NAAQS for a new pollutant, or revises the NAAQS for an existing pollutant, it may revise or set a new schedule for flagging data for initial designation of areas for those NAAQS."

For the specific case of SO_2, the signature date for the revised SO_2 NAAQS is June 2, 2010. State/Tribal area designations recommendations will be due by June 2, 2011, and EPA will make initial area designations under the revised NAAQS by June 1, 2012 (since June 2, 2012 would be on a Saturday) and will be informed by air quality data from the years 2008–2010 or 2009–2011 if there is sufficient data for these data years and by any refined modeling that is conducted. (*See* Sections III, V and VI above for more detailed discussions of the designation schedule and what data EPA expects to use.) Because final designations would be made by June 1, 2012, all events to be considered during the designations process would have to be flagged and fully documented by States one year prior to designations, by June 1, 2011. A State would not be able to flag and submit documentation regarding events that occurred between June to December 2011 by one year before designations are made in June 2012.

EPA is adopting revisions to 40 CFR 50.14 only to change submission dates for information supporting claimed exceptional events affecting SO_2 data. The rule text at the end of this notice shows the changes that will apply to the new 1-hour SO_2 NAAQS. For air quality data collected in 2008, we are extending the generic July 1, 2009 deadline for flagging data (and providing a brief initial description of the event) to October 1, 2010. EPA believes this extension will provide adequate time for States to review the impact of exceptional events from 2008 on the revised standard and notify EPA by flagging the relevant data in AQS. EPA is not changing the foreshortened deadline of June 1, 2011 for submitting documentation to justify an SO_2-related exceptional event from 2008. We believe the generic deadline provides adequate time for States to develop and submit proper documentation.

For data collected in 2009, EPA is extending the generic deadline of July 1, 2010 for flagging data and providing initial event descriptions to October 1, 2010. EPA is retaining the deadline of June 1, 2011 for States to submit documentation to justify an SO_2-related exceptional event from 2009. For data collected in 2010, EPA is promulgating a deadline of June 1, 2011 for flagging data and providing initial event descriptions and for submitting documentation to justify exclusion of the flagged data. EPA believes that this deadline provides States with adequate time to review and identify potential exceptional events that occur in calendar year 2010, even for those events that might occur late in the year. EPA believes these deadlines will be feasible because experience suggests that exceptional events affecting SO_2 data are few in number and easily assessed, so no State is likely to have a large workload.

If a State intends 2011 data to be considered in SO_2 designations, 2011 data must be flagged and detailed event documentation submitted 60 days after the end of the calendar quarter in which the event occurred or by March 31, 2012, whichever date occurs first. Again, EPA believes these deadlines will be feasible because experience suggest that exceptional events affecting SO_2 data are few in number and easily assessed, so no State is likely to have a large workload.

Table 1 summarizes the designation deadlines discussed in this section and provides designation schedule information from recent, pending or prior NAAQS revisions for other pollutants. EPA is revising the final SO_2 exceptional event flagging and documentation submission deadlines accordingly to provide States with reasonably adequate opportunity to review, identify, and document exceptional events that may affect an area designation under a revised NAAQS.

TABLE 1—SCHEDULE FOR EXCEPTIONAL EVENT FLAGGING AND DOCUMENTATION SUBMISSION FOR DATA TO BE USED IN DESIGNATIONS DECISIONS FOR NEW OR REVISED NAAQS

NAAQS pollutant/standard/(level)/promulgation date	Air quality data collected for calendar year	Event flagging & initial description deadline	Detailed documentation submission deadline
$PM_{2.5}$/24-Hr Standard (35 µg/m^3) Promulgated October 17, 2006.	2004–2006	October 1, 2007 [a]	April 15, 2008 [a].
Ozone/8-Hr Standard (0.075 ppm) Promulgated March 12, 2008.	2005–2007	June 18, 2009 [a]	June 18, 2009 [a].
	2008	June 18, 2009 [a]	June 18, 2009 [a].
	2009	60 Days after the end of the calendar quarter in which the event occurred or February 5, 2010, whichever date occurs first [b].	60 Days after the end of the calendar quarter in which the event occurred or February 5, 2010, whichever date occurs first [b].
NO_2/1-Hour Standard (80–100 PPB, final level TBD).	2008	July 1, 2010 [a]	January 22, 2011 [a].
	2009	July 1, 2010 [a]	January 22, 2011 [a].
	2010	April 1, 2011 [a]	July 1, 2011 [a].
SO_2/1-Hour Standard (50–100 PPB, final level TBD).	2008	October 1, 2010 [b]	June 1, 2011 [b].
	2009	October 1, 2010 [b]	June 1, 2011 [b].
	2010	June 1, 2011 [b]	June 1, 2011 [b].
	2011	60 Days after the end of the calendar quarter in which the event occurred or March 31, 2012, whichever date occurs first [b].	60 Days after the end of the calendar quarter in which the event occurred or March 31, 2012, whichever date occurs first [b].

[a] These dates are unchanged from those published in the original rulemaking, and are shown in this table for informational purposes—the Agency is not opening these dates for comment under this rulemaking.
[b] Indicates change from general schedule in 40 CFR 50.14.
Note: EPA notes that the table of revised deadlines *only* applies to data EPA will use to establish the final initial designations for new or revised NAAQS. The general schedule applies for all other purposes, most notably, for data used by EPA for redesignations to attainment.

Note further that EPA is reprinting portions of this Table in section 5014 but, with respect to the pollutants other than SO_2, is doing so only for readers' convenience and is not reopening or otherwise reconsidering any aspect of the rules related to these other pollutants.

VIII. Communication of Public Health Information

Information on the public health implications of ambient concentrations of criteria pollutants is currently made available primarily through EPA's Air Quality Index (AQI) program. The current AQI has been in use since its inception in 1999 (64 FR 42530). It provides accurate, timely, and easily understandable information about daily levels of pollution (40 CFR 58.50). The AQI establishes a nationally uniform system of indexing pollution levels for nitrogen dioxide, carbon monoxide, ozone, particulate matter and SO_2. The AQI converts pollutant concentrations in a community's air to a number on a scale from 0 to 500. Reported AQI values enable the public to know whether air pollution levels in a particular location are characterized as good (0–50), moderate (51–100), unhealthy for sensitive groups (101–150), unhealthy (151–200), very unhealthy (201–300), or hazardous (300–500). The AQI index value of 100 typically corresponds to the level of the short-term primary NAAQS for each pollutant. An AQI value greater than 100 means that a pollutant is in one of the unhealthy categories (*i.e.,* unhealthy for sensitive groups, unhealthy, very unhealthy, or hazardous) on a given day; an AQI value at or below 100 means that a pollutant concentration is in one of the satisfactory categories (*i.e.,* moderate or good). Decisions about the pollutant concentrations at which to set the various AQI breakpoints, that delineate the various AQI categories, draw directly from the underlying health information that supports the review of the primary NAAQS.

The Agency recognizes the importance of revising the AQI in a timely manner to be consistent with any revisions to the primary NAAQS. Therefore, EPA proposed to finalize conforming changes to the AQI in connection with the Agency's final decision on the SO_2 NAAQS. Conforming changes that were proposed include setting the 100 level of the AQI at the same level as the revised primary SO_2 standard if a short-term primary standard was promulgated, and revising the other AQI breakpoints at the lower end of the AQI scale (*i.e.,* AQI values of 50 and 150). EPA did not propose to change breakpoints at the higher end of the AQI scale (from 200 to 500), which would apply to State contingency plans or the Significant Harm Level (40 CFR 51.16), because the information from this review does not inform decisions about breakpoints at those higher levels.

With regard to an AQI value of 50, the breakpoint between the good and moderate categories, historically this value is set at the level of the annual NAAQS, if there is one, or one-half the level of the short-term NAAQS in the absence of an annual NAAQS (63 FR 67823, Dec. 12, 1998). Taking into consideration this practice, EPA proposed to set the AQI value of 50 to be between 25 and 50 ppb SO_2, 1-hour average; stating that concentrations toward the lower end of this range would be appropriate if the standard was set at the lower end of the range of proposed standard levels, while concentrations toward the higher end of this range would be more appropriate if the standard was set at the higher end of the range of proposed standard levels. EPA solicited comments on this range for an AQI value of 50 and the appropriate basis for selecting an AQI value of 50.

With regard to an AQI value of 150, the breakpoint between the unhealthy for sensitive groups and unhealthy categories, historically values between the short-term standard and an AQI value of 500 are set at levels that are approximately equidistant between the AQI values of 100 and 500 unless there is health evidence that suggests a specific level would be appropriate (63 FR 67829, Dec. 12, 1998). For an AQI value of 150, EPA proposed to set the breakpoint within the range from 175 to 200 ppb SO_2, 1-hour average, since it represents the midpoint between the proposed range for the short-term standard and the level of an AQI value of 200 (300 ppb SO_2, 1-hour average).

EPA received few comments on the proposed breakpoints. Consistent with the level of the short-term primary SO_2 standard promulgated in this rule, EPA is setting the AQI value of 100, the breakpoint between the moderate and unhealthy for sensitive groups category, at 75 ppb, 1-hour average. EPA is setting the AQI value of 50, the breakpoint between the good and moderate categories, at 35 ppb SO_2, 1-hour average, which is approximately one-half the level of the new short-term standard, since the annual SO_2 standard is being revoked. EPA is setting the AQI value of 150, the breakpoint between the unhealthy for sensitive groups and unhealthy categories, at 185 ppb SO_2, 1-hour average, which represents the approximate midpoint between the level of the new short-term standard (75 ppb SO_2, 1-hour average) and the level of an AQI value of 200 (300 ppb SO_2, 1-hour average).

EPA received comments from several State environmental organizations and organizations of State and local air agencies about forecasting and reporting the AQI for SO_2. These commenters expressed the view that forecasting hourly SO_2 concentrations would be difficult. One commenter requested that EPA delay the forecasting requirement for one year and other agencies requested that EPA provide assistance in developing a forecast model. Another commenter expressed the view that it is impractical to incorporate SO_2 into its forecasting and public health notification program because SO_2 does not behave like a regional pollutant, and that exceedances may occur with little or no warning and for two hours or less. This commenter requested EPA consider the resources necessary for public communications at the State and local levels, particularly in areas where other air quality exceedances are relatively rare.

EPA recommends and encourages air quality forecasting but it is not required (64 FR 42548; August 4, 1999). We agree that there will be new challenges associated with creating and communicating an SO_2 forecast, and will work with State and local agencies that want to develop an SO_2 forecasting program on issues including, but not limited to, forecasting air quality for short time periods. We plan to work with State and local air agencies to figure out the best way to present this information to the public using the AQI.

With respect to the comment that it is impractical to incorporate SO_2 into a forecasting and public health notification program because SO_2 does not behave like a regional pollutant, this final rule departs from the proposed rule in that it allows for a combined monitoring and modeling approach. Because of this, the monitoring network is not required to be wholly source-oriented in nature. States have flexibility to allow required monitoring sites to serve multiple monitoring objectives including characterizing source impacts, highest concentrations, population exposure, background, and regional transport. Further, EPA expects that much of the existing network will be retained by States to satisfy the minimum monitoring requirements. This means that it is unlikely that AQI reporting and forecasting will be heavily driven by source-oriented monitors. Rather, many of the existing monitors (a majority of which are community-wide monitors) will remain in place, which prevents the need for new geographic regions to be delineated. With respect to concerns expressed about the resources required to report the AQI in areas were exceedances of the standard are very rare, Appendix G to Part 58 specifies that if the index value for a particular pollutant remains below 50 for a season or year, then a State or local agency may exclude the pollutant from the calculation of the AQI.

