Appendix B. Supplement to the NO_2 Exposure Assessment

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B-1 Overview

This appendix contains supplemental descriptions of the methods and data used in the NO_2 exposure assessment, as well as detailed results from the exposure analyses performed. First, a broad description of the exposure modeling approach is described, applicable to the two exposure modeling case-studies conducted to date: Philadelphia and Atlanta. This is followed with details regarding the required inputs for the model and the assumptions made for both of the case-study assessments. The primary output for each exposure assessment was the numbers of exceedances of short-term (1-hour) potential health effect benchmark levels experienced by the asthmatic population residing within each location.

The first simulation location included Philadelphia County and was summarized in the 1st draft Risk and Exposure Assessment (REA). The results from this assessment are presented here as they existed in that document and the draft Technical Support Document draft (TSD) and no adjustments were made to modeling approach used to generate the exposure results. However, additional comparative analyses are presented here to clarify certain issues raised in the review of this case-study by CASAC in May, 2008. These include additional comparisons of the AERMOD modeled air quality with the available ambient monitor data (section 3.6.2) as well as a comparison of the two on-road concentration estimation approaches used (section 3.6.3)

A second case-study was conducted in portions of the Atlanta Metropolitan Statistical Area (MSA) that includes four counties. Some of the recommendations by CASAC on the modeling approach, evaluation, and assumptions made have been incorporated in this case-study. Details on the exposure modeling approach for the Atlanta exposure case-study are provided here.

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 being 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, can be found 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, described in the APEX User's Guide and the APEX Technical Support Document (US EPA, 2006a; 2006b) and referred to here as the APEX User's Guide and TSD.

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. The model simulation can be broadly described in five steps that follow:

1. **Characterize the study area**. APEX selects census tracts 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 census data for the study area and human profile distribution data (such as age-specific employment probabilities).
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 and based on the activity pattern data.
4. **Calculate 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 then calculates hourly concentrations of a pollutant in each of these microenvironments for the period of simulation, based on the user-provided microenvironment descriptions and hourly air quality data. Microenvironmental concentrations are calculated for each of the simulated individuals.
5. **Estimate exposures**.

APEX estimates a concentration for each exposure event based on the microenvironment occupied during the event. These values can be averaged by clock hour to produce a sequence of hourly average exposures spanning the specified exposure period. These hourly values may be further aggregated to produce daily, monthly, and annual average exposure values.

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.

B-2.2.1.1 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 (EPA, 2004). The following steps were performed using AERMOD.

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. **Estimate emissions**. The emission sources modeled included, major stationary emission sources, on-road emissions that occur on major roadways, and fugitive emissions.
3. **Define receptor locations**. Three sets of receptors were identified for the dispersion modeling, including ambient monitoring locations, census block centroids, and links along major roadways.
4. **Estimate concentrations at receptors**. Hourly concentrations were estimated for each year of the simulation (years 2001 through 2003) by combining concentration contributions from each of the emission sources and accounting for sources not modeled.

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.

B-2.2.1.2 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 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-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-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

B-2.2.2.1 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.

B-2.2.2.2 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 fairly rapidly with increasing distance. Beyond 120 km, the majority of the flow is made up 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:

$$Ambient\ Concentration = LeaverMult \times avg(t) + LeaverAdd \qquad \text{equation (1)}$$

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 this 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 (2).

$$Flow_{block} = Flow_{tract} \times F_{pop} \times F_{land} \qquad \text{equation (2)}$$

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.

B-2.2.2.3 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-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-1. Example of a profile function file for A/C prevalence.

B-2.2.3 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), 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).

B-2.2.3.1 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

B-2.2.3.2 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. 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)

B-2.2.3.3 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., NO_2 1-hour 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 1-hour average NO_2 concentration of 200 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 Attachment 1.

B-2.2.4 Calculating Microenvironmental Concentrations

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 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.

B-2.2.4.1 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 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.

Table B-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-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:

$$\frac{dC_{ME}(t)}{dt} = \Delta C_{in} - \Delta C_{out} - \Delta C_{removal} + \Delta C_{source} \qquad \text{equation (3)}$$

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 time period of an hour each of the rates of change, ΔC_{in}, ΔC_{out}, $\Delta C_{removal}$, and ΔC_{source}, is assumed to be constant. At each hour time step of the simulation period, APEX estimates the hourly equilibrium, hourly ending, and hourly 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 User's Guide. APEX reports hourly mean concentration as hourly concentration for a specific hour. The calculation then continues to the next hour by using the end concentration for the previous hour as the initial microenvironmental concentration. A description of the input parameters estimates used for microenvironments using the mass balance approach is provided below.

B-2.2.4.2 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-4 lists the parameters required by the factors method to calculate concentrations in a microenvironment without emissions sources.

Table B-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 hourly mean concentration in a microenvironment from the user-provided hourly air quality data:

$$C_{ME}^{hourlymean} = C_{ambient} \ x \ f_{proximity} \ x \ f_{penetration} \qquad \text{equation (4)}$$

where:

$C_{ME}^{hourlymean}$	=	Hourly concentration in a microenvironment (ppb)
$C_{ambient}$	=	Hourly 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.

B-2.2.4.3 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-5.

Table B-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

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.

B-2.2.4.4 Mapping of APEX Microenvironments to CHAD Diaries

The *Microenvironment Mapping* file matches the APEX Microenvironments to CHAD Location codes. Table B-6 gives the mapping used for the APEX simulations.

Table B-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:

$$C_i = \frac{\sum_{j=1}^{N} C_{ME(j)}^{hourlymean} \; t_{(j)}}{T} \qquad \text{equation (5)}$$

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.
$C_{ME(j)}^{hourlymean}$	=	Hourly mean concentration in microenvironment *j* (ppm)
$t_{(j)}$	=	Time spent in microenvironment *j* (minutes)
T	=	60 minutes

From the hourly exposures, APEX calculates time series of 1-hour average exposure concentrations that a simulated individual would experience during the simulation period. APEX then statistically summarizes and tabulates the hourly (or daily, annual average) exposures. In this analysis, the exposure indicator is 1-hr exposures above selected 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 NO_2 concentration level 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 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 200 to 300 ppb by 50 ppb increments for 1-hour average exposures. These results are tabulated for the population and subpopulations of interest.

B-2.2.6 Exposure Model Output

All of the output files written by APEX are ASCII text files. Table B-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-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 Philadelphia Exposure Assessment Case-Study

This section documents detailed methodology and input data used in the Philadelphia inhalation exposure assessment for NO_2 conducted in support of the current review of the NO_2 primary NAAQS. Two important components of the analysis include the approach for estimating temporally and spatially variable NO_2 concentrations and simulating contact of humans with these pollutant concentrations. A combined air quality and exposure modeling approach has been used here to generate estimates of 1-hour NO_2 exposures within Philadelphia. Details on the approaches used are provided below and include the following:

- Description of the area assessed and populations considered
- Summary of the air quality modeling methodology and associated input data
- Description of the inhalation exposure model and associated input data
- Evaluation of estimated NO_2 exposures using modeling methodology

B-3.1 Study Area Selection and Description

The selection of areas to include in the exposure analysis takes into consideration the location of field and epidemiology studies, the availability of ambient monitoring and other input data, the desire to represent a range of geographic areas, population demographics, general climatology, and results of the ambient air quality characterization.

Philadelphia was selected as a location of interest through a similar statistical analysis of the ambient NO_2 air quality data described in Appendix A for each monitoring site within a location. Criteria were established for selecting sites with high annual means and/or high numbers of exceedances of potential health effect benchmark concentrations. The analysis considered all data combined, as well as the more recent air quality data (2001-2006) separately.

The 90^{th} percentile served as the point of reference for the annual means, and across all complete site-years for 2001-2006, this value was 23.5 ppb. Seventeen locations contained one or more site-years with an annual average concentration at or above the 90^{th} percentile. When combined with the number of 1-hour NO_2 concentrations at or above 200 ppb, only two locations fit these criteria, Philadelphia and Los Angeles. In comparing the size of the potential modeling domains and the anticipated complexity in modeling influence of roadway exposures, Philadelphia was determined to be a more manageable case-study.

Philadelphia County is comprised of 17,315 blocks containing a population of 1,517,550 persons. For this analysis the population studied was limited those residents of Philadelphia County residing in census blocks that were either within 400 meters of a major roadway or within 10 km of a major emission source (see section B-3.5 for definition). This was done to maintain balance between the representation of the study area/objectives and the computational load regarding file size and processing time. There were 16,857 such blocks containing a population of 1,475,651.

B-3.2 Exposure Period of Analysis

The exposure periods modeled were 2001 through 2003 to envelop the most recent year of travel demand modeling (TDM) data available for the respective study locations (i.e., 2002) and to include a 3 years of meteorological data to achieve a degree of stability in the dispersion and exposure model estimates.

B-3.3 Populations Analyzed

A detailed consideration of the population residing in each modeled area was included where the exposure modeling was performed. The assessment includes the general population (All Persons) residing in each modeled area and considered susceptible and vulnerable populations as identified in the ISA. These include population subgroups defined from either an exposure or health perspective. The population subgroups identified by the ISA (US EPA, 2007a) that were included and that can be modeled in the exposure assessment include:

- Children (ages 5-18)
- Asthmatic children (ages 5-18)
- All persons (all ages)
- All Asthmatics (all ages)

In addition to these population subgroups, individuals anticipated to be exposed more frequently to NO_2 were considered, including those commuting on roadways and persons residing near major roadways. To date, this document provides a summary of the subpopulations of interest (all asthmatics and asthmatic children), supplemented with additional exposure and risk results for the total population where appropriate.

B-3.4 Simulated Individuals

Due to the large size of the air quality input files, the modeled area was separated into three sections. The number of simulated persons in each model run (3 sections per 3 years) was set to 50,000, yielding a total of 150,000 persons simulated for each year. The parameters controlling the location and size of the simulated area were set to include the county(s) in the selected study area. The settings that allow for replacement of CHAD data that are missing gender, employment or age values were all set to preclude replacing missing data. The width of the age window was set to 20 percent to increase the pool of diaries available for selection. The variable that controls the use of additional ages outside the target age window was set to 0.1 to further enhance variability in diary selection. See the APEX User's Guide for further explanation of these parameters. The total population simulated for Philadelphia County was approximately 1.48 million persons, of which there a total simulated population of 163,000 asthmatics. The model simulated approximately 281,000 children, of which there were about 48,000 asthmatics. Due to random sampling, the actual number of specific subpopulations modeled varied slightly by year.

B-3.4.1 Asthma Prevalence Rates

One of the important population subgroups for the exposure assessment is asthmatic children. Evaluation of the exposure of this group 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; 2007e). Specifically, the analysis generated age and gender specific asthma prevalence rates for children ages 0-17 using data provided in the National Health Interview Survey (NHIS) for 2003 (CDC, 2007). These asthma rates were characterized by geographic regions, namely Midwest, Northeast, South, and West. Adult asthma prevalence rates for Philadelphia County were obtained from the Behavioral Risk Factor Surveillance System (BRFSS) survey information (PA DOH, 2008). The average rates for adult males and females in Philadelphia for 2001-2003 were 7% and 12%, respectively. These rates were assumed to apply to all adults uniformly. Table B-8 provides a summary of the prevalence rates used in the exposure analysis by age and gender.

Table B-8. Asthma prevalence rates by age and gender used for Philadelphia.

Region (Study Area)	Age	Females				Males			
		Prevalence	se	L95	U95	Prevalence	se	L95	U95
Northeast (Philadelphia)	0	0.068	0.066	0.007	0.442	0.048	0.033	0.010	0.200
	1	0.072	0.038	0.021	0.221	0.046	0.018	0.019	0.108
	2	0.075	0.022	0.038	0.145	0.052	0.015	0.027	0.097
	3	0.077	0.020	0.042	0.138	0.068	0.018	0.037	0.120
	4	0.082	0.023	0.043	0.151	0.100	0.023	0.059	0.164
	5	0.116	0.030	0.063	0.205	0.149	0.029	0.094	0.226
	6	0.161	0.037	0.092	0.266	0.207	0.042	0.129	0.316
	7	0.185	0.041	0.108	0.298	0.228	0.045	0.143	0.343
	8	0.171	0.040	0.096	0.284	0.222	0.043	0.142	0.332
	9	0.145	0.035	0.080	0.246	0.212	0.041	0.136	0.316
	10	0.135	0.031	0.078	0.223	0.177	0.037	0.108	0.275
	11	0.141	0.031	0.084	0.227	0.166	0.035	0.102	0.259
	12	0.166	0.034	0.102	0.259	0.183	0.036	0.116	0.276
	13	0.174	0.034	0.109	0.266	0.171	0.031	0.113	0.250
	14	0.151	0.029	0.095	0.232	0.170	0.029	0.115	0.244
	15	0.146	0.028	0.093	0.221	0.182	0.029	0.127	0.254
	16	0.146	0.031	0.088	0.232	0.204	0.032	0.142	0.284
	17	0.157	0.054	0.068	0.322	0.242	0.061	0.133	0.399
	18+	0.070		0.040	0.140	0.120		0.090	0.150

Notes:
se – Standard error
L95 – Lower limit on 95th confidence interval
U95 – Upper limit on 95th confidence interval

B-3.5 Air Quality Data Generated by AERMOD

Air quality data input to the model were generated by air quality modeling using AERMOD. Principal emission sources included both mobile and stationary sources as well as fugitive emissions. The methodology is described below.

B-3.5.1 Meteorological Inputs

All meteorological data used for the AERMOD dispersion model simulations were processed with the AERMET meteorological preprocessor, version 06341. This section describes the input data and processing methodologies used to derive input meteorological fields for each of the five regions of interest.

B-3.5.1.1 Data Selection

Raw surface meteorological data for the 2001 to 2003 period were obtained from the Integrated Surface Hourly (ISH) Database,[1] maintained by the National Climatic Data Center (NCDC). The ISH data used for this study consists of typical hourly surface parameters (including air and dew point temperature, atmospheric pressure, wind speed and direction, precipitation amount, and cloud cover) from hourly Automated Surface Observing System (ASOS) stations. No on-site observations were used.

The surface meteorological station used for this analysis is located at Philadelphia International (KPHL) airport. The selection of surface meteorological stations minimized the distance from the station to city center, minimized missing data, and maximized land-use representativeness of the station site compared to the city center.

The total number of surface observations and the percentage of those observations accepted by AERMET (i.e., those observations that were both not missing and within the expected ranges of values), are shown by Table B-9. Note that instances of calm winds are not rejected by the AERMET processor, but are later treated as calms in the dispersion analysis. There were 1,772 hours in Philadelphia (7%) with calm winds (see Table B-10).

Table B-9. Number of AERMET raw hourly surface meteorology observations, percent acceptance rate, 2001-2003.

Surface Variable	Philadelphia (KPHL) n=26,268
	% Accepted [a]
Precipitation	100
Station Pressure	99
Cloud Height	99
Sky Cover	95
Horizontal Visibility	99
Temperature	99 *
Dew Point Temperature	99
Relative Humidity	99
Wind Direction	97
Wind Speed	99

Notes:
[a] Percentages are rounded down to the nearest integer.
* The majority of unaccepted records are due to values being out of range.

[1] http://www1.ncdc.noaa.gov/pub/data/techrpts/tr200101/tr2001-01.pdf

Table B-10. Number of calms reported by AERMET by year for Philadelphia.

Year	Number of Calms
2001	610
2002	470
2003	692
Total	**1772**

Mandatory and significant levels of upper-air data were obtained from the NOAA Radiosonde Database.[2] Upper air observations show less spatial variation than do surface observations; thus they are both representative of larger areas and measured with less spatial frequency than are surface observations. The selection of upper-air station locations for each city minimized both the proximity of the station to city center and the amount of missing data in the records. The selected stations for Philadelphia was Washington Dulles Airport (KIAD). The total number of upper-air observations per station per height interval, and the percentage of those observations accepted by AERMET, are shown in Table B-11.

Table B-11. Number and AERMET acceptance rate of upper-air observations 2001-2003.

Height Level	Variable	Philadelphia (KIAD)	
		n	% Accepted
Surface	Pressure	2152	100
	Height	2152	100
	Temperature	2152	100
	DewPoint Temperature	2152	100
	WindDirection	2152	100
	WindSpeed	2152	85 *
0-500m	Pressure	4320	100
	Height	4320	100
	Temperature	4320	100
	DewPoint Temperature	4320	99
	WindDirection	4320	63
	WindSpeed	4320	62
500-1000m	Pressure	3702	100
	Height	3702	100
	Temperature	3702	100
	DewPointTemperature	3702	99 *
	WindDirection	3702	73
	WindSpeed	3702	73
1000-1500m	Pressure	4204	100
	Height	4204	100
	Temperature	4204	100
	DewPointTemperature	4204	97 *
	WindDirection	4204	71
	WindSpeed	4204	71
1500-2000m	Pressure	3354	100
	Height	3354	100
	Temperature	3354	100
	DewPointTemperature	3354	95 *
	WindDirection	3354	50
	WindSpeed	3354	50

[2] http://raob.fsl.noaa.gov/

Height Level	Variable	Philadelphia (KIAD)	
		n	% Accepted
2000-2500m	Pressure	3246	100
	Height	3246	100
	Temperature	3246	100
	DewPointTemperature	3246	93 *
	WindDirection	3246	50
	WindSpeed	3246	50
2500-3000m	Pressure	3736	100
	Height	3736	100
	Temperature	3736	100
	DewPointTemperature	3736	90 *
	WindDirection	3736	64
	WindSpeed	3736	64
3000-3500m	Pressure	3614	100
	Height	3614	100
	Temperature	3614	100
	DewPointTemperature	3614	90 *
	WindDirection	3614	65
	WindSpeed	3614	65
3500-4000m	Pressure	2830	100
	Height	2830	100
	Temperature	2830	100
	DewPointTemperature	2830	87 *
	WindDirection	2830	50
	WindSpeed	2830	50
>4000 m	Pressure	7619	88 *
	Height	7619	71 *
	Temperature	7619	99 *
	DewPointTemperature	7619	79 *
	WindDirection	7619	55
	WindSpeed	7619	55

Notes:
[a] Percentages are rounded down to the nearest integer.
* The majority of unaccepted records are due to values being out of range.
Shading:
≤95 of observations were accepted.
≤75 of observations were accepted.
≤50 of observations were accepted.

B-3.5.2 Surface Characteristics and Land Use Analysis

In addition to the standard meteorological observations of wind, temperature, and cloud cover, AERMET analyzes three principal variables to help determine atmospheric stability and mixing heights: the Bowen ratio[3], surface albedo[4] as a function of the solar angle, and surface roughness. [5]

[3] For any moist surface, the Bowen Ratio is the ratio of heat energy used for sensible heating (conduction and convection) to the heat energy used for latent heating (evaporation of water or sublimation of snow). The Bowen ratio ranges from about 0.1 for the ocean surface to more than 2.0 for deserts. Bowen ratio values tend to decrease with increasing surface moisture for most land-use types.

The January 2008 version of AERSURFACE was used to estimate land-use patterns and calculate the Bowen ratio, surface albedo, and surface roughness as part of the AERMET processing. AERSURFACE uses the US Geological Survey (USGS) National Land Cover Data 1992 archives (NLCD92). [6] Three to four land-use sectors were manually identified around the surface meteorological station using this land-use data. These land-use sectors are used to identify the Bowen ratio and surface albedo, which are assumed to represent an area around the station of radius 10 km, and to calculate surface roughness by wind direction.

A monthly temporal resolution was used for the Bowen ratio, albedo, and surface roughness at the meteorological site. Because the site was located at an airport, a lower surface roughness was calculated for the 'Commercial/Industrial/Transportation' land-use type to reflect the dominance of transportation land cover rather than commercial buildings. Philadelphia has at least one winter month of continuous snow cover, which tends to increase albedo, decrease Bowen ratio, and decrease surface roughness for most land-use types during the winter months compared to a snow-free area. Seasons were assigned based on 1971-2000 NCDC 30-year climatic normals and on input from the state climatologist (Table B-12).

Table B-12. Seasonal definitions and specifications for Philadelphia.

Location	Winter (continuous snow)	Winter (no snow)	Spring	Summer	Fall
Philadelphia	Dec, Jan, Feb		Mar, Apr, May	Jun, Jul, Aug	Sep, Oct, Nov

Season definitions provided by the AERSURFACE manual as follows:

Winter (continuous snow):	Winter with continuous snow on ground
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
Fall:	Autumn with unharvested cropland

Figure B-2 illustrates show the manually created land-use sectors around the application site; a 1.9 mile (3 km) radius circle was used. Data are from the NLCD92 database. Prior to the release of AERSURFACE, the user was required to manually pull values of Bowen ratio (β_0), albedo (α), and surface roughness (z_0) per season and per land-use sector from look-up tables in the *AERMET User's Guide*. Using the look-up tables, values of these three surface characteristics vary by the four seasons and by eight basic land-use categories. Furthermore, the *AERMOD Implementation Guide* was somewhat ambiguous about whether Bowen ratio values should also vary with wind direction sector, as does the surface roughness. AERSURFACE resolves these issues by providing a uniform methodology for calculation of surface effects on dispersion; it also only varies surface roughness by wind direction.

[4] The ratio of the amount of electromagnetic radiation reflected by the earth's surface to the amount incident upon it. Value varies with surface composition. For example, snow and ice vary from 80% to 85% and bare ground from 10% to 20%.
[5] The presence of buildings, trees, and other irregular land topography that is associated with its efficiency as a momentum sink for turbulent air flow, due to the generation of drag forces and increased vertical wind shear.
[6] http://seamless.usgs.gov/

Before AERSURFACE, without an automated algorithm to determine land-use patterns, it was simplest for the user to visually estimate land usage by sector. With AERSURFACE, the land-use is automatically determined. The proximity of the meteorological site to an airport and whether the site was located in an arid region were previously not explicitly accounted for as they now are in AERSURFACE. Snow cover, too, is critical for determination of α, but was largely left to user's discretion regarding its presence. With AERSURFACE, the lookup tables have separate columns for winter without much snow and for winter with abundant snow. The user determines if winter at a particular location contains at least one month of continuous snow cover, and AERSURFACE will pull values of the surface characteristics from the appropriate winter column.

We conducted a sensitivity test to evaluate the impacts of using this new tool on the present analysis. Figure B-3 shows a sample comparison of surface roughness values at the Philadelphia site with and without the use of AERSURFACE. In the Figure, estimated surface roughness values using visual land-use estimations and look-up table values are shown in muted shades and AERSURFACE values in dark shades. Monthly season definitions are the same in both cases. However, in the AERSURFACE case, winter was specified as having a one-month period of snow cover. Also, in the AERSURFACE case the site was specified as being at an airport.

In this case, z_0 values are much lower with AERSURFACE than with a visual estimation of land-use. In the AERSURFACE tool, Philadelphia was noted as being at an airport, tending to represent the lower building heights in the region and the inverse distance weighting implemented in the tool. Thus, lower z_0 values were obtained over most developed-area sectors in this scenario. The indication that at least one month of continuous snow cover is present also tends to lower wintertime z_0 values. In addition to these systematic differences, the automated AERSURFACE land-use analysis for Philadelphia tended to identify less urban coverage and more water coverage, lowering roughness values, but it also tended to identify more forest cover and less cultivated land cover than our visual analysis, increasing some z_0 values.

β_0 and α also varied significantly between the scenarios. However, this was largely due to two practical matters: First, the independence of these variables of wind direction in the AERSURFACE case and secondly the use of monthly-varying moisture conditions in one test case and not another. Thus we have not presented those results

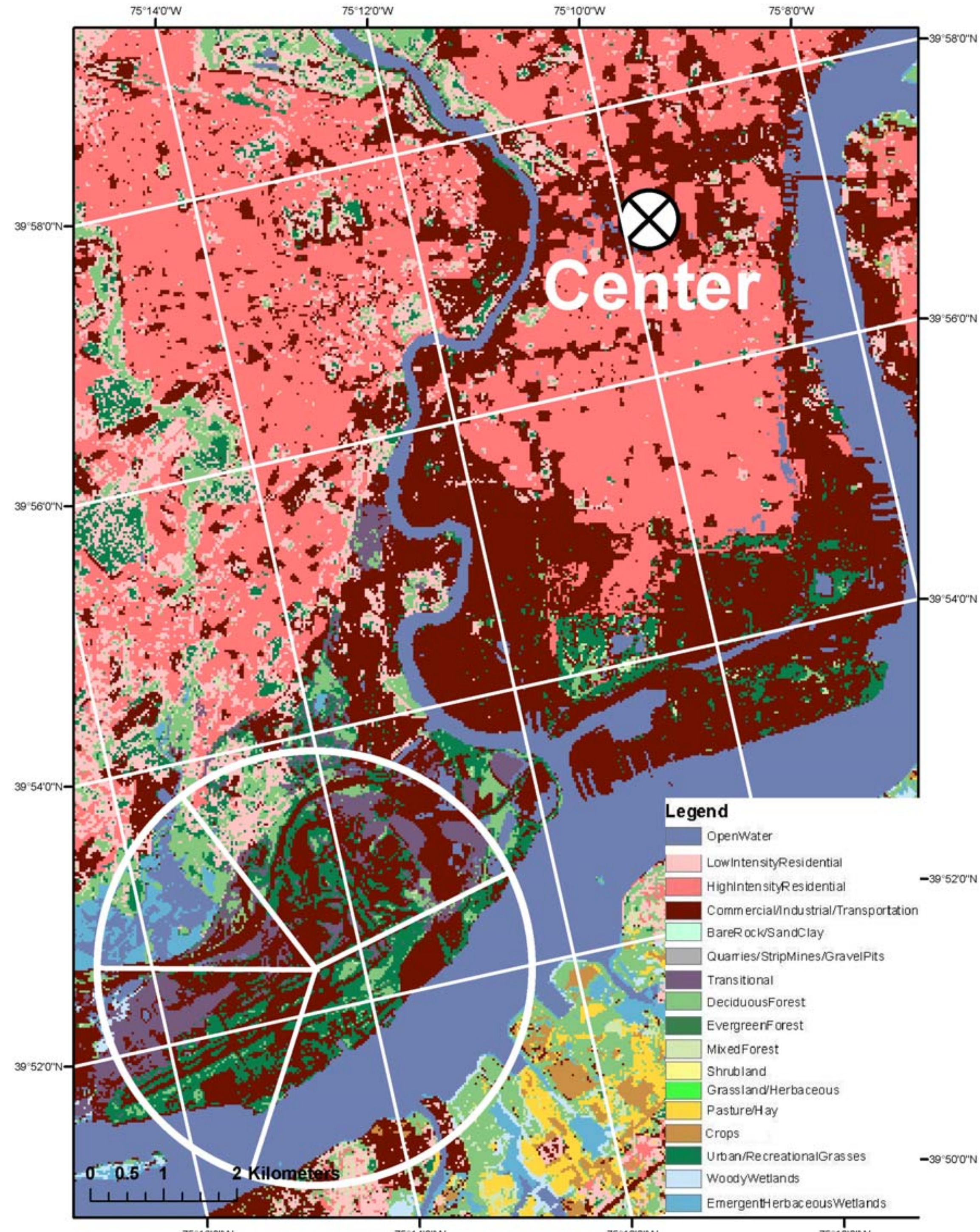

Figure B-2. Land-use and sectors around the Philadelphia-area surface meteorological station (KPHL). Sector borders are 80, 184, 262, and 312 degrees from geographic North. Philadelphia city center is labeled.

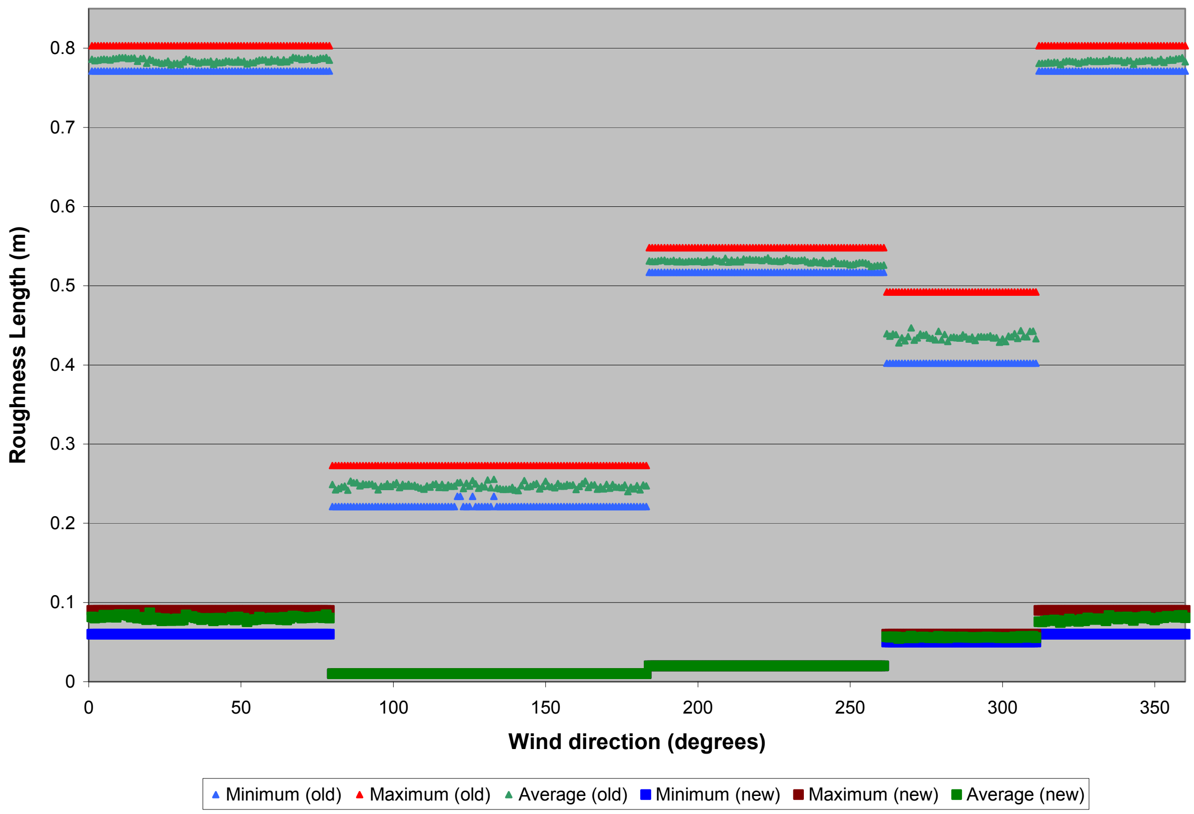

Figure B-3. Estimated z_0 values for the Philadelphia case-study analysis using visual and AERSURFACE land-use estimations.

B-3.5.3 Meteorological Data Analysis

The AERMET application location and elevation were taken as the center of the modeled city, estimated using Google Earth version 4.2.0198.2451 (beta) and defined as 39.952 °N, 75.164 °W, 12 m. The 2001-2003 AERSURFACE processing was run three times – once assuming the entire period was drier than normal, once assuming the entire period was wetter than normal, and once assuming the entire period was of average precipitation accumulation. These precipitation assumptions influence the Bowen ratio, discussed above.

To create meteorological input records that best represent the city for each of the three years, the resulting surface output files for each site were then pieced together on a month-by-month basis, with selection based on the relative amount of precipitation in each month. Any month where the actual precipitation amount received was at least twice the 1971-2000 NCDC 30-year climatic normal monthly precipitation amount was considered wetter than normal, while any month that received less than half the normal amount of precipitation amount was considered drier than normal; all other months were considered to have average surface moisture conditions. Table B-13 indicates the surface moisture condition for each month evaluated in this Philadelphia case-study.

Table B-13. Monthly precipitation compared to NCDC 30-year climatic normal for Philadelphia, 2001-2003.

Year	Jan	Feb	Mar	Apr	May	Jun
2001	74.8%	103.6%	144.2%	43.9%	102.9%	180.1%
	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
	29.9%	26.0%	67.1%	30.6%	17.9%	64.6%
2002	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**
	69.9%	17.7%	96.4%	52.7%	89.2%	93.9%
	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
	51.0%	59.0%	89.1%	202.7%	94.2%	117.9%
2003	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**
	53.2%	165.0%	102.7%	62.0%	108.5%	246.2%
	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
	46.5%	86.1%	120.8%	162.8%	92.9%	158.6%

Shading:	
(light shading)	Less than or equal to half the normal monthly precipitation amount
(no shading)	Less than twice the normal precipitation level and greater than half the normal amount
(dark shading)	At least twice the normal precipitation level

B-3.5.4 On-Road Emissions Preparation

Information on traffic data in the Philadelphia area was obtained from the Delaware Valley Regional Planning Council (DVRPC[7]) via their most recent, baseline travel demand modeling (TDM) simulation – that is, the most recent simulation calibrated to match observed traffic data. DVRPC provided the following files.

- Shapefiles of TDM outputs for the 2002 baseline year for all links in their network.
- Input files for the MOBILE6.2 emissions model that characterize local inputs that differ from national defaults, including fleet registration distribution information.
- Postprocessing codes they employ for analysis of TDM outputs into emission inventory data, to ensure as much consistency as possible between the methodology used for this study and that of DVRPC. These include DVRPC's versions of the local SVMT.DEF, HVMT.DEF, and FVMT.DEF MOBILE6.2 input files describing the vehicle miles traveled (VMT) by speed, hour, and facility, respectively, by county in the Delaware Valley area.
- A lookup table used to translate average annual daily traffic (AADT) generated by the TDM into hourly values.

Although considerable effort was expended to maintain consistency between the DVRPC approach to analysis of TDM data and that employed in this analysis, including several personal communications with agency staff on data interpretation, complete consistency was not possible due to the differing analysis objectives. The DVRPC creates countywide emission inventories. This study created spatially and temporally resolved emission strengths for dispersion modeling.

B-3.5.4.1 Emission Sources and Locations

[7] http://www.dvrpc.org/

The TDM simulation's shapefile outputs include annual average daily traffic (AADT) volumes and a description of the loaded highway network. The description of the network consists of a series of nodes joining individual model links (i.e., roadway segments) to which the traffic volumes are assigned, and the characteristics of those links, such as endpoint location, number of lanes, link distance, and TDM-defined link daily capacity.[8]

To reduce the scope of the analysis, the full set of links in the DVRPC network was first filtered to include only those roadway types considered *major* (i.e., freeway, parkway, major arterial, ramp), and that had AADT values greater than 15,000 vehicles per day (one direction).

However, the locations of links in the model do not necessarily agree well with the roads they are attempting to represent. While the exact locations of the links may not be mandatory for DVRPC's travel demand modeling, the impacts of on-road emissions on fixed receptors is crucially linked to the distance between the roadways and receptors. Hence, it was necessary to modify the link locations from the TDM to the best known locations of the actual roadways. The correction of link locations was done based on the locations of the nodes that define the end points of links with a GIS analysis, as follows.

A procedure was developed to relocate TDM nodes to more realistic locations. The nodes in the TDM represent the endpoints of links in the transportation planning network and are specified in model coordinates. The model coordinate system is a Transverse Mercator projection of the TranPlan Coordinate System with a false easting of 31068.5, false northing of -200000.0, central meridian: -75.00000000, origin latitude of 0.0, scale factor of 99.96, and in units of miles. The procedure moved the node locations to the true road locations and translated to dispersion model coordinates. The Pennsylvania Department of Transportation (PA DOT) road network database[9] was used as the specification of the true road locations. The nodes were moved to coincide with the nearest major road of the corresponding roadway type using a built-in function of ArcGIS. Once the nodes had been placed in the corrected locations, a line was drawn connecting each node pair to represent a link of the adjusted planning network.

To determine hourly traffic on each link, the AADT volumes were converted to hourly values by applying DVRPC's seasonal and hourly scaling factors. To determine hourly traffic on each link, the AADT volumes were converted to hourly values by applying DVRPC's seasonal and hourly scaling factors. The heavy-duty vehicle fraction – which is assumed by DVRPC to be about 6% in all locations and times – was also applied.[10] Another important

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[8] The TDM capacity specifications are not the same as those defined by the Highway Capacity Manual (HCM). Following consultation with DVRPC, the HCM definition of capacity was used in later calculations discussed below.

[9] http://www.pasda.psu.edu/

[10] As shown by Figure B-4 NO_x emissions from HDVs tend to be higher than their LDV counterparts by about a factor of 10. However, the HDV fraction is less than 10% of the total VMT in most circumstances, mitigating their influence on composite emission factors, although this mitigating effect is less pronounced at some times than others. For example, nighttimes on freeways tend to show a smaller reduction in HDV volume than in total volume, and thus an increased HDV fraction. This effect is not captured in most TDMs or emission postprocessors and – both to maintain consistency with the local MPO's vehicle characterizations and emissions modeling and due to lack of other relevant data – was also not included here. The net result of this is likely to be slightly underestimated emissions from major freeways during late-night times.

variable, the number of traffic signals occurring on a given link, was taken from the TDM link-description information.

Several of these parameters are shown in the following set of tables.

- Table B-14 hourly scaling factors
- Table B-15 seasonal scaling factors
- Table B-16 number of signals per roadway mile
- Table B-17 statistical summaries of AADT volumes for links included in the study.

Table B-14. Hourly scaling factors (in percents) applied to Philadelphia County AADT volumes.

Road Type	Region	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00
Freeway	CBD	1.23	0.86	0.74	0.84	1.23	2.50	4.87	6.52	6.47	5.75	4.99	5.02
	Fringe	1.23	0.86	0.74	0.84	1.23	2.50	4.87	6.52	6.47	5.75	4.99	5.02
	Urban	1.23	0.86	0.74	0.84	1.23	2.50	4.87	6.52	6.47	5.75	4.99	5.02
	Suburban	0.96	0.64	0.54	0.61	0.90	2.16	5.39	7.33	6.85	5.52	4.90	4.94
	Rural	0.71	0.48	0.38	0.48	0.95	2.54	6.05	7.77	6.79	5.22	4.64	4.78
Arterial	CBD	1.43	0.96	0.61	0.50	0.58	1.17	2.89	5.50	6.87	5.87	5.37	5.17
	Fringe	1.53	0.97	0.62	0.47	0.54	1.10	2.99	5.77	6.53	5.60	5.14	4.86
	Urban	1.13	0.68	0.52	0.45	0.63	1.68	4.26	6.68	6.86	5.47	5.09	5.17
	Suburban	0.70	0.40	0.32	0.33	0.55	1.71	4.51	7.04	6.84	5.37	4.95	5.36
	Rural	0.60	0.36	0.34	0.41	0.77	2.29	5.47	7.37	6.62	5.36	5.09	5.35
Local	CBD	1.11	0.71	0.45	0.37	0.41	0.97	2.39	4.82	6.72	6.50	4.60	4.93
	Fringe	1.00	0.55	0.37	0.21	0.39	0.98	1.98	5.31	5.91	5.78	5.14	5.19
	Urban	1.19	0.74	0.53	0.43	0.54	1.32	3.37	6.54	6.86	5.09	4.65	4.95
	Suburban	0.53	0.29	0.21	0.20	0.37	1.25	3.94	7.51	7.50	5.24	4.66	5.22
	Rural	0.55	0.32	0.25	0.30	0.57	1.89	5.26	7.93	6.84	4.94	4.57	4.89
Ramp	CBD	1.23	0.86	0.74	0.84	1.23	2.50	4.87	6.52	6.47	5.75	4.99	5.02
	Fringe	1.23	0.86	0.74	0.84	1.23	2.50	4.87	6.52	6.47	5.75	4.99	5.02
	Urban	1.23	0.86	0.74	0.84	1.23	2.50	4.87	6.52	6.47	5.75	4.99	5.02
	Suburban	0.96	0.64	0.54	0.61	0.90	2.16	5.39	7.33	6.85	5.52	4.90	4.94
	Rural	0.71	0.48	0.38	0.48	0.95	2.54	6.05	7.77	6.79	5.22	4.64	4.78
Road Type	**Region**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**	**21:00**	**22:00**	**23:00**
Freeway	CBD	4.97	5.77	6.40	6.60	7.02	6.76	6.27	4.20	3.52	3.06	2.50	1.92
	Fringe	4.97	5.77	6.40	6.60	7.02	6.76	6.27	4.20	3.52	3.06	2.50	1.92
	Urban	4.97	5.77	6.40	6.60	7.02	6.76	6.27	4.20	3.52	3.06	2.50	1.92
	Suburban	5.05	5.19	5.90	6.80	7.58	7.67	6.51	4.27	3.34	2.97	2.32	1.66
	Rural	4.92	5.01	5.75	7.12	7.88	8.18	6.27	4.31	3.45	2.97	2.10	1.27
Arterial	CBD	5.27	5.57	5.95	6.63	7.39	7.81	6.36	4.78	4.05	3.74	3.18	2.36
	Fringe	5.52	5.40	6.08	6.88	7.36	8.08	6.24	4.98	4.21	3.82	3.13	2.19
	Urban	5.42	5.54	6.16	7.04	7.39	7.42	6.08	4.74	3.77	3.31	2.61	1.93
	Suburban	5.75	5.71	6.12	7.05	7.66	7.98	6.42	4.81	3.83	3.13	2.15	1.34
	Rural	5.55	5.50	6.00	7.11	7.82	7.98	6.26	4.48	3.50	2.80	1.88	1.11
Local	CBD	6.26	6.74	6.88	6.78	7.64	8.10	6.57	4.96	3.96	3.02	2.88	2.25
	Fringe	6.31	5.64	6.64	7.32	7.85	9.52	6.25	5.50	5.29	2.87	2.46	1.56
	Urban	5.25	5.40	6.44	7.35	7.80	7.85	6.41	5.02	4.04	3.46	2.79	2.01

	Suburban	5.78	5.57	6.01	7.11	8.20	8.98	6.83	5.02	3.83	2.90	1.82	1.05
	Rural	5.20	5.11	5.89	7.41	8.53	8.93	6.75	4.82	3.64	2.70	1.73	0.99
Ramp	CBD	4.97	5.77	6.40	6.60	7.02	6.76	6.27	4.20	3.52	3.06	2.50	1.92
	Fringe	4.97	5.77	6.40	6.60	7.02	6.76	6.27	4.20	3.52	3.06	2.50	1.92
	Urban	4.97	5.77	6.40	6.60	7.02	6.76	6.27	4.20	3.52	3.06	2.50	1.92
	Suburban	5.05	5.19	5.90	6.80	7.58	7.67	6.51	4.27	3.34	2.97	2.32	1.66
	Rural	4.92	5.01	5.75	7.12	7.88	8.18	6.27	4.31	3.45	2.97	2.10	1.27

Table B-15. Seasonal scaling factors applied to Philadelphia County AADT volumes.

Season	Road Type	Factor
Winter	Freeway	0.945
Spring	Freeway	1.006
Summer	Freeway	1.041
Autumn	Freeway	1.009
Winter	Arterial	0.942
Spring	Arterial	1.004
Summer	Arterial	1.041
Autumn	Arterial	1.013
Winter	Local	0.933
Spring	Local	1.012
Summer	Local	1.05
Autumn	Local	1.004
Winter	Ramp	0.944
Spring	Ramp	1.005
Summer	Ramp	1.041
Autumn	Ramp	1.011

Table B-16. Signals per mile, by link type, applied to Philadelphia County AADT volumes.

	Region Type				
Functional Class	CBD	Fringe	Rural	Suburban	Urban
Freeway	0	0	0	0	0
Local	8	6	1.5	3	5
Major Arterial	8	6	1	2	4
Minor Arterial	8	6	1.3	2	4
Parkway	4	2	0.5	1	1.5
Ramp	0	0	0	0	0

Table B-17. Statistical summary of AADT volumes (one direction) for Philadelphia County AERMOD simulations.

Statistic	Road Type	CBD	Fringe	Suburban	Urban
Count	Arterial	186	58	210	580
	Freeway	11	10	107	98
	Ramp	0	4	3	1
Minimum AADT	Arterial	15088	15282	15010	15003
	Freeway	15100	18259	15102	15100
	Ramp		16796	15679	16337
Maximum AADT	Arterial	44986	44020	48401	44749
	Freeway	39025	56013	68661	68661

	Ramp		40538	24743	16337
Average AADT	Arterial	21063	21196	20736	22368
	Freeway	25897	40168	33979	31294
	Ramp		24468	18814	16337

B-3.5.4.2 Emission Source Strength

On-road mobile emission factors were derived from the MOBILE6.2 emissions model as follows. The DVRPC-provided external data files describing the vehicle miles traveled (VMT) distribution by speed, functional class, and hour, as well as the registration distribution and *Post-1994 Light Duty Gasoline Implementation* for Philadelphia County were all used in the model runs without modification. To further maintain consistency with the recent DVRPC inventory simulations and maximize temporal resolution, the DVRPC's seasonal particulate matter (PM) MOBILE6 input control files were also used. These files include county-specific data describing the vehicle emissions inspection and maintenance (I/M) programs, on-board diagnostics (OBD) start dates, VMT mix, vehicle age distributions, default diesel fractions, and representative minimum and maximum temperatures, humidity, and fuel parameters. The simulations are designed to calculate average running NO_x emission factors.[11]

These input files were modified for the current project to produce running NOx emissions in grams per mile for a specific functional class (Freeway, Arterial, or Ramp) and speed. Iterative MOBILE6.2 simulations were conducted to create tables of average Philadelphia County emission factors resolved by speed (2.5 to 65 mph), functional class, season, and year (2001, 2002, or 2003) for each of the eight combined MOBILE vehicle classes (LDGV, LDGT12, LDGT34, HDGV, LDDV, LDDT, HDDV, and MC)[12]. The resulting tables were then consolidated into speed, functional class, and seasonal values for combined light- and heavy-duty vehicles. Figure B-4 shows an example of the calculated emission factors for Autumn, 2001.

[11] Basing the present emissions model input files on MPO-provided PM, rather than NO_x input files should not cause confusion. MPO-provided PM files were used because they contain quarterly rather than annual or biannual information. In all cases the output species were modified to produce gaseous emissions. Further, many of the specified input parameters do not affect PM emissions, but were included by the local MPO to best represent local conditions, which were preserved in the present calculations of NO_x emissions. This usage is consistent with the overall approach of preserving local information wherever possible.

[12] HDDV - Heavy-Duty Diesel Vehicle, HDGV - Heavy-Duty Gasoline Vehicle, LDDT - Light-Duty Diesel Truck, LDDV - Light-Duty Diesel Vehicle, LDGT12 - Light-Duty Gasoline Truck with gross vehicle weight rating ≤ 6,000 lbs and a loaded vehicle weight of ≤ 5,750 lbs, LDGT 34 - Light-Duty Gasoline Truck with gross vehicle weight rating between 6,001 - 8,500 and a loaded vehicle weight of ≤ 5,750 lbs, LDGV - Light-Duty Gasoline Vehicle, MC - Motorcycles.

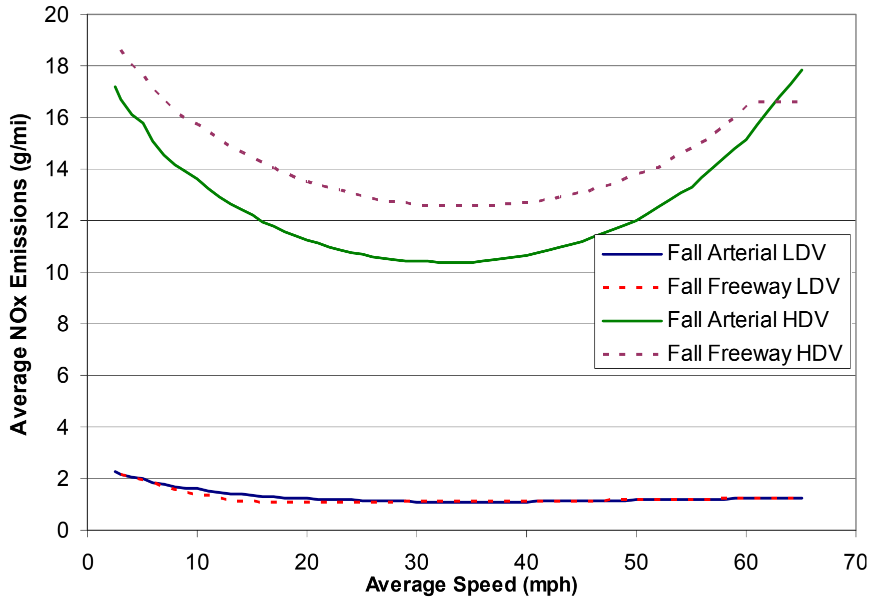

Figure B-4. Example of Light- and heavy-duty vehicle NOx emissions grams/mile (g/mi) for arterial and freeway functional classes, 2001.

To determine the emission strengths for each link for each hour of the year, the Philadelphia County average MOBILE6.2 speed-resolved emissions factor tables were merged with the TDM link data, which had been processed to determine time-resolved speeds. The speed calculations were made as follows.

The spatial-mean speed of each link at each time was calculated following the methodology of the Highway Capacity Manual.[13] Generally, the spatial-mean speed calculation is a function of the time-resolved volume-to-capacity ratio, with capacity the limiting factor. In the case of freeway calculations, this is determined by the HDV fraction, posted speed, and the general hilliness of the terrain, which was assumed to be uniformly flat for this region. The case of arterials without intersections is similar, but also considers urban effects. The case of arterials with intersections further considers the number of signals and length of each link and signalization parameters. It was assumed that all signals are identical, operating with a 120-second cycle and a protected left turn phase. Each link's speed is calculated independently. For example, a series of adjacent arterial links could show very different spatial-mean speeds if one link contains one or more intersections. That is, no up- or down-stream impacts are considered on individual link speeds. Speeds were assumed to be equal for light- and heavy-duty vehicles.

Table B-18 shows the resulting average speed for each functional class within each TDM region. Several values are shown as N/A, due to the focus only on major links as discussed above.

Table B-18. Average calculated speed by link type.

	Average Speed (mph)				
	CBD	Fringe	Suburban	Urban	Rural

[13] As defined in Chapter 9 of Recommended Procedure for Long-Range Transporation Planning and Sketch Planning, NCHRP Report 387, National Academy Press, 1997. 151 pp., ISBN No: 0-309-060-58-3.

Ramp	N/A	35	35	35	N/A
Arterial	34	31	44	32	N/A
Freeway	51	62	66	62	N/A

The resulting emission factors were then coupled with the TDM-based activity estimates to calculate emissions from each of the 1,268 major roadway links. However, many of the links were two sides of the same roadway segment. To speed model execution time, those links that could be combined into a single emission source were merged together. This was done only for the 628 links (314 pairs) where opposing links were paired in space and exhibited similar activity levels within 20% of each other.

B-3.5.4.3 Other Emission Parameters

Each roadway link is characterized as a rectangular area source with the width given by the number of lanes and an assumed universal lane width of 12 ft (3.66 m). The length and orientation of each link is determined as the distance and angle between end nodes from the adjusted TDM locations. In cases where the distance is such that the aspect ratio is greater than 100:1, the links were disaggregated into sequential links, each with a ratio less than that threshold. There were 27 links that exceeded this ratio and were converted to 55 segmented sources. Thus, the total number of area sources included in the dispersion simulations is 982. Table B-19 shows the distribution of on-road area source sizes. Note that there are some road segments whose length was zero after GIS adjustment of node location. This is assumed to be compensated by adjacent links whose length will have been expanded by a corresponding amount.

Table B-19. On-road area source sizes.

	Segment Width (m)	Lanes	Segment Length (m)
Minimum	3.7	1.0	0.0
Median	11.0	3.0	220.6
Average	13.7	3.8	300.2
1-σ Deviation	7.7	2.1	259.5
Maximum	43.9	12.0	1340.2

Resulting daily emission estimates were temporally allocated to hour of the day and season using MOBILE6.2 emission factors, coupled with calculated hourly speeds from the postprocessed TDM and allocated into SEASHR emission profiles for the AERMOD dispersion model. That is, 96 emissions factors are attributed to each roadway link to describe the emission strengths for 24 hours of each day of each of four seasons and written to the AERMOD input control file.

The release height of each source was determined as the average of the light- and heavy-duty vehicle fractions, with an assumed light- and heavy-duty emission release heights of 1.0 ft (0.3048 m) and 13.1 ft (4.0 m), respectively.[14] Because AERMOD only accepts a single release height for each source, the 24-hour average of the composite release heights is used in the modeling. Since surface-based mobile emissions are anticipated to be terrain following, no

[14] 4.0 m includes plume rise from truck exhaust stacks. See Diesel Particulate Matter Exposure Assessment Study for the Ports of Los Angeles and Long Beach, State of California Air Resources Board, Final Report, April 2006.

elevated or complex terrain was included in the modeling. That is, all sources are assumed to lie in a flat plane.

B-3.5.5 Stationary Sources Emissions Preparation

Data for the parameterization of major point sources in Philadelphia comes primarily from two sources: the 2002 National Emissions Inventory (NEI; US EPA, 2007b) and Clean Air Markets Division (CAMD) Unit Level Emissions Database (US EPA, 2007c). These two databases have complimentary information.

The NEI database contains stack locations, emissions release parameters (i.e., height, diameter, exit temperature, exit velocity), and annual emissions for 707 NO_x-emitting stacks (206 of which are considered fugitive release points) in Philadelphia County. The CAMD database, on the other hand, has information on hourly NO_x emission rates for all the units in the US, where the units are the boilers or equivalent, each of which can have multiple stacks. The alignment of facilities between the two databases is not exact, however. Some facilities listed in the NEI, are not included in the CAMD database. Of those facilities that do match, in many cases there is no clear pairing between the individual stacks assigned within the databases.

B-3.5.5.1 Data Source Alignment

To align the information between the two databases and extract the useful portion of each for dispersion modeling, the following methodology was used.

1. Attention was limited stacks within the NEI data base that (a) lie within Philadelphia County and (b) were part of a facility with total emissions from all stacks exceeding 100 tpy NO_x.
2. Individual stacks that had identical stack physical parameters and were co-located within about 10 m were combined to be simulated as a single stack with their emissions summed.
3. All fugitive releases were removed from the list, to be analyzed as a separate source group.

The resulting 19 distinct, combined stacks from the NEI are shown in Table B-20.

The CAMD database was then queried for facilities that matched the facilities identified from the NEI database. Facility matching was done on the facility name, Office of Regulatory Information Systems (ORIS) identification code (when provided) and facility total emissions to ensure a best match between the facilities. Once facilities were paired, individual units and stacks in the data bases were paired, based on annual emission totals. Table B-21 shows the matching scheme for the seven major facilities in Philadelphia County.[15]

[15] Note that Jefferson Smurfit does not exist in the CAMD database. The matching here was based on facility types as follows. Smurfit in PA was taken as a packaging/recycling facility, and the stack assumed to be a Cogen facility, based on information in the NEEDS database (http://www.epa.gov/interstateairquality/pdfs/NEEDS-NODA.xls). The best matched cogen plant in Philadelphia County in both the NEEDS and CAMD database is the Gray's Ferry Cogen Partnership (ORIS 54785), which was a reasonable match for Smurfit's total emissions. It was assumed that the hourly emission profile also matches well.

In Table B-21, there are sometimes multiple CAMD units that pair with a single NEI combined stack. In these cases the hourly emission rates from the matching CAMD units are summed for each hour. For example, in the case of stack 859 for "Sunoco, Inc – Philadelphia" five CAMD hourly records are summed into a single hourly record. Then each resulting hourly value is scaled by a factor of 1032.8 / 938.9 = 1.10, so that the annual total matches the NEI annual total.

Similarly, there are sometimes multiple combined stacks that pair with single units. In this case the CAMD values are disaggregated according to NEI-defined stack contributions. For example, "Sunoco, Inc – Philadelphia" stack 855's profile is determined by taking the hourly profile from CAMD unit number 52106-150101, and scaling each value by a factor of 26.2 tpy / 48.2 tpy total = 0.54. Then each resulting hourly value is scaled by a factor of 48.2/162.1 = 0.3 so that the sum of the annual totals for the 4 stacks corresponding to unit number 52106-150101 matches the NEI total. For consistency, in each case the 2001 and 2003 hourly emission profiles were determined using the same scaling factors, but applied to the respective CAMD emission profile.

It is clear from Table B-21 that most facilities agree well in total annual NO_x emissions between the two databases. However, in the case of the "Sunoco Chemicals (Former Allied Signal)" facility, nearly half of the NEI emissions (without fugitives) do not appear in the CAMD database. The reason for this is unknown and no information was readily available on the relative accuracy of the two databases.

Figure B-5 illustrates the discrepancy versus fraction of hours with positive emissions, according to the CAMD data base. The figure suggests that the discrepancies are not primarily the result of facilities with episodic emissions (i.e., "peak load" facilities). Although there is good agreement on facility-wide emissions between the two data bases, there are larger discrepancies between CAMD unit emissions and NEI stack emissions. This is to be expected given the discrepancy in resolution between the two data bases.

Table B-20. Combined stacks parameters for stationary NOx emission sources in Philadelphia County.

Stack No	NEI Site ID	Facility Name	SIC Code	NAICS Code	ORIS Facility Code	Stack Emissions (tpy)	Stack X (deg)	Stack Y (deg)	Stack Ht (m)	Exit Temp (K)	Stack Diam (m)	Exit Velocity (m/s)	Facility Emission with Fugitive (tpy)
817	NEIPA2218	EXELON GENERATION CO - DELAWARE STATION	4911	221112	3160	4.82	-75.1358	39.96769	49	515	4.2	0	297.8
818	NEIPA2218	EXELON GENERATION CO - DELAWARE STATION	4911	221112	3160	287.8	-75.1358	39.96769	64	386	3.7	17	297.8
819	NEI40720	JEFFERSON SMURFIT CORPORATION (U S)	2631	32213		0.148	-75.2391	40.03329	16	477	0.4	19	228.4
820	NEI40720	JEFFERSON SMURFIT CORPORATION (U S)	2631	32213		113.8	-75.2391	40.03329	53	427	2.4	10	228.4
821	NEI40720	JEFFERSON SMURFIT CORPORATION (U S)	2631	32213		114.46	-75.2391	40.03329	53	477	2.4	12	228.4
855	NEI40723	Sunoco Inc. - Philadelphia	2911	32411		26.2	-75.2027	39.92535	24	450	2.1	9	3112.2
856	NEI40723	Sunoco Inc. - Philadelphia	2911	32411		1.3	-75.2003	39.91379	24	644	1.5	22	3112.2
857	NEI40723	Sunoco Inc. - Philadelphia	2911	32411		1.4	-75.203	39.92539	25	511	1.9	10	3112.2
858	NEI40723	Sunoco Inc. - Philadelphia	2911	32411		19.3	-75.2027	39.92535	25	527	1.9	11	3112.2
859	NEI40723	Sunoco Inc. - Philadelphia	2911	32411		1032.8	-75.2124	39.90239	61	489	5.8	11	3112.2
860	NEI7330	SUNOCO CHEMICALS (FORMER ALLIED SIGNAL)	2869	325998		0.033	-75.0715	40.00649	5	476	0.5	7	160.9
861	NEI7330	SUNOCO CHEMICALS (FORMER ALLIED SIGNAL)	2869	325998		49.1	-75.0715	40.00649	41	422	1.4	22	160.9
862	NEI7330	SUNOCO CHEMICALS (FORMER ALLIED SIGNAL)	2869	325998		34.6	-75.0715	40.00649	42	422	1.6	17	160.9
863	NEI7330	SUNOCO CHEMICALS (FORMER ALLIED SIGNAL)	2869	325998		77.2	-75.0715	40.00649	42	422	1.6	22	160.9
864	NEIPA101353	TRIGEN - SCHUYLKILL	4961	22		128.6	-75.1873	39.94239	69	450	4.9	6	190.1
865	NEIPA101353	TRIGEN - SCHUYLKILL	4961	22		61.5	-75.1873	39.94239	78	450	7.3	2	190.1
866	NEIPA101356	GRAYS FERRY COGENERATION PARTNERS	4911	22	54785	143.2	-75.1873	39.94239	78	396	5.5	20	233.5
867	NEIPA101356	GRAYS FERRY COGENERATION PARTNERS	4911	22	54785	90.3	-75.1873	39.94239	85	443	3.2	21	233.5
868	NEIPA2222	TRIGEN - EDISON	4961	62		130.5	-75.1569	39.94604	78	589	3.7	9	130.5

Table B-21. Matched stacks between the CAMD and NEI database.

NEI Facility Name	NEI *Comb. Stack* Number	NEI *Comb. Stack* Emiss (tpy)	NEI Unit Emiss (tpy)	NEI Facility Emiss (tpy, w/out Fugitive)	CAMD Facility Name	CAMD Units *	CAMD Unit Emiss (tpy) *	CAMD Comb. Unit Totals (tpy)	CAMD Facility Totals (tpy)	Stack δ (%, relative to CAMD value)	Stack δ (tpy)	Facility δ (% relative to CAMD value)	Facility δ (tpy)
Exelon Generation Co - Delaware Station	817	4.8	4.8	**292.6**	Delaware	3160-9	1.542	1.542	**289.3**	213%	3.3	**1%**	**3.3**
	818	287.8	287.8			3160-71	123.8	287.8		0%	0.0		
						3160-81	164						
Sunoco Inc. - Philadelphia	855	26.2	48.2	**1081.0**	Philadelphia Refinery	52106-150101	162.1	162.1	**1101.0**	-70%	-113.9	**-2%**	**-20.3**
	856	1.3											
	857	1.4											
	858	19.3											
	859	1032.8	1032.8			52106-150137	194.2	938.9		10%	93.9		
						52106-150110	162.1						
						52106-150138	194.2						
						52106-150139	194.2						
						52106-150140	194.2						
Sunoco Chemicals (Former Allied Signal)	860	0.0	160.9	**160.9**	Sunoco Chemicals Frankford Plant	880007-52	84.5	84.5	**84.5**	90%	76.4	**90%**	**76.4**
	861	49.1											
	862	34.6											
	863	77.2											
Trigen - Schuylkill	864	128.6	128.6	**190.1**	Trigen Energy - Schuylkill	50607-23	163.1	163.1	**178.7**	-21%	-34.5	**6%**	**11.4**
	865	61.5	61.5			50607-24	2.9	15.6		293%	45.9		

NEI Facility Name	NEI *Comb. Stack* Number	NEI *Comb. Stack* Emiss (tpy)	NEI Unit Emiss (tpy)	NEI Facility Emiss (tpy, w/out Fugitive)	CAMD Facility Name	CAMD Units *	CAMD Unit Emiss (tpy) *	CAMD Comb. Unit Totals (tpy)	CAMD Facility Totals (tpy)	Stack δ (%, relative to CAMD value)	Stack δ (tpy)	Facility δ (% relative to CAMD value)	Facility δ (tpy)
						50607-26	12.7						
Grays Ferry Cogeneration Partners	866	143.2	143.2	**233.5**	Grays Ferry Cogen Partnership	54785-2	143.2	143.2	**233.5**	0%	0.0	**0%**	**0.0**
	867	90.3	90.3			54785-25	90.3	90.3		0%	0.0		
Trigen - Edison	868	130.5	130.5	**130.5**	Trigen Energy Corporation-Edison St	880006-1	19.8	111	**111.0**	18%	19.4	**18%**	**19.4**
						880006-2	17.3						
						880006-3	36.1						
						880006-4	37.8						
Jefferson Smurfit Corporation (U S) ***	819	0.1	228.4	**228.4**		54785-2	143.2	233.5	**233.5**	-2%	-5.1	**-2%**	**-5.1**
	820	113.8				54785-25	90.3						
	821	114.5											

Notes:
* In the format "ORIS ID - UNIT ID"
** All CAMD values are for 2002
*** Jefferson Smurfit not in CAMD; will use Grays Ferry as surrogate

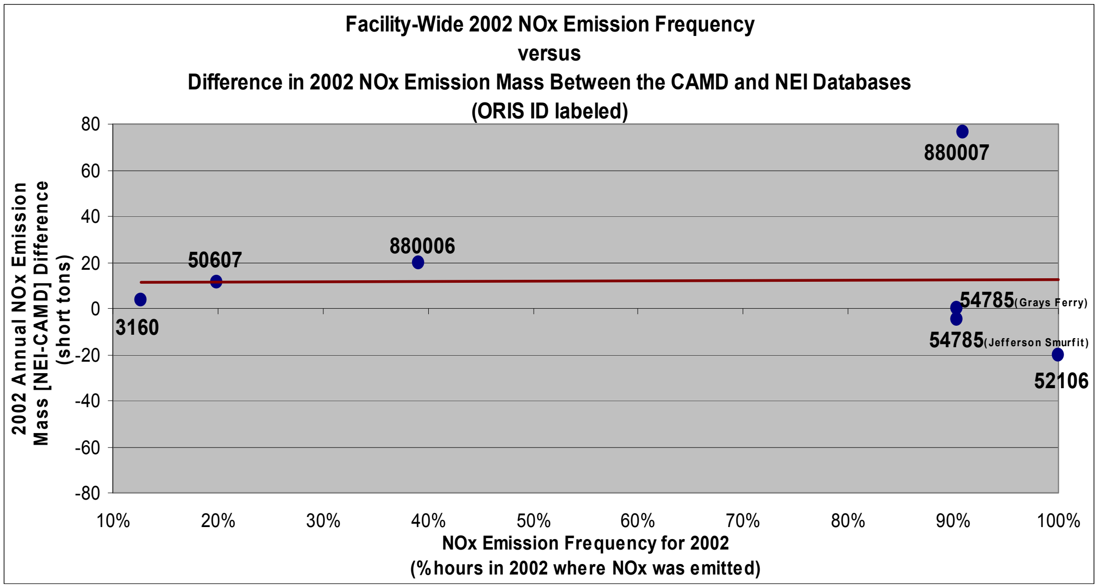

Figure B-5. Differences in facility-wide annual NOx emission totals between NEI and CAMD data bases for Philadelphia County 2002.

B-3.5.6 Fugitive and Airport Emissions Preparation

Fugitive emission releases in Philadelphia County, as totaled in the NEI database, were modeled as area sources with the profile of these releases determined by the overall facility profile of emissions. In addition, emissions associated with the Philadelphia International Airport were estimated.

B-3.5.6.1 Fugitive Releases

Thirty five *combined stacks* were identified during the point source analysis (see previous section) that were associated with facilities considered major emitters, but where the emissions from the stacks are labeled *Fugitive* in the NEI. These stacks have zero stack diameter, zero emission velocity, and exit temperature equal to average ambient conditions (295 K). Thus, we determined it was not appropriate to include these in the point source group simulation.

These 35 stacks occur at only two facilities in the County: Exelon Generation Co – Delaware Station (NEI Site ID: NEIPA2218) and Sunoco Inc. – Philadelphia (NEI Site ID: NEI40723). Consequently, they were grouped by facility. The Sunoco emissions further fall into two distinct categories based on release heights. Thus, to accommodate all these sources most efficiently, we created three area source groups: one for Sunoco emissions at 3.0 m, one for Sunoco emissions greater than 23.0 m, and one for Exelon. The "stacks" within the NEI and their parameters comprising each of these sources are shown in Table B-22 along with their groupings and the resulting combined area source parameters.

Table B-22. Emission parameters for the three Philadelphia County fugitive NOx area emission sources.

Grp. No.	NEI Site ID	Facility Name	NEI 2002 Emissions (tpy)	Stack X	Stack Y	Stack Height (m)	Stacks Used for Emission Profile [1]	Scaled Emissions (tpy) [2]		
								2001	2002	2003

Grp. No.	NEI Site ID	Facility Name	NEI 2002 Emissions (tpy)	Stack X	Stack Y	Stack Height (m)	Stacks Used for Emission Profile [1]	Scaled Emissions (tpy) [2]		
								2001	2002	2003
	NEIPA 2218	EXELON GENERATIO N CO - DELAWARE STATION	0.1	-75.13582	39.96769	5				
			5.1	-75.12528	39.96680	8				
1			**5.2**			**6.5**	**817+818**	**4.8**	**5.2**	**6.4**
	NEI40 723	Sunoco Inc. - Philadelphia	65.3	-75.21408	39.90811	3				
			350.9	-75.21300	39.90878	3				
			12.7	-75.20972	39.90467	3				
			355.7	-75.20945	39.90778	3				
			31.1	-75.20876	39.90185	3				
			6.2	-75.20845	39.90708	3				
			182.4	-75.20809	39.91580	3				
			1.1	-75.20707	39.90946	3				
			7.5	-75.20651	39.90988	3				
			1.0	-75.20301	39.91362	3				
			2.0	-75.20114	39.91273	3				
			49.4	-75.20090	39.91621	3				
			106.3	-75.20079	39.91615	3				
			188.5	-75.20047	39.91366	3				
			87.8	-75.20043	39.91377	3				
			36.1	-75.20024	39.91406	3				
			9.7	-75.20020	39.91410	3				
			61.2	-75.19995	39.91596	3				
			13.6	-75.19766	39.91696	3				
			17.0	-75.19751	39.91696	3				
			17.2	-75.19735	39.91590	3				
			12.2	-75.19723	39.91597	3				
			12.6	-75.19720	39.91698	3				
			23.7	-75.19713	39.91596	3				
			19.2	-75.19699	39.91599	3				
			10.0	-75.19644	39.91493	3				
2			**1,680.4**			**3.0**	**855+856+ 857+858+ 859**	**1,873. 8**	**1,681. 4**	**2,202 .4**
	NEI40 723	Sunoco Inc. - Philadelphia	79.5	-75.21322	39.90899	23				
			13.1	-75.20833	39.90278	26				
			15.3	-75.20850	39.90246	27				
			2.5	-75.20844	39.90239	27				
			10.2	-75.20838	39.90231	27				
			19.0	-75.20828	39.90237	27				
			211.2	-75.20889	39.90279	30				
3			**350.8**			**26.7**	**855+856+ 857+858+ 859**	**391.2**	**351.0**	**459.8**

[1] See Table B-20 for stack definitions.

[2] Scaled emissions are determined by summing the scaled, hourly values from the CAMD database, as used in the dispersion modeling.

1

In the case of the Sunoco emissions, the vertices of the area sources were determined by a convex hull encapsulating all the points. In the case of Excelon, only two points are provided, which is insufficient information to form a closed polygon. Instead, the boundary of the facility was digitized into a 20-sided polygon. Figure B-6 shows the locations of these polygons.

Emission profiles for the fugitive releases were determined from the CAMD hourly emission database in a method similar to that for the point sources. We determined scaling factors based on the ratio of the 2002 fugitive releases described by the NEI to the total, non-fugitive point source releases from the same facility. All stacks within that facility were combined on an hourly basis for each year and the fugitive to non-fugitive scaling factor applied, ensuring that the same temporal emission profile was used for fugitives as for other releases from the facility, since the origins of the emissions should be parallel. We created external hourly emissions files for each of the three fugitive area sources with appropriate units (grams per second per square meter).

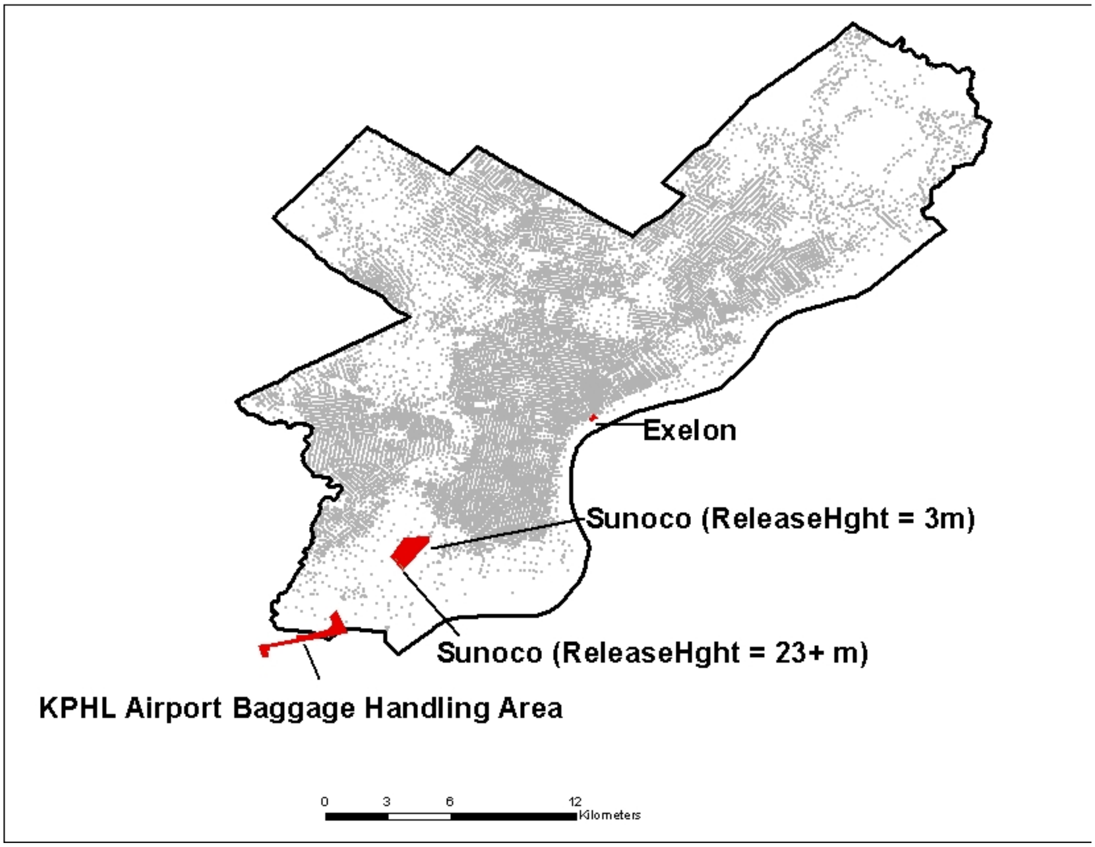

Figure B-6. Locations of the four ancillary area sources. Also shown are centroid receptor locations.

B-3.5.6.2 Philadelphia International Airport Emissions

Another significant source of NOx emissions in Philadelphia County not captured in the earlier simulations is from operation of the Philadelphia International Airport (PHL). PHL is the only major commercial airport in the County and is the largest airport in the Delaware Valley.

The majority of NOx emissions in the NEI[16] database attributable to airports in Philadelphia County are from non-road mobile sources, specifically ground support equipment. There is another airport in the County: Northeast Philadelphia Airport. However, because it serves general aviation, is generally much smaller in operations than PHL, and has little ground support equipment activity – which is associated primarily with commercial aviation – all airport emissions in the County were attributed to PHL. The PHL emissions were taken from the non-road section of the 2002 NEI, and are shown by Table B-23.

Table B-23. Philadelphia International airport (PHL) NO_x emissions.