IX. Statutory and Executive Order Reviews

A. Executive Order 12866: Regulatory Planning and Review

Under section 3(f)(1) of Executive Order 12866 (58 FR 51735, October 4, 1993), this action is an "economically significant regulatory action" because it is likely to have an annual effect on the economy of $100 million or more. Accordingly, EPA submitted this action to the Office of Management and Budget (OMB) for review under EO 12866 and any changes made in response to OMB recommendations have been documented in the docket for this action. In addition, EPA prepared a Regulatory Impact Analysis (RIA) of the potential costs and benefits associated with this action. However, the CAA and judicial decisions make clear that the economic and technical feasibility of attaining the national ambient standards cannot be considered in setting or revising NAAQS, although such factors may be considered in the development of State implementation plans to implement the standards. Accordingly, although an RIA has been prepared, the results of the RIA have not been considered by EPA in developing this final rule.

When estimating the SO_2- and $PM_{2.5}$-related human health benefits and compliance costs in Table 2 below, EPA applied methods and assumptions consistent with the state-of-the-science for human health impact assessment, economics and air quality analysis. EPA applied its best professional judgment in performing this analysis and believes that these estimates provide a reasonable indication of the expected benefits and costs to the nation of the selected SO_2 standard and alternatives considered by the Agency. The Regulatory Impacts Analysis (RIA) available in the docket describes in detail the empirical basis for EPA's assumptions and characterizes the various sources of uncertainties affecting the estimates below.

EPA's 2009 Integrated Science Assessment for Particulate Matter concluded, based on the scientific literature, that a no-threshold log-linear model most adequately portrays the PM-mortality concentration-response relationship. Nonetheless, consistent with historical practice and our commitment to characterizing the uncertainty in our benefits estimates, EPA has included a sensitivity analysis with an assumed threshold in the PM-mortality health impact function in the RIA. EPA has included a sensitivity analysis in the RIA to help inform our understanding of the health benefits which can be achieved at lower air quality concentration levels. While the primary estimate and the sensitivity analysis are not directly comparable, due to differences in population data and use of different analysis years, as well as the difference in the assumption of a threshold in the sensitivity analysis, comparison of the two results provide a rough sense of the proportion of the health benefits that occur at lower $PM_{2.5}$ air quality levels. Using a threshold of 10 $\mu g/m^3$ is an arbitrary choice (EPA could have assumed 6, 8, or 12 $\mu g/m^3$ for the sensitivity analysis). Assuming a threshold of 10 $\mu g/m^3$, the sensitivity analysis shows that roughly one-third of the benefits occur at air quality levels below that threshold. Because the primary estimates reflect EPA's current methods and data, EPA notes that caution should be exercised when comparing the results of the primary and sensitivity analyses. EPA appreciates the value of sensitivity analyses in highlighting the uncertainty in the benefits estimates and will continue to work to refine these analyses, particularly in those instances in which air quality modeling data are available.

Table 2 shows the results of the cost and benefits analysis for each standard alternative. As indicated above, implementation of the SO_2 control measures identified from AirControlNET and other sources does not result in attainment with the all target NAAQS levels in several areas. In these areas, additional unspecified emission reductions might be necessary to reach some alternative standard levels. The first part of the table, labeled *Partial attainment (identified controls),* shows only those benefits and costs from control measures we were able to identify. The second part of the table, labeled *Unidentified Controls,* shows only additional benefits and costs resulting from unidentified controls. The third part of the table, labeled *Full attainment,* shows total benefits and costs resulting from both identified and unidentified controls. It is important to emphasize that we were able to identify control measures for a significant portion of attainment for many of those counties that would not fully attain the target NAAQS level with identified controls. Note also that in addition to separating full and partial attainment, the table also separates the portion of benefits associated with reduced SO_2 exposure (*i.e.,* SO_2 benefits) from the additional benefits associated with reducing SO_2 emissions, which are precursors to $PM_{2.5}$ formation—(*i.e.,* the $PM_{2.5}$ co-benefits). For instance, for the selected standard of 75 ppb, $2.2 million in benefits are associated with reduced SO_2 exposure while $15 billion to $37 billion are associated with reduced $PM_{2.5}$ exposure.

TABLE 2—MONETIZED BENEFITS AND COSTS TO ATTAIN ALTERNATE STANDARD LEVELS IN 2020

[Millions of 2006$] [a]

	Number of counties fully controlled	Discount rate (percent)	Monetized SO_2 benefits	Monetized $PM_{2.5}$ co-benefits,[c,d]	Costs	Net benefits
Partial Attainment (identified controls)						
50 ppb	40	3	[b]	$30,000 to $74,000	$2,600	$27,000 to $71,000.
		7		$28,000 to $67,000		$25,000 to $64,000.
75 ppb	20	3	[b]	$14,000 to $35,000	$960	$13,000 to $34,000.
		7		$13,000 to $31,000		$12,000 to $30,000.
100 ppb	6	3	[b]	$6,900 to $17,000	$470	$6,400 to $17,000.
		7		$6,200 to $15,000		$5,700 to $15,000.
Unidentified Controls						
50 ppb	16	3	[b]	$4,000 to $9,000	$1,800	$2,200 to $7,200.
		7		$3,000 to $8,000		$1,200 to $6,200.
75 ppb	4	3	[b]	$1,000 to $3,000	$500	$500 to $1,500.
		7		$1,000 to $3,000		$500 to $2,500.
100 ppb	3	3	[b]	$500 to $1,000	$260	$240 to $740.
		7		$500 to $1,000		$240 to $740.
Full Attainment						
50 ppb	56	3	$8.50	$34,000 to $83,000	$4,400	$30,000 to $79,000.
		7		$31,000 to $75,000		$27,000 to $71,000.
75 ppb	24	3	$2.20	$15,000 to $37,000	$1,500	$14,000 to $36,000
		7		$14,000 to $34,000		$13,000 to $33,000.
100 ppb	9	3	$0.60	$7,400 to $18,000	$730	$6,700 to $17,000.
		7		$6,700 to $16,000		$6,000 to $15,000.

[a] Estimates have been rounded to two significant figures and therefore summation may not match table estimates.

[b] The approach used to simulate air quality changes for SO_2 did not provide the data needed to distinguish partial attainment benefits from full attainment benefits from reduced SO_2 exposure. Therefore, a portion of the SO_2 benefits is attributable to the known controls and a portion of the SO_2 benefits are attributable to the unidentified controls. Because all SO_2-related benefits are short-term effects, the results are identical for all discount rates.

[c] Benefits are shown as a range from Pope *et al.* (2002) to Laden *et al.* (2006). Monetized benefits do not include unquantified benefits, such as other health effects, reduced sulfur deposition, or improvements in visibility.

[d] These models assume that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality because there is no clear scientific evidence that would support the development of differential effects estimates by particle type. Reductions in SO_2 emissions from multiple sectors to meet the SO_2 NAAQS would primarily reduce the sulfate fraction of $PM_{2.5}$. Because this rule targets a specific particle precursor (*i.e.,* SO_2), this introduces some uncertainty into the results of the analysis.

B. Paperwork Reduction Act

The information collection requirements in this final rule have been submitted for approval to the Office of Management and Budget (OMB) under the Paperwork Reduction Act, 44 U.S.C. 3501 *et seq.* The Information Collection Request (ICR) document prepared by EPA for these revisions to part 58 has been assigned EPA ICR number 2370.02. The information collected under 40 CFR part 53 (*e.g.,* test results, monitoring records, instruction manual, and other associated information) is needed to determine whether a candidate method intended for use in determining attainment of the NAAQS in 40 CFR part 50 will meet the design, performance, and/or comparability requirements for designation as a Federal reference method (FRM) or Federal equivalent method (FEM). We do not expect the number of FRM or FEM determinations to increase over the number that is currently used to estimate burden associated with SO_2 FRM/FEM determinations provided in the current ICR for 40 CFR part 53 (EPA ICR numbers 2370.01). As such, no change in the burden estimate for 40 CFR part 53 has been made as part of this rulemaking.

The information collected and reported under 40 CFR part 58 is needed to determine compliance with the NAAQS, to characterize air quality and associated health impacts, to develop emissions control strategies, and to measure progress for the air pollution program. The amendments would revise the technical requirements for SO_2 monitoring sites, require the siting and operation of additional SO_2 ambient air monitors, and the reporting of the collected ambient SO_2 monitoring data to EPA's Air Quality System (AQS). The ICR is estimated to involve 102 respondents for a total approximate cost of $15,203,762 (total capital, and labor and non-labor operation and maintenance) and a total burden of 207,662 hours. The labor costs associated with these hours is $11,130,409. Included in the $15,203,762 total are other costs of other non-labor operations and maintenance of $1,104,377 and equipment and contract costs of $2,968,975. In addition to the costs at the State and local air quality management agencies, there is a burden to EPA for a total of 14,749 hours and $1,060,621. Burden is defined at 5 CFR 1320.3(b). State, local, and Tribal entities are eligible for State assistance grants provided by the Federal government under the CAA which can be used for monitors and related activities. An agency may not conduct or sponsor, and a person is not required to respond to, a collection of information unless it displays a currently valid OMB control number. The OMB control numbers for EPA's regulations in 40 CFR are listed in 40 CFR part 9.

C. Regulatory Flexibility Act

The Regulatory Flexibility Act (RFA) generally requires an agency to prepare a regulatory flexibility analysis of any rule subject to notice and comment rulemaking requirements under the Administrative Procedure Act or any other statute unless the agency certifies that the rule will not have a significant economic impact on a substantial number of small entities. Small entities include small businesses, small organizations, and small governmental jurisdictions.

For purposes of assessing the impacts of this rule on small entities, small entity is defined as: (1) A small business that is a small industrial entity as defined by the Small Business Administration's (SBA) regulations at 13 CFR 121.201; (2) a small governmental jurisdiction that is a government of a city, county, town, school district or special district with a population of less than 50,000; and (3) a small organization that is any not-for-profit enterprise which is independently owned and operated and is not dominant in its field.

After considering the economic impacts of this final rule on small entities, I certify that this action will not have a significant economic impact on a substantial number of small entities. This final rule will not impose any requirements on small entities. Rather, this rule establishes national standards for allowable concentrations of SO_2 in ambient air as required by section 109 of the CAA. *American Trucking Ass'ns* v. *EPA,* 175 F.3d 1027, 1044–45 (DC Cir. 1999) (NAAQS do not have significant impacts upon small entities because NAAQS themselves impose no regulations upon small entities). Similarly, the amendments to 40 CFR Part 58 address the requirements for States to collect information and report compliance with the NAAQS and will not impose any requirements on small entities.

D. Unfunded Mandates Reform Act

This action is not subject to the requirements of sections 202 and 205 of the UMRA. EPA has determined that this final rule does not contain a Federal mandate that may result in expenditures of $100 million or more for State, local, and Tribal governments, in the aggregate, or the private sector in any one year. The revisions to the SO_2 NAAQS impose no enforceable duty on any State, local or Tribal governments or the private sector. The expected costs associated with the monitoring requirements are described in EPA's ICR document, but those costs are not expected to exceed $100 million in the aggregate for any year. Furthermore, as indicated previously, in setting a NAAQS, EPA cannot consider the economic or technological feasibility of attaining ambient air quality standards. Because the CAA prohibits EPA from considering the types of estimates and assessments described in section 202 when setting the NAAQS, the UMRA does not require EPA to prepare a written statement under section 202 for the revisions to the SO_2 NAAQS.

With regard to implementation guidance, the CAA imposes the obligation for States to submit SIPs to implement the SO_2 NAAQS. In this final rule, EPA is merely providing an interpretation of those requirements. However, even if this rule did establish an independent obligation for States to submit SIPs, it is questionable whether an obligation to submit a SIP revision would constitute a Federal mandate in any case. The obligation for a State to submit a SIP that arises out of section 110 and section 191 of the CAA is not legally enforceable by a court of law, and at most is a condition for continued receipt of highway funds. Therefore, it is possible to view an action requiring such a submittal as not creating any enforceable duty within the meaning of U.S.C. 658 for purposes of the UMRA. Even if it did, the duty could be viewed as falling within the exception for a condition of Federal assistance under U.S.C. 658.