State and County	SCC	NOx (tpy)	SCC Level 1 Description	SCC Level 3 Description	SCC Level 6 Description	SCC Level 8 Description
Philadelphia, PA	2265008005	4.6	Mobile Sources	Off-highway Vehicle Gasoline, 4-Stroke	Airport Ground Support Equipment	Airport Ground Support Equipment
	2267008005	5.1	Mobile Sources	LPG	Airport Ground Support Equipment	Airport Ground Support Equipment
	2270008005	196.2	Mobile Sources	Off-highway Vehicle Diesel	Airport Ground Support Equipment	Airport Ground Support Equipment
	2275020000	0.01	Mobile Sources	Aircraft	Commercial Aircraft	Total: All Types
	2275050000	2.5	Mobile Sources	Aircraft	General Aviation	Total
PHL Total		**208.4**				

As with the fugitive sources discussed above, the airport emissions are best parameterized as area sources. The boundary of the area source was taken as the region of operation of baggage handling equipment, including the terminal building and the region surrounding the gates. This region was digitized into an 18-sided polygon of size 1,326,000 m^2, and included in the AERMOD input control file.

The activity profile for PHL was taken to have seasonal and hourly variation (SEASHR), based on values from the EMS-HAP model.[17] These factors are disaggregated in the EMS-HAP model database based on source classification codes (SCCs), which were linked to those from the NEI database. The EMS-HAP values provide hourly activity factors by season, day type, and hour; to compress to simple SEASHR modeling, the hourly values from the three individual day types were averaged together. The total emissions for each SCC were then disaggregated into seasonal and hourly components and the resulting components summed to create total PHL emissions for each hour of the four annual seasons. These parameterized emissions were then normalized to the total cargo handling operational area, to produce emission factors in units of grams per second per square meter and included in the AERMOD input file. Figure B-6 also illustrates the location of the PHL area source.

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[16] http://www.epa.gov/ttn/chief/net/2002inventory.html

[17] EPA 2004, User's Guide for the Emissions Modeling System for Hazardous Air Pollutants (EMS-HAP) Version 3.0, EPA-454/B-03-006.

B-3.5.7 Receptor Locations

Three sets of receptors were chosen to represent the locations of interest. First, all NOx monitor locations, shown by Table B-24, within the Philadelphia county were included as receptor locations. Although all receptors are assumed to be on a flat plane, they are placed at the standard breathing height of 5.9 ft (1.8 m).

Table B-24. Philadelphia County NOx monitors.

Site ID	Latitude	Longitude
421010004	40.0089	-75.0978
421010029	39.9572	-75.1731
421010047	39.9447	-75.1661

The second receptor locations were selected to represent the locations of census block centroids near major NO_x sources. GIS analysis was used to determine all block centroids in Philadelphia County that lie within a 0.25 mile (400 m) of the roadway segments and also all block centroids that lie within 6.2 miles (10 km) of any major point source. 12,982 block centroids were selected due to their proximity to major roadways; 16,298 centroids were selected due to their proximity to major sources. The union of these sets produced 16,857 unique block centroid receptor locations, each of which was assigned a height of 5.9 ft (1.8 m). The locations of centroids that met either distance criteria – and were thus included in the modeling – is shown by Figure B-7.

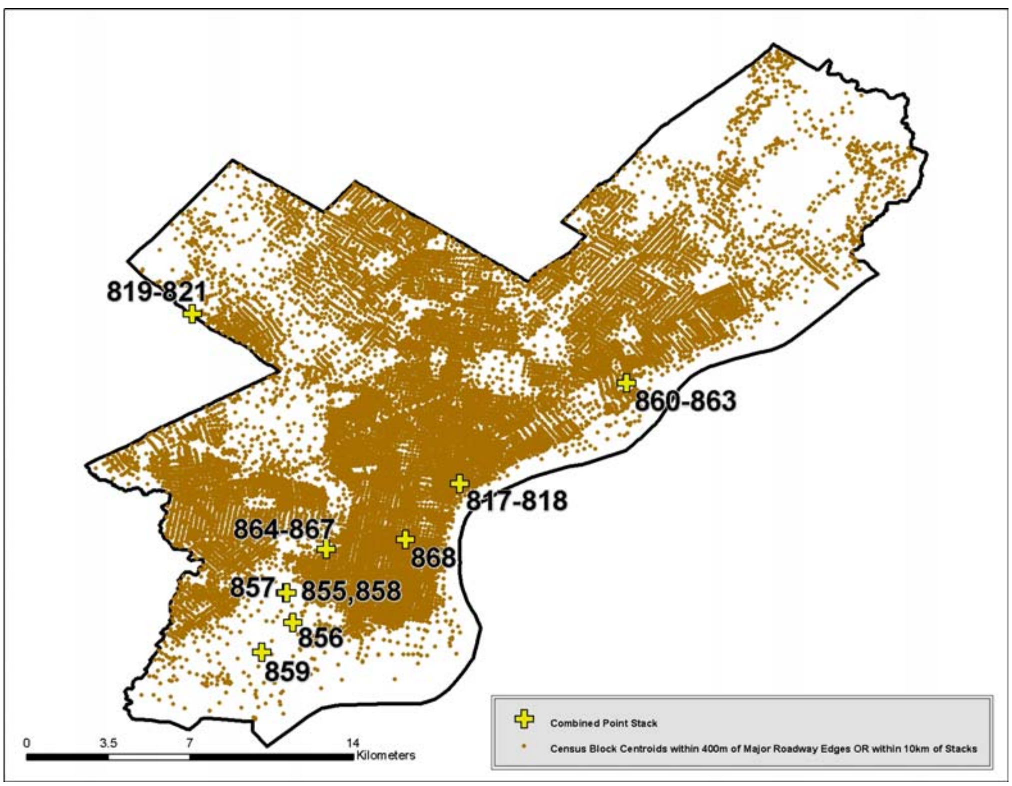

Figure B-7. Centroid locations within fixed distances to major point and mobile sources in Philadelphia county.

The third set of receptors was chosen to represent the on-road microenvironment. For this set, one receptor was placed at the center of each of the 982 sources.

The distance relationship between the road segments and block centroids can be estimated by looking at the distance between the road-centered and the block centroid receptors. Figure B-8 shows the histogram of the shortest distance between each centroid receptor and its nearest roadway-centered receptor.

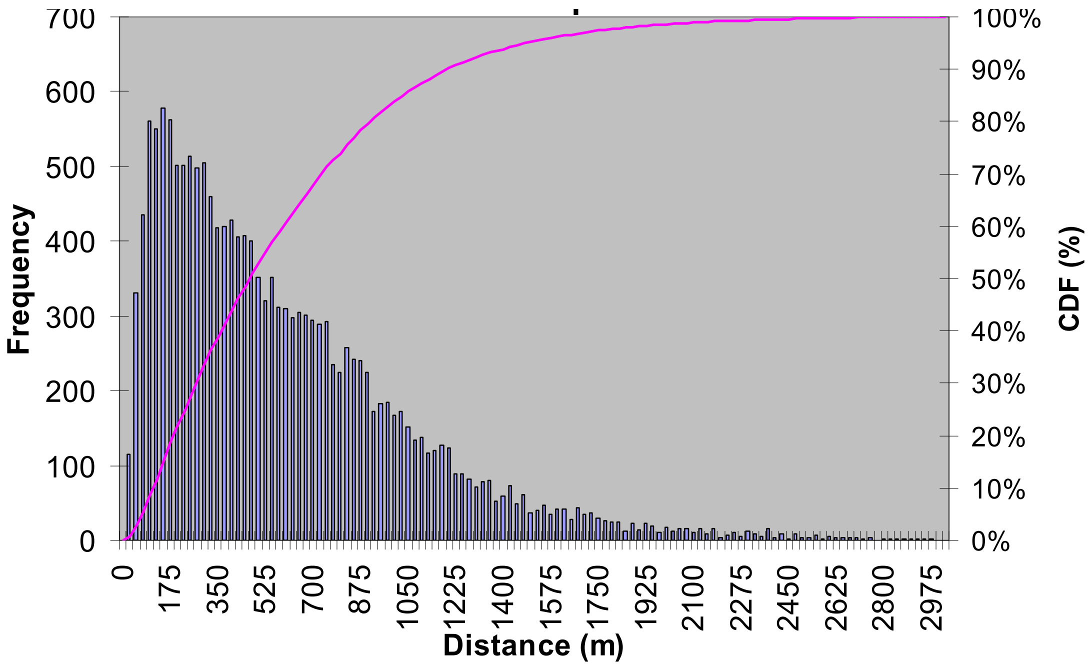

Figure B-8. Frequency distribution of distance between each Census receptor and its nearest road-centered receptor in Philadelphia County.

The block centroids selected were those within 10 km of any major point source or 400 m from any receptor edge, so the distances to the nearest major road segment can be significantly greater than 400 m. The mode of the distribution is about 150 m and the median distance to the closest roadway segment center is about 450 m. However, these values represent the distances of the block centroids to road centers instead of road edges, so that they overestimate the actual distances to the zone most influenced by roadway by an average of 14 m and a range of 4 m to 44 m (see Table B-19 above).

B-3.5.8 Other AERMOD Specifications

Since each of the case-study locations were MSA/CMSAs, all emission sources were characterized as urban. The AERMOD *toxics* enhancements were also employed to speed calculations from area sources. NO_x chemistry was applied to all sources to determine NO_2 concentrations. For the each of the roadway, fugitive, and airport emission sources, the ozone limiting method (OLM) was used, with plumes considered ungrouped. Because an initial NO_2 fraction of NO_x is anticipated to be about 10% or less (Finlayson-Pitts and Pitts, 2000; Yao et al., 2005), a conservative value of 10% for all sources was selected. For all point source simulations the Plume Volume Molar Ratio Method (PVMRM) was used to estimate the conversion of NO_x to NO_2, with the following settings:

1. Hourly series of O_3 concentrations were taken from EPA's AQS database[18]. The complete national hourly record of monitored O_3 concentrations were filtered for the four monitors within Philadelphia County (stations 421010004, 421010014, 421010024, and 421010136). The hourly records of these stations were then averaged together to provide an average Philadelphia County concentrations of O_3 for each hour of 2001-2003.
2. The equilibrium value for the NO_2:NO_x ratio was taken as 75%, the national average ambient ratio.[19]
3. The initial NO_2 fraction of NO_x is anticipated to be about 10% or less. A default value of 10% was used for all stacks (Finlayson-Pitts and Pitts, 2000).

B-3.5.9 Air Quality Concentration Adjustment

The hourly concentrations estimated from each of the three source categories were combined at each receptor. Then a local concentration, reflecting the concentration contribution from emission sources not included in the simulation, was added to the sum of the concentration contributions from each of these sources at each receptor. The local concentration was estimated from the difference between the model predictions at the local NO_2 monitors and the observed values. It should be noted that this local concentration may also include any model error present in estimating concentration at the local monitoring sites. Table B-25 presents a summary of the estimated local concentration added to the AERMOD hourly concentration data.

Table B-25. Comparison of ambient monitoring and AERMOD predicted NO_2 concentrations in Philadelphia.

Year and Monitor ID	Annual Average NO_2 concentration (ppb)			
	Monitor	AERMOD Inititial	Difference[1]	AERMOD Final[2]
2001				
4210100043	26	7	18	19
4210100292	28	22	6	33
4210100471	30	20	10	32
mean			11	
2002				
4210100043	24	7	17	18
4210100292	28	21	7	32
4210100471	29	19	10	31
mean			11	
2003				
4210100043	24	7	17	13
4210100292	25	22	3	28
4210100471*	25	26	-1	32

[18] http://www.epa.gov/ttn/airs/airsaqs/detaildata/downloadaqsdata.htm
[19] Appendix W to CFR 51, page 466. http://www.epa.gov/scram001/guidance/guide/appw_03.pdf.

mean		6	
[1] the difference represents concentrations attributed to sources not modeled by AERMOD and model error. [2] the mean difference between measured and modeled was added uniformly at each receptor hourly concentration to generate the AERMOD final concentrations. * monitor did not meet completeness criteria used in the air quality characterization.			

B-3.5.10 Meteorological Data Used By APEX

APEX used the same meteorological data that was used for the AERMOD modeling, the station located at Philadelphia International (KPHL) airport.

B-3.5.11 Microenvironment Descriptions

B-3.5.11.1 Microenvironment 1: Indoor-Residence

The Indoors-Residence microenvironment uses several variables that affect NO_2 exposure: whether or not air conditioning is present, the average outdoor temperature, the NO_2 removal rate, and an indoor concentration source. The first two of these variables affect the air exchange rate.

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. For this study, location-specific air conditioning prevalence was taken from the American Housing Survey of 2003 (AHS, 2003a; 2003b). Previous analyses (US EPA, 2007d) detail the specification of uncertainty estimates in the form of confidence intervals for the air conditioner prevalence using the following:

$$\text{Standard Error}\,(P) = \sqrt{\frac{3850\,P\,(1-P)}{N}},$$
$$\text{Confidence Interval}\,(P) = P \pm 1.96 \times \text{Standard Error}\,(P)$$

where P is the estimated percentage and N is the estimated total number of housing units. Table B-26 contains the values for air conditioning prevalence used for each modeled location.

Table B-26. Air conditioning prevalence estimates with 95% confidence intervals.

AHS Survey	Housing Units	A/C Prevalence (%)	se	L95	U95
Philadelphia	1,943,492	90.6	1.3	88.1	93.2
Notes: se – Standard error L95 – Lower limit on 95th confidence interval U95 – Upper limit on 95th confidence interval					

Air exchange rate data for the indoor residential microenvironment were obtained from US EPA (2007d). Briefly, residential air exchange rate (AER) data were obtained from several studies (Avol et al., 1998; Williams et al., 2003a, 2003b; Meng et al., 2004; Weisel et al., 2004; Chillrud at al, 2004; Kinney et al., 2002; Sax et al., 2004; Wilson et al., 1986, 1996; Colome et al., 1993, 1994; Murray and Burmaster, 1995). Influential characteristics (e.g., temperature, air conditioning), where reported in the study, were also compiled for use in statistical analyses. Descriptive statistics were generated for each location/variable type and evaluated using statistical comparison testing (e.g., ANOVA). Based on the summary statistics and the statistical comparisons, different AER distributions were fit for each combination of A/C type, city, and temperature. 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.

For Philadelphia, a distribution was selected from a location thought to have similar characteristics to the city to be modeled, qualitatively considering 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 used for Philadelphia are provided in Table B-27.

Table B-27. Geometric means (GM) and standard deviations (GSD) for air exchange rates by city, A/C type, and temperature range.

Area Modeled	Study City	A/C Type	Temp (ºC)	N	GM	GSD
Philadelphia	New York City	Central or Room A/C	<=10	20	0.7108	2.0184
			10-25	42	1.1392	2.6773
			>25	19	1.2435	2.1768
		No A/C	<=10	48	1.0165	2.1382
			10-20	59	0.7909	2.0417
			>20	32	1.6062	2.1189

For this analysis, the same NO_2 removal rate distribution was used for all microenvironments that use the mass balance method. This removal rate is based on data provided by Spicer et al. (1993). A total of 6 experiments, under variable source emission characteristics including operation of gas stove, were conducted in an unoccupied test house. A distribution could not be described with the limited data set, therefore a uniform distribution was approximated by the bounds of the 6 values, a minimum of 1.02 and a maximum of 1.45 h^{-1}.

An excerpt from the APEX input file describing the indoor residential microenvironment is provided in Figure B-9. The first section of the input file excerpt specifies the air exchange rate distributions for the microenvironment. Average temperature and air conditioning presence, which are city-specific, were coded into air exchange rate *conditional variables, C1* and *C2*, respectively. Average temperatures were separated into five categories (variable *C1*, numbered 1-5): 50 º F, 50-68 º F, 68-77 º F, 77-86 º F, and 86 º F and above. For variable *C2*, air conditioning status can range from *1* to *2* (*1* for having air conditioning, *2* for not having it). The air exchange rate estimates generated previously in the form of lognormal distributions were entered into the appropriate temperature and A/C category for each location for a total of ten distributions (i.e., 5 temperature distributions by 2 air conditioning distributions). In the input file example however, there are actually four AER distributions for homes with an air conditioner and three for those without; the last few distributions for each air conditioning setting were the same due to the available data to populate the field. The parameter estimates for the removal factor (DE) is also shown following the AER data.

```
Micro number      = 1        !     Indoors - residence - AIR EXCHANGE RATES
Parameter Type    = AER
Condition # 1     = AvgTempCat
Condition # 2     = AC_Home
ResampHours       = NO
ResampDays        = YES
ResampWork        = YES
Block DType Season Area C1  C2  C3   Shape       Par1    Par2  Par3 Par4  LTrunc UTrunc
1     1     1      1    1   1   1    Lognormal   0.711   2.018   0    .     0.1    10
1     1     1      1    2   1   1    Lognormal   1.139   2.677   0    .     0.1    10
1     1     1      1    3   1   1    Lognormal   1.139   2.677   0    .     0.1    10
1     1     1      1    4   1   1    Lognormal   1.244   2.177   0    .     0.1    10
1     1     1      1    5   1   1    Lognormal   1.244   2.177   0    .     0.1    10
1     1     1      1    1   2   1    Lognormal   1.016   2.138   0    .     0.1    10
1     1     1      1    2   2   1    Lognormal   0.791   2.042   0    .     0.1    10
1     1     1      1    3   2   1    Lognormal   1.606   2.119   0    .     0.1    10
1     1     1      1    4   2   1    Lognormal   1.606   2.119   0    .     0.1    10
1     1     1      1    5   2   1    Lognormal   1.606   2.119   0    .     0.1    10

Micro number      = 1              !    DECAY RATES
Pollutant = 1
Parameter Type    = DE
ResampHours       = NO
ResampDays        = NO
ResampWork        = YES
Block DType Season Area C1  C2  C3   Shape       Par1   Par2  Par3 Par4  LTrunc UTrunc
1     1     1      1    1   1   1    Uniform     1.02   1.45   .    .     1.02   1.45
```

Figure B-9. Example input file from APEX for Indoors-residence microenvironment.

Indoor source contributions

A number of studies, as described in the NO_x ISA, have noted the importance of gas cooking appliances as sources of NO_2 emissions. An indoor emission source term was included in the APEX simulations to estimate exposure to indoor sources of NO_2. Three types of data were used to implement this factor:

- The fraction of households in the Philadelphia MSA that use gas for cooking fuel
- The range of contributions to indoor NO_2 concentrations that occur from cooking with gas
- The diurnal pattern of cooking in households.

The fraction of households in Philadelphia County that use gas cooking fuel (i.e., 55%) was taken from the *US Census Bureau's American Housing Survey for the Philadelphia Metropolitan Area: 2003*.

Data used for estimating the contribution to indoor NO_2 concentrations that occur during cooking with gas fuel were derived from a study sponsored by the California Air Resources Board (CARB, 2001). For this study a test house was set up for continuous measurements of NO_2 indoors and outdoors, among several other parameters, and conducted under several different cooking procedures and stove operating conditions. A uniform distribution of concentration contributions for input to APEX was estimated as follows.

- The concurrent outdoor NO_2 concentration measurement was subtracted from each indoor concentration measurement, to yield net indoor concentrations
- Net indoor concentrations for duplicate cooking tests (same food cooked the same way) were averaged for each indoor room, to yield average net indoor concentrations
- The minimum and maximum average net indoor concentrations for any test in any room were used as the lower and upper bounds of a uniform distribution

This resulted in a minimum average net indoor concentration of 4 ppb and a maximum net average indoor concentration of 188 ppb.

An analysis by Johnson et al (1999) of survey data on gas stove usage collected by Koontz et al (1992) showed an average number of meals prepared each day with a gas stove of 1.4. The diurnal allocation of these cooking events was estimated as follows.

- Food preparation time obtained from CHAD diaries was stratified by hour of the day, and summed for each hour, and summed for total preparation time.
- The fraction of food preparation occurring in each hour of the day was calculated as the total number of minutes for that hour divided by the overall total preparation time. The result was a measure of the probability of food preparation taking place during any hour, given one food preparation event per day.
- Each hourly fraction was multiplied by 1.4, to normalize the expected value of daily food preparation events to 1.4.

The estimated probabilities of cooking by hour of the day are presented in Table B-28. For this analysis it was assumed that the probability that food preparation would include stove usage was the same for each hour of the day, so that the diurnal allocation of food preparation events would be the same as the diurnal allocation of gas stove usage. It was also assumed that each cooking event lasts for exactly 1 hour, implying that the average total daily gas stove usage is 1.4 hours.

Table B-28. Probability of gas stove cooking by hour of the day.

Hour of Day	Probability of Cooking (%)[1]
0	0
1	0
2	0
3	0
4	0
5	5
6	10
7	10
8	10
9	5

Hour of Day	Probability of Cooking (%)[1]
10	5
11	5
12	10
13	5
14	5
15	5
16	15
17	20
18	15
19	10
20	5
21	5
22	0
23	0
[1] Values rounded to the nearest 5%. Data sum to 145% due to rounding and scaling to 1.4 cooking events/day.	

B-3.5.11.2 *Microenvironments 2-7: All other indoor microenvironments*

The remaining five indoor microenvironments, which represent Bars and Restaurants, Schools, Day Care Centers, Office, Shopping, and Other environments, are all modeled using the same data and functions (Figure B-10). As with the Indoor-Residence microenvironment, these microenvironments use both air exchange rates and removal rates to calculate exposures within the microenvironment. The air exchange rate distribution (GM = 1.109, GSD = 3.015, Min = 0.07, Max = 13.8) was developed based on an indoor air quality study (Persily et al, 2005; see US EPA, 2007d for details in derivation). The decay rate is the same as used in the Indoor-Residence microenvironment discussed previously. The Bars and Restaurants microenvironment included an estimated contribution from indoor sources as was described for the Indoor-Residence, only there was an assumed 100% prevalence rate and the cooking with the gas appliance occurred at any hour of the day.

```
Micro number     = 2       !    Bars & restaurants     - AIR EXCHANGE RATES
Parameter Type    = AER
ResampHours      = NO
ResampDays       = YES
ResampWork       = YES
Block DType Season Area C1  C2  C3   Shape        Par1   Par2  Par3 Par4  LTrunc UTrunc
1         1          1        1    1    1    1   LogNormal   1.109  3.015   0     .      0.07       13.8

Micro number     = 2               !    DECAY RATES
Pollutant = 1
Parameter Type    = DE
ResampHours      = NO
ResampDays       = YES
ResampWork       = YES
Block DType Season Area C1  C2  C3   Shape      Par1   Par2  Par3 Par4  LTrunc UTrunc
1         1         1         1     1     1  1   Uniform     1.02    1.45   .      .       1.02       1.45
```

Figure B-10. Example input file from APEX for all Indoors microenvironments (non-residence).

Microenvironments 8 and 9: Outdoor microenvironments

Two outdoor microenvironments, the Near Road and Public Garage/Parking Lot, used the factors method to calculate pollutant exposure. Penetration factors are not applicable to outdoor environments (effectively, PEN=1). Proximity factors were developed from the AERMOD concentration predictions, i.e., the block-centroid-to-nearest-roadway concentration ratios. Based on the resulting sets of ratio values, the ratio distributions were stratified by hour of the day into 3 groups as indicated by the "hours-block" specification in the example file in Figure B-11. The lower and upper bounds for sampling were specified as the 5th and 95th percentile values, respectively, of each distribution.

```
Micro number     = 8       !    Outdoor near road      PROXIMITY FACTOR
Pollutant = 1
Parameter Type    = PR
Hours - Block     =      1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 3 3 3 1 1
ResampHours      = YES
ResampDays       = YES
ResampWork       = YES
Block DType Season Area C1  C2  C3   Shape      Par1   Par2  Par3 Par4  LTrunc UTrunc  ResampOut
1    1    1     1    1   1   1  LogNormal   1.251  1.478  0.    .    0.86  2.92     Y
2    1    1     1    1   1   1  LogNormal   1.555  1.739  0.    .    0.83  4.50     Y
3    1    1     1    1   1   1  LogNormal   1.397  1.716  0.    .    0.73  4.17     Y
```

Figure B-11. Example input file from APEX for outdoor near road microenvironment.

B-3.5.11.3 Microenvironment 10: Outdoors-General.

The general outdoor environment concentrations are well represented by the modeled concentrations. Therefore, both the penetration factor and proximity factor for this microenvironment were set to 1.

B-3.5.11.4 Microenvironments 11 and 12: In Vehicle- Cars and Trucks, and Mass Transit

Penetration factors were developed from data provided in Chan and Chung (2003). Inside-vehicle and outdoor NO_2 concentrations were measured with for three ventilation conditions, air-recirculation, fresh air intake, and with windows opened. Since major roads were the focus of this assessment, reported indoor/outdoor ratios for highway and urban streets were used here. Mean values range from about 0.6 to just over 1.0, with higher values associated with increased ventilation (i.e., window open). A uniform distribution was selected for the penetration factor for Inside-Cars/Trucks (ranging from 0.6 to 1.0) 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 ranging from 0.8 to 1.0 based on the reported mean values for fresh air intake and open windows. Proximity factors were developed as described above for Microenvironments 8 and 9.

B-3.5.12 Adjustment for Just Meeting the Current Standard

To simulate just meeting the current standard, dispersion modeled concentration were not rolled-up as was done for the monitor concentrations used in the air quality characterization. A proportional approach was used as done in the Air Quality Characterization, but to reduce computer processing time, the health effect benchmark levels were proportionally reduced by the similar factors described for each specific location and simulated year. 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 difference in the exposure and risk modeling was that the modeled air quality concentrations were used to generate the adjustment factors. Table B-29 provides the adjustment factors used and the adjusted potential health effect benchmark concentrations to simulate just meeting the current standard. When modeling indoor sources, the indoor concentration contributions needed to be scaled downward by the same proportions.

Table B-29. Adjustment factors and potential health effect benchmark levels used by APEX to simulate just meeting the current standard.

Simulated Year (factor)	Potential Health Effect Benchmark Level (ppb)	
	Actual	Adjusted
2001 (1.59)	150	94
	200	126
	250	157
	300	189
2002 (1.63)	150	92
	200	122
	250	153
	300	184
2003 (1.64)	150	91
	200	122
	250	152
	300	183

When considering the indoor sources, an additional scaling was performed so as not to affect their estimated concentrations while adjusting the benchmark levels downward. To clarify how this was done, exposure concentrations an individual experiences are first defined as the sum of the contribution from ambient concentrations and from indoor sources (if present) and this concentration can be either above or below a selected concentration level of interest:

$$C_{esposure} = A \times C_{ambient} + B \times C_{indoor} > C_{threshold} \quad \text{equation (6)}$$

where,

$C_{exposure}$ = individual exposure concentration
A = proportion of exposure concentration from ambient
$C_{ambient}$ = ambient concentration in the absence of indoor sources

B = proportion of exposure concentration from indoor
C_{indoor} = indoor source concentration contribution
$C_{threshold}$ = an exposure concentration of interest

It follows that if we are interested in adjusting the ambient concentrations upwards by some proportional factor F, this can be described with the following:

$$F \times A \times C_{ambient} + B \times C_{indoor} > C_{threshold} \qquad \text{equation (7)}$$

This is equivalent to

$$A \times C_{ambient} + B \times (C_{indoor} / F) > (C_{threshold} / F) \qquad \text{equation (8)}$$

Therefore, if the potential health effect benchmark level and the indoor concentrations are both proportionally scaled downward by the same adjustment factor, the contribution of both sources of exposure (i.e., ambient and indoor) are maintained and the same number of estimated exceedances would be obtained as if the ambient concentration were proportionally adjusted upwards by factor F.

B-3.6 Philadelphia Exposure Modeling Results

B-3.6.1 Overview

The results of the exposure and risk characterization are presented here for Philadelphia County. Several scenarios were considered for the exposure assessment, including two averaging time for NO_2 concentrations (annual and 1-hour), inclusion of indoor sources, and for evaluating just meeting the current standard. To date, year 2002 served as the base year for all scenarios, years 2001 and 2003 were only evaluated for a limited number of scenarios. Exposures were simulated for four groups; children and all persons, and the asthmatic population within each of these.

The exposure results summarized below focus on the population group where exposure estimations are of greatest interest, namely asthmatic individuals. The complete results for each of these two population subgroups are provided in section B-3.6.7. However, due to certain limitations in the data summaries output from the current version of APEX, some exposure data could only be output for the entire population modeled (i.e., all persons - includes asthmatics and healthy persons of all ages). The summary data for the entire population (e.g., annual average exposure concentrations, time spent in microenvironments at or above a potential health effect benchmark level) can be representative of the asthmatic population since the asthmatic population does not have its microenvironmental concentrations and activities estimated any differently from those of the total population.

B-3.6.2 Evaluation of Modeled NO_2 Air Quality Concentrations (as is)

Since the current NO_2 standard is 0.053 ppm annual average, the predicted air quality concentrations were first summarized by calculating annual average concentration. The distribution for the AERMOD predicted NO_2 concentrations at each of the 16,857 receptors for years 2001 through 2003 are illustrated in Figure B-12. Variable concentrations were estimated by the dispersion model over the three year period (2001-2003). The NO_2 concentration distribution was similar for years 2001 and 2002, with mean annual average concentrations of about 21 ppb and a COV of just over 30%. On average, NO_2 annual average concentrations were lowest during simulated year 2003 (mean annual average concentration was about 16 ppb), largely a result of the comparably lower local concentration added (Table B-28). While the mean annual average concentrations were lower than those estimated for 2001 and 2002, a greater number of annual average concentrations were estimated above 53 ppb for year 2003. In addition, year 2003 also contained greater variability in annual average concentrations as indicated by a COV of 53%.

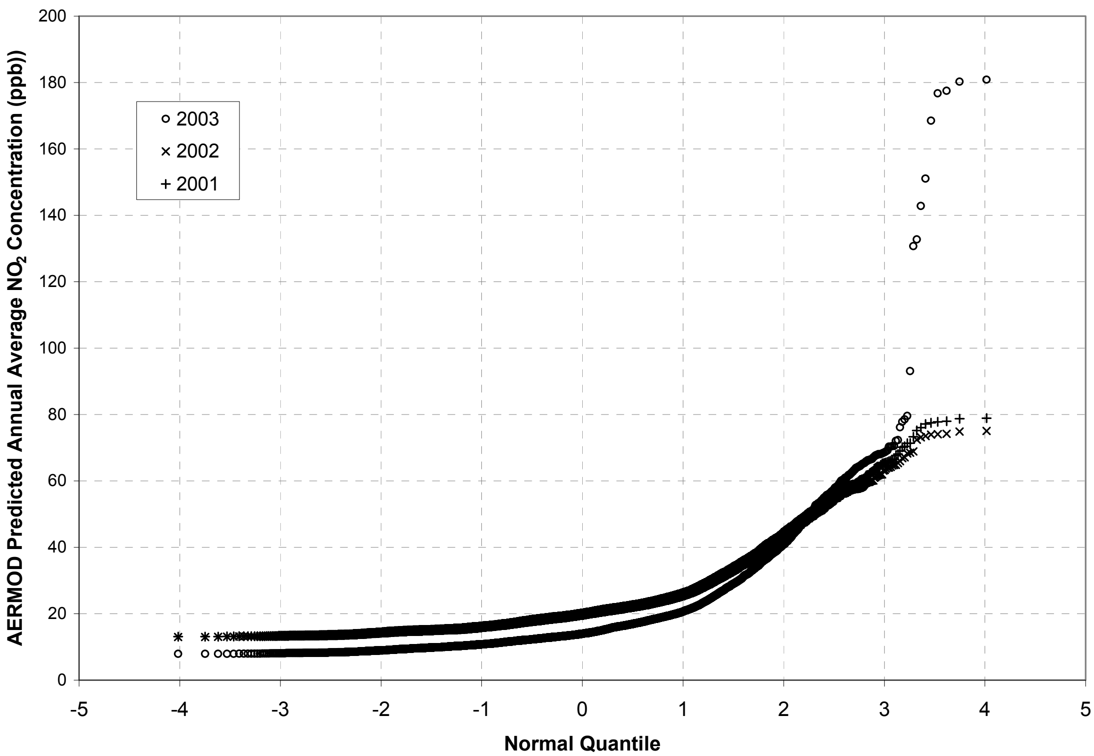

Figure B-12 . Distribution of AERMOD estimated annual average NO_2 concentrations at each of the 16,857 receptors in Philadelphia County for years 2001-2003.

Diurnal variability in NO_2 concentrations was evaluated by comparing the modeled concentrations at the monitor receptors with the measured concentrations at the ambient monitors. Figure B-13 presents the annual average NO_2 concentration at each hour of the day for the three monitors located in Philadelphia County. The diurnal distributions among the modeled versus measured concentrations are similar at all of the monitors, with peak NO_2 concentrations generally coinciding with the typical peak commute times of 6:00-9:00 AM and 5:00-8:00 PM. The pattern is represented best at monitor 4210100043 (top graph in Figure B-13), however the AERMOD concentrations are approximately 8 ppb lower at the earlier times of the day following the adjustment for sources not modeled (section B-3.5.9). There is greater variability in the modeled NO_2 concentrations at the other two monitors when compared with the measured data (middle and bottom graphs of Figure B-13), although the patterns are still similar. The greatest difference in NO_2 concentrations occurs during the later commute period, most notable at monitor 4210100292. Given the concentration adjustment to correct for sources not modeled was applied to all receptors equally across the entire modeling domain, it is not surprising that the modeled concentrations are higher in some instances while others not. The pattern in the concentrations is the important feature to replicate, of which AERMOD does reasonably, and based on these three receptors, may slightly overestimate peak concentrations more times than underestimate them.

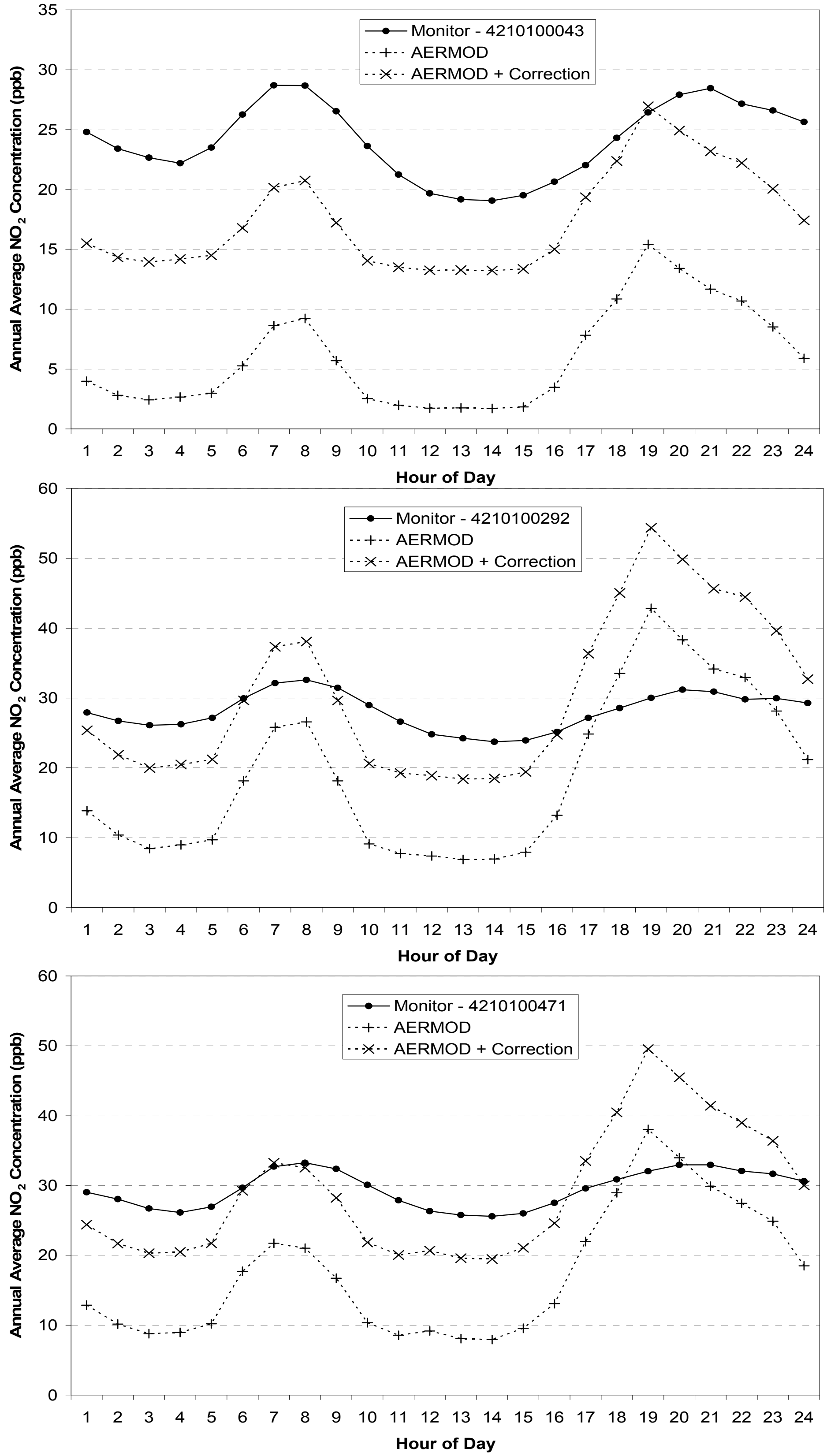

Figure B-13. Measured and modeled diurnal pattern of NO_2 concentrations at three ambient monitor sites.

B-3.6.3 Comparison of estimated on-road NO_2 concentrations

The two independent approaches used to estimate on-road NO_2 concentrations, one using ambient monitor data combined with an on-road simulation factor (section A-8) and the other using the AERMOD dispersion model (section B-3.5), were compared to one another. There are no on-road NO_2 concentration measurements in Philadelphia for the modeled data to be compared with, although it should be noted that the data used to estimate the simulation factors and applied to the monitor data are measurement based.