EPA has determined that this final rule contains no regulatory requirements that might significantly or uniquely affect small governments because it imposes no enforceable duty on any small governments. Therefore, this rule is not subject to the requirements of section 203 of the UMRA.

E. Executive Order 13132: Federalism

This final rule does not have federalism implications. It will not have substantial direct effects on the States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government, as specified in Executive Order 13132. The rule does not alter the relationship between the Federal government and the States regarding the establishment and implementation of air quality improvement programs as codified in the CAA. Under section 109 of the CAA, EPA is mandated to establish NAAQS; however, CAA section 116 preserves the rights of States to establish more stringent requirements if deemed necessary by a State. Furthermore, this rule does not impact CAA section 107 which establishes that the States have primary responsibility for implementation of the NAAQS. Finally, as noted in section E (above) on UMRA, this rule does not impose significant costs on State, local, or Tribal governments or the private sector. Thus, Executive Order 13132 does not apply to this rule.

F. Executive Order 13175: Consultation and Coordination With Indian Tribal Governments

Executive Order 13175, entitled "Consultation and Coordination with Indian Tribal Governments" (65 FR 67249, November 9, 2000), requires EPA to develop an accountable process to ensure "meaningful and timely input by Tribal officials in the development of regulatory policies that have Tribal implications." This final rule does not have Tribal implications, as specified in Executive Order 13175. It does not have a substantial direct effect on one or more Indian Tribes, on the relationship between the Federal government and Indian Tribes, or on the distribution of power and responsibilities between the

Federal government and Tribes. The rule does not alter the relationship between the Federal government and Tribes as established in the CAA and the TAR. Under section 109 of the CAA, EPA is mandated to establish NAAQS; however, this rule does not infringe existing Tribal authorities to regulate air quality under their own programs or under programs submitted to EPA for approval. Furthermore, this rule does not affect the flexibility afforded to Tribes in seeking to implement CAA programs consistent with the TAR, nor does it impose any new obligation on Tribes to adopt or implement any NAAQS. Finally, as noted in section E (above) on UMRA, this rule does not impose significant costs on Tribal governments. Thus, Executive Order 13175 does not apply to this rule.

G. Executive Order 13045: Protection of Children From Environmental Health and Safety Risks

This action is subject to Executive Order (62 FR 19885, April 23, 1997) because it is an economically significant regulatory action as defined by Executive Order 12866, and we believe that the environmental health risk addressed by this action has a disproportionate effect on children. The final rule will establish uniform national ambient air quality standards for SO_2; these standards are designed to protect public health with an adequate margin of safety, as required by CAA section 109. The protection offered by these standards may be especially important for asthmatics, including asthmatic children, because respiratory effects in asthmatics are among the most sensitive health endpoints for SO_2 exposure. Because asthmatic children are considered a sensitive population, we have evaluated the potential health effects of exposure to SO_2 pollution among asthmatic children. These effects and the size of the population affected are discussed in chapters 3 and 4 of the ISA; chapters 3, 4, 7, 8, 9 of the REA, and sections II.A through II.E of this preamble.

H. Executive Order 13211: Actions That Significantly Affect Energy Supply, Distribution or Use

This rule is not a "significant energy action" as defined in Executive Order 13211, "Actions Concerning Regulations That Significantly Affect Energy Supply, Distribution, or Use" (66 FR 28355; May 22, 2001) because it is not likely to have a significant adverse effect on the supply, distribution, or use of energy. The purpose of this rule is to establish revised NAAQS for SO_2. The rule does not prescribe specific control strategies by which these ambient standards will be met. Such strategies will be developed by States on a case-by-case basis, and EPA cannot predict whether the control options selected by States will include regulations on energy suppliers, distributors, or users. Thus, EPA concludes that this rule is not likely to have any adverse energy effects.

I. National Technology Transfer and Advancement Act

Section 12(d) of the National Technology Transfer and Advancement Act of 1995 (NTTAA), Public Law 104–113, section 12(d) (15 U.S.C. 27) directs EPA to use voluntary consensus standards in its regulatory activities unless to do so would be inconsistent with applicable law or otherwise impractical. Voluntary consensus standards are technical standards (*e.g.,* materials specifications, test methods, sampling procedures, and business practices) that are developed or adopted by voluntary consensus standards bodies. The NTTAA directs EPA to provide Congress, through OMB, explanations when the Agency decides not to use available and applicable voluntary consensus standards.

This final rulemaking involves technical standards with regard to ambient monitoring of SO_2. The use of this voluntary consensus standard would be impractical because the analysis method does not provide for the method detection limits necessary to adequately characterize ambient SO_2 concentrations for the purpose of determining compliance with the final revisions to the SO_2 NAAQS.

J. Executive Order 12898: Federal Actions To Address Environmental Justice in Minority Populations and Low-Income Populations

Executive Order 12898 (59 FR 7629; Feb. 16, 1994) establishes Federal executive policy on environmental justice. Its main provision directs Federal agencies, to the greatest extent practicable and permitted by law, to make environmental justice part of their mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of their programs, policies, and activities on minority populations and low-income populations in the United States.

EPA has determined that this final rule will not have disproportionately high and adverse human health or environmental effects on minority or low-income populations because it increases the level of environmental protection for all affected populations without having any disproportionately high and adverse human health effects on any population, including any minority or low-income population. The final rule will establish uniform national standards for SO_2 in ambient air.

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List of Subjects

40 CFR Part 50

Environmental protection, Air pollution control, Carbon monoxide, Lead, Nitrogen dioxide, Ozone, Particulate matter, Sulfur oxides.

40 CFR Part 53

Environmental protection, Administrative practice and procedure, Air pollution control, Intergovernmental relations, Reporting and recordkeeping requirements.

40 CFR Part 58

Environmental protection, Administrative practice and procedure, Air pollution control, Intergovernmental relations, Reporting and recordkeeping requirements.

Dated: June 2, 2010.

Lisa P. Jackson,

Administrator.

■ For the reasons stated in the preamble, title 40, chapter I of the Code of Federal Regulations is amended as follows:

PART 50—NATIONAL PRIMARY AND SECONDARY AMBIENT AIR QUALITY STANDARDS

■ 1. The authority citation for part 50 continues to read as follows:

Authority: 42 U.S.C. 7401, *et seq.*

■ 2. Section 50.4 is amended by adding paragraph (e) to read as follows:

§ 50.4 National primary ambient air quality standards for sulfur oxides (sulfur dioxide).

* * * * *

(e) The standards set forth in this section will remain applicable to all areas notwithstanding the promulgation of SO_2 national ambient air quality standards (NAAQS) in § 50.17. The SO_2 NAAQS set forth in this section will no longer apply to an area one year after the effective date of the designation of that area, pursuant to section 107 of the Clean Air Act, for the SO_2 NAAQS set forth in § 50. 17; except that for areas designated nonattainment for the SO_2 NAAQS set forth in this section as of the effective date of § 50. 17, and areas not meeting the requirements of a SIP call with respect to requirements for the SO_2 NAAQS set forth in this section, the SO_2 NAAQS set forth in this section will apply until that area submits, pursuant to section 191 of the Clean Air Act, and EPA approves, an implementation plan providing for attainment of the SO_2 NAAQS set forth in § 50.17.

■ 3. Section 50.14 is amended by revising paragraph (c)(2)(vi) to read as follows:

§ 50.14 Treatment of air quality monitoring data influenced by exceptional events.

* * * * *

(c) * * *

(2) * * *

(vi) When EPA sets a NAAQS for a new pollutant or revises the NAAQS for an existing pollutant, it may revise or set a new schedule for flagging exceptional event data, providing initial data descriptions and providing detailed data documentation in AQS for the initial designations of areas for those NAAQS. Table 1 provides the schedule for submission of flags with initial descriptions in AQS and detailed documentation. These schedules shall apply for those data which will or may influence the initial designation of areas for those NAAQS. EPA anticipates revising Table 1 as necessary to accommodate revised data submission schedules for new or revised NAAQS.

TABLE 1—SCHEDULE OF EXCEPTIONAL EVENT FLAGGING AND DOCUMENTATION SUBMISSION FOR DATA TO BE USED IN DESIGNATIONS DECISIONS FOR NEW OR REVISED NAAQS

NAAQS Pollutant/standard/(level)/promulgation date	Air quality data collected for calendar year	Event flagging & initial description deadline	Detailed documentation submission deadline
$PM_{2.5}$/24-Hr Standard (35 µg/m3) Promulgated October 17, 2006.	2004–2006	October 1, 2007[a]	April 15, 2008.[a]
Ozone/8-Hr Standard (0.075 ppm) Promulgated March 12, 2008.	2005–2007	June 18, 2009[a]	June 18, 2009[a]
	2008	June 18, 2009[a]	June 18, 2009[1]
	2009	60 days after the end of the calendar quarter in which the event occurred or February 5, 2010, whichever date occurs first[b].	60 days after the end of the calendar quarter in which the event occurred or February 5, 2010, whichever date occurs first.[b]
NO_2/1-Hour Standard (80–100 PPB, final level TBD).	2008	July 1, 2010[a]	January 22, 2011.[a]
	2009	July 1, 2010[a]	January 22, 2011.[a]
	2010	April 1, 2011[a]	July 1, 2010.[a]
SO_2/1-Hour Standard (50–100 PPB, final level TBD).	2008	October 1, 2010[b]	June 1, 2011.[b]
	2009	October 1, 2010[b]	June 1, 2011.[b]
	2010	June 1, 2011.[b]	June 1, 2011.[b]
	2011	60 days after the end of the calendar quarter in which the event occurred or March 31, 2012, whichever date occurs first[b].	60 days after the end of the calendar quarter in which the event occurred or March 31, 2012, whichever date occurs first.[b]

[a] These dates are unchanged from those published in the original rulemaking, or are being proposed elsewhere and are shown in this table for informational purposes—the Agency is not opening these dates for comment under this rulemaking.
[b] Indicates change from general schedule in 40 CFR 50.14.

Note: EPA notes that the table of revised deadlines *only* applies to data EPA will use to establish the final initial designations for new or revised NAAQS. The general schedule applies for all other purposes, most notably, for data used by EPA for redesignations to attainment.

* * * * *

■ 4. A new 50.17 is added to read as follows:

§ 50.17 National primary ambient air quality standards for sulfur oxides (sulfur dioxide).

(a) The level of the national primary 1-hour annual ambient air quality standard for oxides of sulfur is 75 parts per billion (ppb, which is 1 part in 1,000,000,000), measured in the ambient air as sulfur dioxide (SO_2).

(b) The 1-hour primary standard is met at an ambient air quality monitoring site when the three-year average of the annual (99th percentile) of the daily maximum 1-hour average concentrations is less than or equal to 75 ppb, as determined in accordance with Appendix T of this part.

(c) The level of the standard shall be measured by a reference method based on Appendix A or A–1 of this part, or by a Federal Equivalent Method (FEM) designated in accordance with part 53 of this chapter.

■ 5. Add Appendix A–1 to Part 50 to read as follows:

Appendix A–1 to Part 50—Reference Measurement Principle and Calibration Procedure for the Measurement of Sulfur Dioxide in the Atmosphere (Ultraviolet Fluorescence Method)

1.0 Applicability

1.1 This ultraviolet fluorescence (UVF) method provides a measurement of the concentration of sulfur dioxide (SO_2) in ambient air for determining compliance with the national primary and secondary ambient air quality standards for sulfur oxides (sulfur dioxide) as specified in § 50.4, § 50.5, and § 50.17 of this chapter. The method is applicable to the measurement of ambient SO_2 concentrations using continuous (real-time) sampling. Additional quality assurance procedures and guidance are provided in part 58, Appendix A, of this chapter and in Reference 3.

2.0 Principle

2.1 This reference method is based on automated measurement of the intensity of the characteristic fluorescence released by SO_2 in an ambient air sample contained in a measurement cell of an analyzer when the air sample is irradiated by ultraviolet (UV) light passed through the cell. The fluorescent light released by the SO_2 is also in the ultraviolet region, but at longer wavelengths than the excitation light. Typically, optimum instrumental measurement of SO_2 concentrations is obtained with an excitation wavelength in a band between approximately 190 to 230 nm, and measurement of the SO_2 fluorescence in a broad band around 320 nm, but these wavelengths are not necessarily constraints of this reference method. Generally, the measurement system (analyzer) also requires means to reduce the effects of aromatic hydrocarbon species, and possibly other compounds, in the air sample to control measurement interferences from these compounds, which may be present in the ambient air. References 1 and 2 describe UVF method.

2.2 The measurement system is calibrated by referencing the instrumental fluorescence measurements to SO_2 standard concentrations traceable to a National Institute of Standards and Technology (NIST) primary standard for SO_2 (*see* Calibration Procedure below).

2.3 An analyzer implementing this measurement principle is shown schematically in Figure 1. Designs should include a measurement cell, a UV light source of appropriate wavelength, a UV detector system with appropriate wave length sensitivity, a pump and flow control system for sampling the ambient air and moving it into the measurement cell, sample air conditioning components as necessary to minimize measurement interferences, suitable control and measurement processing capability, and other apparatus as may be necessary. The analyzer must be designed to provide accurate, repeatable, and continuous measurements of SO_2 concentrations in ambient air, with measurement performance as specified in Subpart B of Part 53 of this chapter.

2.4 *Sampling considerations:* The use of a particle filter on the sample inlet line of a UVF SO_2 analyzer is required to prevent interference, malfunction, or damage due to particles in the sampled air.

3.0 Interferences

3.1 The effects of the principal potential interferences may need to be mitigated to meet the interference equivalent requirements of part 53 of this chapter. Aromatic hydrocarbons such as xylene and naphthalene can fluoresce and act as strong positive interferences. These gases can be removed by using a permeation type scrubber (hydrocarbon "kicker"). Nitrogen oxide (NO) in high concentrations can also fluoresce and cause positive interference. Optical filtering can be employed to improve the rejection of interference from high NO. Ozone can absorb UV light given off by the SO_2 molecule and cause a measurement offset. This effect can be reduced by minimizing the measurement path length between the area where SO_2 fluorescence occurs and the photomultiplier tube detector (*e.g.* <5 cm). A hydrocarbon scrubber, optical filter and appropriate distancing of the measurement path length may be required method components to reduce interference.

4.0 Calibration Procedure

Atmospheres containing accurately known concentrations of sulfur dioxide are prepared using a compressed gas transfer standard diluted with accurately metered clean air flow rates.

4.1 *Apparatus:* Figure 2 shows a typical generic system suitable for diluting a SO_2 gas cylinder concentration standard with clean air through a mixing chamber to produce the desired calibration concentration standards. A valve may be used to conveniently divert the SO_2 from the sampling manifold to provide clean zero air at the output manifold for zero adjustment. The system may be made up using common laboratory components, or it may be a commercially manufactured system. In either case, the principle components are as follows:

4.1.1 SO_2 standard gas flow control and measurement devices (or a combined device) capable of regulating and maintaining the standard gas flow rate constant to within ±2 percent and measuring the gas flow rate accurate to within ±2, properly calibrated to a NIST-traceable standard.

4.1.2 Dilution air flow control and measurement devices (or a combined device) capable of regulating and maintaining the air flow rate constant to within ±2 percent and measuring the air flow rate accurate to within ±2, properly calibrated to a NIST-traceable standard.

4.1.3 Mixing chamber, of an inert material such as glass and of proper design to provide thorough mixing of pollutant gas and diluent air streams.

4.1.4 Sampling manifold, constructed of glass, polytetrafluoroethylene (PTFE Teflon™), or other suitably inert material and of sufficient diameter to insure a minimum pressure drop at the analyzer connection, with a vent designed to insure a minimum over-pressure (relative to ambient air pressure) at the analyzer connection and to prevent ambient air from entering the manifold.

4.1.5 Standard gas pressure regulator, of clean stainless steel with a stainless steel diaphragm, suitable for use with a high pressure SO_2 gas cylinder.

4.1.6 Reagents

4.1.6.1 SO_2 gas concentration transfer standard having a certified SO_2 concentration of not less than 10 ppm, in N_2, traceable to a NIST Standard Reference Material (SRM).

4.1.6.2 Clean zero air, free of contaminants that could cause a detectable response or a change in sensitivity of the analyzer. Since ultraviolet fluorescence analyzers may be sensitive to aromatic hydrocarbons and O_2-to-N_2 ratios, it is important that the clean zero air contains less than 0.1 ppm aromatic hydrocarbons and O_2 and N_2 percentages approximately the same as in ambient air. A procedure for generating zero air is given in reference 1.

4.2 Procedure

4.2.1 Obtain a suitable calibration apparatus, such as the one shown schematically in Figure 1, and verify that all materials in contact with the pollutant are of glass, Teflon™, or other suitably inert material and completely clean.

4.2.2 Purge the SO_2 standard gas lines and pressure regulator to remove any residual air.

4.2.3 Ensure that there are no leaks in the system and that the flow measuring devices are properly and accurately calibrated under the conditions of use against a reliable volume or flow rate standard such as a soap-bubble meter or a wet-test meter traceable to a NIST standard. All volumetric flow rates should be corrected to the same reference temperature and pressure by using the formula below:

$$F_c = F_m \frac{298.15 P_m}{760\left(T_m + 273.15\right)}$$

Where:

F_c = corrected flow rate (L/min at 25 °C and 760 mm Hg),
F_m = measured flow rate, (at temperature, T_m and pressure, P_m),
P_m = measured pressure in mm Hg, (absolute), and
T_m = measured temperature in degrees Celsius.

4.2.4 Allow the SO_2 analyzer under calibration to sample zero air until a stable response is obtained, then make the proper zero adjustment.

4.2.5 Adjust the airflow to provide an SO_2 concentration of approximately 80 percent of the upper measurement range limit of the SO_2 instrument and verify that the total air flow of the calibration system exceeds the demand of all analyzers sampling from the output manifold (with the excess vented).

4.2.6 Calculate the actual SO_2 calibration concentration standard as:

$$[SO_2] = C\frac{F_p}{F_t}$$

Where:

C = the concentration of the SO_2 gas standard
F_p = the flow rate of SO_2 gas standard
F_t = the total air flow rate of pollutant and diluent gases

4.2.7 When the analyzer response has stabilized, adjust the SO_2 span control to obtain the desired response equivalent to the calculated standard concentration. If substantial adjustment of the span control is needed, it may be necessary to re-check the zero and span adjustments by repeating steps 4.2.4 through 4.2.7 until no further adjustments are needed.

4.2.8 Adjust the flow rate(s) to provide several other SO_2 calibration concentrations over the analyzer's measurement range. At least five different concentrations evenly spaced throughout the analyzer's range are suggested.

4.2.9 Plot the analyzer response (vertical or Y-axis) versus SO_2 concentration (horizontal or X-axis). Compute the linear regression slope and intercept and plot the regression line to verify that no point deviates from this line by more than 2 percent of the maximum concentration tested.

Note: Additional information on calibration and pollutant standards is provided in Section 12 of Reference 3.

5.0 Frequency of Calibration

The frequency of calibration, as well as the number of points necessary to establish the calibration curve and the frequency of other performance checking will vary by analyzer; however, the minimum frequency, acceptance criteria, and subsequent actions are specified in Reference 3, Appendix D: Measurement Quality Objectives and Validation Template for SO_2 (page 9 of 30). The user's quality control program should provide guidelines for initial establishment of these variables and for subsequent alteration as operational experience is accumulated. Manufacturers of analyzers should include in their instruction/operation manuals information and guidance as to these variables and on other matters of operation, calibration, routine maintenance, and quality control.

6.0 References for SO_2 Method

1. H. Okabe, P. L. Splitstone, and J. J. Ball, "Ambient and Source SO_2 Detector Based on a Fluorescence Method", *Journal of the Air Control Pollution Association,* vol. 23, p. 514–516 (1973).
2. F. P. Schwarz, H. Okabe, and J. K. Whittaker, "Fluorescence Detection of Sulfur Dioxide in Air at the Parts per Billion Level," *Analytical Chemistry,* vol. 46, pp. 1024–1028 (1974).
3. *QA Handbook for Air Pollution Measurement Systems—Volume II. Ambient Air Quality Monitoring Programs.* U.S. EPA. EPA–454/B–08–003 (2008).

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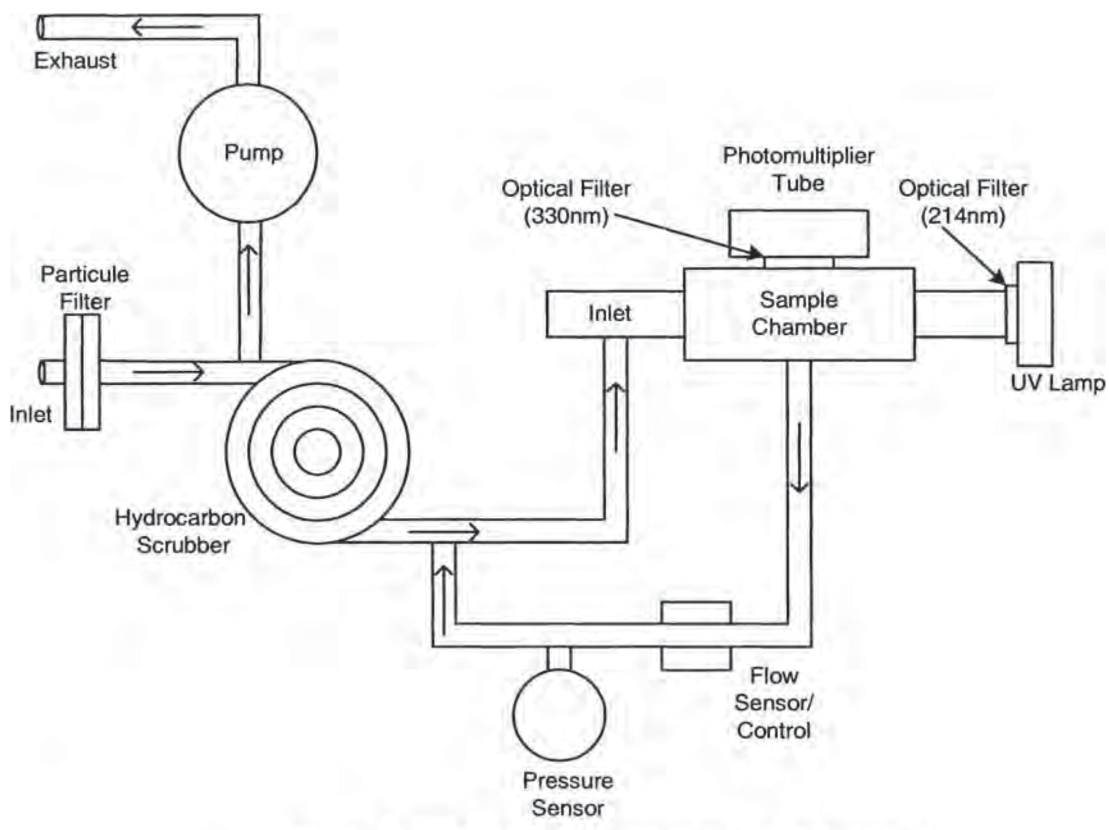

Figure 1. UVF SO_2 analyzer schematic diagram.