First a comparison can be made between the factor used for estimating on-road concentrations in the air quality analysis and similar factors calculated using AERMOD estimated concentrations. As described in section A-8, an empirical distribution of on-road simulation factors was derived from on-road and near-road NO_2 concentration measurements published in the extant literature. The derived empirical distribution was separated into two components, one for application to summertime ambient concentrations, and the second for all other seasons. The two empirical distributions are presented in Figure B-14, and represent the factors multiplied by the ambient monitor concentration (> 100 m from a major road) and used to estimate the on-road concentration in the air quality characterization. The one-hour NO_2 concentrations estimated at every AERMOD receptor in Philadelphia were compared with the concentrations estimated at their closest on-road receptor to generate a similar ratio (i.e., on-road/non-road concentrations). These ratios were also stratified into two seasonal categories, one containing the summer ratios (June, July, and August) and the other for all other times of the year. The AERMOD on-road factor distributions in semi-empirical form are also presented in Figure B-14. There are similarities in comparing each of the AERMOD with the measurement study derived distributions, most importantly at the upper percentiles. Intersection of the two approaches occurs at about the 70^{th} percentile and continues through the 90^{th} percentile. While the two seasonal distributions for AERMOD are very similar to one another, they diverge at the upper percentiles, with the summer ratios containing greater values at the same percentiles. This is similar to what was observed in the measurement derived distribution, although the summer ratio distribution consistently contained greater values at all percentiles compared with the non-summer distribution.

There are differences that exist when comparing the two approaches at the mid to lower percentiles, with the AERMOD ratios consistently lower than the empirically derived factors. This is likely due to the differences in the population of samples used to generate each type of distribution. The measurement study derived distribution used data from on-road concentration measurements and from monitoring sites located at a distance from the road, sites that by design of the algorithm and the factor selection criteria are likely not under the influence of non-road NO_2 emission sources. Thus, the measurement study derived ratios never fall below a value of one, there are no on-road concentrations less than any corresponding non-road influenced concentrations. This was, by design, a reasonable assumption for estimating the on-road concentrations for the air quality characterization. The AERMOD receptors however, include all types of emission sources such that there are possibilities for concentrations at non-road receptors that are greater than on-road, a more realistic depiction of the actual relationship between on-road and non-road receptors. Furthermore, the AERMOD distribution extends beyond the range of values offered by the measurement study derived ratios at the very upper percentiles. This could indicate that the AERMOD approach is better accounting for locally high NO_2 concentrations than those reported by the limited measurement studies.

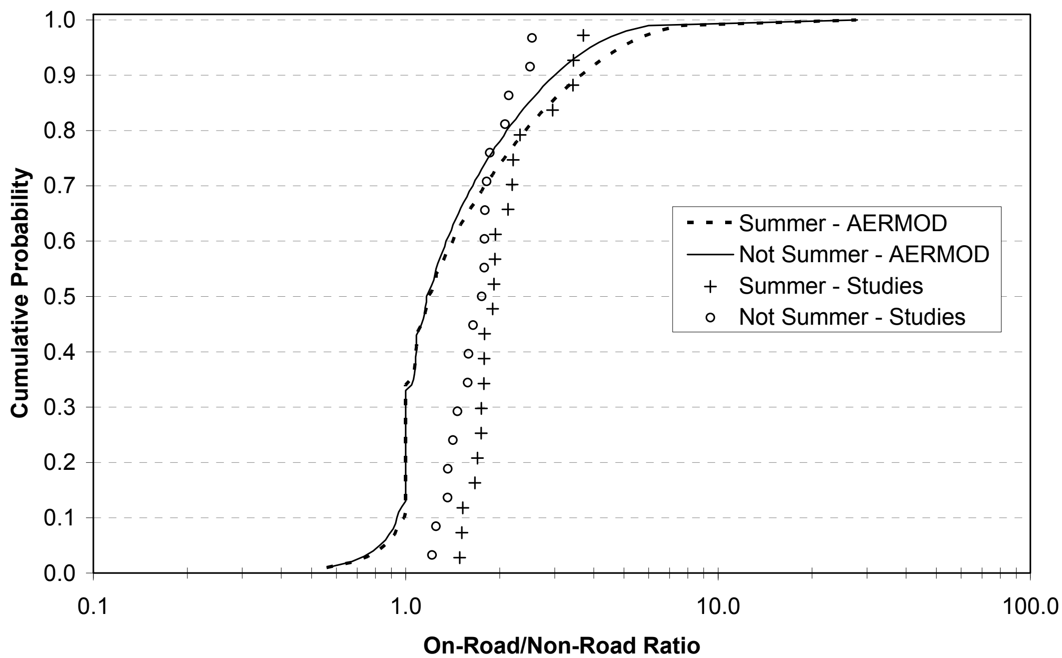

Figure B-14. Comparison of on-road factors developed from AERMOD concentration estimates and those derived from published NO_2 measurement studies.

Briefly for the second comparison, hourly on-road NO_2 concentrations were estimated using AERMOD for 979 on-road receptors in Philadelphia for the year 2002. The 24 hourly values modeled for each day at each receptor were rounded to the nearest 1 ppb and then adjusted for sources not modeled using the ambient monitor data (Table B-25). The second set of estimated on-road NO_2 concentrations was generated as part of the Air Quality Characterization by applying randomly selected on-road factors to the ambient monitor concentrations in the Philadelphia CMSA.

Table B-30 compares the summary statistics of the hourly concentrations and the number of exceedances of the potential health effect benchmark levels. The AERMOD predicted and ambient monitor simulated concentration distributions have very similar means and percentiles. However the variance of the modeled values is about 60 % higher than the variance of the simulated on-road monitor concentrations. This variance difference is largely a function of differences in the extreme upper tails of the distributions and most notable when comparing the numbers of exceedances of the potential health effect benchmark levels. The AERMOD on-road receptors consistently have a greater number of exceedances of potential health effect benchmark levels than that estimated using the on-road monitor simulation. For example, the AERMOD receptors had an average of 35 exceedances of 200 ppb per site-year while the simulated on-road monitors had an average of 2 exceedances per year. The maximum number of exceedances per site-year was 530 for the AERMOD modeled data and 59 for the simulated on-road monitor data.

The apparent contradiction between the similarity of the hourly concentration distributions and the large differences in the exceedance distributions can be explained by the fact that 200 ppb is the 99.605th percentile of the AERMOD hourly concentrations and is the 99.974th percentile of the simulated on-road monitor concentrations. Thus on average, 0.395 % of hourly AERMOD values exceed 200 ppb per year and 0.026 % of hourly simulated on-road monitored values exceed 200 ppb per year. These differences could be due to the greater number of receptors modeled by AERMOD (n=979) compared with the on-road monitor simulation (n=5). Again, the AERMOD generated data could include locations greatly influenced by roadway emissions that are not captured by the simplified approach conducted in the Air Quality Characterization.

Table B-30. Summary statistics of on-road hourly NO_2 concentrations (ppb) and the numbers of potential health effect benchmark levels using AERMOD and the on-road ambient monitor simulation approaches in Philadelphia.

	1-hour NO_2 concentrations		Exceedances of 150 ppb		Exceedances of 200 ppb		Exceedances of 250 ppb	
Statistic	AERMOD	Monitor Simulation	AERMOD	Monitor Simulation	AERMOD	Monitor Simulation	AERMOD	Monitor Simulation
N	8,576,040	4,183,900	979	500	979	500	979	500
Mean	36.2	35.4	113	18	35	2	12	0.6
Stdev	32.1	24.9	142	47	61	8	30	1.6
Variance	1,030	620	20,171	2,187	3,751	61	900	2.6
p0	12	0	0	0	0	0	0	0
p5	12	5	2	0	0	0	0	0
p10	12	9	8	0	0	0	0	0
p15	13	11	13	0	1	0	0	0
p20	14	14	21	0	2	0	0	0
p25	15	16	27	1	3	0	0	0
p30	17	19	32	1	4	0	0	0
p35	18	22	39	1	6	0	1	0
p40	20	25	45	1	8	0	1	0
p45	22	27	56	1	10	0	2	0
p50	25	30	65	1	13	0	2	0
p55	28	34	73	1	15	0	3	0
p60	31	38	86	2	20	1	4	0
p65	35	41	106	3	24	1	5	0
p70	40	45	122	6	31	1	7	0
p75	45	49	143	8	39	1	10	1
p80	52	54	176	15	56	1	15	1
p85	61	60	216	24	72	1	21	1
p90	75	68	267	63	95	4	31	1
p95	98	81	390	92	148	11	58	1
p100	707	681	1,072	278	530	59	299	11

B-3.6.4 Annual Average Exposure Concentrations (as is)

The hourly NO_2 concentrations output from AERMOD were input into the exposure model, providing a range of estimated exposures output by APEX. Figure B-15 illustrates the annual average exposure concentrations for the entire simulated population (both asthmatics and healthy individual of all ages), for each of the years analyzed and where indoor sources were modeled. While years 2001 and 2002 contained very similar population exposure concentration distributions, the modeled year 2003 contained about 20% lower annual average concentrations. The lower exposure concentrations for year 2003 are similar to what was observed for the predicted air quality (Figure B-12), however, all persons were estimated to contain exposures below an annual average concentration of 53 ppb, even considering indoor source concentration contributions. Again, while Figure B-15 summarizes the entire population, the data are representative of what would be observed for the population of asthmatics or asthmatic children.

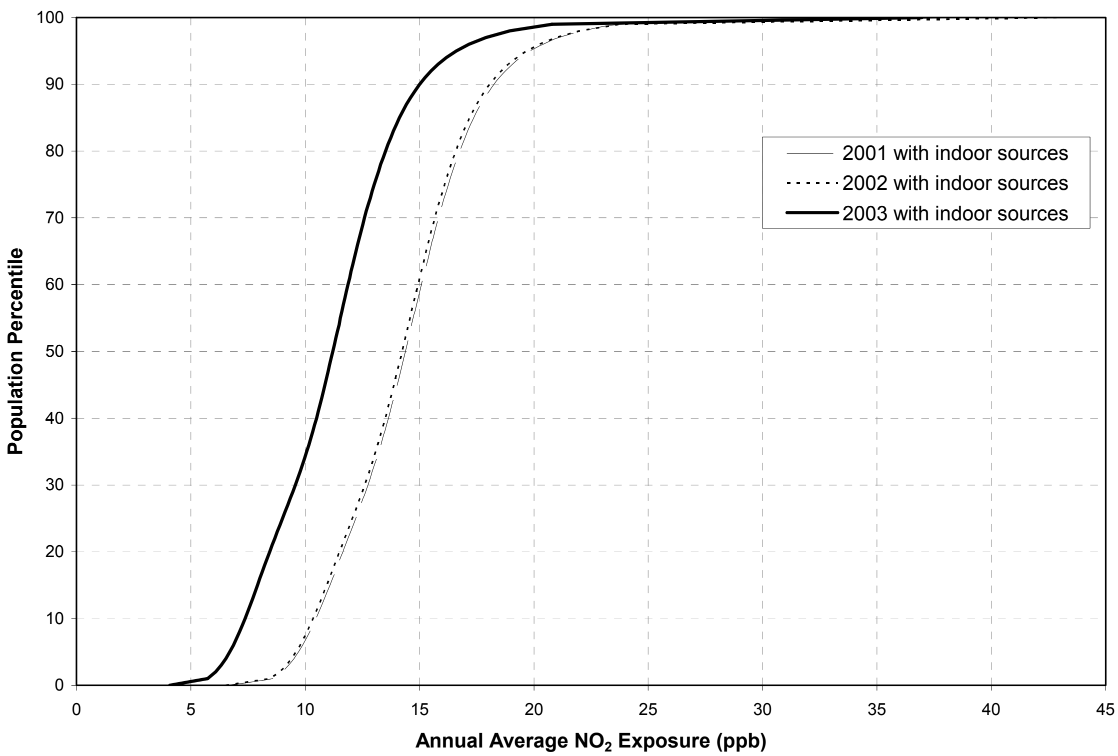

Figure B-15. Estimated annual average total NO_2 exposure concentrations for all simulated persons in Philadelphia County, using modeled 2001-2003 air quality (as is), with modeled indoor sources.

The AERMOD predicted air quality and the estimated exposures for year 2002 were compared using their respective annual average NO_2 concentrations (Figure B-16). As a point of reference, the annual average concentration for 2002 ambient monitors ranged from 24 ppb to 29 ppb. Many of the AERMOD predicted annual average concentrations were below that of the lowest ambient monitoring concentration of 24 ppb, although a few of the receptors contained concentrations above the highest measured annual average concentration. Estimated exposure concentrations were below that of both the modeled and measured air quality. For example, exposure concentrations were about 5 ppb less than the modeled air quality when the exposure estimation included indoor sources, and about 10 ppb less for when exposures were estimated without indoor sources. In comparing the estimated exposures with and without indoor sources, indoor sources were estimated to contribute between 1 and 5 ppb to the total annual average exposures.

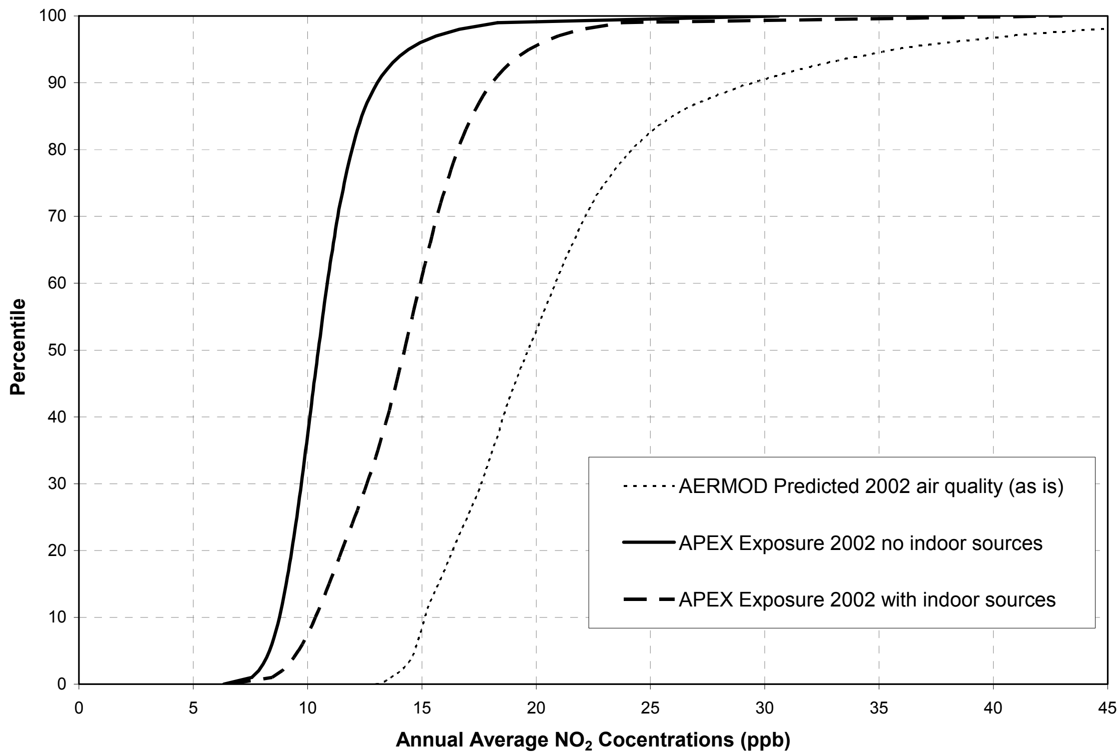

Figure B-16. Comparison of AERMOD predicted and ambient monitoring annual average NO_2 concentrations (as is) and APEX exposure concentrations (with and without modeled indoor sources) in Philadelphia County for year 2002.

B-3.6.5 One-Hour Exposures (as is)

Since there is interest in short-term exposures, a few analyses were performed using the APEX estimated exposure concentrations. As part of the standard analysis, APEX reports the maximum exposure concentration for each simulated individual in the simulated population. This can provide insight into the proportion of the population experiencing any NO_2 exposure concentration level of interest. In addition, exposures are estimated for each of the selected potential health effect benchmark levels (200, 250, and 300 ppb, 1-hour average). An exceedance was recorded when the maximum exposure concentration observed for the individual was above the selected level in a day (therefore, the maximum number of exceedances is 365 for a single person). Estimates of repeated exposures are also recorded, that is where 1-hour exposure concentrations were above a selected level in a day added together across multiple days (therefore, the maximum number of multiple exceedances is also 365). Persons of interest in this exposure analysis are those with particular susceptibility to NO_2 exposure, namely individuals with asthma. The health effect benchmark levels are appropriate for estimating the potential risk of adverse health effects for asthmatics. The majority of the results presented in this section are for the simulated asthmatic population. However, the exposure analysis was performed for the total population to assess numbers of persons exposed to these levels and to provide additional information relevant to the asthmatic population (such as time spent in particular microenvironments).

B-3.6.5.1 Maximum Estimated Exposure Concentrations

A greater variability was observed in maximum exposure concentrations for the 2003 year simulation compared with years 2001 and 2002 (Figure B-17). While annual average exposure concentrations for the total population were the lowest of the 3-year simulation, year 2003 contained a greater number of individual maximum exposures at and above the lowest potential health effect benchmark level. When indoor sources are not modeled however, over 90% of the simulated persons do not have an occurrence of a 1-hour exposure above 200 ppb in a year.

B-3.6.5.2 Number of Estimated Exposures above Selected Levels

When considering the total asthmatic population simulated in Philadelphia County and using current air quality of 2001-2003, nearly 50,000 persons were estimated to be exposed at least one time to a one-hour concentration of 200 ppb in a year (Figure B-18). These exposures include both the NO_2 of ambient origin and that contributed by indoor sources. The number of asthmatics exposed to greater concentrations (e.g., 250 or 300 ppb) drops dramatically and is estimated to be somewhere between 1,000 – 15,000 depending on the 1-hour concentration level and the year of air quality data used. Exposures simulated for year 2003 contained the greatest number of asthmatics exposed in a year consistently for all potential health effect benchmark levels, while year 2002 contained the lowest number of asthmatics. Similar trends across the benchmark levels and the simulation years were observed for asthmatic children, albeit with lower numbers of asthmatic children with exposures at or above the potential health effect benchmark levels.

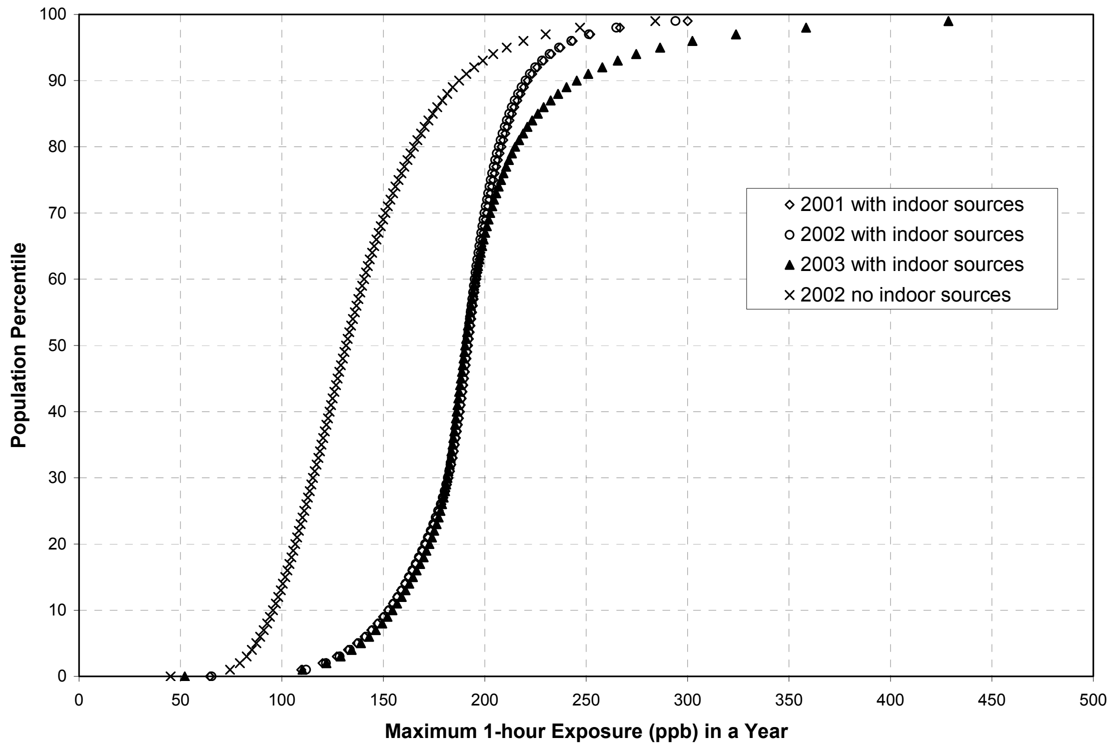

Figure B-17. Estimated maximum NO_2 exposure concentration for all simulated persons in Philadelphia County, using modeled 2001-2003 air quality (as is), with and without modeled indoor sources. Values above the 99th percentile are not shown.

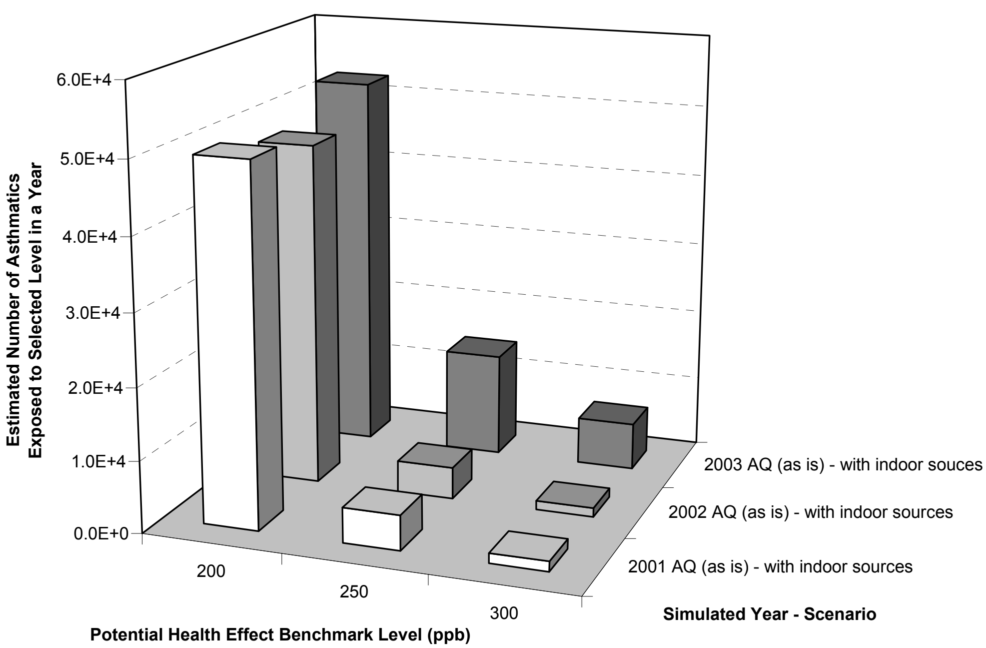

Figure B-18. Estimated number of all simulated asthmatics in Philadelphia County with at least one NO_2 exposure at or above the potential health effect benchmark levels, using modeled 2001-2003 air quality (as is), with modeled indoor sources.

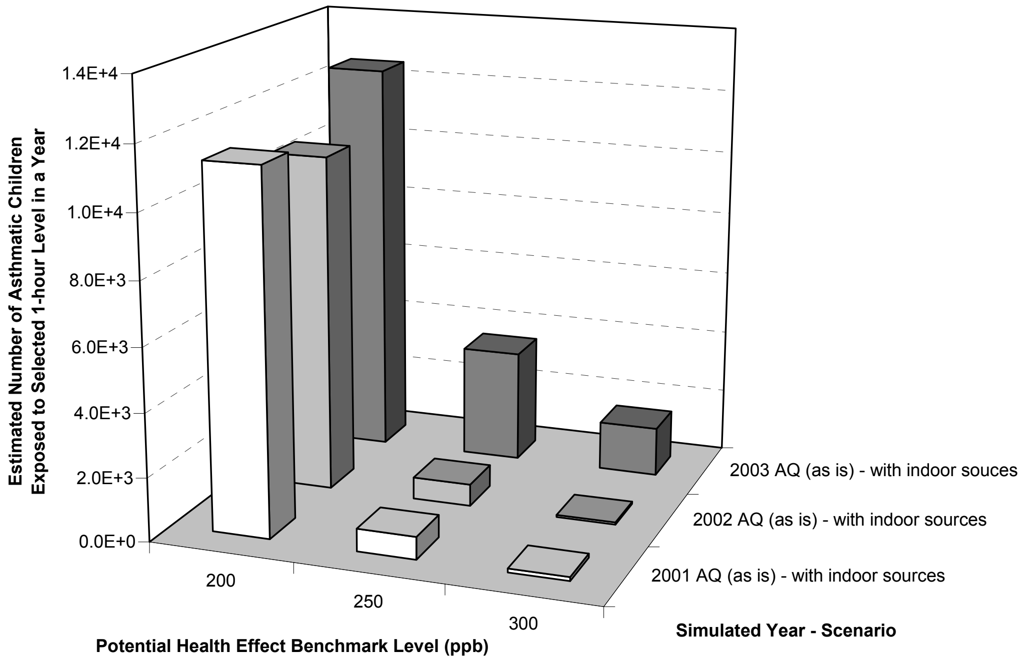

Figure B-19. Estimated number of simulated asthmatic children in Philadelphia County with at least one NO_2 exposure at or above the potential health effect benchmark levels, using modeled 2001-2003 air quality (as is), with modeled indoor sources.

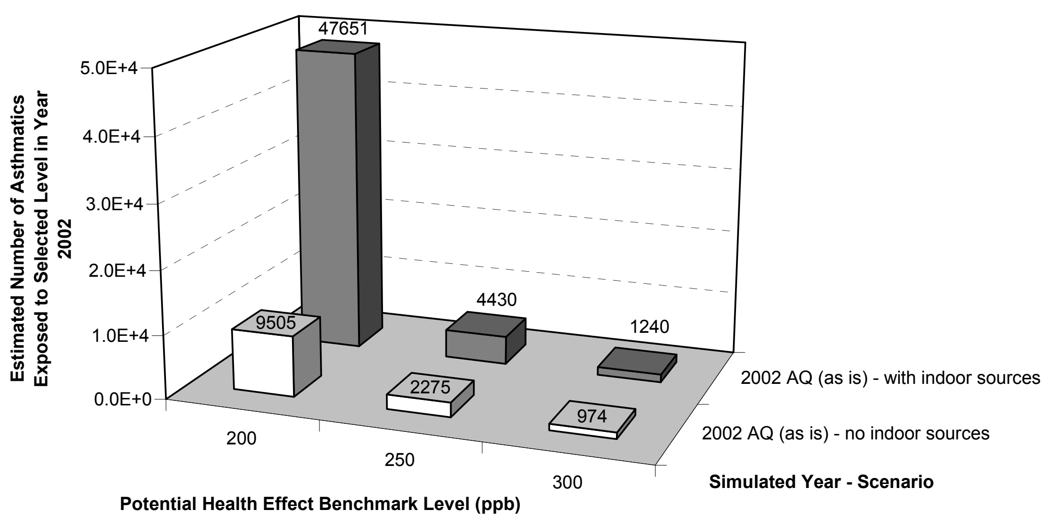

Figure B-20. Comparison of the estimated number of all simulated asthmatics in Philadelphia County with at least one NO_2 exposure at or above potential health effect benchmark levels, using modeled 2002 air quality (as is) , with and without modeled indoor sources.

For example, nearly 12,000 were estimated to be exposed to at least a one-hour NO_2 concentration of 200 ppb in a year (Figure B-19). Additional exposure estimates were generated using the modeled 2002 air quality (as is) and where the contribution from indoor sources was not included in the exposure concentrations. APEX allows for the same persons to be simulated, i.e., demographics of the population were conserved, as well as using the same individual time-location-activity profiles generated for each person. Figure B-20 compares the estimated number of asthmatics experiencing exposures above the potential health effect benchmarks, both with indoor sources and without indoor sources included in the model runs. The number of asthmatics at or above the selected concentrations is reduced by between 50-80%, depending on benchmark level, when not including indoor source (i.e., gas cooking) concentration contributions.

An evaluation of the time spent in the 12 microenvironments was performed to estimate where simulated individuals are exposed to concentrations above the potential health effect benchmark levels. Currently, the output generated by APEX is limited to compiling the microenvironmental time for the total population (includes both asthmatic individuals and healthy persons) and is summarized to the total time spent above the selected potential health effect benchmark levels. As mentioned above, the data still provide a reasonable approximation for each of the population subgroups (e.g., asthmatics or asthmatic children) since their microenvironmental concentrations and activities are not estimated any differently from those of the total population by APEX.

As an example, Figure B-21 (a, b, c) summarizes the percent of total time spent in each microenvironment for simulation year 2002 that was associated with estimated exposure concentrations at or above 200, 250, and 300 ppb (results for years 2001 and 2003 were similar). Estimated exposures included the contribution from one major category of indoor sources (i.e., gas cooking). The time spent in the indoor residence and bars/restaurants were the most important for concentrations ≥200 ppb, contributing to approximately 75% of the time persons were exposed (Figure B-21a). This is likely a result of the indoor source concentration contribution to each individual's exposure concentrations. The importance of the particular microenvironment however changes with differing potential health effect benchmark levels. This is evident when considering the in-vehicle and outdoor near-road microenvironments, progressing from about 19% of the time exposures were at the lowest potential health effect benchmark level (200 ppb) to a high of 64% of the time exposures were at the highest benchmark level (300 ppb, Figure B-21c).

The microenvironments where higher exposure concentrations occur were also evaluated for the exposure estimates generated without indoor source contributions. Figure B-22 illustrates that the time spent in the indoor microenvironments contributes little to the estimated exposures above the selected benchmark levels. The contribution of these microenvironments varied only slightly with increasing benchmark concentration, ranging from about 2-5%. Most of the time associated with high exposures was associated with the transportation microenvironments (In-Vehicle or In-Public Transport) or outdoors (Out-Near Road, Out-Parking Lot, Out-Other). The importance of time spent outdoors near roadways exhibited the greatest change in contribution with increased health benchmark level, increasing from around 30 to 44% of time associated with concentrations of 200 and 300 ppb, respectively. While more persons are likely to spend time inside a vehicle than outdoors near roads, there is attenuation of the on-road concentration that penetrates the in-vehicle microenvironment, leading to lowered concentrations, occurring less frequently above 300 ppb than outdoors near roads.

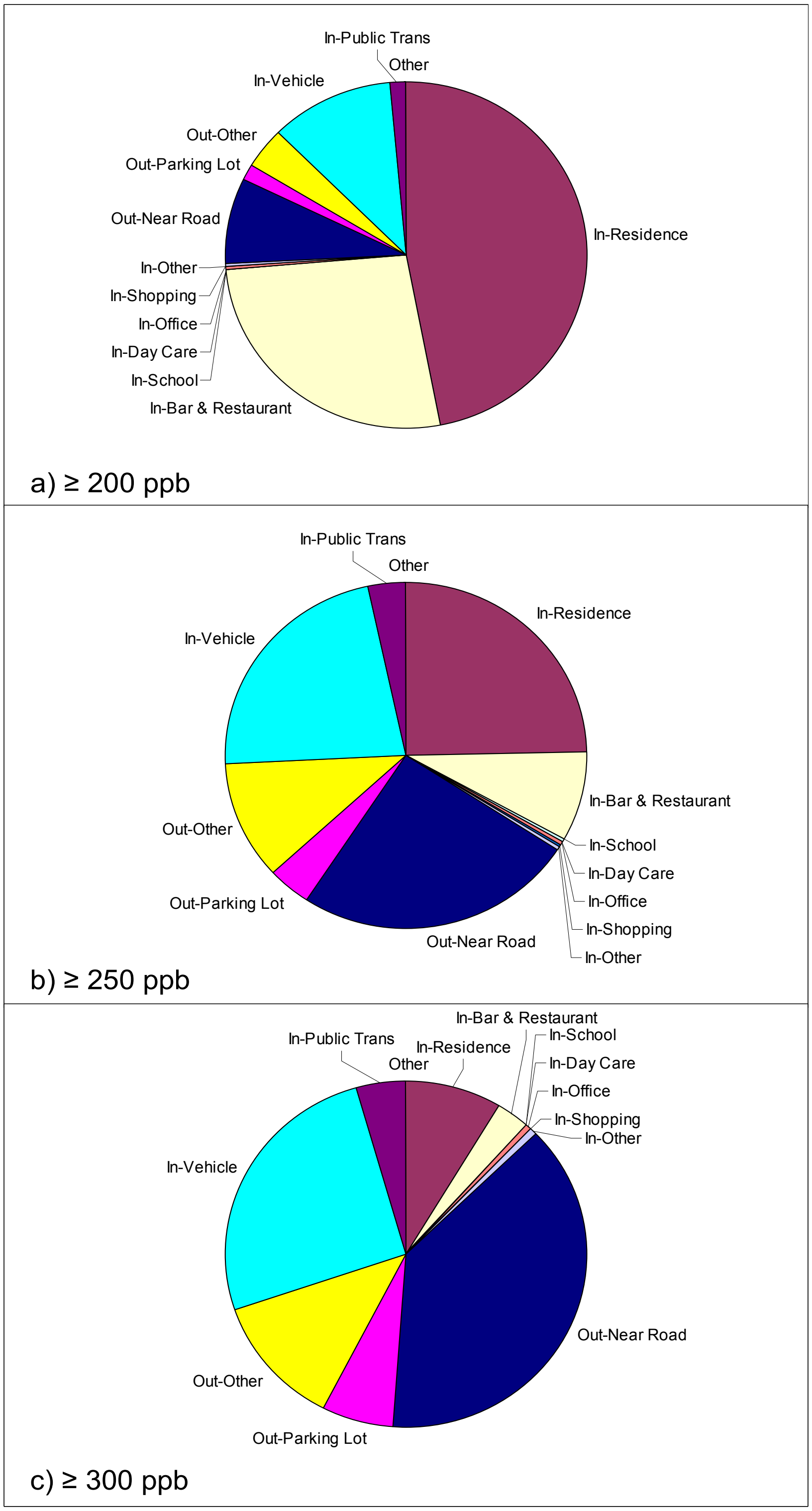

Figure B-21. Fraction of time all simulated persons in Philadelphia County spend in the twelve microenvironments associated with the potential NO_2 health effect benchmark levels, a) ≥ 200 ppb, b) ≥ 250 ppb, and c) ≥ 300 ppb, year 2002 simulation with indoor sources.

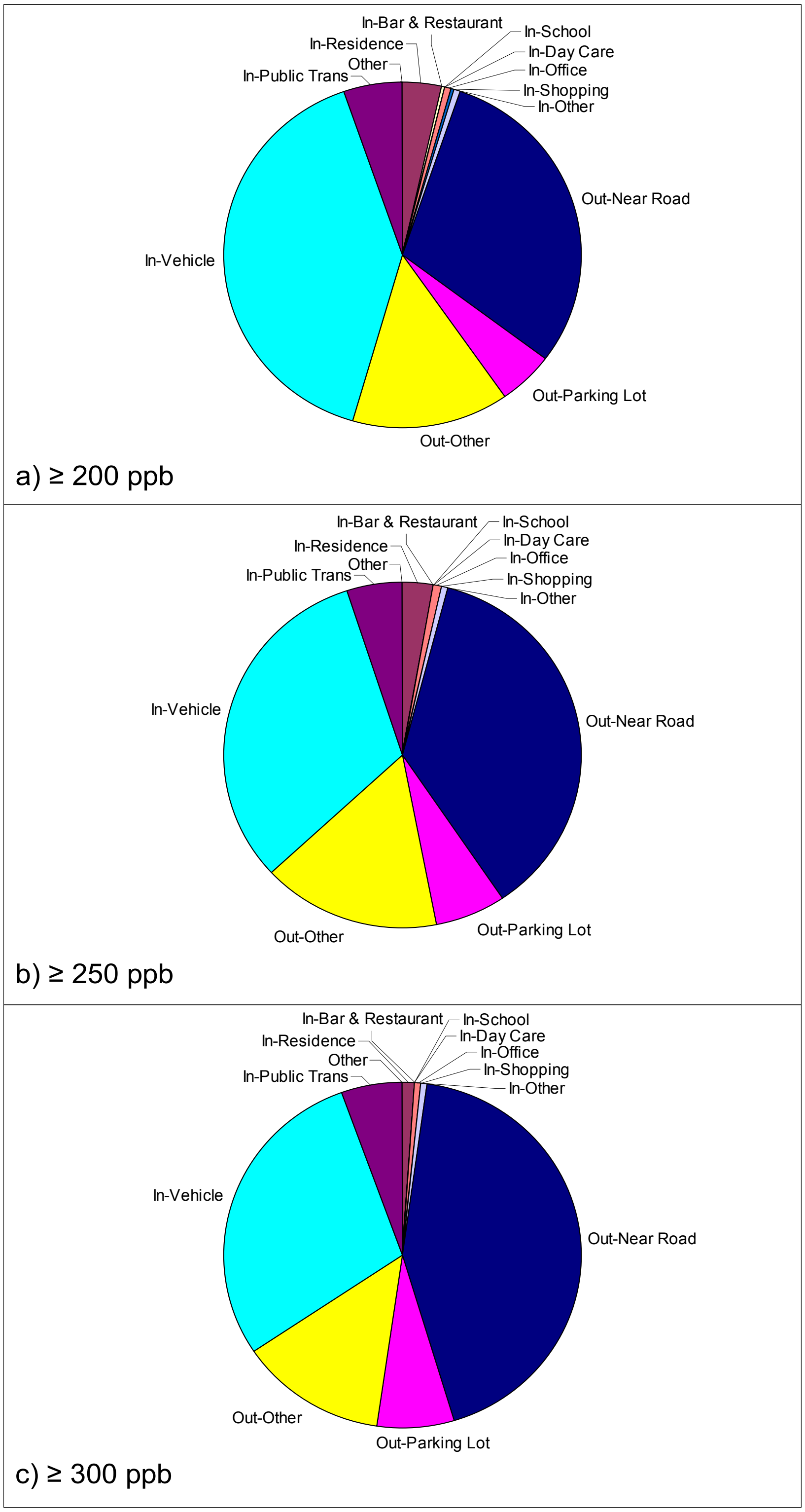

Figure B-22. Fraction of time all simulated persons in Philadelphia County spend in the twelve microenvironments associated with the potential NO_2 health effect benchmark levels, a) ≥ 200 ppb, b) ≥ 250 ppb, and c) ≥ 300 ppb, year 2002 simulation without indoor sources.