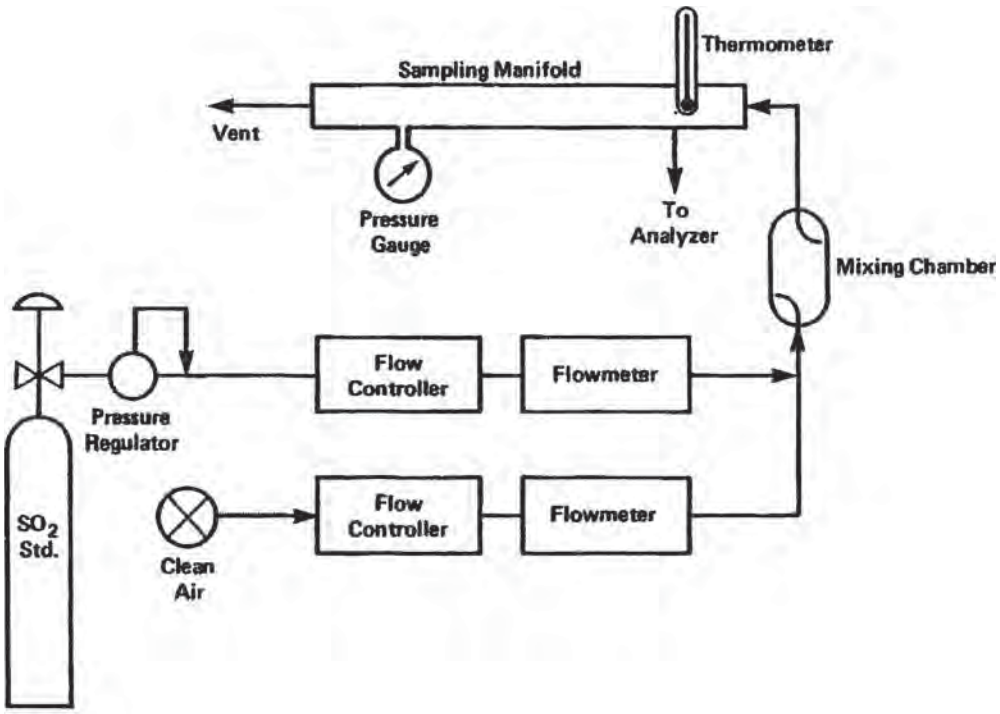

Figure 2. Calibration system using a compressed gas standard.

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■ 6. Appendix A to Part 50 is redesignated as Appendix A–2 to Part 50.

■ 7. Appendix T to Part 50 is added to read as follows:

Appendix T to Part 50—Interpretation of the Primary National Ambient Air Quality Standards for Oxides of Sulfur (Sulfur Dioxide)

1. General

(a) This appendix explains the data handling conventions and computations necessary for determining when the primary national ambient air quality standards for Oxides of Sulfur as measured by Sulfur Dioxide ("SO_2 NAAQS") specified in § 50.17 are met at an ambient air quality monitoring site. Sulfur Dioxide (SO_2) is measured in the ambient air by a Federal reference method (FRM) based on appendix A or A–1 to this part or by a Federal equivalent method (FEM) designated in accordance with part 53 of this chapter. Data handling and computation procedures to be used in making comparisons between reported SO_2 concentrations and the levels of the SO_2 NAAQS are specified in the following sections.

(b) Decisions to exclude, retain, or make adjustments to the data affected by exceptional events, including natural events, are made according to the requirements and process deadlines specified in §§ 50.1, 50.14 and 51.930 of this chapter.

(c) The terms used in this appendix are defined as follows:

Daily maximum 1-hour values for SO_2 refers to the maximum 1-hour SO_2 concentration values measured from midnight to midnight (local standard time) that are used in NAAQS computations.

Design values are the metrics (*i.e.,* statistics) that are compared to the NAAQS levels to determine compliance, calculated as specified in section 5 of this appendix. The design value for the primary 1-hour NAAQS is the 3-year average of annual 99th percentile daily maximum 1-hour values for a monitoring site (referred to as the "1-hour primary standard design value").

99th percentile daily maximum 1-hour value is the value below which nominally 99 percent of all daily maximum 1-hour concentration values fall, using the ranking and selection method specified in section 5 of this appendix.

Pollutant Occurrence Code (POC) refers to a numerical code (1, 2, 3, *etc.*) used to distinguish the data from two or more monitors for the same parameter at a single monitoring site.

Quarter refers to a calendar quarter.

Year refers to a calendar year.

2. Requirements for Data Used for Comparisons With the SO_2 NAAQS and Data Reporting Considerations

(a) All valid FRM/FEM SO_2 hourly data required to be submitted to EPA's Air Quality System (AQS), or otherwise available to EPA, meeting the requirements of part 58 of this chapter including appendices A, C, and E shall be used in design value calculations. Multi-hour average concentration values collected by wet chemistry methods shall not be used.

(b) Data from two or more monitors from the same year at the same site reported to EPA under distinct Pollutant Occurrence Codes shall not be combined in an attempt to meet data completeness requirements. The Administrator will combine annual 99th percentile daily maximum concentration values from different monitors in different years, selected as described here, for the purpose of developing a valid 1-hour primary standard design value. If more than one of the monitors meets the completeness requirement for all four quarters of a year, the steps specified in section 5(a) of this appendix shall be applied to the data from the monitor with the highest average of the four quarterly completeness values to derive a valid annual 99th percentile daily maximum concentration. If no monitor is complete for all four quarters in a year, the steps specified in section 3(c) and 5(a) of this appendix shall be applied to the data from the monitor with the highest average of the four quarterly completeness values in an attempt to derive a valid annual 99th percentile daily maximum concentration. This paragraph does not prohibit a monitoring agency from making a local designation of one physical monitor as the primary monitor for a Pollutant Occurrence Code and substituting the 1-hour data from a second physical monitor whenever a valid concentration value is not obtained from the primary monitor; if a monitoring agency substitutes data in this manner, each substituted value must be accompanied by an

AQS qualifier code indicating that substitution with a value from a second physical monitor has taken place.

(c) Hourly SO_2 measurement data shall be reported to AQS in units of parts per billion (ppb), to at most one place after the decimal, with additional digits to the right being truncated with no further rounding.

3. Comparisons With the 1-Hour Primary SO_2 NAAQS

(a) The 1-hour primary SO_2 NAAQS is met at an ambient air quality monitoring site when the valid 1-hour primary standard design value is less than or equal to 75 parts per billion (ppb).

(b) An SO_2 1-hour primary standard design value is valid if it encompasses three consecutive calendar years of complete data. A year meets data completeness requirements when all 4 quarters are complete. A quarter is complete when at least 75 percent of the sampling days for each quarter have complete data. A sampling day has complete data if 75 percent of the hourly concentration values, including State-flagged data affected by exceptional events which have been approved for exclusion by the Administrator, are reported.

(c) In the case of one, two, or three years that do not meet the completeness requirements of section 3(b) of this appendix and thus would normally not be useable for the calculation of a valid 3-year 1-hour primary standard design value, the 3-year 1-hour primary standard design value shall nevertheless be considered valid if one of the following conditions is true.

(i) At least 75 percent of the days in each quarter of each of three consecutive years have at least one reported hourly value, and the design value calculated according to the procedures specified in section 5 is above the level of the primary 1-hour standard.

(ii) (A) A 1-hour primary standard design value that is equal to or below the level of the NAAQS can be validated if the substitution test in section 3(c)(ii)(B) results in a "test design value" that is below the level of the NAAQS. The test substitutes actual "high" reported daily maximum 1-hour values from the same site at about the same time of the year (specifically, in the same calendar quarter) for unknown values that were not successfully measured. *Note* that the test is merely diagnostic in nature, intended to confirm that there is a very high likelihood that the original design value (the one with less than 75 percent data capture of hours by day and of days by quarter) reflects the true under-NAAQS-level status for that 3-year period; the result of this data substitution test (the "test design value", as defined in section 3(c)(ii)(B)) is not considered the actual design value. For this test, substitution is permitted only if there are at least 200 days across the three matching quarters of the three years under consideration (which is about 75 percent of all possible daily values in those three quarters) for which 75 percent of the hours in the day, including State-flagged data affected by exceptional events which have been approved for exclusion by the Administrator, have reported concentrations. However, maximum 1-hour values from days with less than 75 percent of the hours reported shall also be considered in identifying the high value to be used for substitution.

(B) The substitution test is as follows: Data substitution will be performed in all quarter periods that have less than 75 percent data capture but at least 50 percent data capture, including State-flagged data affected by exceptional events which have been approved for exclusion by the Administrator; if any quarter has less than 50 percent data capture then this substitution test cannot be used. Identify for each quarter (*e.g.,* January–March) the highest reported daily maximum 1-hour value for that quarter, excluding State-flagged data affected by exceptional events which have been approved for exclusion by the Administrator, looking across those three months of all three years under consideration. All daily maximum 1-hour values from all days in the quarter period shall be considered when identifying this highest value, including days with less than 75 percent data capture. If after substituting the highest reported daily maximum 1-hour value for a quarter for as much of the missing daily data in the matching deficient quarter(s) as is needed to make them 100 percent complete, the procedure in section 5 yields a recalculated 3-year 1-hour standard "test design value" less than or equal to the level of the standard, then the 1-hour primary standard design value is deemed to have passed the diagnostic test and is valid, and the level of the standard is deemed to have been met in that 3-year period. As noted in section 3(c)(i), in such a case, the 3-year design value based on the data actually reported, not the "test design value", shall be used as the valid design value.

(iii) (A) A 1-hour primary standard design value that is above the level of the NAAQS can be validated if the substitution test in section 3(c)(iii)(B) results in a "test design value" that is above the level of the NAAQS. The test substitutes actual "low" reported daily maximum 1-hour values from the same site at about the same time of the year (specifically, in the same three months of the calendar) for unknown hourly values that were not successfully measured. Note that the test is merely diagnostic in nature, intended to confirm that there is a very high likelihood that the original design value (the one with less than 75 percent data capture of hours by day and of days by quarter) reflects the true above-NAAQS-level status for that 3-year period; the result of this data substitution test (the "test design value", as defined in section 3(c)(iii)(B)) is not considered the actual design value. For this test, substitution is permitted only if there are a minimum number of available daily data points from which to identify the low quarter-specific daily maximum 1-hour values, specifically if there are at least 200 days across the three matching quarters of the three years under consideration (which is about 75 percent of all possible daily values in those three quarters) for which 75 percent of the hours in the day have reported concentrations. Only days with at least 75 percent of the hours reported shall be considered in identifying the low value to be used for substitution.

(B) The substitution test is as follows: Data substitution will be performed in all quarter periods that have less than 75 percent data capture. Identify for each quarter (*e.g.,* January–March) the lowest reported daily maximum 1-hour value for that quarter, looking across those three months of all three years under consideration. All daily maximum 1-hour values from all days with at least 75 percent capture in the quarter period shall be considered when identifying this lowest value. If after substituting the lowest reported daily maximum 1-hour value for a quarter for as much of the missing daily data in the matching deficient quarter(s) as is needed to make them 75 percent complete, the procedure in section 5 yields a recalculated 3-year 1-hour standard "test design value" above the level of the standard, then the 1-hour primary standard design value is deemed to have passed the diagnostic test and is valid, and the level of the standard is deemed to have been exceeded in that 3-year period. As noted in section 3(c)(i), in such a case, the 3-year design value based on the data actually reported, not the "test design value", shall be used as the valid design value.

(d) A 1-hour primary standard design value based on data that do not meet the completeness criteria stated in 3(b) and also do not satisfy section 3(c), may also be considered valid with the approval of, or at the initiative of, the Administrator, who may consider factors such as monitoring site closures/moves, monitoring diligence, the consistency and levels of the valid concentration measurements that are available, and nearby concentrations in determining whether to use such data.

(e) The procedures for calculating the 1-hour primary standard design values are given in section 5 of this appendix.

4. Rounding Conventions for the 1-Hour Primary SO_2 NAAQS

(a) Hourly SO_2 measurement data shall be reported to AQS in units of parts per billion (ppb), to at most one place after the decimal, with additional digits to the right being truncated with no further rounding.