B-3.6.5.3 Number of Repeated Exposures Above Selected Levels

In the analysis of persons exposed, the results show the number or percent of those with at least one exposure at or above the selected potential health effect benchmark level. Given that the benchmark is for a small averaging time (i.e., one-hour) it may be possible that individuals are exposed to concentrations at or above the potential health effect benchmark levels more than once in a given year. Since APEX simulates the longitudinal diary profile for each individual, the number of times above a selected level is retained for each person. Figure B-23 presents such an analysis for the year 2003, the year containing the greatest number of exposure concentrations at or above the selected benchmarks. Estimated exposures include both those resulting from exposures to NO_2 of ambient origin and those resulting from indoor source NO_2 contributions. While a large fraction of individuals experience at least one exposure to 200 ppb or greater over a 1-hour time period in a year (about 32 percent), only around 14 percent were estimated to contain at least 2 exposures. Multiple exposures at or above the selected benchmarks greater than or equal to 3 or more times per year are even less frequent, with around 5 percent or less of asthmatics exposed to 1-hour concentrations greater than or equal to 200 ppb 3 or more times in a year.

Exposure estimates for year 2002 are presented to provide an additional perspective, including a lower bound of repeated exposures for this population subgroup and for exposure estimates generated with and without modeled indoor sources (Figure B-24). Most asthmatics exposed to a 200 ppb concentration are exposed once per year and only around 11 percent would experience 2 or more exposures at or above 200 ppb when including indoor source contributions. The percent of asthmatics experiencing multiple exposures a and abovet 250 and 300 ppb is much lower, typically less than 1 percent of all asthmatics are exposed at the higher potential benchmark levels. Also provided in Figure B-24 are the percent of asthmatics exposed to selected levels in the absence of indoor sources. Again, without the indoor source contribution, there are reduced occurrences of multiple exposures at all of the potential health effect benchmark levels compared with when indoor sources were modeled.

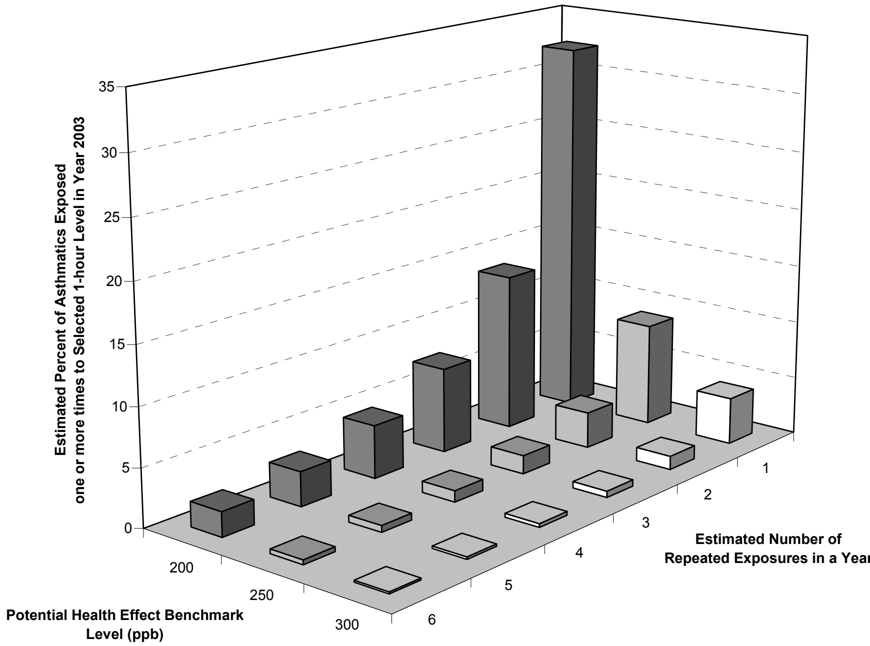

Figure B-23. Estimated percent of all asthmatics in Philadelphia County with repeated NO_2 exposures above potential health effect benchmark levels, using 2003 modeled air quality (as is), with modeled indoor sources.

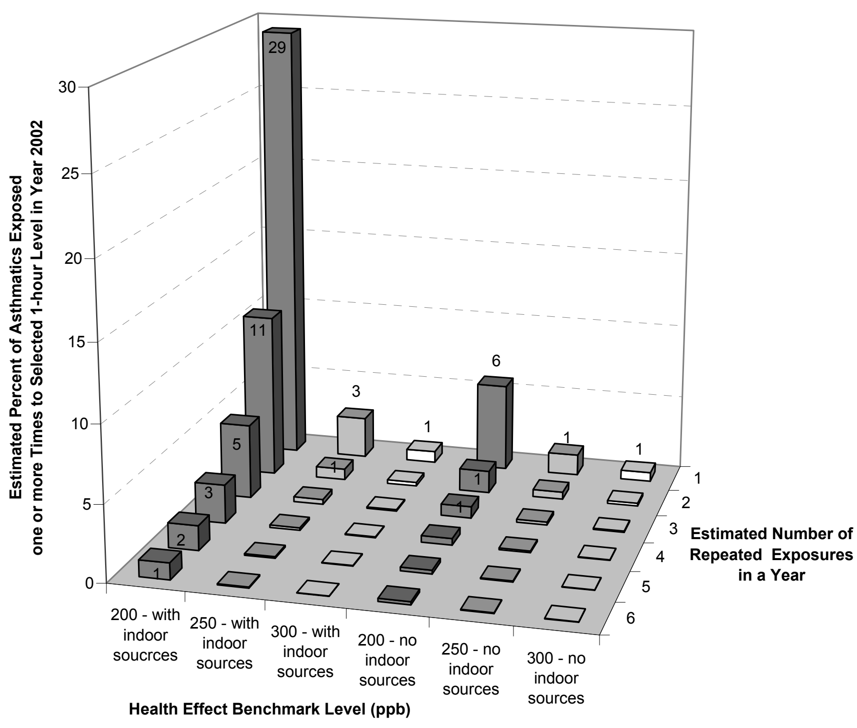

Figure B-24. Estimated percent of all asthmatics in Philadelphia County with repeated NO_2 exposures above potential health effect benchmark levels, using modeled 2002 air quality (as is), with and without indoor sources.

B-3.6.6 One-Hour Exposures Associated with Just Meeting the Current Standard

To simulate just meeting the current NO_2 standard, the potential health effect benchmark level was adjusted in the exposure model, rather than adjusting all of the hourly concentrations for each receptor and year simulated. Similar estimates of short-term exposures (i.e., 1-hour) were generated for the total population and population subgroups of interest (i.e., asthmatics and asthmatic children).

B-3.6.6.1 Number of Estimated Exposures above Selected Levels

In considering exposures estimated to occur associated with air quality simulated to just meet the current annual average NO_2 standard, the number of persons experiencing concentrations at or above the potential health effect benchmarks increased. To allow for reasonable comparison, the number of persons affected considering each scenario is expressed as the percent of the subpopulation of interest. Figure B-25 illustrates the percent of asthmatics estimated to experience at least one exposure at or above the selected potential health effect benchmark concentrations, with just meeting the current standard and including indoor source contributions. While it was estimated that about 30% percent of asthmatics would be exposed to 200 ppb (1-hour average) at least once in a year for as is air quality, it was estimated that around 80 percent of asthmatics would experience at least one concentration above the lowest potential health effect benchmark level in a year representing just meeting the current standard. Again, estimates for asthmatic children exhibited a similar trend, with between 75 to 80 percent exposed to a concentration at or above the lowest potential health effect benchmark level at least once per year for a year just meeting the current standard (data not shown). The percent of all asthmatics experiencing the higher benchmark levels is reduced to between 31 and 45 percent for the 250 ppb, 1-hour benchmark, and between 10 and 24 percent for the 300 ppb, 1-hour benchmark level associated with air quality representing just meeting the current annual average standard.

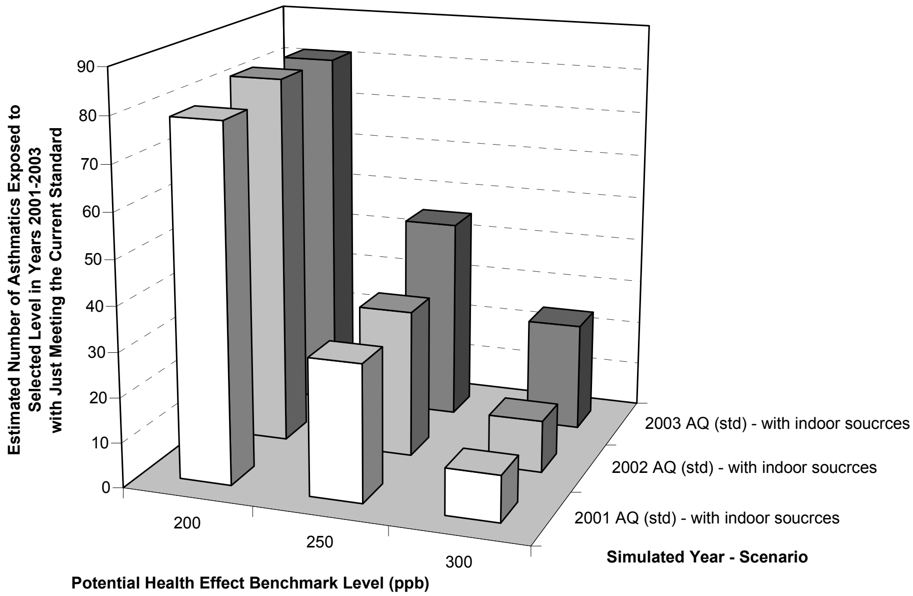

Figure B-25. Estimated percent of all asthmatics in Philadelphia with at least one exposure at or above the potential health effect benchmark level, using modeled 2001-2003 air quality just meeting the current standard, with modeled indoor sources.

In evaluating the influence of indoor source contribution for the scenario just meeting the current standard, the numbers of individuals exposed at selected levels are reduced without indoor sources, ranging from about 26 percent lower for the 200 ppb level to around 11 percent for the 300 ppb level when compared with exposure estimates that accounted for indoor sources (Figure B-26).

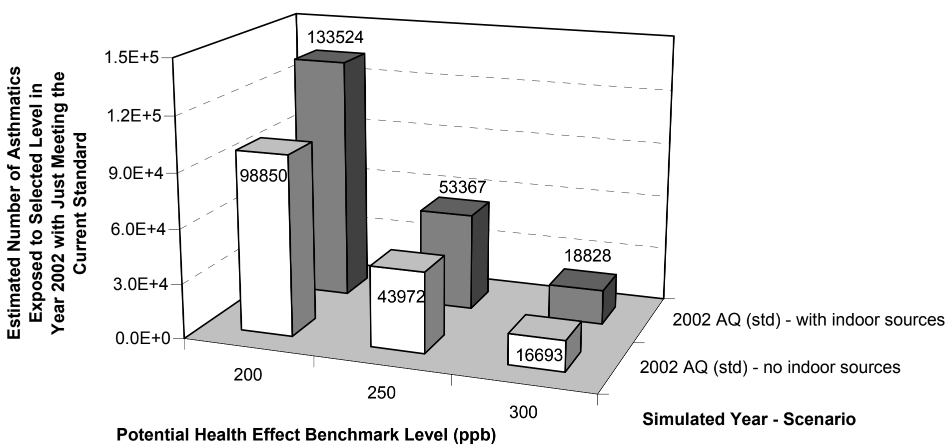

Figure B-26. Estimated number of all asthmatics in Philadelphia with at least one exposure at or above the potential health effect benchmark level, using modeled 2002 air quality just meeting the current standard, with and without modeled indoor sources.

B-3.6.6.2 Number of Repeated Exposures Above Selected Levels

For air quality simulated to just meet the current standard, repeated exposures at the selected potential health effect benchmarks are more frequent than that estimated for the modeled as is air quality. Figure B-27 illustrates this using the simulated asthmatic population for year 2002 data as an example. Many asthmatics that are exposed at or above the selected levels are exposed more than one time. Repeated exposures above the potential health effect benchmark levels are reduced however, when not including the contribution from indoor sources. The percent of asthmatics exposed drops with increasing benchmark level, with progressively fewer persons experiencing multiple exposures for each benchmark level.

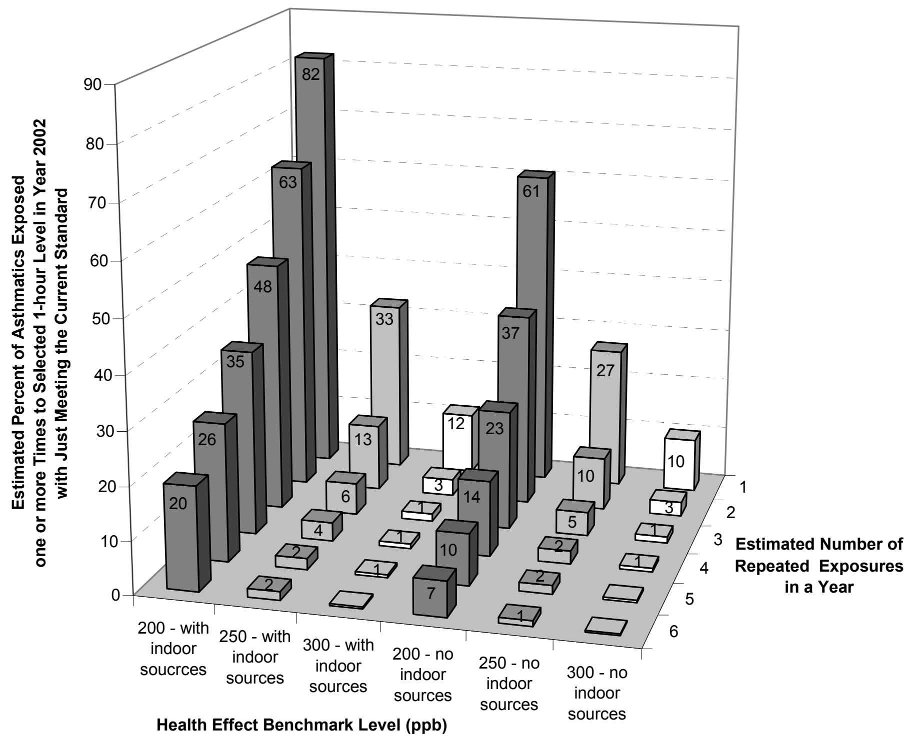

Figure B-27. Estimated percent of asthmatics in Philadelphia County with repeated exposures above health effect benchmark levels, using modeled 2002 air quality just meeting the current standard, with and without modeled indoor sources.

B-3.6.7 Additional Exposure Results

This section provides supplemental exposure and risk characterization results for two subpopulations, all asthmatics and asthmatic children. The data are presented in series of summary tables and figures across each of the scenarios investigated (i.e. with modeled air quality as is and simulating just meeting the current standard), with and without modeled indoor sources (i.e., gas stoves), for each of the potential health effect benchmark levels (i.e., 200, 250, 300 ppb 1-hour), and across three years of modeled air quality (i.e., 2001 to 2003). Repeated exposures are presented only for the lowest potential health effect benchmark level (i.e., 200 ppb 1-hour).

B-3.6.7.1 All Asthmatics

Table B-31. Estimated number of asthmatics in Philadelphia County exposed at or above potential health effect benchmark levels (1 to 6 times per year), using modeled air quality (as is) and with just meeting the current standard (std), and with and without indoor sources.

Year (AQ)	Indoor Source	Level (ppb)	Persons with Number of Repeated Exposures					
			1	2	3	4	5	6
2001 (as is)	Yes	200	49796	19544	8959	4516	2666	1732
		250	4867	1414	658	381	265	157
		300	1388	404	157	108	59	39
	No	200	10544	2577	1230	795	520	422
		250	2584	765	413	295	186	118
		300	1013	344	177	98	39	29
2001 (std)	Yes	200	128147	96119	70079	50253	35965	26167
		250	49632	18322	8523	4808	3095	2152
		300	16805	4480	1828	1219	866	638
	No	200	90211	51600	31720	19805	12899	8938
		250	40466	14362	6155	3225	2141	1414
		300	15100	3590	1595	1003	755	569
2002 (as is)	Yes	200	47652	17720	8056	4170	2662	1765
		250	4430	1173	530	274	166	127
		300	1240	393	147	88	69	49
	No	200	9505	2411	1240	706	401	323
		250	2276	778	332	185	117	88
		300	975	304	137	59	49	49
2002 (std)	Yes	200	133524	102861	77512	57152	42473	31800
		250	53367	20737	9855	5784	3489	2623
		300	18828	5220	2324	1447	925	648
	No	200	98849	60056	36913	23238	15850	10875
		250	43972	16367	7370	4066	2680	1734
		300	16693	4389	1950	1131	766	510
2003 (as is)	Yes	200	52639	22084	11950	7441	4863	3457
		250	14407	5040	2599	1577	935	650
		300	6568	1892	887	512	335	245
	No	200	26120	10007	5857	3783	2609	1842
		250	11142	3927	2040	1261	777	550
		300	5605	1627	778	462	285	206
2003 (std)	Yes	200	132640	102034	76909	58857	44719	34990
		250	73387	38505	22953	15416	11101	8499
		300	39283	16213	9280	6175	4374	3259
	No	200	109726	73489	51133	36551	27509	21181
		250	65437	33096	18948	12710	8964	6862
		300	35948	14502	8474	5654	4098	2935

Table B-32. Estimated percent of asthmatics in Philadelphia County exposed at or above potential health effect benchmark levels (1 to 6 times per year), using modeled air quality (as is) and with just meeting the current standard (std), and with and without indoor sources.

Year (AQ)	Indoor Source	Level (ppb)	Percent (%) of Persons With Repeated Exposures					
			1	2	3	4	5	6
2001 (as is)	Yes	200	31	12	6	3	2	1
		250	3	1	0	0	0	0
		300	1	0	0	0	0	0
	No	200	6	2	1	0	0	0
		250	2	0	0	0	0	0
		300	1	0	0	0	0	0
2001 (std)	Yes	200	79	59	43	31	22	16
		250	31	11	5	3	2	1
		300	10	3	1	1	1	0
	No	200	55	32	20	12	8	5
		250	25	9	4	2	1	1
		300	9	2	1	1	0	0
2002 (as is)	Yes	200	29	11	5	3	2	1
		250	3	1	0	0	0	0
		300	1	0	0	0	0	0
	No	200	6	1	1	0	0	0
		250	1	0	0	0	0	0
		300	1	0	0	0	0	0
2002 (std)	Yes	200	82	63	48	35	26	20
		250	33	13	6	4	2	2
		300	12	3	1	1	1	0
	No	200	61	37	23	14	10	7
		250	27	10	5	2	2	1
		300	10	3	1	1	0	0
2003 (as is)	Yes	200	32	14	7	5	3	2
		250	9	3	2	1	1	0
		300	4	1	1	0	0	0
	No	200	16	6	4	2	2	1
		250	7	2	1	1	0	0
		300	3	1	0	0	0	0
2003 (std)	Yes	200	81	63	47	36	27	21
		250	45	24	14	9	7	5
		300	24	10	6	4	3	2
	No	200	67	45	31	22	17	13
		250	40	20	12	8	6	4
		300	22	9	5	3	3	2

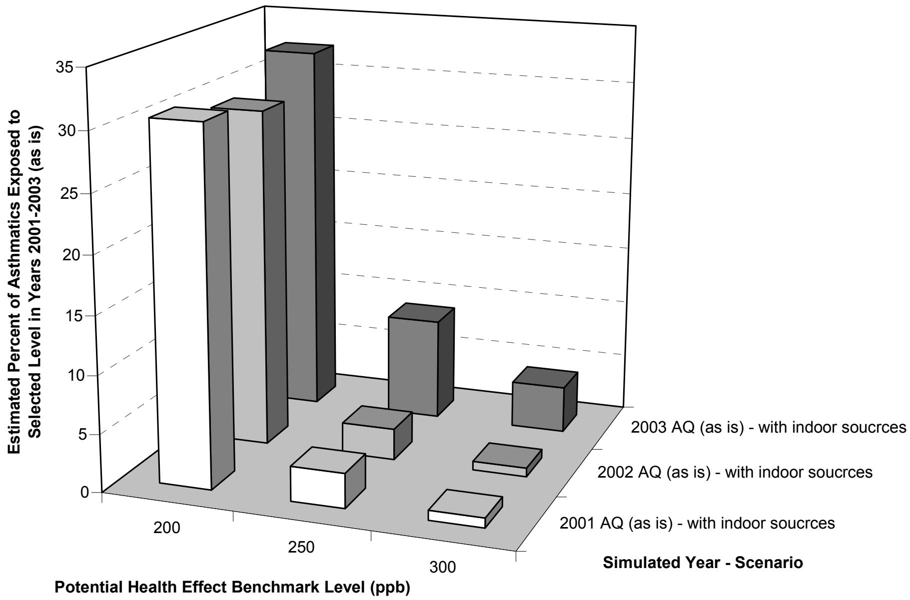

Figure B-28. Estimated percent of all asthmatics in Philadelphia County with at least one NO_2 exposure at or above potential health effect benchmark level, using 2001-2003 modeled air quality (as is), with modeled indoor sources.

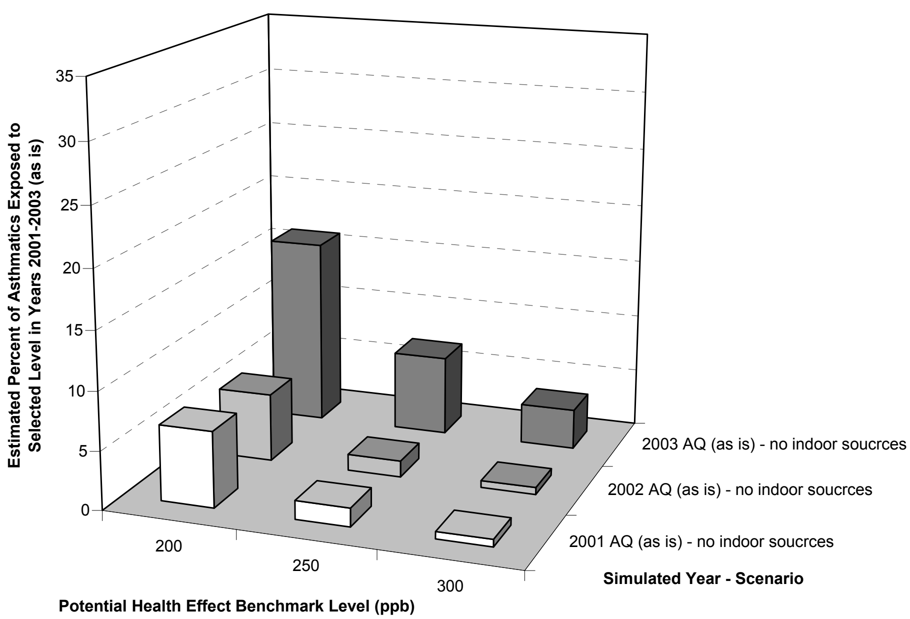

Figure B-29. Estimated percent of all asthmatics in Philadelphia County with at least one NO_2 exposure at or above potential health effect benchmark level, using 2001-2003 modeled air quality (as is), with no indoor sources.

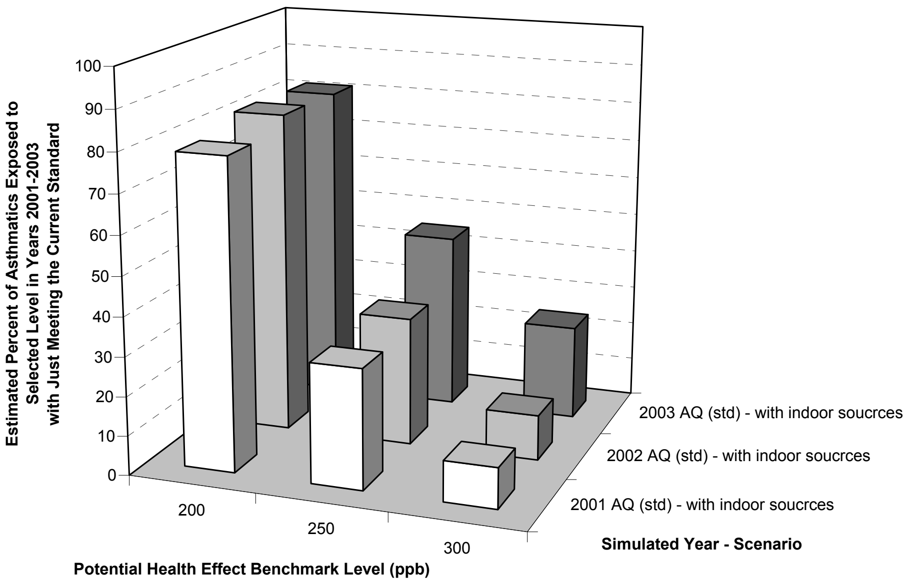

Figure B-30. Estimated percent of all asthmatics in Philadelphia County with at least one NO_2 exposure at or above potential health effect benchmark level, using 2001-2003 modeled air quality just meeting the current standard (std), with modeled indoor sources.

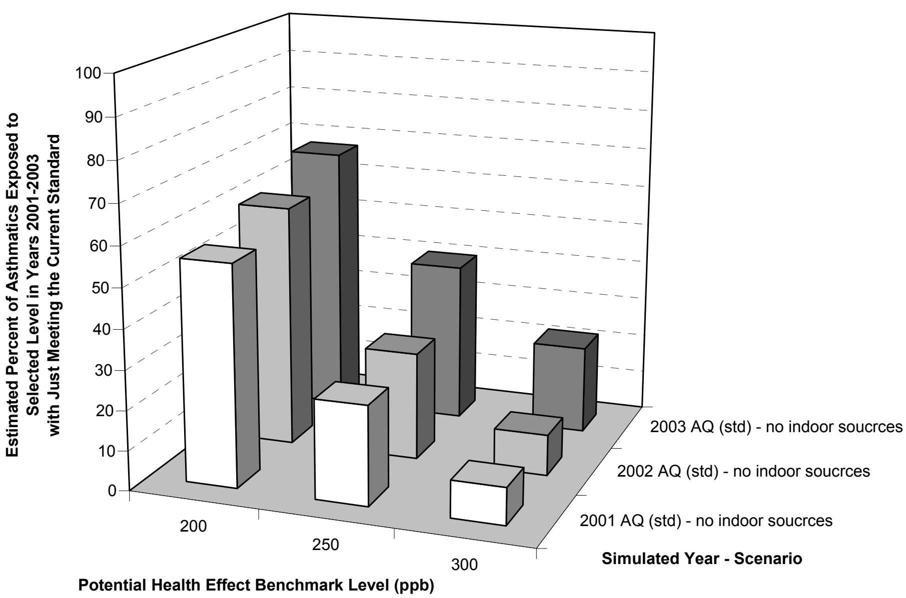

Figure B-31. Estimated percent of all asthmatics in Philadelphia County with at least one NO_2 exposure at or above potential health effect benchmark level, using 2001-2003 modeled air quality just meeting the current standard (std), with no indoor sources.

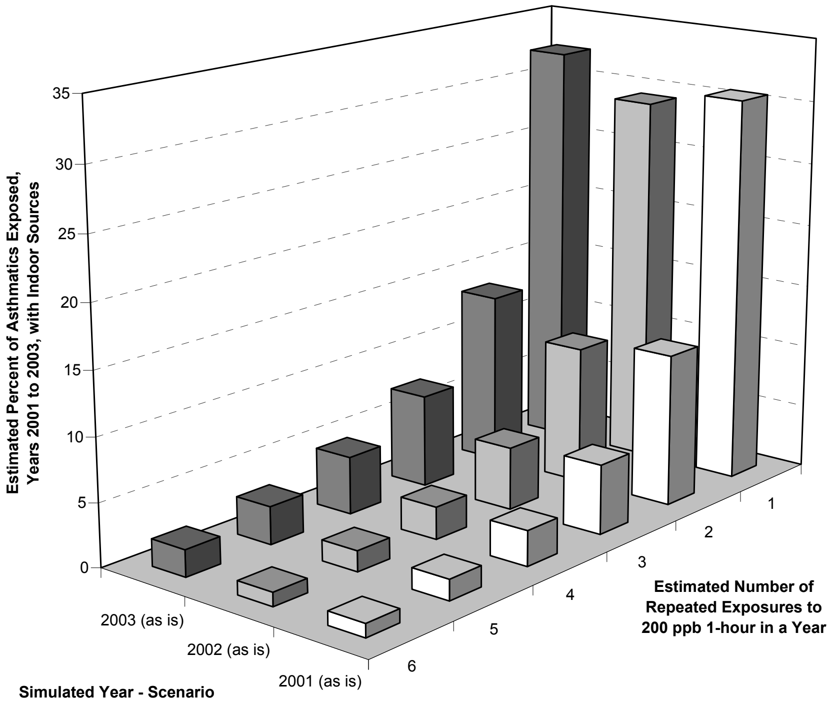

Figure B-32. Estimated percent of all asthmatics in Philadelphia County with repeated NO_2 exposures at or above 200 ppb 1-hr, using 2001-2003 modeled air quality (as is), with modeled indoor sources.

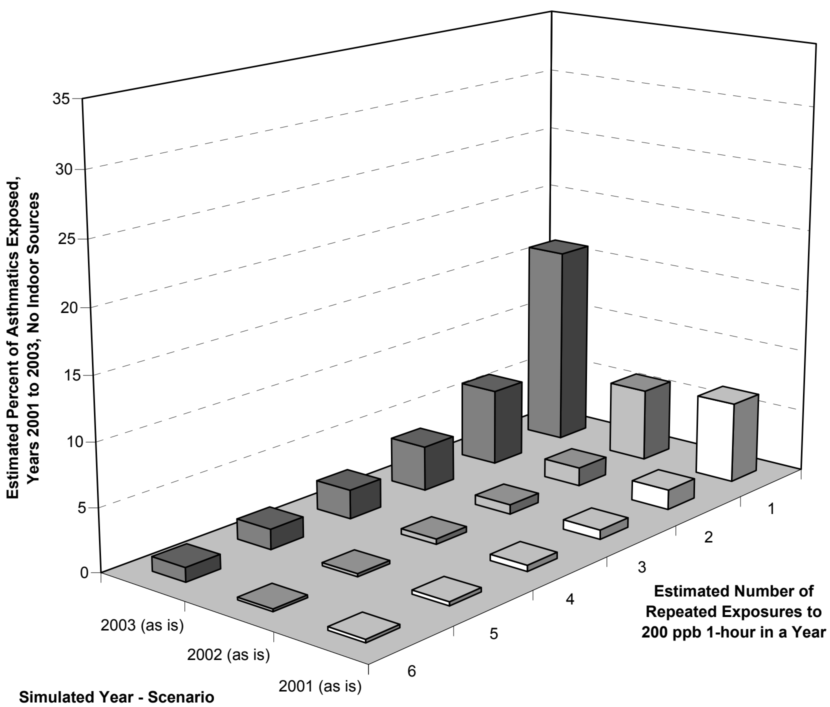

Figure B-33. Estimated percent of all asthmatics in Philadelphia County with repeated NO2 exposures at or above 200 ppb 1-hr, using 2001-2003 modeled air quality (as is), without indoor sources.

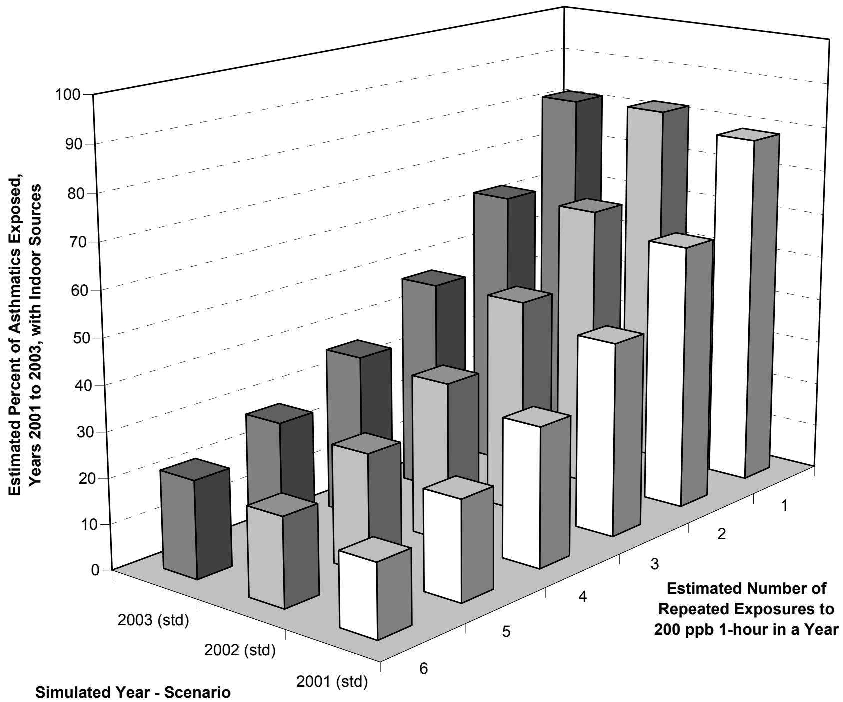

Figure B-34. Estimated percent of all asthmatics in Philadelphia County with repeated NO_2 exposures at or above 200 ppb 1-hour, using 2001-2003 modeled air quality just meeting the current standard (std), with modeled indoor sources.

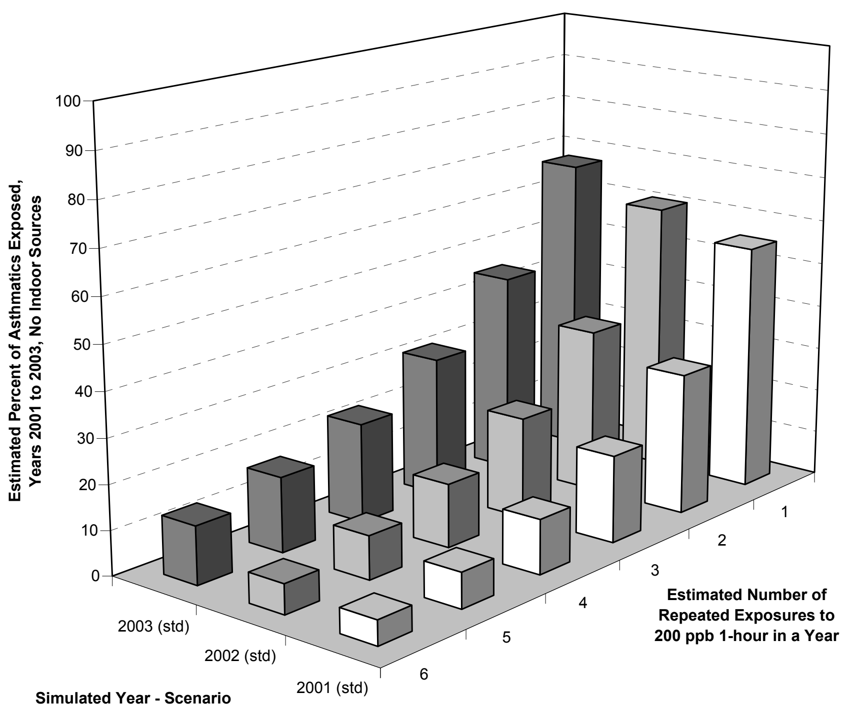

Figure B-35. Estimated percent of all asthmatics in Philadelphia County with repeated NO_2 exposures at or above 200 ppb 1-hour, using 2001-2003 modeled air quality just meeting the current standard (std), with no indoor sources.

B-3.6.7.2 Asthmatic Children

Table B-33. Estimated number of asthmatic children in Philadelphia County exposed at or above potential health effect benchmark levels (1 to 6 times per year), using modeled air quality (as is) and with just meeting the current standard (std), and with and without indoor sources.