(b) Daily maximum 1-hour values and therefore the annual 99th percentile of those daily values are not rounded.

(c) The 1-hour primary standard design value is calculated pursuant to section 5 and then rounded to the nearest whole number or 1 ppb (decimals 0.5 and greater are rounded up to the nearest whole number, and any decimal lower than 0.5 is rounded down to the nearest whole number).

5. Calculation Procedures for the 1-Hour Primary SO_2 NAAQS

(a) *Procedure for identifying annual 99th percentile values.* When the data for a particular ambient air quality monitoring site and year meet the data completeness requirements in section 3(b), or if one of the conditions of section 3(c) is met, or if the Administrator exercises the discretionary authority in section 3(d), identification of annual 99th percentile value is accomplished as follows.

(i) The annual 99th percentile value for a year is the higher of the two values resulting from the following two procedures.

(1) *Procedure 1.* For the year, determine the number of days with at least 75 percent of the hourly values reported.

(A) For the year, determine the number of days with at least 75 percent of the hourly values reported including State-flagged data affected by exceptional events which have been approved for exclusion by the Administrator.

(B) For the year, from only the days with at least 75 percent of the hourly values reported, select from each day the maximum hourly value excluding State-flagged data affected by exceptional events which have been approved for exclusion by the Administrator.

(C) Sort all these daily maximum hourly values from a particular site and year by descending value. (For example: (x[1], x[2], x[3], * * *, x[n]). In this case, x[1] is the largest number and x[n] is the smallest value.) The 99th percentile is determined from this sorted series of daily values which is ordered from the highest to the lowest number. Using the left column of Table 1, determine the appropriate range (*i.e.,* row) for the annual number of days with valid data for year y (cn_y). The corresponding "n" value in the right column identifies the rank of the annual 99th percentile value in the descending sorted list of daily site values for year y. Thus, $P_{0.99,\,y}$ = the nth largest value.

(2) *Procedure 2.* For the year, determine the number of days with at least one hourly value reported.

(A) For the year, determine the number of days with at least one hourly value reported including State-flagged data affected by exceptional events which have been approved for exclusion by the Administrator.

(B) For the year, from all the days with at least one hourly value reported, select from each day the maximum hourly value excluding State-flagged data affected by exceptional events which have been approved for exclusion by the Administrator.

(C) Sort all these daily maximum values from a particular site and year by descending value. (For example: (x[1], x[2], x[3], * * *, x[n]). In this case, x[1] is the largest number and x[n] is the smallest value.) The 99th percentile is determined from this sorted series of daily values which is ordered from the highest to the lowest number. Using the left column of Table 1, determine the appropriate range (*i.e.,* row) for the annual number of days with valid data for year y (cn_y). The corresponding "n" value in the right column identifies the rank of the annual 99th percentile value in the descending sorted list of daily site values for year y. Thus, $P_{0.99,y}$ = the nth largest value.

(b) The 1-hour primary standard design value for an ambient air quality monitoring site is mean of the three annual 99th percentile values, rounded according to the conventions in section 4.

TABLE 1

Annual number of days with valid data for year "y" (cn_y)	$P_{0.99,y}$ is the nth maximum value of the year, where n is the listed number
1–100	1
101–200	2
201–300	3
301–366	4

PART 53–AMBIENT AIR MONITORING REFERENCE AND EQUIVALENT METHODS

■ 8. The authority citation for part 53 continues to read as follows:

Authority: Sec. 301(a) of the Clean Air Act (42 U.S.C. sec. 1857g(a)), as amended by sec. 15(c)(2) of Pub. L. 91–604, 84 Stat. 1713, unless otherwise noted.

Subpart A—[Amended]

■ 9. Section 53.2 is amended by revising paragraphs (a)(1) and (b) to read as follows:

§ 53.2 General requirements for a reference method determination.

* * * * *

(a) *Manual methods*—(1) *Sulfur dioxide (SO_2)* and Lead. For measuring SO_2 and lead, appendixes A–2 and G of part 50 of this chapter specify unique manual FRM for measuring those pollutants. Except as provided in § 53.16, other manual methods for lead will not be considered for a reference method determination under this part.

* * * * *

(b) *Automated methods.* An automated FRM for measuring SO_2, CO, O_3, or NO_2 must utilize the measurement principle and calibration procedure specified in the appropriate appendix to part 50 of this chapter (appendix A–1 only for SO_2 methods) and must have been shown in accordance with this part to meet the requirements specified in this subpart A and subpart B of this part.

■ 10. Section 53.8 is amended by revising paragraph (c) to read as follows:

§ 53.8 Designation of reference and equivalent methods.

* * * * *

(c) The Administrator will maintain a current list of methods designated as FRM or FEM in accordance with this part and will send a copy of the list to any person or group upon request. A copy of the list will be available via the Internet and may be available from other sources.

■ 11. Table A–1 to Subpart A is revised to read as follows:

TABLE A–1 TO SUBPART A OF PART 53—SUMMARY OF APPLICABLE REQUIREMENTS FOR REFERENCE AND EQUIVALENT METHODS FOR AIR MONITORING OF CRITERIA POLLUTANTS

Pollutant	Reference or equivalent	Manual or automated	Applicable part 50 appendix	Applicable subparts of part 53					
				A	B	C	D	E	F
SO_2	Reference	Manual	A–2						
		Automated	A–1	✓	✓				
	Equivalent	Manual	A–1	✓		✓			
		Automated	A–1	✓	✓	✓			
CO	Reference	Automated	C	✓	✓				
	Equivalent	Manual	C	✓		✓			
		Automated	C	✓	✓	✓			
O_3	Reference	Automated	D	✓	✓				
	Equivalent	Manual	D	✓		✓			
		Automated	D	✓	✓	✓			
NO_2	Reference	Automated	F	✓	✓				
	Equivalent	Manual	F	✓		✓			
		Automated	F	✓	✓	✓			
Pb	Reference	Manual	G						
	Equivalent	Manual	G	✓		✓			
		Automated	G	✓		✓			
PM_{10}-Pb	Reference	Manual	Q						
	Equivalent	Manual	Q	✓		✓			

TABLE A–1 TO SUBPART A OF PART 53—SUMMARY OF APPLICABLE REQUIREMENTS FOR REFERENCE AND EQUIVALENT METHODS FOR AIR MONITORING OF CRITERIA POLLUTANTS—Continued

Pollutant	Reference or equivalent	Manual or automated	Applicable part 50 appendix	Applicable subparts of part 53					
				A	B	C	D	E	F
		Automated	Q	✓		✓			
PM_{10}	Reference	Manual	J	✓			✓		
	Equivalent	Manual	J	✓		✓	✓		
		Automated	J	✓		✓	✓		
$PM_{2.5}$	Reference	Manual	L	✓				✓	
	Equivalent Class I	Manual	L	✓		✓		✓	
	Equivalent Class II	Manual	L[1]	✓		✓[2]		✓	✓[1,2]
	Equivalent Class III	Automated	L[1]	✓		✓		✓	✓[1]
$PM_{10-2.5}$	Reference	Manual	L, O	✓				✓	
	Equivalent Class I	Manual	L, O	✓		✓		✓	
	Equivalent Class II	Manual	L, O	✓		✓[2]		✓	✓[1,2]
	Equivalent Class III	Automated	L[1], O[1]	✓		✓		✓	✓[1]

1. Some requirements may apply, based on the nature of each particular candidate method, as determined by the Administrator.
2. Alternative Class III requirements may be substituted.

Subpart B—[Amended]

■ 12. Section 53.20 is amended by revising paragraph (b) and Table B–1 in paragraph (c) to read as follows:

§ 53.20 General provisions.

* * * * *

(b) For a candidate method having more than one selectable measurement range, one range must be that specified in table B–1 (standard range for SO_2), and a test analyzer representative of the method must pass the tests required by this subpart while operated in that range. The tests may be repeated for one or more broader ranges (*i.e.,* ones extending to higher concentrations) than the range specified in table B–1, provided that the range does not extend to concentrations more than four times the upper range limit specified in table B–1. For broader ranges, only the tests for range (calibration), noise at 80% of the upper range limit, and lag, rise and fall time are required to be repeated. The tests may be repeated for one or more narrower ranges (ones extending to lower concentrations) than that specified in table B–1. For SO_2 methods, table B–1 specifies special performance requirements for narrower (lower) ranges. For methods other than SO_2, only the tests for range (calibration), noise at 0% of the measurement range, and lower detectable limit are required to be repeated. If the tests are conducted or passed only for the specified range (standard range for SO_2), any FRM or FEM method determination with respect to the method will be limited to that range. If the tests are passed for both the specified range and one or more broader ranges, any such determination will include the additional range(s) as well as the specified range, provided that the tests required by subpart C of this part (if applicable) are met for the broader range(s). If the tests are passed for both the specified range and one or more narrower ranges, any FRM or FEM method determination for the method will include the narrower range(s) as well as the specified range. Appropriate test data shall be submitted for each range sought to be included in a FRM or FEM method determination under this paragraph (b).

(c) * * *

TABLE B–1—PERFORMANCE SPECIFICATIONS FOR AUTOMATED METHODS

Performance parameter	Units [1]	SO_2		O_3	CO	NO_2	Definitions and test procedures
		Std. range [3]	Lower range [2,3]				
1. Range	ppm	0–0.5	<0.5	0–0.5	0–50	0–0.5	Sec. 53.23(a).
2. Noise	ppm	0.001	0.0005	0.005	0.5	0.005	Sec. 53.23(b).
3. Lower detectable limit	ppm	0.002	0.001	0.010	1.0	0.010	Sec. 53.23(c).
4. Interference equivalent							
Each interferent	ppm	±0.005	[4]±0.005	±0.02	±1.0	±0.02	Sec. 53.23(d).
Total, all interferents	ppm	—	—	0.06	1.5	0.04	Sec. 53.23(d).
5. Zero drift, 12 and 24 hour	ppm	±0.004	±0.002	±0.02	±1.0	±0.02	Sec. 53.23(e).
6. Span drift, 24 hour							
20% of upper range limit	Percent	—	—	±20.0	±10.0	±20.0	Sec. 53.23(e).
80% of upper range limit	Percent	±3.0	±3.0	±5.0	±2.5	±5.0	Sec. 53.23(e).
7. Lag time	Minutes	2	2	20	10	20	Sec. 53.23(e).
8. Rise time	Minutes	2	2	15	5	15	Sec. 53.23(e).
9. Fall time	Minutes	2	2	15	5	15	Sec. 53.23(e).
10. Precision							
20% of upper range limit	ppm	—	—	0.010	0.5	0.020	Sec. 53.23(e).
	Percent	2	2	....	....	....	Sec. 53.23(e).
80% of upper range limit	ppm	—	—	0.010	0.5	0.030	Sec. 53.23(e).
	Percent	2	2	—	—	—	Sec. 53.23(e).

1. To convert from parts per million (ppm) to µg/m³ at 25 °C and 760 mm Hg, multiply by M/0.02447, where M is the molecular weight of the gas. Percent means percent of the upper range limit.
2. Tests for interference equivalent and lag time do not need to be repeated for any lower SO_2 range provided the test for the standard range shows that the lower range specification is met for each of these test parameters.

3. For candidate analyzers having automatic or adaptive time constants or smoothing filters, describe their functional nature, and describe and conduct suitable tests to demonstrate their function aspects and verify that performances for calibration, noise, lag, rise, fall times, and precision are within specifications under all applicable conditions. For candidate analyzers with operator-selectable time constants or smoothing filters, conduct calibration, noise, lag, rise, fall times, and precision tests at the highest and lowest settings that are to be included in the FRM or FEM designation.

4. For nitric oxide interference for the SO_2 UVF method, interference equivalent is ±0.003 ppm for the lower range.

* * * * *

■ 13. Section 53.21 is amended by revising paragraph (a) to read as follows:

§ 53.21 Test conditions.