Year (AQ)	Indoor Source	Level (ppb)	Persons With Number of Repeated Exposures					
			1	2	3	4	5	6
2001 (as is)	Yes	200	11351	3649	1418	709	424	267
		250	709	167	68	49	20	10
		300	128	49	10	10	0	0
	No	200	2329	401	147	98	58	58
		250	393	97	39	20	0	0
		300	97	29	10	10	0	0
2001 (std)	Yes	200	36656	26353	18272	12133	8271	5783
		250	13543	4530	1877	926	533	295
		300	3909	768	236	187	128	88
	No	200	27511	16067	9890	6094	3757	2430
		250	11282	3735	1413	500	333	197
		300	3440	638	187	128	109	79
2002 (as is)	Yes	200	10636	3338	1439	800	494	346
		250	692	139	49	30	0	0
		300	70	10	0	0	0	0
	No	200	1771	315	158	79	10	0
		250	158	49	20	10	0	0
		300	30	10	0	0	0	0
2002 (std)	Yes	200	38834	28678	20840	14308	10063	6996
		250	14855	4887	1978	1086	652	514
		300	4203	947	336	228	119	79
	No	200	30548	18685	11394	7063	4336	2782
		250	12487	3775	1288	738	493	365
		300	3736	670	276	158	99	39
2003 (as is)	Yes	200	12525	4693	2736	1712	1100	797
		250	3541	1240	678	423	247	178
		300	1545	423	237	138	89	39
	No	200	6724	2526	1515	984	708	492
		250	2784	1032	531	335	188	128
		300	1368	355	208	119	69	39
2003 (std)	Yes	200	37931	28305	20344	15230	11013	8483
		250	20044	9893	6016	4088	2888	2253
		300	10562	4100	2381	1643	1211	906
	No	200	32066	21662	14938	10326	7647	6018
		250	18770	8897	4974	3371	2388	1859
		300	9547	3704	2223	1496	1072	817

Table B-34. Estimated percent of asthmatic children in Philadelphia County exposed at or above potential health effect benchmark levels (1 to 6 times per year), using modeled air quality (as is) and with just meeting the current standard (std), and with and without indoor sources.

Year (AQ)	Indoor Source	Level (ppb)	Percent (%) of Persons With Repeated Exposures					
			1	2	3	4	5	6
2001 (as is)	Yes	200	23	8	3	1	1	1
		250	1	0	0	0	0	0
		300	0	0	0	0	0	0
	No	200	5	1	0	0	0	0
		250	1	0	0	0	0	0
		300	0	0	0	0	0	0
2001 (std)	Yes	200	75	54	38	25	17	12
		250	28	9	4	2	1	1
		300	8	2	0	0	0	0
	No	200	57	33	20	13	8	5
		250	23	8	3	1	1	0
		300	7	1	0	0	0	0
2002 (as is)	Yes	200	22	7	3	2	1	1
		250	1	0	0	0	0	0
		300	0	0	0	0	0	0
	No	200	4	1	0	0	0	0
		250	0	0	0	0	0	0
		300	0	0	0	0	0	0
2002 (std)	Yes	200	81	60	43	30	21	15
		250	31	10	4	2	1	1
		300	9	2	1	0	0	0
	No	200	64	39	24	15	9	6
		250	26	8	3	2	1	1
		300	8	1	1	0	0	0
2003 (as is)	Yes	200	26	10	6	4	2	2
		250	7	3	1	1	1	0
		300	3	1	0	0	0	0
	No	200	14	5	3	2	1	1
		250	6	2	1	1	0	0
		300	3	1	0	0	0	0
2003 (std)	Yes	200	79	59	43	32	23	18
		250	42	21	13	9	6	5
		300	22	9	5	3	3	2
	No	200	67	45	31	22	16	13
		250	39	19	10	7	5	4
		300	20	8	5	3	2	2

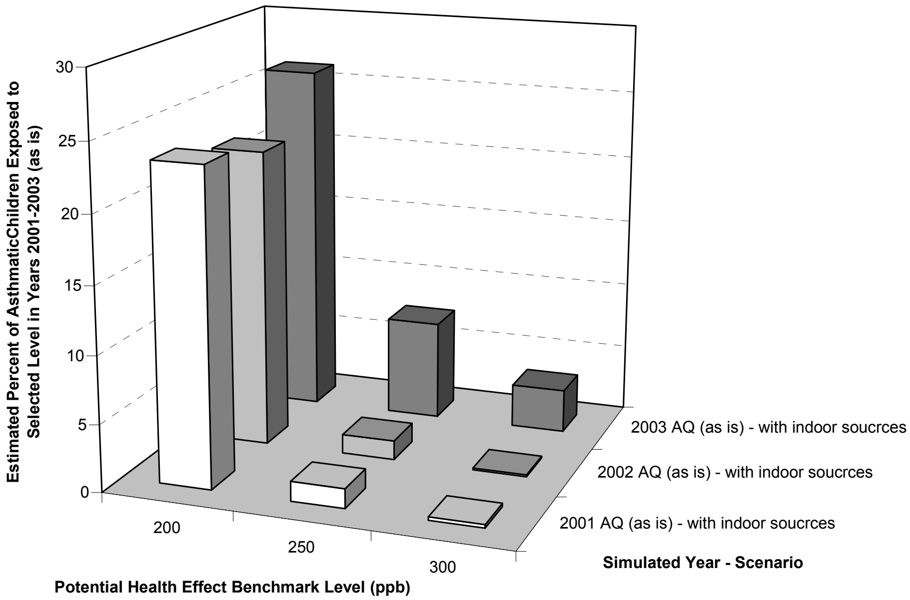

Figure B-36. Estimated percent of asthmatic children in Philadelphia County with at least one NO_2 exposure at or above potential health effect benchmark level, using 2001-2003 modeled air quality (as is), with modeled indoor sources.

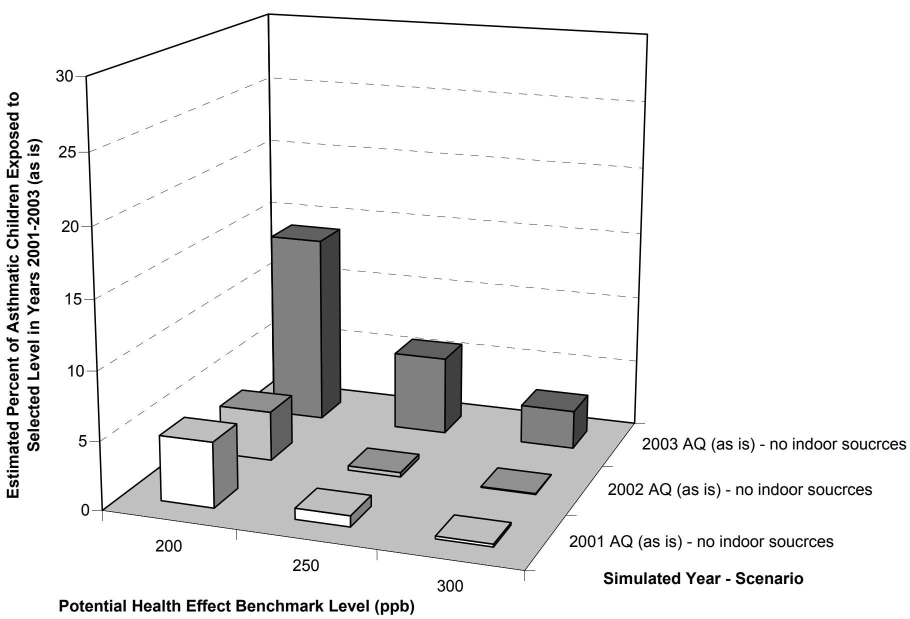

Figure B-37. Estimated percent of asthmatic children in Philadelphia County with at least one NO_2 exposure at or above potential health effect benchmark level, using 2001-2003 modeled air quality (as is), with no indoor sources.

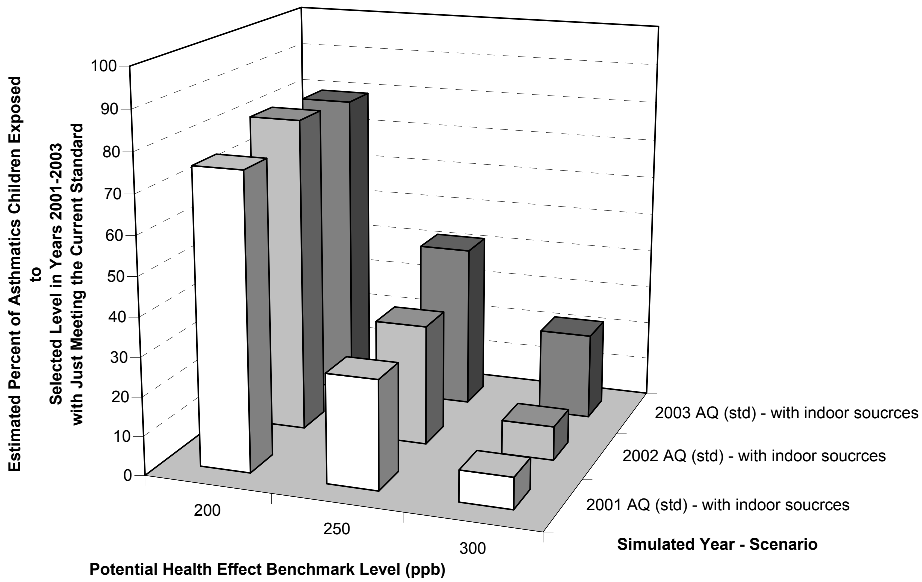

Figure B-38. Estimated percent of asthmatic children in Philadelphia County with at least one NO_2 exposure at or above potential health effect benchmark level, using 2001-2003 modeled air quality just meeting the current standard (std), with modeled indoor sources.

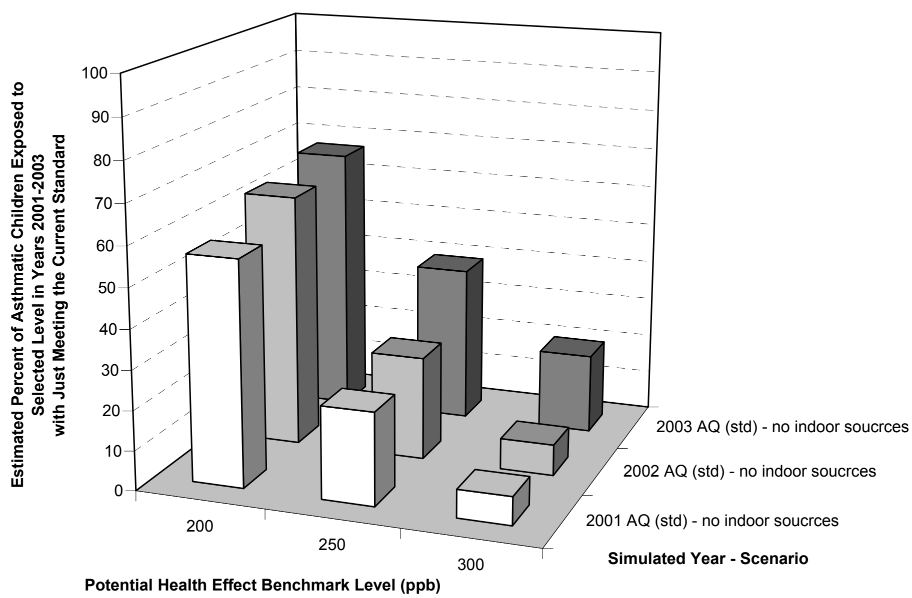

Figure B-39. Estimated percent of asthmatic children in Philadelphia County with at least one NO_2 exposure at or above potential health effect benchmark level, using 2001-2003 modeled air quality just meeting the current standard (std), with no indoor sources.

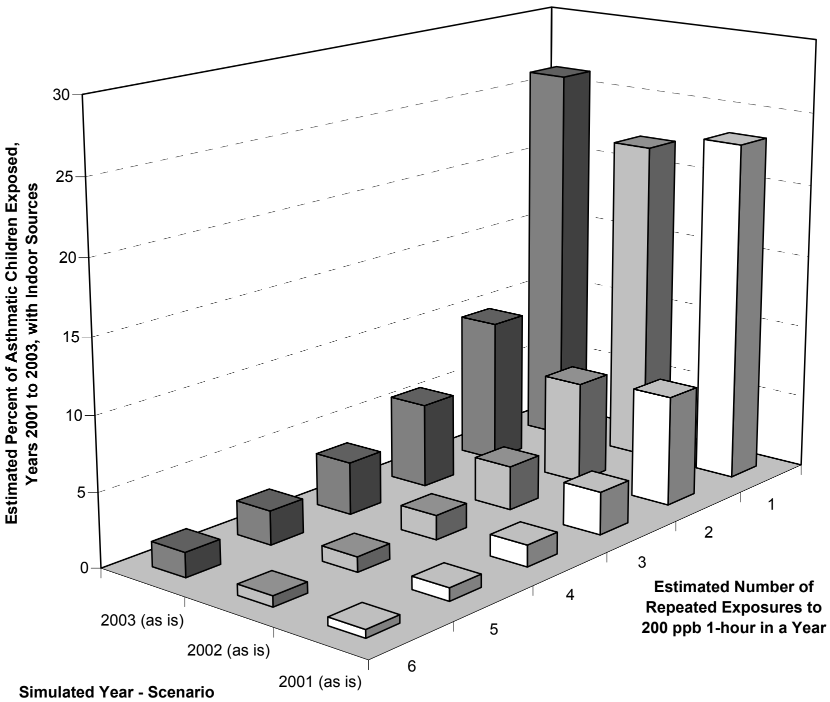

Figure B-40. Estimated percent of asthmatic children in Philadelphia County with repeated NO_2 exposures at or above 200 ppb 1-hr, using 2001-2003 modeled air quality (as is), with modeled indoor sources.

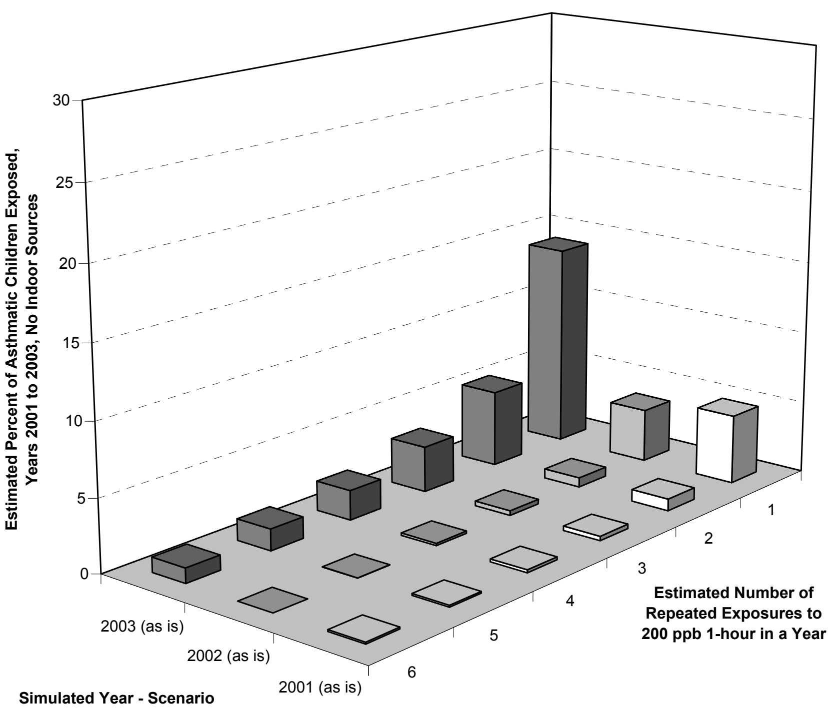

Figure B-41. Estimated percent of asthmatic children in Philadelphia County with repeated NO_2 exposures at or above 200 ppb 1-hr, using 2001-2003 modeled air quality (as is), with no indoor sources.

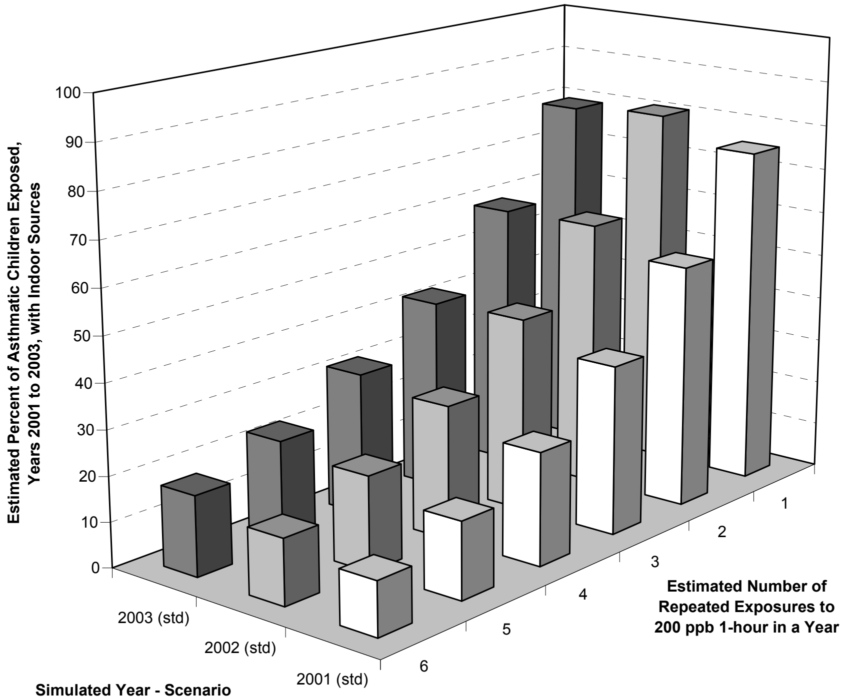

Figure B-42. Estimated percent of asthmatic children in Philadelphia County with repeated NO_2 exposures at or above 200 ppb 1-hr, using 2001-2003 modeled air quality meeting the current standard (std), with modeled indoor sources.

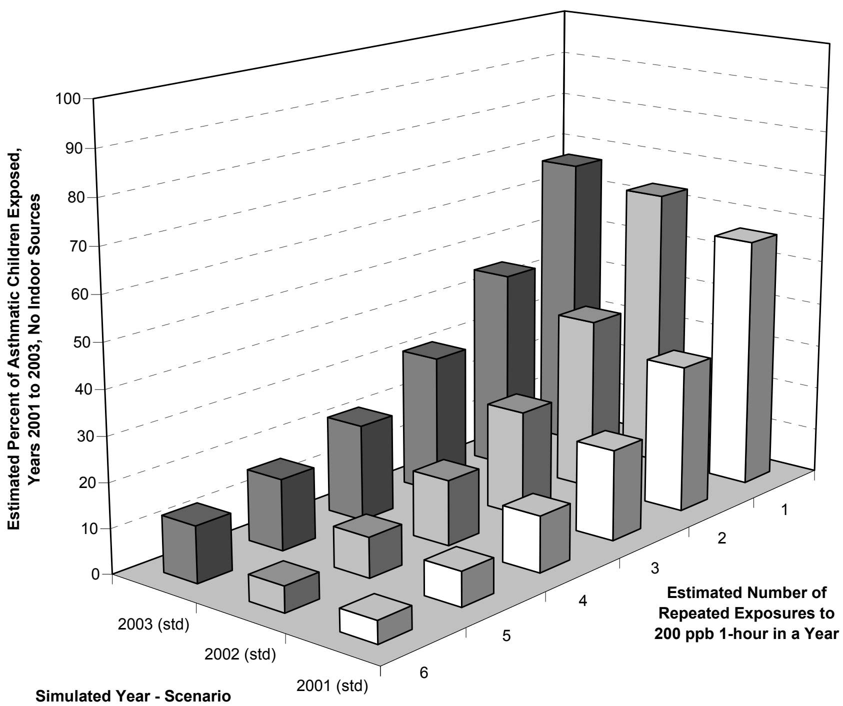

Figure B-43. Estimated percent of asthmatic children in Philadelphia County with repeated NO_2 exposures at or above 200 ppb 1-hr, using 2001-2003 modeled air quality meeting the current standard (std), with no indoor sources.

B-4 Atlanta Exposure Assessment Case-Study

This section provides supplemental discussion on methodology and additional detailed input data used in the Atlanta inhalation exposure assessment for NO_2 conducted in support of the current review of the NO_2 primary NAAQS. The general exposure modeling approach has been broadly defined in Appendix section B-2.

B-4.1 Supplemental AERMOD Modeling Inputs and Discussion

Air quality data input to the APEX exposure model were generated by air quality modeling using AERMOD. Principal emission sources included both mobile and stationary sources as well as emissions from Atlanta Hartsfield International Airport.[20] The supplemental data used for estimating the emission sources, in addition to other AERMOD parameters used for the Atlanta exposure analysis are described below.

B-4.1.1 Major Link On-Road Emission Estimates

Information on traffic data in the Atlanta area was obtained from the Atlanta Regional Commission (ARC) – the regional planning and intergovernmental coordination agency for the 10-county metropolitan area.- via their most recent, baseline travel demand modeling (TDM) simulation – that is, the most recent simulation calibrated to match observed traffic data. ARC provided the following files.

- Excel ™ files of loaded network TDM outputs for the 2005 ARC baseline year for all links in the 13 county network domain.
- Excel ™ data file of node end point locations.
- Arterial and freeway MOBILE6.2 emissions model input files for the 2008 summer ozone season, characterizing local inputs that differ from national defaults, and 2002 registration distribution.

Although considerable effort was expended to maintain consistency between the ARC approach to analysis of TDM data and that employed in this analysis, complete consistency was not possible due to the differing analysis objectives. The ARC creates countywide emission inventories. This study created spatially and temporally resolved emission strengths for dispersion modeling. Information about expected differences in traffic between the 2005 data year and 2001-2003 modeled years was not provided, nor was information about seasonal differences in MOBILE6.2 inputs. These are discussed further below.

B-4.1.1.1 Emission Sources and Locations

The TDM simulation's data file outputs include a description of the fixed information for the highway network links and traffic descriptors for four time periods: morning, afternoon, evening, and nighttime. Each period's data includes freeflow speed, total vehicle count, total heavy duty truck count, total single occupancy vehicle count, and TDM-calculated congested speeds for the period. The description of the network consists of a series of nodes joining individual model links (i.e., roadway segments) to which the traffic volumes are assigned, and

[20] Fugitive emissions from major point sources in the Atlanta area were not included as was done in the Philadelphia County case study, since the NEI shows all emissions to be accounted by stack totals.

the characteristics of those links, such as endpoint location, number of lanes, link distance, and TDM-defined link daily capacity.[21]

The full set of links in the 13 county regional network was filtered to include only those roadway links that are considered *major* as determined by TDM- based vehicle counts and within the four part of a fifth county (Clayton), which contains a small portion of the beltway. That is, all links with AADT values greater than 15,000 vehicles per day (one direction) in Cobb, DeKalb, Fulton, and Gwinnett were included, and those with greater than 15,000 AADT in Clayton County that lie north of 3,717,036 m N in the UTM Zone 16, WGS84 datum were also included. The treatment of non-major links is discussed below.

Link locations from the TDM were modified to represent the best known locations of the actual roadways, since there was not always a direct correlation between the two. The correction of link locations was done based on the locations of the nodes that define the end points of links with a GIS analysis, as follows.

A procedure was developed to relocate TDM nodes to more realistic locations. The nodes in the TDM represent the endpoints of links in the transportation planning network and are specified by node indices, cross-referenced to locations in the Georgia West Stateplane. The procedure moved the node locations to the true road locations and translated to dispersion model coordinates. The ESRI StreetMap™ Pro road network database, an enhanced version of the Tele Atlas North America, Inc database was used as the specification of the true road locations. The nodes were moved to coincide with the nearest major road of the corresponding roadway type using a built in function of ArcGIS. Once the nodes had been placed in the corrected locations, a line was drawn connecting each node pair to represent a link of the adjusted planning network.

B-4.1.1.2 Emission Source Strength

On-road mobile emission factors were derived from the MOBILE6.2 emissions. The simulations were executed to calculate average running NO_x emission factors in grams per mile for a specific functional class (Freeway, Arterial, Local, or Ramp) and speed. Iterative MOBILE6.2 simulations were conducted to create tables of average Atlanta region emission factors resolved by speed (2.5 to 65 mph), functional class, season, and year (2001, 2002, or 2003) for each of the eight combined MOBILE vehicle classes.[22] The resulting tables were then consolidated into speed, functional class, and seasonal values for combined light- and heavy-duty vehicles. To create seasonal-hourly resolved emissions, spring and fall values were taken as the average of corresponding summer and winter values. Figure B-44 shows an example of the calculated emission factors for Summer, 2001.

The resulting emission factors were then coupled with the TDM-based activity estimates to calculate emissions from each of the 4,899 major roadway links. However, many of the links

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[21] The TDM capacity specifications are not the same as those defined by the Highway Capacity Manual (HCM). Following previous analyses, the HCM definition of capacity was used in later calculations, as discussed below.
[22] HDDV - Heavy-Duty Diesel Vehicle, HDGV - Heavy-Duty Gasoline Vehicle, LDDT - Light-Duty Diesel Truck, LDDV - Light-Duty Diesel Vehicle, LDGT12 - Light-Duty Gasoline Truck with gross vehicle weight rating ≤ 6,000 lbs and a loaded vehicle weight of ≤ 5,750 lbs, LDGT 34 - Light-Duty Gasoline Truck with gross vehicle weight rating between 6,001 - 8,500 and a loaded vehicle weight of ≤ 5,750 lbs, LDGV - Light-Duty Gasoline Vehicle, MC - Motorcycles.

were two sides of the same roadway segment. To speed model execution time, those links that could be combined into a single emission source were merged together. This was done only for the 734 links (367 pairs) where opposing links were paired in space and exhibited similar activity levels within 20% of each other.

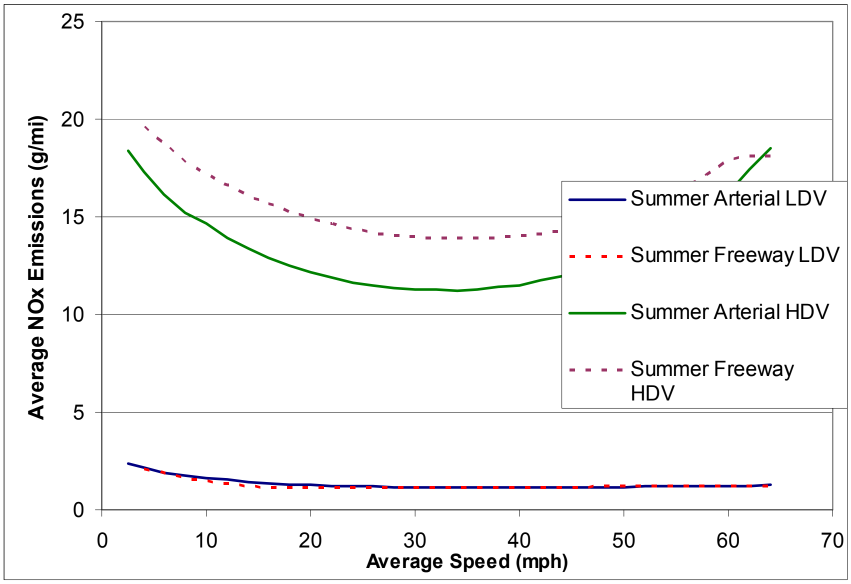

Figure B-44. Example of Light- and heavy-duty vehicle NOx emissions grams/mile (g/mi) for arterial and freeway functional classes, 2001.

B-4.1.2 Stationary Sources Emissions Preparation

Data for the parameterization of major point sources in Atlanta comes primarily from three sources: the 2002 National Emissions Inventory (NEI; US EPA, 2007b), Clean Air Markets Division (CAMD) Unit Level Emissions Database (US EPA, 2007c), and temporal emission profile information contained in the EMS-HAP (version 3.0) emissions model.[23] The NEI database contains stack locations, emissions release parameters (i.e., height, diameter, exit temperature, exit velocity), and annual emissions for NO_x-emitting facilities. The CAMD database, on the other hand, has information on hourly NO_x emission rates for units in the US, where the units are the boilers or equivalent, each of which can have multiple stacks. The alignment of facilities between the two databases is not exact, however. Some facilities listed in the NEI, are not included in the CAMD database. Of those facilities that do match, in many cases there is no clear pairing between the individual stacks assigned within the databases.

Major stationary sources for this analysis were selected from the NEI according to the following criteria:

(1) Stacks within facilities whose total NOx emissions are at least 100 tpy, and
(2) Stacks within facilities located either within the 4-county modeling domain or within 10 km of the modeling domain.

[23] http://www.epa.gov/ttn/chief/emch/projection/emshap30.html

There are 7 NOx-emitting facilities in the NEI that meet these criteria. Stacks within the facilities that were listed separately in the NEI were combined for modeling purposes if they had identical stack physical parameters and were co-located within about 10 m. This process resulted in 28 combined stacks, listed in Table B-35. These 28 major-facility combined stacks account for 16% of the of NO_x point sources and 51% of the total NO_x point source emissions in this buffered four county Atlanta area.

The CAMD database was then queried for facilities that matched the facilities identified from the NEI database. Facility matching was done on the facility name, Office of Regulatory Information Systems (ORIS) identification code (when provided) and facility total emissions to ensure a best match between the facilities. However, because Georgia was not part of many of the market-based reduction programs that constitute the CAMD emissions database, only one of the 7 major facilities in the four-county focus area was found in the CAMD data base:the Georgia Power Company McDonough Steam-Generating Plant. The CAMD hourly emissions profiles for these two units are summed together and then, after appropriate scaling, used to represent 2 major-facility combined stacks.

For the remaining 26 major-facility combined stacks, hourly NO_x emissions profiles were created based on the hourly profile typical of that stack's SCC, the season, and the day of week. These SCC-based temporal profiles are year-independent, and were developed for the EPA's EMS-HAP model,[24] described in the EMS-HAP model Version 2 User's Guide, Section D-7.[25] As with CAMD hourly emissions, these SCC-based emission profiles are scaled such that the annual total emissions are equal to those of NEI 2002.

B-4.1.3 Airport Emissions Preparation

The Atlanta-Hartsfield International Airport emissions were assigned to a polygon that defined an area source for simulation. The perimeter dimensions of the Atlanta-Hartsfield International Airport were determined by GIS analysis of aerial photographs, and the polygon representing the airport is estimated to have an area of 3 km^2 (see Figure B-45). As with some point source emissions, the annual NO_x emission totals were extracted from the NEI and the temporal profiles from the EPA's EMS-HAP model. These seasonal, SCC-based emissions were scaled such that the annual total emissions are equal to those of NEI 2002: 5,761 tpy, with about 90% coming from commercial aircraft.

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[24] http://www.epa.gov/scram001/dispersion_related.htm#ems-hap
[25] http://www.epa.gov/scram001/userg/other/emshapv2ug.pdf

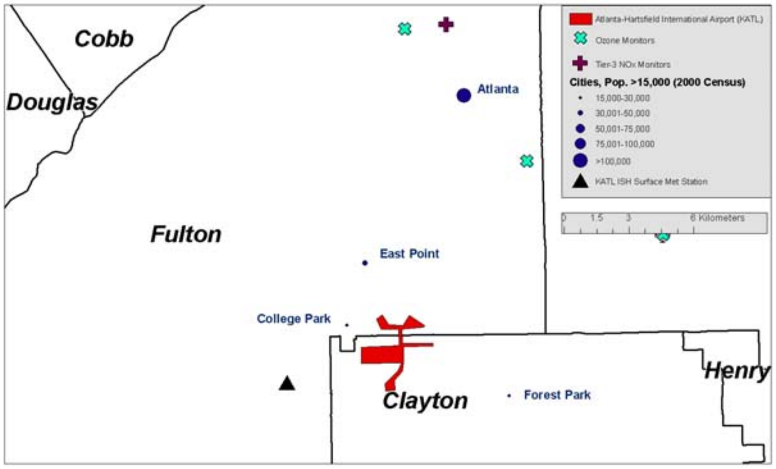

Figure B-45. Polygon representing the Atlanta-Hartsfield International Airport area source.

Table B-35. The major-facility combined stacks within 10 km of the Atlanta modeling domain.

County	NEI Site ID	Facility Name	SCC[1]	Lat.	Lon.	Stack-Total NOx Emiss. (TPY)	Facility-Total Emiss. (TPY)	Stack Hght.[2] (m)	Exit Gas Temp.[2] (K)	Stack Diam.[2] (m)	Exit Gas Vel.[2] (m/s)
Clayton	NEI2GA300105	Delta Air Lines Inc TOC	20200102, 20200401	33.6425	-84.41556	1.23	101.6	8	527	0.4	18
Clayton	NEI2GA300105	Delta Air Lines Inc TOC	20400110	33.64417	-84.41805	0.04	101.6	9	977	6.9	10
Clayton	NEI2GA300105	Delta Air Lines Inc TOC	20400110	33.64361	-84.41805	67.51	101.6	14	444	11.3	2
Clayton	NEI2GA300105	Delta Air Lines Inc TOC	10200502, 10200602, 10200603	33.64194	-84.41278	32.82	101.6	18	590	0.8	18
Cobb	NEI12840	Georgia Power Company McDonough Steam-Electric Generating Plant	20100101, 20100201	33.82472	-84.475	11.91	4895.3	17	663	3.5	19
Cobb	NEI12840	Georgia Power Company McDonough Steam-Electric Generating Plant	10100212	33.82472	-84.475	4883.4	4895.3	255	405	7.9	20
Cobb	NEI2GA700022	Caraustar Mill Group Inc	30790001, 30790003	33.81778	-84.64889	1.81	364.1	13	367	0.8	10
Cobb	NEI2GA700022	Caraustar Mill Group Inc	10200202, 10200501, 10200601	33.81778	-84.64889	362.3	364.1	38	450	1.8	25
Fulton	NEIGA1210021	Owens Corning - Fairburn Plant	30501299	33.53861	-84.61694	2.14	602.1	16	352	0.7	13
Fulton	NEIGA1210021	Owens Corning - Fairburn Plant	30501204, 30501205, 30501299	33.53861	-84.61694	12	602.1	19	347	3	13
Fulton	NEIGA1210021	Owens Corning - Fairburn Plant	30501204, 30501205, 30501299	33.53861	-84.61694	13.29	602.1	19	347	3.2	8
Fulton	NEIGA1210021	Owens Corning - Fairburn Plant	30501204, 30501205, 30501299	33.53861	-84.61694	5.63	602.1	19	391	2.4	7
Fulton	NEIGA1210021	Owens Corning - Fairburn Plant	30501203	33.53861	-84.61694	327	602.1	21	316	1.2	8
Fulton	NEIGA1210021	Owens Corning - Fairburn Plant	30501203	33.53861	-84.61694	242	602.1	204	322	1.2	8
Fulton	NEIGA1210401	Lafarge Building Materials	30500606	33.8225	-84.47	943	1252.9	20	586	2	13

County	NEI Site ID	Facility Name	SCC[1]	Lat.	Lon.	Stack-Total NOx Emiss. (TPY)	Facility-Total Emiss. (TPY)	Stack Hght.[2] (m)	Exit Gas Temp.[2] (K)	Stack Diam.[2] (m)	Exit Gas Vel.[2] (m/s)
Fulton	NEIGA1210401	Lafarge Building Materials	30500606, 30500613	33.8225	-84.47	309.89	1252.9	24	336	0.9	12
Fulton	NEIGA1210020	Owens-Brockway Glass Container Inc - Atlanta GA plant	10200602	33.66972	-84.41861	10.06	710.5	18	497	1	8
Fulton	NEIGA1210020	Owens-Brockway Glass Container Inc - Atlanta GA plant	10200602	33.67083	-84.42083	208.49	710.5	27	589	1.2	24
Fulton	NEIGA1210020	Owens-Brockway Glass Container Inc - Atlanta GA plant	10200602	33.67083	-84.42083	402.49	710.5	27	589	1.4	19
Fulton	NEIGA1210020	Owens-Brockway Glass Container Inc - Atlanta GA plant	10200602	33.67083	-84.42083	89.42	710.5	27	644	0.9	25
Henry	NEIGA1315100	Transcontinental Gas Pipe Line - Station 120	20200202	33.56944	-84.255	7.88	2347.4	5	744	0.2	22
Henry	NEIGA1315100	Transcontinental Gas Pipe Line - Station 120	20200252	33.56944	-84.255	642.88	2347.4	8	625	0.6	38
Henry	NEIGA1315100	Transcontinental Gas Pipe Line - Station 120	20200252	33.56944	-84.255	184.17	2347.4	8	625	0.7	31
Henry	NEIGA1315100	Transcontinental Gas Pipe Line - Station 120	20200252	33.56944	-84.255	945.58	2347.4	8	637	0.7	28
Henry	NEIGA1315100	Transcontinental Gas Pipe Line - Station 120	20200202	33.56944	-84.255	36.6	2347.4	8	669	0.4	17
Henry	NEIGA1315100	Transcontinental Gas Pipe Line - Station 120	20200252	33.56944	-84.255	280.57	2347.4	8	670	0.6	41
Henry	NEIGA1315100	Transcontinental Gas Pipe Line - Station 120	20200252	33.56944	-84.255	218.68	2347.4	9	625	0.6	38
Henry	NEIGA1315100	Transcontinental Gas Pipe Line - Station 120	20200201	33.56944	-84.255	31.08	2347.4	10	743	1	42

[1] Combined stacks may have multiple Source Classification Codes (SCCs)
[2] The physical stack parameters are converted from English units into metric units. The stack height, exit gas temperature, and exit gas velocity are rounded to integers, and the stack diameter is rounded to one decimal place.

B-4.1.4 Receptor Locations

The distance relationship between the major roadway link and block centroids receptors can be estimated by looking at the distance between the road-centered and the block centroid receptors. Figure B-46 presents the histogram of the shortest distance between each centroid receptor and its nearest major-roadway-link-centered receptor. Approximately 1% of the blocks are within 50 m of a major roadway link and the geometric mean of the distribution is between 750 m and 800 m. Approximately 26% of the blocks are within 400 m of a major roadway link center. However, these values represent the distances of the block centroids to road centers instead of road edges, so that they overestimate the actual distances to the zone most influenced by roadway by an average of 10 m and a range of 4 m to 29 m (based on the distribution of the on-road area source widths).

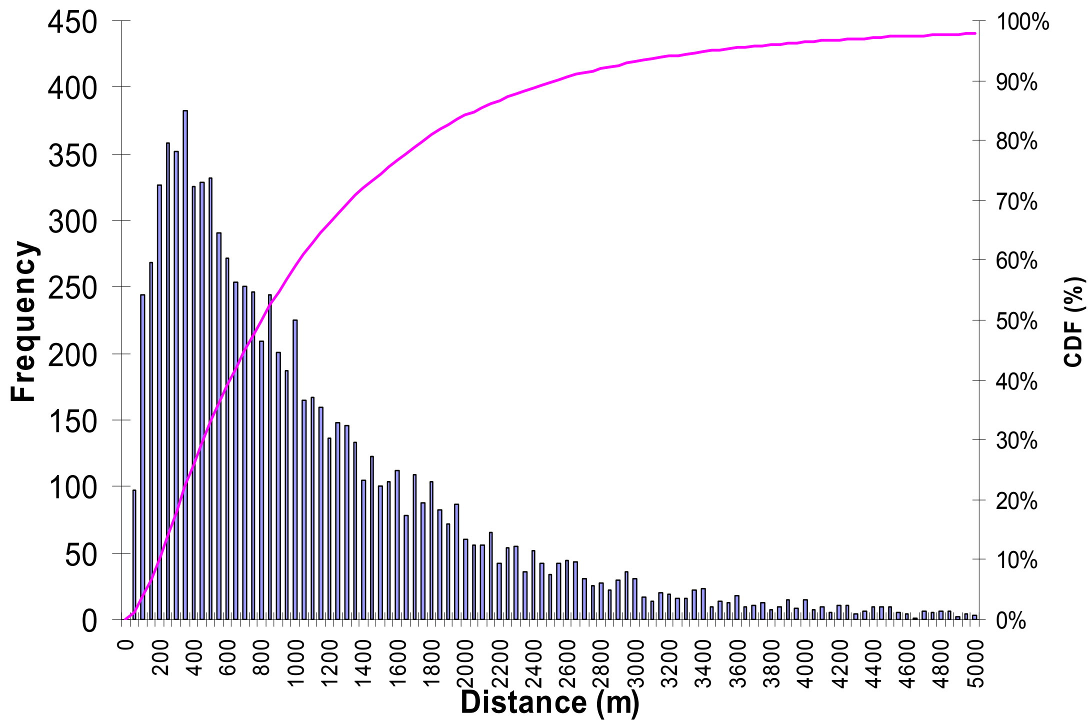

Figure B-46. Frequency distribution of distance between each Census block receptor and its nearest major-roadway-link-centered receptor.

B-4.1.5 Comparison of estimated on-road NO_2 concentrations

Table B-36 provides the semi-empirical distribution derived from the relationship of the on-road concentrations estimated by AERMOD and the concentrations at receptors located at least 100 meters form a major road. The data were separated in to two season categories, summer (June, July and August) and not summer (all other months). Table B-37 contains the values for each of the same distribution types, however were derived from measurement data reported in published literature sources (see Appendix A-8 for details). Each of the distributions were illustrated in Figure 8-7 of the REA.

Table B-36. On-road/non road NO_2 concentration ratios using AERMOD roadway link concentration prediction and nearest corresponding receptor concentration ≥ 100 m of a major road.

	AERMOD Predicted	
Probability	Not Summer Ratio	Summer Ratio
0.01	0.86	0.86
0.02	0.95	0.96
0.03	1.00	1.00
0.04	1.00	1.00
0.05	1.00	1.02
0.06	1.02	1.04
0.07	1.03	1.04
0.08	1.04	1.06
0.09	1.05	1.07
0.10	1.06	1.09
0.11	1.07	1.10
0.12	1.08	1.11
0.13	1.09	1.13
0.14	1.10	1.15
0.15	1.11	1.16
0.16	1.13	1.18
0.17	1.14	1.20
0.18	1.15	1.22
0.19	1.16	1.24
0.20	1.17	1.26
0.21	1.19	1.28
0.22	1.20	1.30
0.23	1.22	1.32
0.24	1.23	1.34
0.25	1.25	1.37
0.26	1.26	1.40
0.27	1.28	1.42
0.28	1.30	1.45
0.29	1.32	1.48
0.30	1.33	1.51
0.31	1.35	1.55
0.32	1.38	1.58
0.33	1.40	1.62
0.34	1.42	1.67

	AERMOD Predicted	
Probability	Not Summer Ratio	Summer Ratio
0.35	1.44	1.70
0.36	1.46	1.74
0.37	1.50	1.79
0.38	1.50	1.83
0.39	1.54	1.88
0.40	1.57	1.93
0.41	1.60	2.00
0.42	1.63	2.04
0.43	1.67	2.11
0.44	1.69	2.17
0.45	1.72	2.24
0.46	1.75	2.30
0.47	1.80	2.38
0.48	1.83	2.45
0.49	1.88	2.53
0.50	1.92	2.61
0.51	2.00	2.70
0.52	2.00	2.79
0.53	2.04	2.88
0.54	2.10	3.00
0.55	2.16	3.07
0.56	2.21	3.18
0.57	2.27	3.29
0.58	2.33	3.40
0.59	2.40	3.50
0.60	2.48	3.67
0.61	2.54	3.78
0.62	2.62	3.93
0.63	2.70	4.00
0.64	2.78	4.21
0.65	2.88	4.38
0.66	3.00	4.53
0.67	3.00	4.71
0.68	3.16	4.91
0.69	3.26	5.08
0.70	3.38	5.30
0.71	3.50	5.50
0.72	3.65	5.75
0.73	3.79	6.00
0.74	4.00	6.25
0.75	4.07	6.50
0.76	4.25	6.78
0.77	4.45	7.00
0.78	4.67	7.40
0.79	4.86	7.75
0.80	5.00	8.00

	AERMOD Predicted	
Probability	Not Summer Ratio	Summer Ratio
0.81	5.33	8.50
0.82	5.63	9.00
0.83	6.00	9.40
0.84	6.25	10.00
0.85	6.63	10.50
0.86	7.00	11.00
0.87	7.50	11.75
0.88	8.00	12.50
0.89	8.63	13.40
0.90	9.33	14.50
0.91	10.00	15.50
0.92	11.00	17.00
0.93	12.00	18.67
0.94	13.50	21.00
0.95	15.33	23.33
0.96	17.67	26.67
0.97	21.00	31.50
0.98	26.00	39.00
0.99	35.50	51.00
1.00	278.00	241.00

Table B-37. On-road/non road NO_2 concentration ratios derived from data reported in published NO_2 measurement studies.

	Measurement Derived	
Season	Probability	Ratio
Not Summer	0.03	1.22
	0.08	1.25
	0.14	1.36
	0.19	1.36
	0.24	1.42
	0.29	1.47
	0.34	1.58
	0.40	1.59
	0.45	1.64
	0.50	1.75
	0.55	1.78
	0.60	1.79
	0.66	1.79
	0.71	1.82
	0.76	1.86
	0.81	2.08
	0.86	2.14
	0.92	2.50
	0.97	2.54
Summer	0.03	1.49

Season	Measurement Derived	
	Probability	Ratio
	0.07	1.51
	0.12	1.52
	0.16	1.67
	0.21	1.70
	0.25	1.74
	0.30	1.75
	0.34	1.78
	0.39	1.78
	0.43	1.79
	0.48	1.90
	0.52	1.92
	0.57	1.93
	0.61	1.94
	0.66	2.13
	0.70	2.19
	0.75	2.21
	0.79	2.32
	0.84	2.95
	0.88	3.43
	0.93	3.45
	0.97	3.70

B-4.2 Supplemental APEX Modeling Inputs and Discussion

B-4.2.1 Simulated Individuals

The number of simulated persons in each model run was set to 50,000 persons simulated for each year. The parameters controlling the location and size of the simulated area were set to include the counties in the selected study area. The settings that allow for replacement of CHAD data that are missing gender, employment or age values were all set to preclude replacing missing data. The width of the age window was set to 20 percent to increase the pool of diaries available for selection. The variable that controls the use of additional ages outside the target age window was set to 0.1 to further enhance variability in diary selection. See the APEX User's Guide for further explanation of these parameters.

B-4.2.2 Asthma Prevalence Rates

One of the important population subgroups for the exposure assessment is asthmatic children. Evaluation of the exposure of this group 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 (EPA, 2007d; 2007e). Specifically, the analysis generated age and gender specific asthma prevalence rates for children ages 0-17 using data provided in the National Health Interview Survey (NHIS) for 2003 (CDC, 2007). These asthma rates were characterized by geographic regions, namely Midwest, Northeast, South, and West. Adult asthma prevalence rates for Atlanta were derived from the Behavioral Risk Factor Surveillance

System (BRFSS) survey information for year 2004-2005 (Blackwell and Kanny, 2007; Georgia Department of Human Resources, 2007). Average rates for adult males and females in Atlanta were derived from reported county prevalence rates for both genders. First each of the four county prevalence rates was weighted by their population, then averaged, and finally stratified by gender using the statewide reported gender prevalence. The adult prevalence rates were assumed to apply to all individuals uniformly. Table B-38 provides a summary of the prevalence rates used in the exposure analysis by age and gender.

Table B-38. Mean asthma prevalence rates, along with lower and upper 95% confidence limits, by age and gender used for Atlanta.

Region (Study Area)	Age	Females				Males			
		Prevalence[1]	se	L95	U95	Prevalence[1]	se	L95	U95
Atlanta (South)	0	0.034	0.013	0.015	0.077	0.041	0.019	0.015	0.110
	1	0.052	0.012	0.031	0.085	0.070	0.016	0.041	0.116
	2	0.071	0.014	0.046	0.109	0.102	0.017	0.070	0.146
	3	0.088	0.017	0.056	0.134	0.129	0.021	0.088	0.184
	4	0.099	0.019	0.064	0.150	0.144	0.024	0.099	0.205
	5	0.119	0.022	0.079	0.175	0.165	0.024	0.118	0.224
	6	0.122	0.023	0.079	0.182	0.164	0.025	0.116	0.226
	7	0.112	0.022	0.072	0.170	0.133	0.023	0.090	0.194
	8	0.093	0.019	0.059	0.144	0.138	0.023	0.095	0.197
	9	0.091	0.018	0.059	0.139	0.168	0.025	0.121	0.230
	10	0.108	0.020	0.071	0.162	0.178	0.025	0.130	0.240
	11	0.132	0.023	0.090	0.191	0.162	0.022	0.119	0.218
	12	0.123	0.020	0.085	0.175	0.145	0.020	0.106	0.195
	13	0.097	0.017	0.065	0.142	0.143	0.019	0.105	0.192
	14	0.095	0.016	0.064	0.137	0.153	0.019	0.116	0.200
	15	0.100	0.016	0.070	0.141	0.151	0.017	0.116	0.194
	16	0.115	0.016	0.084	0.156	0.140	0.018	0.105	0.185
	17	0.145	0.029	0.091	0.223	0.122	0.026	0.075	0.193
	17+	0.083				0.050			

Notes:
[1] prevalence is given in fraction of the population. Multiply by 100 to obtain the percent.
se – Standard error
L95 – Lower limit on 95th confidence interval
U95 – Upper limit on 95th confidence interval

B-4.2.3 Meteorological Data Used by APEX

APEX used meteorological data from the station located at Atlanta Hartsfield International (KATL) airport. This was one of the stations used for the AERMOD simulations.

B-4.2.4 Method Used for Indoor Source Contributions

Data used for estimating the contribution to indoor NO_2 concentrations that occur during cooking with gas fuel were derived from a study sponsored by the California Air Resources Board (CARB, 2001). For this study a test house was set up for continuous measurements of NO_2 indoors and outdoors, among several other parameters, and conducted under several different cooking procedures and stove operating conditions. A uniform distribution of concentration contributions for input to APEX was estimated as follows.

- The concurrent outdoor NO_2 concentration measurement was subtracted from each in door concentration measurement, to yield net indoor concentrations
- Net indoor concentrations for duplicate cooking tests (same food cooked the same way) were averaged for each indoor room, to yield average net indoor concentrations
- The minimum and maximum average net indoor concentrations for any test in any room were used as the lower and upper bounds of a uniform distribution.

This resulted in a minimum average net indoor concentration of 4 ppb and a maximum net average indoor concentration of 188 ppb.

B-4.2.5 Method Used for Cooking Probabilities

An analysis by Johnson et al (1999) of survey data on gas stove usage collected by Koontz et al (1992) showed an average number of meals prepared each day with a gas stove of 1.4. The diurnal allocation of these cooking events was estimated as follows.

- Food preparation time obtained from CHAD diaries was stratified by hour of the day, and summed for each hour, and summed for total preparation time.
- The fraction of food preparation occurring in each hour of the day was calculated as the total number of minutes for that hour divided by the overall total preparation time. The result was a measure of the probability of food preparation taking place during any hour, given one food preparation event per day.
- Each hourly fraction was multiplied by 1.4, to normalize the expected value of daily food preparation events to 1.4.

This resulted in estimated probabilities of cooking by hour of the day. For this analysis it was assumed that the probability that food preparation would include stove usage was the same for each hour of the day, so that the diurnal allocation of food preparation events would be the same as the diurnal allocation of gas stove usage. It was also assumed that each cooking event lasts for exactly 1 hour, implying that the average total daily gas stove usage is 1.4 hours.

B-4.2.6 Supplemental Exposure Results

B-4.2.6 Supplemental Exposure Results

This section provides complete exposure and risk characterization results for the two subpopulations, all asthmatics and asthmatic children. The data are presented in series of summary tables across each of the scenarios investigated (i.e. with modeled air quality as is and simulating just meeting the current and alternative standards), with and without modeled indoor sources (i.e., gas stoves), for each of the potential health effect benchmark levels (i.e., 100, 150, 200, 250, 300 ppb 1-hour), and across three years of modeled air quality (i.e., 2001 to 2003). Due to limits on the number of benchmarks allowed by APEX per simulation, only the benchmarks of 100, 200, and 300 ppb were evaluated for the potential alternative standards. When evaluating the indoor source contributions, the 99th percentile form was used for each the 50, 100, and 150 ppb 1-hour standard levels, the 98th percentile form was evaluated only at a 100 ppb 1-hour standard level for comparison with the 99th form.

B-4.2.6.1 All Asthmatics, Year 2001, No Indoor sources

Table B-39. Estimated number of asthmatics in the Atlanta modeling domain exposed at or above potential health effect benchmark levels (1 to 6 times per year), using 2001 modeled air quality (as is), with just meeting the current standard (cs), and potential alternative standards, without indoor sources.

Air Quality Adjustment		1-hour Benchmark (ppb)	Persons With Number of Repeated Exposures					
Level[1] (ppb)	Form[2]		1	2	3	4	5	6
100	98	100	212426	212426	212426	212372	212212	211997
100	98	200	207070	197375	185109	170648	155436	140760
100	98	300	162453	118639	87359	63524	47402	35511
100	99	100	212426	212426	212265	212051	211997	211515
100	99	200	203267	187734	170380	150883	133154	118586
100	99	300	145688	96733	66202	44510	31869	22657
150	98	100	212426	212426	212426	212426	212426	212426
150	98	200	212319	211783	211033	209908	208623	205945
150	98	300	207070	197375	185109	170648	155436	140760
150	99	100	212426	212426	212426	212426	212426	212426
150	99	200	211944	211462	210123	208087	204927	200910
150	99	300	203267	187734	170380	150883	133154	118586
200	98	100	212426	212426	212426	212426	212426	212426
200	98	200	212426	212426	212426	212372	212212	211997
200	98	300	211837	210980	208998	205784	201981	197107
200	99	100	212426	212426	212426	212426	212426	212426
200	99	200	212426	212426	212265	212051	211997	211515
200	99	300	211301	209159	205409	200053	193197	186609
50	98	100	207070	197375	185109	170648	155436	140760
50	98	200	97322	49063	25710	14890	8838	5410
50	98	300	23621	5035	1553	750	428	268
50	99	100	203267	187734	170380	150883	133154	118586
50	99	200	77290	34654	16551	8195	5142	2892
50	99	300	15640	2678	911	536	268	161
asis	asis	000	212426	212426	212426	212426	212426	212426
asis	asis	100	212426	212051	211837	211408	210658	209801
asis	asis	150	209426	203963	195018	185217	174343	162078
asis	asis	200	191912	167166	141135	117997	100053	83449
asis	asis	250	158650	112587	81200	58757	43171	31816
asis	asis	300	118104	66738	39636	24960	15801	10337
cs01	cs01	100	212426	212426	212426	212426	212426	212426
cs01	cs01	150	212426	212426	212426	212426	212426	212372
cs01	cs01	200	212426	212426	212319	212158	211997	211730
cs01	cs01	250	212212	211730	210926	209801	208087	205731
cs01	cs01	300	211355	209266	205731	200696	194643	187734

[1] value is the 1-hour concentration that air quality is adjusted considering particular form; cs is the current annual average value of 0.053 ppm.
[2] asis – current air quality, not adjusted; 98 – 98th percentile 1-hour concentration averaged across three years; 99 – 99th 1-hour concentration averaged across three years; cs – current annual average standard.

Table B-40. Estimated percent of asthmatics in the Atlanta modeling domain exposed at or above potential health effect benchmark levels (1 to 6 times per year), using 2001 modeled air quality (as is), with just meeting the current standard (cs), and potential alternative standards, without indoor sources.

Air Quality Adjustment		1-hour Benchmark (ppb)	Percent of Persons With Number of Repeated Exposures					
Level[1] (ppb)	Form[2]		1	2	3	4	5	6
100	98	100	100%	100%	100%	100%	100%	100%
100	98	200	97%	93%	87%	80%	73%	66%
100	98	300	76%	56%	41%	30%	22%	17%
100	99	100	100%	100%	100%	100%	100%	100%
100	99	200	96%	88%	80%	71%	63%	56%
100	99	300	69%	46%	31%	21%	15%	11%
150	98	100	100%	100%	100%	100%	100%	100%
150	98	200	100%	100%	99%	99%	98%	97%
150	98	300	97%	93%	87%	80%	73%	66%
150	99	100	100%	100%	100%	100%	100%	100%
150	99	200	100%	100%	99%	98%	96%	95%
150	99	300	96%	88%	80%	71%	63%	56%
200	98	100	100%	100%	100%	100%	100%	100%
200	98	200	100%	100%	100%	100%	100%	100%
200	98	300	100%	99%	98%	97%	95%	93%
200	99	100	100%	100%	100%	100%	100%	100%
200	99	200	100%	100%	100%	100%	100%	100%
200	99	300	99%	98%	97%	94%	91%	88%
50	98	100	97%	93%	87%	80%	73%	66%
50	98	200	46%	23%	12%	7%	4%	3%
50	98	300	11%	2%	1%	0%	0%	0%
50	99	100	96%	88%	80%	71%	63%	56%
50	99	200	36%	16%	8%	4%	2%	1%
50	99	300	7%	1%	0%	0%	0%	0%
asis	asis	000	100%	100%	100%	100%	100%	100%
asis	asis	100	100%	100%	100%	100%	99%	99%
asis	asis	150	99%	96%	92%	87%	82%	76%
asis	asis	200	90%	79%	66%	56%	47%	39%
asis	asis	250	75%	53%	38%	28%	20%	15%
asis	asis	300	56%	31%	19%	12%	7%	5%
cs01	cs01	100	100%	100%	100%	100%	100%	100%
cs01	cs01	150	100%	100%	100%	100%	100%	100%
cs01	cs01	200	100%	100%	100%	100%	100%	100%
cs01	cs01	250	100%	100%	99%	99%	98%	97%
cs01	cs01	300	99%	99%	97%	94%	92%	88%

[1] value is the 1-hour concentration that air quality is adjusted considering particular form; cs is the current annual average value of 0.053 ppm.
[2] asis – current air quality, not adjusted; 98 – 98^{th} percentile 1-hour concentration averaged across three years; 99 – 99^{th} 1-hour concentration averaged across three years; cs – current annual average standard.

B-4.2.6.2 Asthmatic Children, Year 2001, No Indoor Sources

Table B-41. Estimated number of asthmatic children in the Atlanta modeling domain exposed at or above potential health effect benchmark levels (1 to 6 times per year), using 2001 modeled air quality (as is), with just meeting the current standard (cs), and potential alternative standards, without indoor sources.

Air Quality Adjustment		1-hour Benchmark (ppb)	Persons With Number of Repeated Exposures					
Level[1] (ppb)	Form[2]		1	2	3	4	5	6
100	98	100	64113	64113	64113	64113	64113	64113
100	98	200	62881	60953	58275	54847	51366	48313
100	98	300	51794	39957	31226	23514	17622	14194
100	99	100	64113	64113	64113	64113	64113	64060
100	99	200	61917	58596	54847	50241	45635	41617
100	99	300	47456	33476	23567	16015	12159	9213
150	98	100	64113	64113	64113	64113	64113	64113
150	98	200	64113	64060	64006	63738	63578	63042
150	98	300	62881	60953	58275	54847	51366	48313
150	99	100	64113	64113	64113	64113	64113	64113
150	99	200	64060	64006	63899	63578	63042	62185
150	99	300	61917	58596	54847	50241	45635	41617
200	98	100	64113	64113	64113	64113	64113	64113
200	98	200	64113	64113	64113	64113	64113	64113
200	98	300	64060	63953	63738	63042	62346	61435
200	99	100	64113	64113	64113	64113	64113	64113
200	99	200	64113	64113	64113	64113	64113	64060
200	99	300	64006	63685	62721	61435	60150	58864
50	98	100	62881	60953	58275	54847	51366	48313
50	98	200	32030	17086	9373	5892	3321	2089
50	98	300	7177	1660	321	107	54	0
50	99	100	61917	58596	54847	50241	45635	41617
50	99	200	25656	12587	6535	3053	1821	857
50	99	300	4499	857	107	54	0	0
asis	asis	000	64113	64113	64113	64113	64113	64113
asis	asis	100	64113	64113	64113	64060	64060	63899
asis	asis	150	63685	62560	60525	58168	56722	53883
asis	asis	200	59025	54044	46866	41350	36476	31119
asis	asis	250	51044	38564	29191	22067	15908	12748
asis	asis	300	37868	22924	13444	9320	6374	4338
cs01	cs01	100	64113	64113	64113	64113	64113	64113
cs01	cs01	150	64113	64113	64113	64113	64113	64113
cs01	cs01	200	64113	64113	64113	64113	64113	64060
cs01	cs01	250	64113	64006	63953	63738	63524	63042
cs01	cs01	300	64006	63685	62881	61542	60364	59079

[1] value is the 1-hour concentration that air quality is adjusted considering particular form; cs is the current annual average value of 0.053 ppm.
[2] asis – current air quality, not adjusted; 98 – 98th percentile 1-hour concentration averaged across three years; 99 – 99th 1-hour concentration averaged across three years; cs – current annual average standard.

Table B-42. Estimated percent of asthmatic children in the Atlanta modeling domain exposed at or above potential health effect benchmark levels (1 to 6 times per year), using 2001 modeled air quality (as is), with just meeting the current standard (cs), and potential alternative standards, without indoor sources.

Air Quality Adjustment		1-hour Benchmark (ppb)	Percent of Persons With Number of Repeated Exposures					
Level[1] (ppb)	Form[2]		1	2	3	4	5	6
100	98	100	100%	100%	100%	100%	100%	100%
100	98	200	98%	95%	91%	86%	80%	75%
100	98	300	81%	62%	49%	37%	27%	22%
100	99	100	100%	100%	100%	100%	100%	100%
100	99	200	97%	91%	86%	78%	71%	65%
100	99	300	74%	52%	37%	25%	19%	14%
150	98	100	100%	100%	100%	100%	100%	100%
150	98	200	100%	100%	100%	99%	99%	98%
150	98	300	98%	95%	91%	86%	80%	75%
150	99	100	100%	100%	100%	100%	100%	100%
150	99	200	100%	100%	100%	99%	98%	97%
150	99	300	97%	91%	86%	78%	71%	65%
200	98	100	100%	100%	100%	100%	100%	100%
200	98	200	100%	100%	100%	100%	100%	100%
200	98	300	100%	100%	99%	98%	97%	96%
200	99	100	100%	100%	100%	100%	100%	100%
200	99	200	100%	100%	100%	100%	100%	100%
200	99	300	100%	99%	98%	96%	94%	92%
50	98	100	98%	95%	91%	86%	80%	75%
50	98	200	50%	27%	15%	9%	5%	3%
50	98	300	11%	3%	1%	0%	0%	0%
50	99	100	97%	91%	86%	78%	71%	65%
50	99	200	40%	20%	10%	5%	3%	1%
50	99	300	7%	1%	0%	0%	0%	0%
asis	asis	000	100%	100%	100%	100%	100%	100%
asis	asis	100	100%	100%	100%	100%	100%	100%
asis	asis	150	99%	98%	94%	91%	88%	84%
asis	asis	200	92%	84%	73%	64%	57%	49%
asis	asis	250	80%	60%	46%	34%	25%	20%
asis	asis	300	59%	36%	21%	15%	10%	7%
cs01	cs01	100	100%	100%	100%	100%	100%	100%
cs01	cs01	150	100%	100%	100%	100%	100%	100%
cs01	cs01	200	100%	100%	100%	100%	100%	100%
cs01	cs01	250	100%	100%	100%	99%	99%	98%
cs01	cs01	300	100%	99%	98%	96%	94%	92%

[1] value is the 1-hour concentration that air quality is adjusted considering particular form; cs is the current annual average value of 0.053 ppm.
[2] asis – current air quality, not adjusted; 98 – 98th percentile 1-hour concentration averaged across three years; 99 – 99th 1-hour concentration averaged across three years; cs – current annual average standard.

B-4.2.6.3 All Asthmatics, Year 2002, No Indoor sources

Table B-43. Estimated number of asthmatics in the Atlanta modeling domain exposed at or above potential health effect benchmark levels (1 to 6 times per year), using 2002 modeled air quality (as is), with just meeting the current standard (cs), and potential alternative standards, without indoor sources.

Air Quality Adjustment		1-hour Benchmark (ppb)	Persons With Number of Repeated Exposures					
Level[1] (ppb)	Form[2]		1	2	3	4	5	6
100	98	100	212426	212426	212426	212265	212051	211944
100	98	200	207820	199089	187252	172576	157954	143813
100	98	300	165345	123674	89555	64756	48045	35351
100	99	100	212426	212372	212319	212051	211944	211676
100	99	200	204070	190037	172469	153883	136797	120246
100	99	300	150776	100268	68184	45045	32191	23192
150	98	100	212426	212426	212426	212426	212426	212426
150	98	200	212372	212051	211301	210016	208891	206909
150	98	300	207820	199089	187252	172576	157954	143813
150	99	100	212426	212426	212426	212426	212426	212426
150	99	200	212212	211408	210123	208248	205677	202356
150	99	300	204070	190037	172469	153883	136797	120246
200	98	100	212426	212426	212426	212426	212426	212426
200	98	200	212426	212426	212426	212265	212051	211944
200	98	300	211997	210658	209319	206588	203481	199143
200	99	100	212426	212426	212426	212426	212426	212426
200	99	200	212426	212372	212319	212051	211944	211676
200	99	300	211301	209319	206213	201124	194804	188430
50	98	100	207820	199089	187252	172576	157954	143813
50	98	200	103535	49920	29352	17300	10391	6963
50	98	300	29620	7392	2785	1178	696	321
50	99	100	204070	190037	172469	153883	136797	120246
50	99	200	83824	36904	19496	11141	6160	4178
50	99	300	21264	4285	1500	803	268	107
asis	asis	000	212426	212426	212426	212426	212426	212426
asis	asis	100	212426	212265	211997	211301	210819	209748
asis	asis	150	209855	204713	197429	187359	176540	164756
asis	asis	200	195768	170862	146063	122281	102196	85431
asis	asis	250	161864	117997	84199	59293	43171	32405
asis	asis	300	124531	68988	41350	25870	17782	11944
cs02	cs02	100	212426	212426	212426	212426	212426	212426
cs02	cs02	150	212426	212426	212426	212426	212426	212426
cs02	cs02	200	212426	212426	212426	212426	212372	212319
cs02	cs02	250	212426	212372	212319	211997	211890	211301
cs02	cs02	300	212372	212051	211140	209962	208516	206695

[1] value is the 1-hour concentration that air quality is adjusted considering particular form; cs is the current annual average value of 0.053 ppm.
[2] asis – current air quality, not adjusted; 98 – 98th percentile 1-hour concentration averaged across three years; 99 – 99th 1-hour concentration averaged across three years; cs – current annual average standard.

Table B-44. Estimated percent of asthmatics in the Atlanta modeling domain exposed at or above potential health effect benchmark levels (1 to 6 times per year), using 2002 modeled air quality (as is), with just meeting the current standard (cs), and potential alternative standards, without indoor sources.

Air Quality Adjustment		1-hour Benchmark (ppb)	Percent of Persons With Number of Repeated Exposures					
Level[1] (ppb)	Form[2]		1	2	3	4	5	6
100	98	100	100%	100%	100%	100%	100%	100%
100	98	200	98%	94%	88%	81%	74%	68%
100	98	300	78%	58%	42%	30%	23%	17%
100	99	100	100%	100%	100%	100%	100%	100%
100	99	200	96%	89%	81%	72%	64%	57%
100	99	300	71%	47%	32%	21%	15%	11%
150	98	100	100%	100%	100%	100%	100%	100%
150	98	200	100%	100%	99%	99%	98%	97%
150	98	300	98%	94%	88%	81%	74%	68%
150	99	100	100%	100%	100%	100%	100%	100%
150	99	200	100%	100%	99%	98%	97%	95%
150	99	300	96%	89%	81%	72%	64%	57%
200	98	100	100%	100%	100%	100%	100%	100%
200	98	200	100%	100%	100%	100%	100%	100%
200	98	300	100%	99%	99%	97%	96%	94%
200	99	100	100%	100%	100%	100%	100%	100%
200	99	200	100%	100%	100%	100%	100%	100%
200	99	300	99%	99%	97%	95%	92%	89%
50	98	100	98%	94%	88%	81%	74%	68%
50	98	200	49%	23%	14%	8%	5%	3%
50	98	300	14%	3%	1%	1%	0%	0%
50	99	100	96%	89%	81%	72%	64%	57%
50	99	200	39%	17%	9%	5%	3%	2%
50	99	300	10%	2%	1%	0%	0%	0%
asis	asis	000	100%	100%	100%	100%	100%	100%
asis	asis	100	100%	100%	100%	99%	99%	99%
asis	asis	150	99%	96%	93%	88%	83%	78%
asis	asis	200	92%	80%	69%	58%	48%	40%
asis	asis	250	76%	56%	40%	28%	20%	15%
asis	asis	300	59%	32%	19%	12%	8%	6%
cs02	cs02	100	100%	100%	100%	100%	100%	100%
cs02	cs02	150	100%	100%	100%	100%	100%	100%
cs02	cs02	200	100%	100%	100%	100%	100%	100%
cs02	cs02	250	100%	100%	100%	100%	100%	99%
cs02	cs02	300	100%	100%	99%	99%	98%	97%

[1] value is the 1-hour concentration that air quality is adjusted considering particular form; cs is the current annual average value of 0.053 ppm.
[2] asis – current air quality, not adjusted; 98 – 98th percentile 1-hour concentration averaged across three years; 99 – 99th 1-hour concentration averaged across three years; cs – current annual average standard.

B-4.2.6.4 Asthmatic Children, Year 2002, No Indoor Sources

Table B-45. Estimated number of asthmatic children in the Atlanta modeling domain exposed at or above potential health effect benchmark levels (1 to 6 times per year), using 2002 modeled air quality (as is), with just meeting the current standard (cs), and potential alternative standards, without indoor sources.

Air Quality Adjustment		1-hour Benchmark (ppb)	Persons With Number of Repeated Exposures					
Level[1] (ppb)	Form[2]		1	2	3	4	5	6
100	98	100	64113	64113	64113	64113	64006	63953
100	98	200	63149	61221	58918	55758	52973	49437
100	98	300	53347	42099	31816	22603	16711	12855
100	99	100	64113	64113	64113	64060	64006	63899
100	99	200	62667	59400	55704	51259	47349	43224
100	99	300	49330	34976	24049	15051	10873	7552
150	98	100	64113	64113	64113	64113	64113	64113
150	98	200	64113	64113	63846	63685	63417	63256
150	98	300	63149	61221	58918	55758	52973	49437
150	99	100	64113	64113	64113	64113	64113	64113
150	99	200	64060	64006	63738	63310	62828	61971
150	99	300	62667	59400	55704	51259	47349	43224
200	98	100	64113	64113	64113	64113	64113	64113
200	98	200	64113	64113	64113	64113	64006	63953
200	98	300	64060	63846	63578	62881	62399	61435
200	99	100	64113	64113	64113	64113	64113	64113
200	99	200	64113	64113	64113	64060	64006	63899
200	99	300	64006	63471	62614	61757	60632	59025
50	98	100	63149	61221	58918	55758	52973	49437
50	98	200	34387	16604	9480	5249	3267	2035
50	98	300	8784	1768	428	161	107	54
50	99	100	62667	59400	55704	51259	47349	43224
50	99	200	27263	12051	5999	3321	1928	964
50	99	300	6052	911	107	107	0	0
asis	asis	000	64113	64113	64113	64113	64113	64113
asis	asis	100	64113	64113	64006	63846	63792	63578
asis	asis	150	63524	62506	60900	58971	56775	54097
asis	asis	200	60632	54740	48688	43171	37172	31869
asis	asis	250	52598	40493	30262	20568	14890	11516
asis	asis	300	40975	23996	13819	8034	5731	3428
cs02	cs02	100	64113	64113	64113	64113	64113	64113
cs02	cs02	150	64113	64113	64113	64113	64113	64113
cs02	cs02	200	64113	64113	64113	64113	64113	64113
cs02	cs02	250	64113	64113	64113	64060	64006	63792
cs02	cs02	300	64113	64113	63846	63685	63363	63256

[1] value is the 1-hour concentration that air quality is adjusted considering particular form; cs is the current annual average value of 0.053 ppm.
[2] asis – current air quality, not adjusted; 98 – 98th percentile 1-hour concentration averaged across three years; 99 – 99th 1-hour concentration averaged across three years; cs – current annual average standard.

Table B-46. Estimated percent of asthmatic children in the Atlanta modeling domain exposed at or above potential health effect benchmark levels (1 to 6 times per year), using 2002 modeled air quality (as is), with just meeting the current standard (cs), and potential alternative standards, without indoor sources.

Air Quality Adjustment		1-hour Benchmark (ppb)	Percent of Persons With Number of Repeated Exposures					
Level[1] (ppb)	Form[2]		1	2	3	4	5	6
100	98	100	100%	100%	100%	100%	100%	100%
100	98	200	98%	95%	92%	87%	83%	77%
100	98	300	83%	66%	50%	35%	26%	20%
100	99	100	100%	100%	100%	100%	100%	100%
100	99	200	98%	93%	87%	80%	74%	67%
100	99	300	77%	55%	38%	23%	17%	12%
150	98	100	100%	100%	100%	100%	100%	100%
150	98	200	100%	100%	100%	99%	99%	99%
150	98	300	98%	95%	92%	87%	83%	77%
150	99	100	100%	100%	100%	100%	100%	100%
150	99	200	100%	100%	99%	99%	98%	97%
150	99	300	98%	93%	87%	80%	74%	67%
200	98	100	100%	100%	100%	100%	100%	100%
200	98	200	100%	100%	100%	100%	100%	100%
200	98	300	100%	100%	99%	98%	97%	96%
200	99	100	100%	100%	100%	100%	100%	100%
200	99	200	100%	100%	100%	100%	100%	100%
200	99	300	100%	99%	98%	96%	95%	92%
50	98	100	98%	95%	92%	87%	83%	77%
50	98	200	54%	26%	15%	8%	5%	3%
50	98	300	14%	3%	1%	0%	0%	0%
50	99	100	98%	93%	87%	80%	74%	67%
50	99	200	43%	19%	9%	5%	3%	2%
50	99	300	9%	1%	0%	0%	0%	0%
asis	asis	000	100%	100%	100%	100%	100%	100%
asis	asis	100	100%	100%	100%	100%	99%	99%
asis	asis	150	99%	97%	95%	92%	89%	84%
asis	asis	200	95%	85%	76%	67%	58%	50%
asis	asis	250	82%	63%	47%	32%	23%	18%
asis	asis	300	64%	37%	22%	13%	9%	5%
cs02	cs02	100	100%	100%	100%	100%	100%	100%
cs02	cs02	150	100%	100%	100%	100%	100%	100%
cs02	cs02	200	100%	100%	100%	100%	100%	100%
cs02	cs02	250	100%	100%	100%	100%	100%	99%
cs02	cs02	300	100%	100%	100%	99%	99%	99%

[1] value is the 1-hour concentration that air quality is adjusted considering particular form; cs is the current annual average value of 0.053 ppm.
[2] asis – current air quality, not adjusted; 98 – 98th percentile 1-hour concentration averaged across three years; 99 – 99th 1-hour concentration averaged across three years; cs – current annual average standard.

B-4.2.6.5 All Asthmatics, Year 2003, No Indoor sources

Table B-47. Estimated number of asthmatic in the Atlanta modeling domain exposed at or above potential health effect benchmark levels (1 to 6 times per year), using 2003 modeled air quality (as is), with just meeting the current standard (cs), and potential alternative standards, without indoor sources.