(a) *Set-up and start-up* of the test analyzer shall be in strict accordance with the operating instructions specified in the manual referred to in § 53.4(b)(3). Allow adequate warm-up or stabilization time as indicated in the operating instructions before beginning the tests. The test procedures assume that the test analyzer has an analog measurement signal output that is connected to a suitable strip chart recorder of the servo, null-balance type. This recorder shall have a chart width of a least 25 centimeters, chart speeds up to 10 cm per hour, a response time of 1 second or less, a deadband of not more than 0.25 percent of full scale, and capability either of reading measurements at least 5 percent below zero or of offsetting the zero by at least 5 percent. If the test analyzer does not have an analog signal output, or if other types of measurement data output are used, an alternative measurement data recording device (or devices) may be used for the tests, provided it is reasonably suited to the nature and purposes of the tests and an analog representation of the analyzer measurements for each test can be plotted or otherwise generated that is reasonably similar to the analog measurement recordings that would be produced by a conventional chart recorder.

* * * * *

■ 14. Section 53.22(d) is amended by revising Table B–2 to read as follows:

§ 53.22 Generation of test atmospheres.

* * * * *

(d) * * *

TABLE B–2—TEST ATMOSPHERES

Test gas	Generation	Verification
Ammonia	Permeation device. Similar to system described in references 1 and 2.	Indophenol method, reference 3.
Carbon dioxide	Cylinder of zero air or nitrogen containing CO_2 as required to obtain the concentration specified in Table B–3.	Use NIST-certified standards whenever possible. If NIST standards are not available, obtain 2 standards from independent sources which agree within 2 percent, or obtain one standard and submit it to an independent laboratory for analysis, which must agree within 2 percent of the supplier's nominal analysis.
Carbon monoxide	Cylinder of zero air or nitrogen containing CO as required to obtain the concentration specified in Table B–3.	Use a FRM CO analyzer as described in reference 8.
Ethane	Cylinder of zero air or nitrogen containing ethane as required to obtain the concentration specified in Table B–3.	Gas chromatography, ASTM D2820, reference 10. Use NIST-traceable gaseous methane or propane standards for calibration.
Ethylene	Cylinder of pre-purified nitrogen containing ethylene as required to obtain the concentration specified in Table B–3.	Do.
Hydrogen chloride	Cylinder[1] of pre-purified nitrogen containing approximately 100 ppm of gaseous HCL. Dilute with zero air to concentration specified in Table B–3.	Collect samples in bubbler containing distilled water and analyze by the mercuric thiocyante method, ASTM (D612), p. 29, reference 4.
Hydrogen sulfide	Permeation device system described in references 1 and 2.	Tentative method of analysis for H_2S content of the atmosphere, p. 426, reference 5.
Methane	Cylinder of zero air containing methane as required to obtain the concentration specified in Table B–3.	Gas chromatography ASTM D2820, reference 10. Use NIST-traceable methane standards for calibration.
Naphthalene	1. Permeation device as described in references 1 and 2 .. 2. Cylinder of pre-purified nitrogen containing 100 ppm naphthalene. Dilute with zero air to concentration specified in Table B–3.	Use NIST-certified standards whenever possible. If NIST standards are not available, obtain 2 standards from independent sources which agree within 2 percent, or obtain one standard and submit it to an independent laboratory for analysis, which must agree within 2 percent of the supplier's nominal analysis.
Nitric oxide	Cylinder[1] of pre-purified nitrogen containing approximately 100 ppm NO. Dilute with zero air to required concentration.	Use NIST-certified standards whenever possible. If NIST standards are not available, obtain 2 standards from independent sources which agree within 2 percent, or obtain one standard and submit it to an independent laboratory for analysis, which must agree within 2 percent of the supplier's nominal analysis.
Nitrogen dioxide	1. Gas phase titration as described in reference 6 2. Permeation device, similar to system described in reference 6.	1. Use an FRM NO_2 analyzer calibrated with a gravimetrically calibrated permeation device. 2. Use an FRM NO_2 analyzer calibrated by gas-phase titration as described in reference 6.
Ozone	Calibrated ozone generator as described in reference 9	Use an FEM ozone analyzer calibrated as described in reference 9.
Sulfur dioxide	1. Permeation device as described in references 1 and 2 .. 2. Dynamic dilution of a cylinder containing approximately 100 ppm SO_2 as described in Reference 7.	Use an SO_2 FRM or FEM analyzer as described in reference 7.

TABLE B–2—TEST ATMOSPHERES—Continued

Test gas	Generation	Verification
Water	Pass zero air through distilled water at a fixed known temperature between 20° and 30° C such that the air stream becomes saturated. Dilute with zero air to concentration specified in Table B–3.	Measure relative humidity by means of a dew-point indicator, calibrated electrolytic or piezo electric hygrometer, or wet/dry bulb thermometer.
Xylene	Cylinder of pre-purified nitrogen containing 100 ppm xylene. Dilute with zero air to concentration specified in Table B–3.	Use NIST-certified standards whenever possible. If NIST standards are not available, obtain 2 standards from independent sources which agree within 2 percent, or obtain one standard and submit it to an independent laboratory for analysis, which must agree within 2 percent of the supplier's nominal analysis.
Zero air	1. Ambient air purified by appropriate scrubbers or other devices such that it is free of contaminants likely to cause a detectable response on the analyzer. 2. Cylinder of compressed zero air certified by the supplier or an independent laboratory to be free of contaminants likely to cause a detectable response on the analyzer.	

[1] Use stainless steel pressure regulator dedicated to the pollutant measured.

Reference 1. O'Keefe, A. E., and Ortaman, G. C. "Primary Standards for Trace Gas Analysis," *Anal. Chem.* 38, 760 (1966).

Reference 2. Scaringelli, F. P., A. E. Rosenberg, E., and Bell, J. P., "Primary Standards for Trace Gas Analysis." *Anal. Chem.* 42, 871 (1970).

Reference 3. "Tentative Method of Analysis for Ammonia in the Atmosphere (Indophenol Method)", *Health Lab Sciences,* vol. 10, No. 2, 115–118, April 1973.

Reference 4. 1973 Annual Book of ASTM Standards, American Society for Testing and Materials, 1916 Race St., Philadelphia, PA.

Reference 5. *Methods for Air Sampling and Analysis,* Intersociety Committee, 1972, American Public Health Association, 1015.

Reference 6. 40 CFR 50 Appendix F, "Measurement Principle and Calibration Principle for the Measurement of Nitrogen Dioxide in the Atmosphere (Gas Phase Chemiluminescence)."

Reference 7. 40 CFR 50 Appendix A–1, "Measurement Principle and Calibration Procedure for the Measurement of Sulfur Dioxide in the Atmosphere (Ultraviolet Fluorscence)."

Reference 8. 40 CFR 50 Appendix C, "Measurement Principle and Calibration Procedure for the Measurement of Carbon Monoxide in the Atmosphere" (Non-Dispersive Infrared Photometry)".

Reference 9. 40 CFR 50 Appendix D, "Measurement Principle and Calibration Procedure for the Measurement of Ozone in the Atmosphere".

Reference 10. "Standard Test Method for C, through C5 Hydrocarbons in the Atmosphere by Gas Chromatography", D 2820, 1987 Annual Book of Aston Standards, vol 11.03, American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103.

■ 15. Section 53.23(d) is amended by revising Table B–3 to read as follows:

§ 53.23 Test procedures.

* * * * *

(d) * * *

TABLE B–3—INTERFERENT TEST CONCENTRATION,[1] PARTS PER MILLION

Pollutant	Analyzer type	Hydrochloric acid	Ammonia	Hydrogen sulfide	Sulfur dioxide	Nitrogen dioxide	Nitric oxide	Carbon dioxide	Ethylene	Ozone	M-xylene	Water vapor	Carbon monoxide	Methane	Ethane	Naphthalene
SO_2	Ultraviolet fluorescence	....	....	[5] 0.1	[4] 0.14	0.5	0.5	....	....	0.5	0.2	20,000	....	....	....	[6] 0.05
SO_2	Flame photometric	....	....	0.01	[4] 0.14	....	....	750	....	....	....	[3] 20,000	50	....	....	....
SO_2	Gas chromatography	....	....	0.1	[4] 0.14	....	....	750	....	....	....	[3] 20,000	50	....	....	....
SO_2	Spectrophotometric-wet chemical (pararosanaline).	0.2	0.1	0.1	[4] 0.14	0.5	....	750	....	0.5	....	....	....	....	....	....
SO_2	Electrochemical	0.2	0.1	0.1	[4] 0.14	0.5	0.5	....	0.2	0.5	....	[3] 20,000	....	....	....	....
SO_2	Conductivity	0.2	0.1	....	[4] 0.14	0.5	....	750	....	....	....	....	....	....	....	....
SO_2	Spectrophotometric-gas phase, including DOAS.	....	....	....	[4] 0.14	0.5	....	....	....	0.5	0.2	....	....	....	....	....
O_3	Chemiluminescent	....	....	[3] 0.1	....	....	....	750	....	[4] 0.08	....	[3] 20,000	....	....	....	....
O_3	Electrochemical	....	[3] 0.1	....	0.5	0.5	....	....	....	[4] 0.08	....	....	....	....	....	....
O_3	Spectrophotometric-wet chemical (potassium iodide).	....	[3] 0.1	....	0.5	0.5	[3] 0.5	....	....	[4] 0.08	....	....	....	....	....	....
O_3	Spectrophotometric-gas phase, including ultraviolet absorption and DOAS.	....	....	....	0.5	0.5	0.5	....	....	[4] 0.08	0.02	20,000	....	....	....	....
CO	Infrared	....	....	....	....	....	....	750	....	....	....	20,000	[4] 10	....	....	....
CO	Gas chromatography with flame ionization detector.	....	....	....	....	....	....	....	....	....	....	20,000	[4] 10	....	0.5	....
CO	Electrochemical	....	....	....	....	....	0.5	....	0.2	....	....	20,000	[4] 10	....	....	....
CO	Catalytic combustion-thermal detection.	....	0.1	....	....	....	....	750	0.2	....	....	20,000	[4] 10	5.0	0.5	....
CO	IR fluorescence	....	....	....	....	....	....	750	....	....	....	20,000	[4] 10	....	0.5	....
CO	Mercury replacement-UV photometric.	....	....	....	....	....	....	....	0.2	....	....	....	[4] 10	....	0.5	....
NO_2	Chemiluminescent	....	[3] 0.1	....	0.5	[4] 0.1	0.5	....	....	....	....	20,000	....	....	....	....
NO_2	Spectrophotometric-wet chemical (azo-dye reaction).	....	....	....	0.5	[4] 0.1	0.5	750	....	0.5	....	....	....	....	....	....
NO_2	Electrochemical	0.2	[3] 0.1	....	0.5	[4] 0.1	0.5	750	....	0.5	....	20,000	50	....	....	....
NO_2	Spectrophotometric-gas phase.	....	[3] 0.1	....	0.5	[4] 0.1	0.5	....	....	0.5	....	20,000	50	....	....	....

1. Concentrations of interferent listed must be prepared and controlled to ±10 percent of the stated value.
2. Analyzer types not listed will be considered by the Administrator as special cases.
3. Do not mix with the pollutant.

4. Concentration of pollutant used for test. These pollutant concentrations must be prepared to ±10 percent of the stated value.
5. If candidate method utilizes an elevated-temperature scrubber for removal of aromatic hydrocarbons, perform this interference test.
6. If naphthalene test concentration cannot be accurately quantified, remove the scrubber, use a test concentration that causes a full scale response, reattach the scrubber, and evaluate response for interference

* * * * *

Subpart C [Amended]

■ 16. Section 53.32 is amended by revising paragraph (e)(2) to read as follows:

§ 53.32 Test procedures for methods for SO_2, CO, O_3, and NO_2.

* * * * *

(e) * * *

(2) For a candidate method having more than one selectable range, one range must be that specified in table B–1 of subpart B of this part, and a test analyzer representative of the method must pass the tests required by this subpart while operated on that range. The tests may be repeated for one or more broader ranges (*i.e.,* ones extending to higher concentrations) than the one specified in table B–1 of subpart B of this part, provided that such a range does not extend to concentrations more than four times the upper range limit specified in table B–1 of subpart B of this part and that the test analyzer has passed the tests required by subpart B of this part (if applicable) for the broader range. If the tests required by this subpart are conducted or passed only for the range specified in table B–1 of subpart B of this part, any equivalent method determination with respect to the method will be limited to that range. If the tests are passed for both the specified range and a broader range (or ranges), any such determination will include the broader range(s) as well as the specified range. Appropriate test data shall be submitted for each range sought to be included in such a determination.

* * * * *

■ 17. Table C–1 to Subpart C is revised to read as follows:

TABLE C–1 TO SUBPART C OF PART 53—TEST CONCENTRATION RANGES, NUMBER OF MEASUREMENTS REQUIRED, AND MAXIMUM DISCREPANCY SPECIFICATIONS

Pollutant	Concentration range, parts per million (ppm)	Simultaneous measurements required				Maximum discrepancy specification, parts per million
		1-hour		24-hour		
		First set	Second set	First set	Second set	
Ozone	Low 0.06 to 0.10	5	6			0.02
	Med. 0.15 to 0.25	5	6			0.03
	High 0.35 to 0.46	4	6			0.04
	Total	14	18			
Carbon monoxide	Low 7 to 11	5	6			1.5
	Med. 20 to 30	5	6			2.0
	High 25 to 45	4	6			3.0
	Total	14	18			
Sulfur dioxide	Low 0.02 to 0.05	5	6	3	3	0.02
	Med. 0.10 to 0.15	5	6	2	3	0.03
	High 0.30 to 0.50	4	6	2	2	0.04
	Total	14	18	7	8	
Nitrogen dioxide	Low 0.02 to 0.08			3	3	0.02
	Med. 0.10 to 0.20			2	2	0.02
	High 0.25			2	2	0.03
	Total			7	8	

PART 58—AMBIENT AIR QUALITY SURVEILLANCE

■ The authority citation for part 58 continues to read as follows:

Authority: 42 U.S.C. 7403, 7410, 7601(a), 7611, and 7619.

Subpart B [AMENDED]

■ 19. Section 58.10, is amended by adding paragraph (a)(6) to read as follows:

§ 58.10 Annual monitoring network plan and periodic network assessment.

* * * * *

(a) * * *

(6) A plan for establishing SO_2 monitoring sites in accordance with the requirements of appendix D to this part shall be submitted to the EPA Regional Administrator by July 1, 2011 as part of the annual network plan required in paragraph (a) (1). The plan shall provide for all required SO_2 monitoring sites to be operational by January 1, 2013.

* * * * *

■ 20. Section 58.12 is amended by adding paragraph (g) to read as follows:

§ 58.12 Operating Schedules

* * * * *

(g) For continuous SO_2 analyzers, the maximum 5-minute block average concentration of the twelve 5-minute blocks in each hour must be collected except as noted in § 58.12 (a).

* * * * *

■ 21. Section 58.13 is amended by adding paragraph (d) to read as follows:

§ 58.13 Monitoring network completion.

* * * * *

(d) The network of SO_2 monitors must be physically established no later than January 1, 2013, and at that time, must be operating under all of the requirements of this part, including the requirements of appendices A, C, D, and E to this part.

■ 22. Section 58.16 is amended by adding paragraph (g) to read as follows:

§ 58.16 Data submittal and archiving requirements.

* * * * *

(g) Any State or, where applicable, local agency operating a continuous SO_2 analyzer shall report the maximum 5-minute SO_2 block average of the twelve 5-minute block averages in each hour, in addition to the hourly SO_2 average.

■ 23. Appendix A to Part 58 is amended as by adding paragraph 2.3.1.6 to read as follows:

Appendix A to Part 58—Quality Assurance Requirements for SLAMS, SPMs and PSD Air Monitoring

* * * * *

2.3.1.6 *Measurement Uncertainty for* SO_2. The goal for acceptable measurement uncertainty for precision is defined as an upper 90 percent confidence limit for the coefficient of variation (CV) of 10 percent and for bias as an upper 95 percent confidence limit for the absolute bias of 10 percent.

* * * * *

■ 24. Appendix D to Part 58 is amended as by revising paragraph 4.4 to read as follows:

Appendix D to Part 58—Network Design Criteria for Ambient Air Quality Monitoring

* * * * *

4.4 Sulfur Dioxide (SO_2) Design Criteria.

4.4.1 *General Requirements.* (a) State and, where appropriate, local agencies must operate a minimum number of required SO_2 monitoring sites as described below.

4.4.2 *Requirement for Monitoring by the Population Weighted Emissions Index.* (a) The population weighted emissions index (PWEI) shall be calculated by States for each core based statistical area (CBSA) they contain or share with another State or States for use in the implementation of or adjustment to the SO_2 monitoring network. The PWEI shall be calculated by multiplying the population of each CBSA, using the most current census data or estimates, and the total amount of SO_2 in tons per year emitted within the CBSA area, using an aggregate of the most recent county level emissions data available in the National Emissions Inventory for each county in each CBSA. The resulting product shall be divided by one million, providing a PWEI value, the units of which are million persons-tons per year. For any CBSA with a calculated PWEI value equal to or greater than 1,000,000, a minimum of three SO_2 monitors are required within that CBSA. For any CBSA with a calculated PWEI value equal to or greater than 100,000, but less than 1,000,000, a minimum of two SO_2 monitors are required within that CBSA. For any CBSA with a calculated PWEI value equal to or greater than 5,000, but less than 100,000, a minimum of one SO_2 monitor is required within that CBSA.

(1) The SO_2 monitoring site(s) required as a result of the calculated PWEI in each CBSA shall satisfy minimum monitoring requirements if the monitor is sited within the boundaries of the parent CBSA and is one of the following site types (as defined in section 1.1.1 of this appendix): population exposure, highest concentration, source impacts, general background, or regional transport. SO_2 monitors at NCore stations may satisfy minimum monitoring requirements if that monitor is located within a CBSA with minimally required monitors under this part. Any monitor that is sited outside of a CBSA with minimum monitoring requirements to assess the highest concentration resulting from the impact of significant sources or source categories existing within that CBSA shall be allowed to count towards minimum monitoring requirements for that CBSA.

4.4.3 *Regional Administrator Required Monitoring.* (a) The Regional Administrator may require additional SO_2 monitoring stations above the minimum number of monitors required in 4.4.2 of this part, where the minimum monitoring requirements are not sufficient to meet monitoring objectives. The Regional Administrator may require, at his/her discretion, additional monitors in situations where an area has the potential to have concentrations that may violate or contribute to the violation of the NAAQS, in areas impacted by sources which are not conducive to modeling, or in locations with susceptible and vulnerable populations, which are not monitored under the minimum monitoring provisions described above. The Regional Administrator and the responsible State or local air monitoring agency shall work together to design and/or maintain the most appropriate SO_2 network to provide sufficient data to meet monitoring objectives.

4.4.4 SO_2 *Monitoring Spatial Scales.* (a) The appropriate spatial scales for SO_2 SLAMS monitors are the microscale, middle, neighborhood, and urban scales. Monitors sited at the microscale, middle, and neighborhood scales are suitable for determining maximum hourly concentrations for SO_2. Monitors sited at urban scales are useful for identifying SO_2 transport, trends, and, if sited upwind of local sources, background concentrations.

(1) *Microscale*—This scale would typify areas in close proximity to SO_2 point and area sources. Emissions from stationary point and area sources, and non-road sources may, under certain plume conditions, result in high ground level concentrations at the microscale. The microscale typically represents an area impacted by the plume with dimensions extending up to approximately 100 meters.

(2) *Middle scale*—This scale generally represents air quality levels in areas up to several city blocks in size with dimensions on the order of approximately 100 meters to 500 meters. The middle scale may include locations of expected maximum short-term concentrations due to proximity to major SO_2 point, area, and/or non-road sources.

(3) *Neighborhood scale*—The neighborhood scale would characterize air quality conditions throughout some relatively uniform land use areas with dimensions in the 0.5 to 4.0 kilometer range. Emissions from stationary point and area sources may, under certain plume conditions, result in high SO_2 concentrations at the neighborhood scale. Where a neighborhood site is located away from immediate SO_2 sources, the site may be useful in representing typical air quality values for a larger residential area, and therefore suitable for population exposure and trends analyses.

(4) *Urban scale*—Measurements in this scale would be used to estimate concentrations over large portions of an urban area with dimensions from 4 to 50 kilometers. Such measurements would be useful for assessing trends in area-wide air quality, and hence, the effectiveness of large scale air pollution control strategies. Urban scale sites may also support other monitoring objectives of the SO_2 monitoring network such as identifying trends, and when monitors are sited upwind of local sources, background concentrations.

4.4.5 *NCore Monitoring.* (a) SO_2 measurements are included within the NCore multipollutant site requirements as described in paragraph (3)(b) of this appendix. NCore-based SO_2 measurements are primarily used to characterize SO_2 trends and assist in understanding SO_2 transport across representative areas in urban or rural locations and are also used for comparison with the SO_2 NAAQS. SO_2 monitors at NCore sites that exist in CBSAs with minimum monitoring requirements per section 4.4.2 above shall be allowed to count towards those minimum monitoring requirements.

* * * * *

■ 25. Appendix G to Part 58 is amended as by revising Table 2 to read as follows:

Appendix G to Part 58—Uniform Air Quality Index (AQI) and Daily Reporting

* * * * *

TABLE 2—BREAKPOINTS FOR THE AQI

These breakpoints							Equal these AQI's	
O_3 (ppm) 8-hour	O_3 (ppm) 1-hour [1]	$PM_{2.5}$ ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	CO (ppm)	SO_2 (ppm) 1-hour	NO_2 (ppm) 1-hour	AQI	Category
0.000–0.059 ..		0.0–15.4	0–54	0.0–4.4	0–0.035	0–0.053	0–50	Good.
0.060–0.075 ..		15.5–40.4	55–154	4.5–9.4	0.036–0.075	0.054–0.100	51–100	Moderate.
0.076–0.095 ..	0.125–0.164	40.5–65.4	155–254	9.5–12.4	0.076–0.185	0.101–0.360	101–150	Unhealthy for Sensitive Groups.
0.096–0.115 ..	0.165–0.204	[3] 65.5–150.4	255–354	12.5–15.4	[4] 0.186–0.304	0.361–0.64	151–200	Unhealthy.
0.116–0.374 ..	0.205–0.404	[3] 150.5–250.4	355–424	15.5–30.4	[4] 0.305–0.604	0.65–1.24	201–300	Very Unhealthy.
([2])	0.405–0.504	[3] 250.5–350.4	425–504	30.5–40.4	[4] 0.605–0.804	1.25–1.64	301–400	
([2])	0.505–0.604	[3] 350.5–500.4	505–604	40.5–50.4	[4] 0.805–1.004	1.65–2.04	401–500	Hazardous.

[1] Areas are generally required to report the AQI based on 8-hour ozone values. However, there are a small number of areas where an AQI based on 1-hour ozone values would be more precautionary. In these cases, in addition to calculating the 8-hour ozone index value, the 1-hour ozone index value may be calculated, and the maximum of the two values reported.

[2] 8-hour O_3 values do not define higher AQI values (≥301). AQI values of 301 or greater are calculated with 1-hour O_3 concentrations.

[3] If a different SHL for $PM_{2.5}$ is promulgated, these numbers will change accordingly.

[4] 1-hr SO_2 values do not define higher AQI values (≥200). AQI values of 200 or greater are calculated with 24-hour SO_2 concentrations.

* * * * *

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