Air Quality Adjustment		1-hour Benchmark (ppb)	Persons With Number of Repeated Exposures					
Level[1] (ppb)	Form[2]		1	2	3	4	5	6
100	98	100	212426	212426	212372	212319	212158	212051
100	98	200	206534	197429	184360	168827	154526	139261
100	98	300	162721	117514	84520	61596	45099	33958
100	99	100	212426	212426	212319	212104	211622	210980
100	99	200	202731	187520	169148	149973	131923	115908
100	99	300	143653	94911	63203	44349	31762	22228
150	98	100	212426	212426	212426	212426	212426	212426
150	98	200	212212	211837	210980	209587	207927	205998
150	98	300	206534	197429	184360	168827	154526	139261
150	99	100	212426	212426	212426	212426	212426	212426
150	99	200	211944	211248	209373	207284	204338	199250
150	99	300	202731	187520	169148	149973	131923	115908
200	98	100	212426	212426	212426	212426	212426	212426
200	98	200	212426	212426	212372	212319	212158	212051
200	98	300	211676	210337	208516	205249	201017	195072
200	99	100	212426	212426	212426	212426	212426	212426
200	99	200	212426	212426	212319	212104	211622	210980
200	99	300	211087	208837	205838	199625	193037	184413
50	98	100	206534	197429	184360	168827	154526	139261
50	98	200	98072	48366	26406	15265	8784	5570
50	98	300	25924	5892	2571	857	268	54
50	99	100	202731	187520	169148	149973	131923	115908
50	99	200	79057	33958	16926	8570	5035	2946
50	99	300	17836	3749	1446	428	107	0
asis	asis	000	212426	212426	212426	212426	212426	212426
asis	asis	100	212426	212158	211837	211194	210016	209051
asis	asis	150	209105	203963	194804	183824	172522	160257
asis	asis	200	192447	165452	139582	117568	97429	80450
asis	asis	250	158114	111730	78843	57204	41296	30744
asis	asis	300	117461	66470	39261	25228	15158	9695
cs03	cs03	100	212426	212426	212426	212426	212426	212426
cs03	cs03	150	212426	212426	212426	212426	212426	212426
cs03	cs03	200	212426	212426	212426	212426	212426	212426
cs03	cs03	250	212426	212426	212426	212319	212265	212265
cs03	cs03	300	212426	212372	212212	211997	211408	210712

[1] value is the 1-hour concentration that air quality is adjusted considering particular form; cs is the current annual average value of 0.053 ppm.
[2] asis – current air quality, not adjusted; 98 – 98th percentile 1-hour concentration averaged across three years; 99 – 99th 1-hour concentration averaged across three years; cs – current annual average standard.

Table B-48. Estimated percent of asthmatics in the Atlanta modeling domain exposed at or above potential health effect benchmark levels (1 to 6 times per year), using 2003 modeled air quality (as is), with just meeting the current standard (cs), and potential alternative standards, without indoor sources.

Air Quality Adjustment		1-hour Benchmark (ppb)	Percent of Persons With Number of Repeated Exposures					
Level[1] (ppb)	Form[2]		1	2	3	4	5	6
100	98	100	100%	100%	100%	100%	100%	100%
100	98	200	97%	93%	87%	79%	73%	66%
100	98	300	77%	55%	40%	29%	21%	16%
100	99	100	100%	100%	100%	100%	100%	99%
100	99	200	95%	88%	80%	71%	62%	55%
100	99	300	68%	45%	30%	21%	15%	10%
150	98	100	100%	100%	100%	100%	100%	100%
150	98	200	100%	100%	99%	99%	98%	97%
150	98	300	97%	93%	87%	79%	73%	66%
150	99	100	100%	100%	100%	100%	100%	100%
150	99	200	100%	99%	99%	98%	96%	94%
150	99	300	95%	88%	80%	71%	62%	55%
200	98	100	100%	100%	100%	100%	100%	100%
200	98	200	100%	100%	100%	100%	100%	100%
200	98	300	100%	99%	98%	97%	95%	92%
200	99	100	100%	100%	100%	100%	100%	100%
200	99	200	100%	100%	100%	100%	100%	99%
200	99	300	99%	98%	97%	94%	91%	87%
50	98	100	97%	93%	87%	79%	73%	66%
50	98	200	46%	23%	12%	7%	4%	3%
50	98	300	12%	3%	1%	0%	0%	0%
50	99	100	95%	88%	80%	71%	62%	55%
50	99	200	37%	16%	8%	4%	2%	1%
50	99	300	8%	2%	1%	0%	0%	0%
asis	asis	000	100%	100%	100%	100%	100%	100%
asis	asis	100	100%	100%	100%	99%	99%	98%
asis	asis	150	98%	96%	92%	87%	81%	75%
asis	asis	200	91%	78%	66%	55%	46%	38%
asis	asis	250	74%	53%	37%	27%	19%	14%
asis	asis	300	55%	31%	18%	12%	7%	5%
cs03	cs03	100	100%	100%	100%	100%	100%	100%
cs03	cs03	150	100%	100%	100%	100%	100%	100%
cs03	cs03	200	100%	100%	100%	100%	100%	100%
cs03	cs03	250	100%	100%	100%	100%	100%	100%
cs03	cs03	300	100%	100%	100%	100%	100%	99%

[1] value is the 1-hour concentration that air quality is adjusted considering particular form; cs is the current annual average value of 0.053 ppm.
[2] asis – current air quality, not adjusted; 98 – 98th percentile 1-hour concentration averaged across three years; 99 – 99th 1-hour concentration averaged across three years; cs – current annual average standard.

B-4.2.6.6 Asthmatic Children, Year 2003, No Indoor Sources

Table B-49. Estimated number of asthmatic children in the Atlanta modeling domain exposed at or above potential health effect benchmark levels (1 to 6 times per year), using 2003 modeled air quality (as is), with just meeting the current standard (cs), and potential alternative standards, without indoor sources.

Air Quality Adjustment		1-hour Benchmark (ppb)	Persons With Number of Repeated Exposures					
Level[1] (ppb)	Form[2]		1	2	3	4	5	6
100	98	100	64113	64113	64113	64060	63953	63899
100	98	200	62935	60846	58061	54579	51312	47723
100	98	300	52008	39582	28977	21907	16818	13444
100	99	100	64113	64113	64060	64006	63846	63846
100	99	200	61864	58864	54526	49812	45045	40921
100	99	300	46492	32405	22603	15747	11355	8570
150	98	100	64113	64113	64113	64113	64113	64113
150	98	200	64006	63953	63738	63471	63363	63149
150	98	300	62935	60846	58061	54579	51312	47723
150	99	100	64113	64113	64113	64113	64113	64113
150	99	200	63953	63846	63471	63256	62560	61596
150	99	300	61864	58864	54526	49812	45045	40921
200	98	100	64113	64113	64113	64113	64113	64113
200	98	200	64113	64113	64113	64060	63953	63899
200	98	300	63953	63685	63363	62560	62024	60632
200	99	100	64113	64113	64113	64113	64113	64113
200	99	200	64113	64113	64060	64006	63846	63846
200	99	300	63899	63417	62774	61435	59989	58275
50	98	100	62935	60846	58061	54579	51312	47723
50	98	200	31334	16818	9373	5463	2999	2035
50	98	300	7981	1821	643	161	0	0
50	99	100	61864	58864	54526	49812	45045	40921
50	99	200	25335	11569	5678	3107	1928	857
50	99	300	5142	1071	321	0	0	0
asis	asis	000	64113	64113	64113	64113	64113	64113
asis	asis	100	64113	64006	63899	63738	63524	63417
asis	asis	150	63578	62292	59936	57900	55543	53133
asis	asis	200	59239	52758	45956	39957	34922	30102
asis	asis	250	50830	37600	27316	20193	15158	12051
asis	asis	300	37547	23192	14676	9373	5249	3214
cs03	cs03	100	64113	64113	64113	64113	64113	64113
cs03	cs03	150	64113	64113	64113	64113	64113	64113
cs03	cs03	200	64113	64113	64113	64113	64113	64113
cs03	cs03	250	64113	64113	64113	64060	64006	64006
cs03	cs03	300	64113	64060	64006	63953	63846	63738

[1] value is the 1-hour concentration that air quality is adjusted considering particular form; cs is the current annual average value of 0.053 ppm.
[2] asis – current air quality, not adjusted; 98 – 98th percentile 1-hour concentration averaged across three years; 99 – 99th 1-hour concentration averaged across three years; cs – current annual average standard.

Table B-50. Estimated percent of asthmatic children in the Atlanta modeling domain exposed at or above potential health effect benchmark levels (1 to 6 times per year), using 2003 modeled air quality (as is), with just meeting the current standard (cs), and potential alternative standards, without indoor sources.

Air Quality Adjustment		1-hour Benchmark (ppb)	Percent of Persons With Number of Repeated Exposures					
Level[1] (ppb)	Form[2]		1	2	3	4	5	6
100	98	100	100%	100%	100%	100%	100%	100%
100	98	200	98%	95%	91%	85%	80%	74%
100	98	300	81%	62%	45%	34%	26%	21%
100	99	100	100%	100%	100%	100%	100%	100%
100	99	200	96%	92%	85%	78%	70%	64%
100	99	300	73%	51%	35%	25%	18%	13%
150	98	100	100%	100%	100%	100%	100%	100%
150	98	200	100%	100%	99%	99%	99%	98%
150	98	300	98%	95%	91%	85%	80%	74%
150	99	100	100%	100%	100%	100%	100%	100%
150	99	200	100%	100%	99%	99%	98%	96%
150	99	300	96%	92%	85%	78%	70%	64%
200	98	100	100%	100%	100%	100%	100%	100%
200	98	200	100%	100%	100%	100%	100%	100%
200	98	300	100%	99%	99%	98%	97%	95%
200	99	100	100%	100%	100%	100%	100%	100%
200	99	200	100%	100%	100%	100%	100%	100%
200	99	300	100%	99%	98%	96%	94%	91%
50	98	100	98%	95%	91%	85%	80%	74%
50	98	200	49%	26%	15%	9%	5%	3%
50	98	300	12%	3%	1%	0%	0%	0%
50	99	100	96%	92%	85%	78%	70%	64%
50	99	200	40%	18%	9%	5%	3%	1%
50	99	300	8%	2%	1%	0%	0%	0%
asis	asis	000	100%	100%	100%	100%	100%	100%
asis	asis	100	100%	100%	100%	99%	99%	99%
asis	asis	150	99%	97%	93%	90%	87%	83%
asis	asis	200	92%	82%	72%	62%	54%	47%
asis	asis	250	79%	59%	43%	31%	24%	19%
asis	asis	300	59%	36%	23%	15%	8%	5%
cs03	cs03	100	100%	100%	100%	100%	100%	100%
cs03	cs03	150	100%	100%	100%	100%	100%	100%
cs03	cs03	200	100%	100%	100%	100%	100%	100%
cs03	cs03	250	100%	100%	100%	100%	100%	100%
cs03	cs03	300	100%	100%	100%	100%	100%	99%

[1] value is the 1-hour concentration that air quality is adjusted considering particular form; cs is the current annual average value of 0.053 ppm.
[2] asis – current air quality, not adjusted; 98 – 98th percentile 1-hour concentration averaged across three years; 99 – 99th 1-hour concentration averaged across three years; cs – current annual average standard.

B-4.2.6.7 All Asthmatics, Year 2002, With Indoor Sources

Table B-51. Estimated number of asthmatics in the Atlanta modeling domain exposed at or above potential health effect benchmark levels (1 to 6 times per year), using 2002 modeled air quality (as is), with just meeting the current standard (cs), and potential alternative standards, with indoor sources.

Air Quality Adjustment		1-hour Benchmark (ppb)	Percent of Persons With Number of Repeated Exposures					
Level[1] (ppb)	Form[2]		1	2	3	4	5	6
asis	asis	0	212426	212426	212426	212426	212426	212426
asis	asis	100	212426	212426	212319	212319	212265	212212
asis	asis	150	211890	210873	208516	205570	201231	196679
asis	asis	200	197268	175843	152383	129191	109694	92930
asis	asis	250	166952	121960	87520	62989	46438	33905
asis	asis	300	127156	72630	44242	26995	17943	11409
cs02	cs02	100	212426	212426	212426	212426	212426	212426
cs02	cs02	150	212426	212426	212426	212426	212426	212426
cs02	cs02	200	212426	212426	212426	212426	212426	212426
cs02	cs02	250	212426	212426	212372	212319	211890	211462
cs02	cs02	300	212372	211944	211515	210712	209373	207605
50	99	100	211890	210980	209801	207766	205463	202838
50	99	200	86556	37707	18532	10070	6535	3910
50	99	300	20514	3856	1071	375	107	0
100	99	100	212426	212426	212426	212426	212426	212319
100	99	200	205731	193786	179110	160792	144938	127370
100	99	300	154204	104070	70594	48313	33637	24049
100	98	100	212426	212426	212426	212426	212426	212426
100	98	200	208677	201017	190948	177718	164649	151205
100	98	300	170273	126191	92394	68077	50134	37386
150	99	100	212426	212426	212426	212426	212426	212426
150	99	200	212158	211569	210980	209641	207605	205356
150	99	300	204284	191001	175147	157097	140278	123674

[1] value is the 1-hour concentration that air quality is adjusted considering particular form; cs is the current annual average value of 0.053 ppm.
[2] asis – current air quality, not adjusted; 98 – 98th percentile 1-hour concentration averaged across three years; 99 – 99th 1-hour concentration averaged across three years; cs – current annual average standard.

Table B-52. Estimated percent of asthmatics in the Atlanta modeling domain exposed at or above potential health effect benchmark levels (1 to 6 times per year), using 2002 modeled air quality (as is), with just meeting the current standard (cs), and potential alternative standards, with indoor sources.

Air Quality Adjustment		1-hour Benchmark (ppb)	Percent of Persons With Number of Repeated Exposures					
Level[1] (ppb)	Form[2]		1	2	3	4	5	6
asis	asis	0	100%	100%	100%	100%	100%	100%
asis	asis	100	100%	100%	100%	100%	100%	100%
asis	asis	150	100%	99%	98%	97%	95%	93%
asis	asis	200	93%	83%	72%	61%	52%	44%
asis	asis	250	79%	57%	41%	30%	22%	16%
asis	asis	300	60%	34%	21%	13%	8%	5%
cs02	cs02	100	100%	100%	100%	100%	100%	100%
cs02	cs02	150	100%	100%	100%	100%	100%	100%
cs02	cs02	200	100%	100%	100%	100%	100%	100%
cs02	cs02	250	100%	100%	100%	100%	100%	100%
cs02	cs02	300	100%	100%	100%	99%	99%	98%
50	99	100	100%	99%	99%	98%	97%	95%
50	99	200	41%	18%	9%	5%	3%	2%
50	99	300	10%	2%	1%	0%	0%	0%
100	99	100	100%	100%	100%	100%	100%	100%
100	99	200	97%	91%	84%	76%	68%	60%
100	99	300	73%	49%	33%	23%	16%	11%
100	98	100	100%	100%	100%	100%	100%	100%
100	98	200	98%	95%	90%	84%	78%	71%
100	98	300	80%	59%	43%	32%	24%	18%
150	99	100	100%	100%	100%	100%	100%	100%
150	99	200	100%	100%	99%	99%	98%	97%
150	99	300	96%	90%	82%	74%	66%	58%

[1] value is the 1-hour concentration that air quality is adjusted considering particular form; cs is the current annual average value of 0.053 ppm.
[2] asis – current air quality, not adjusted; 98 – 98th percentile 1-hour concentration averaged across three years; 99 – 99th 1-hour concentration averaged across three years; cs – current annual average standard.

B-4.2.6.8 Asthmatic Children, Year 2002, With Indoor Sources

Table B-53. Estimated number of asthmatic children in the Atlanta modeling domain exposed at or above potential health effect benchmark levels (1 to 6 times per year), using 2002 modeled air quality (as is), with just meeting the current standard (cs), and potential alternative standards, with indoor sources.

Air Quality Adjustment		1-hour Benchmark (ppb)	Percent of Persons With Number of Repeated Exposures					
Level[1] (ppb)	Form[2]		1	2	3	4	5	6
asis	asis	0	64113	64113	64113	64113	64113	64113
asis	asis	100	64113	64113	64060	64060	64006	64006
asis	asis	150	64006	63738	63203	62292	61221	59507
asis	asis	200	60471	55651	50348	44563	39261	34065
asis	asis	250	52812	40653	31012	23085	16979	12694
asis	asis	300	41028	24638	15212	9534	5785	3696
cs02	cs02	100	64113	64113	64113	64113	64113	64113
cs02	cs02	150	64113	64113	64113	64113	64113	64113
cs02	cs02	200	64113	64113	64113	64113	64113	64113
cs02	cs02	250	64113	64113	64113	64060	64006	63953
cs02	cs02	300	64113	64006	63953	63738	63524	63524
50	99	100	63792	63363	62774	61971	60739	59561
50	99	200	27852	12694	6106	2946	1553	696
50	99	300	5517	1018	214	107	54	0
100	99	100	64113	64113	64113	64113	64113	64006
100	99	200	62560	59882	57150	52544	48848	44403
100	99	300	49170	35297	25067	17729	12105	8570
100	98	100	64113	64113	64113	64113	64113	64113
100	98	200	63363	61757	59882	56775	53722	50723
100	98	300	53508	41725	32351	24960	18532	13819
150	99	100	64113	64113	64113	64113	64113	64113
150	99	200	64060	63899	63792	63524	63363	62989
150	99	300	62292	59239	56400	51848	47777	43974

[1] value is the 1-hour concentration that air quality is adjusted considering particular form; cs is the current annual average value of 0.053 ppm.
[2] asis – current air quality, not adjusted; 98 – 98th percentile 1-hour concentration averaged across three years; 99 – 99th 1-hour concentration averaged across three years; cs – current annual average standard.

Table B-54. Estimated percent of asthmatic children in the Atlanta modeling domain exposed at or above potential health effect benchmark levels (1 to 6 times per year), using 2002 modeled air quality (as is), with just meeting the current standard (cs), and potential alternative standards, with indoor sources.

Air Quality Adjustment		1-hour Benchmark (ppb)	Percent of Persons With Number of Repeated Exposures					
Level[1] (ppb)	Form[2]		1	2	3	4	5	6
asis	asis	0	100%	100%	100%	100%	100%	100%
asis	asis	100	100%	100%	100%	100%	100%	100%
asis	asis	150	100%	99%	99%	97%	95%	93%
asis	asis	200	94%	87%	79%	70%	61%	53%
asis	asis	250	82%	63%	48%	36%	26%	20%
asis	asis	300	64%	38%	24%	15%	9%	6%
cs02	cs02	100	100%	100%	100%	100%	100%	100%
cs02	cs02	150	100%	100%	100%	100%	100%	100%
cs02	cs02	200	100%	100%	100%	100%	100%	100%
cs02	cs02	250	100%	100%	100%	100%	100%	100%
cs02	cs02	300	100%	100%	100%	99%	99%	99%
50	99	100	99%	99%	98%	97%	95%	93%
50	99	200	43%	20%	10%	5%	2%	1%
50	99	300	9%	2%	0%	0%	0%	0%
100	99	100	100%	100%	100%	100%	100%	100%
100	99	200	98%	93%	89%	82%	76%	69%
100	99	300	77%	55%	39%	28%	19%	13%
100	98	100	100%	100%	100%	100%	100%	100%
100	98	200	99%	96%	93%	89%	84%	79%
100	98	300	83%	65%	50%	39%	29%	22%
150	99	100	100%	100%	100%	100%	100%	100%
150	99	200	100%	100%	99%	99%	99%	98%
150	99	300	97%	92%	88%	81%	75%	69%

[1] value is the 1-hour concentration that air quality is adjusted considering particular form; cs is the current annual average value of 0.053 ppm.
[2] asis – current air quality, not adjusted; 98 – 98th percentile 1-hour concentration averaged across three years; 99 – 99th 1-hour concentration averaged across three years; cs – current annual average standard.

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Attachment 1: Meteorological data preparation for AERMOD for NO_2 REA for Atlanta, GA 2001-2003

Meteorological data preparation for AERMOD for NO_2 REA for Atlanta, GA 2001-2003

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1. Introduction

While National Weather Service (NWS) surface observational data are often used as the source of meteorological inputs for AERMOD, sometimes the data are not truly representative of the modeling domain, especially for urban applications. Often the meteorological data is from an airport, which has different surface characteristics than the sources being modeled. The airport meteorological tower is often located in open spaces while the sources are located in urban areas with trees, buildings, and other obstacles. For the Atlanta study, the airport, Atlanta Hartsfield Airport was initially chosen as the representative meteorological location. The sources used in the study are located in urban areas. Therefore, the airport data, due to lower surface roughness at the airport, may not adequately represent conditions at the sources.

To address the concern regarding representativeness of the Atlanta NWS data for this study, meteorological data from the Southeast Aerosol Research and Characterization study (SEARCH) site in Atlanta were used as the primary source of meteorology for the AERMOD runs for the years 2001 through 2003. Figure 1a shows the locations of the SEARCH site, located at Jefferson St, and hereafter referenced as JST, and Hartsfield International Airport, hereafter referenced as ATL. The JST site is located in an urban area, while the airport is on the outskirts of the city. Figure 1b provides a closer look at the JST site and it can be clearly seen that the site is in an urban setting.

The methodologies used to prepare meteorological data for AERMOD are described below, including the analysis of surface characteristics data, and AERMET processing for the JST site and ATL. Also discussed is the methodology used to process upper air data from Peachtree City, GA and Birmingham, AL.

Another potential concern related to the use of NWS meteorological data for dispersion modeling is the often high incidence of calms and variable wind conditions. The AERMOD model currently cannot simulate dispersion under these conditions. To reduce the number of calms and missing winds in the ATL data, archived one-minute winds for the ASOS station at ATL were used to calculate hourly average wind speed and directions, which were used to supplement the standard archive of winds reported for ATL in the Integrated Surface Hourly (ISH) database. Details regarding this procedure are described below.

Section 2 describes preparation of the JST data, Section 3 describes the preparation of data and calculation of hourly winds from one-minute ASOS data for ATL, Section 4 describes preparation of upper air data from Peachtree City and Birmingham, Section 5 describes AERSURFACE processing for surface characteristics, and Section 6 describes the AERMET processing. Section 7 describes an additional adjustment that was made to the processed meteorological data to address an issue regarding AERMOD formulation for the urban option that contributed to anomalous modeled concentrations from a preliminary analysis. Section 8 provides a brief analysis of the AERMET output for JST and ATL. References are listed in Section 9.

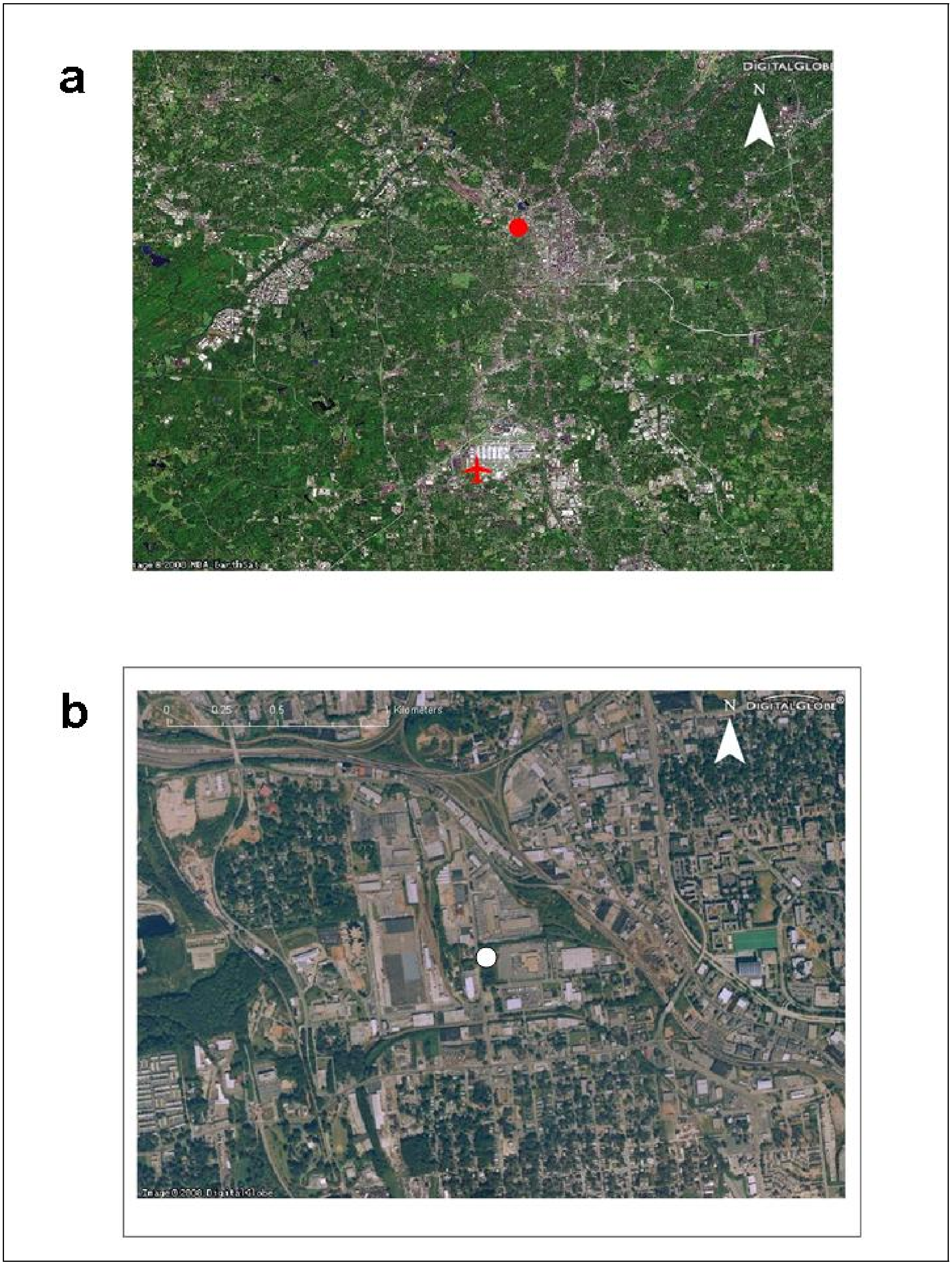

Figure 1. a) location of JST (red dot) relative to ATL (red airplane) and b) zoomed in view of JST (white dot).

2. SEARCH data preparation

SEARCH data for the Jefferson St. monitor (JST) in Atlanta was downloaded from the public archive section of the SEARCH website, http://www.atmospheric-research.com/public/index.html, for 2001 through 2003. Trace gas and met data were chosen. The data in the SEARCH spreadsheets were reported on a 0 to 23 hour basis, with the reported time represented the beginning of the observational hour. The convention for meteorological data input to dispersion models is that the reported time represents the end of the averaging period. The AERMOD model also requires meteorological inputs on a 1 to 23 hour basis. After adjusting the JST data to conform to the AERMOD model conventions, missing values for wind speed, wind direction, and temperature were reset to the missing values of those variables as described in AERMET Appendix B, Table B-3. (U.S. EPA, 2004). The anemometer height for the JST data was set to 10 m.

Since data quality is an important consideration for meteorological inputs to dispersion models, the JST data were reviewed for completeness and reasonableness. Specifically, hourly wind speeds, wind directions, and temperatures for JST were compared to the values for Atlanta Hartsfield Airport (ATL) for the three years of 2001 through 2003. Analysis of the wind directions showed generally good agreement between JST and ATL data throughout most of the period. However, this comparison identified somewhat anomalous directions for the period of May 2 through May 8, 2001 (Figure 2). The original wind directions for the JST data (red lines), revealed an approximate 180 degree shift in wind direction when compared to the ATL wind directions (blue lines). This shift followed a significant period of missing data for JST from late April to early May 2001. After May 8, the wind directions appeared to be in better agreement with airport wind directions. A similar problem had been encountered for a SEARCH site in Birmingham as part of another study, and was later confirmed to be a 120-degree offset. Based on this review and prior experience with a similar problem, it was decided to shift the JST wind direction by 180 degrees for the period beginning with 1700 LST May 2 and ending at 1500 LST May 8. Figure 3 shows the resulting directions (green line), which are more in line with the airport directions. After correcting for the wind directions, the hourly winds and temperatures were written to text files for input in to AERMET. Figure 4 shows the wind roses for each year for JST. Winds were predominantly from the northwest with a secondary maximum from the east.

The number of calms and missing hours (winds or temperature) for JST were compiled for each year to determine if data substitution from the airport was necessary in AERMET processing. Table 1 lists the number of calms and missing winds and temperatures for the JST site for 2001 through 2003. Note that a wind speed threshold of 0.28 m/s was used in processing the JST data through AERMET. As a result, any wind speed reported less than 0.28 m/s was treated as a calm hour. Unlike NWS surface observations, which treat any wind speed below 3 knots as a calm, the JST data are based on a sonic anemometer, which has virtually no threshold since the observations are not dependent on mechanical parts. Several manufacturers of sonic anemometers report starting thresholds of 0.01 m/s. While such low winds speeds may be a reasonable starting threshold for an instantaneous wind speed sample from a sonic anemometer, it may not be appropriate as a threshold for defining a valid hourly average wind speed to be used in a steady-state plume model such as AERMOD, with a single hourly average wind direction. Under conditions that would result in an hourly average wind speed on the order of 0.01 m/s, there would be no well-defined transport direction. The AERMOD model formulation includes adjustments to the minimum wind speed to account for turbulence effects under very light wind conditions, with the minimum effective wind speed that will be used for dilution in AERMOD of about 0.2828 m/s. Based on these considerations, a threshold of 0.28 m/s was selected as the most appropriate value to be applied for the JST data, with any hourly average wind speeds below that threshold being classified as calm. Note that the current meteorological monitoring guidance for dispersion modeling applications (EPA, 2000) specifies a maximum acceptable starting threshold of 0.5 m/s for site-specific meteorological monitoring programs.

Table 1. Number of calms, missing winds, and missing temperatures for each year for 2001 through 2003 for the JST site.

Variable	**Year**		
	2001	**2002**	**2003**
Calms#	427	287	19
Missing winds*	165	497	792
Missing temperature	187	205	379

anything less than 0.28 m/s was considered calm
* missing wind speed and/or wind direction.

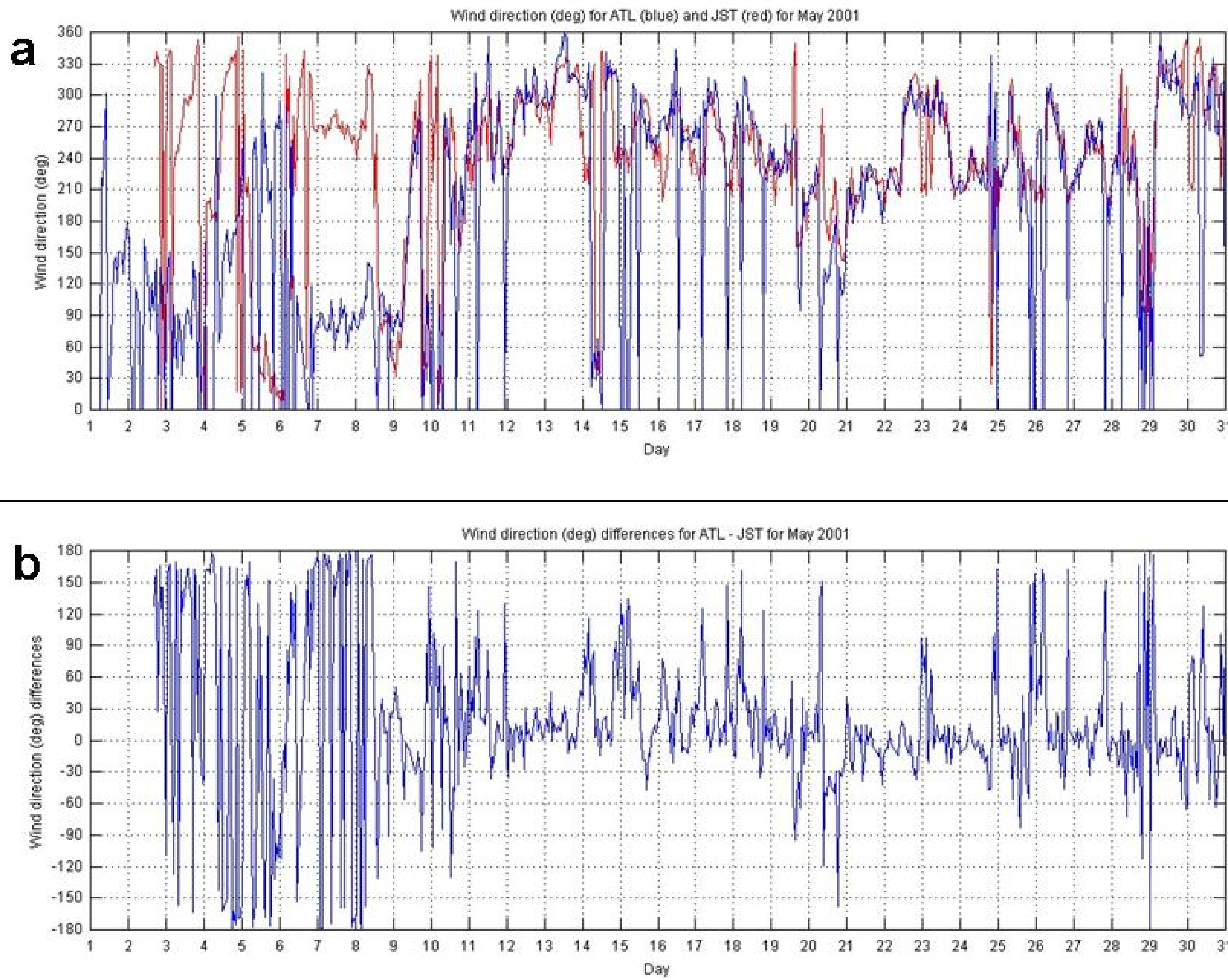

Figure 2. May 2001 a) wind directions for the SEARCH monitor (red line) and Hartsfield International Airport (blue line) and b), wind direction differences (airport – SEARCH).

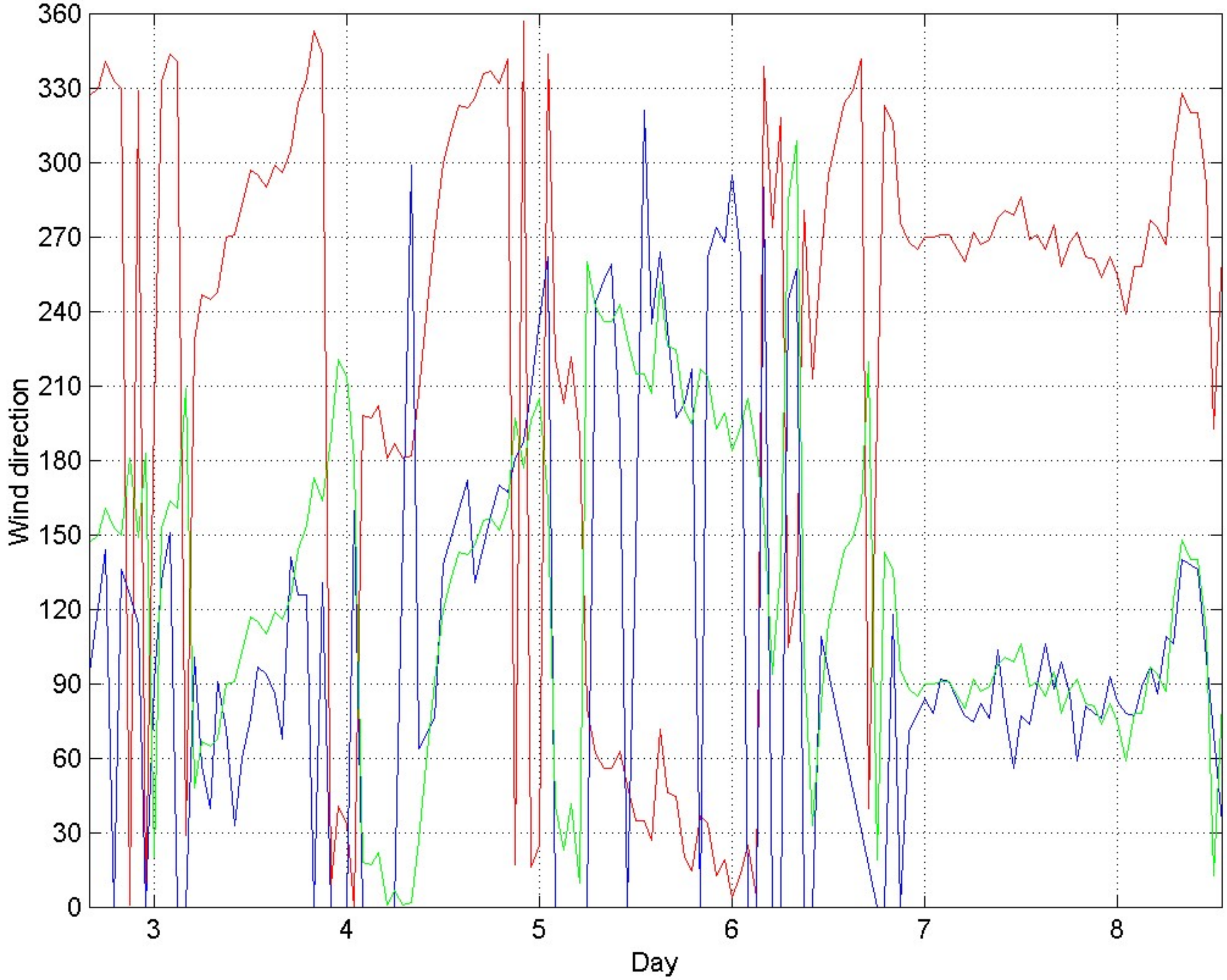

Figure 3. Hourly wind directions for original SEARCH (red), airport (blue) and shifted SEARCH (green) for May 2 through May 8, 2001.

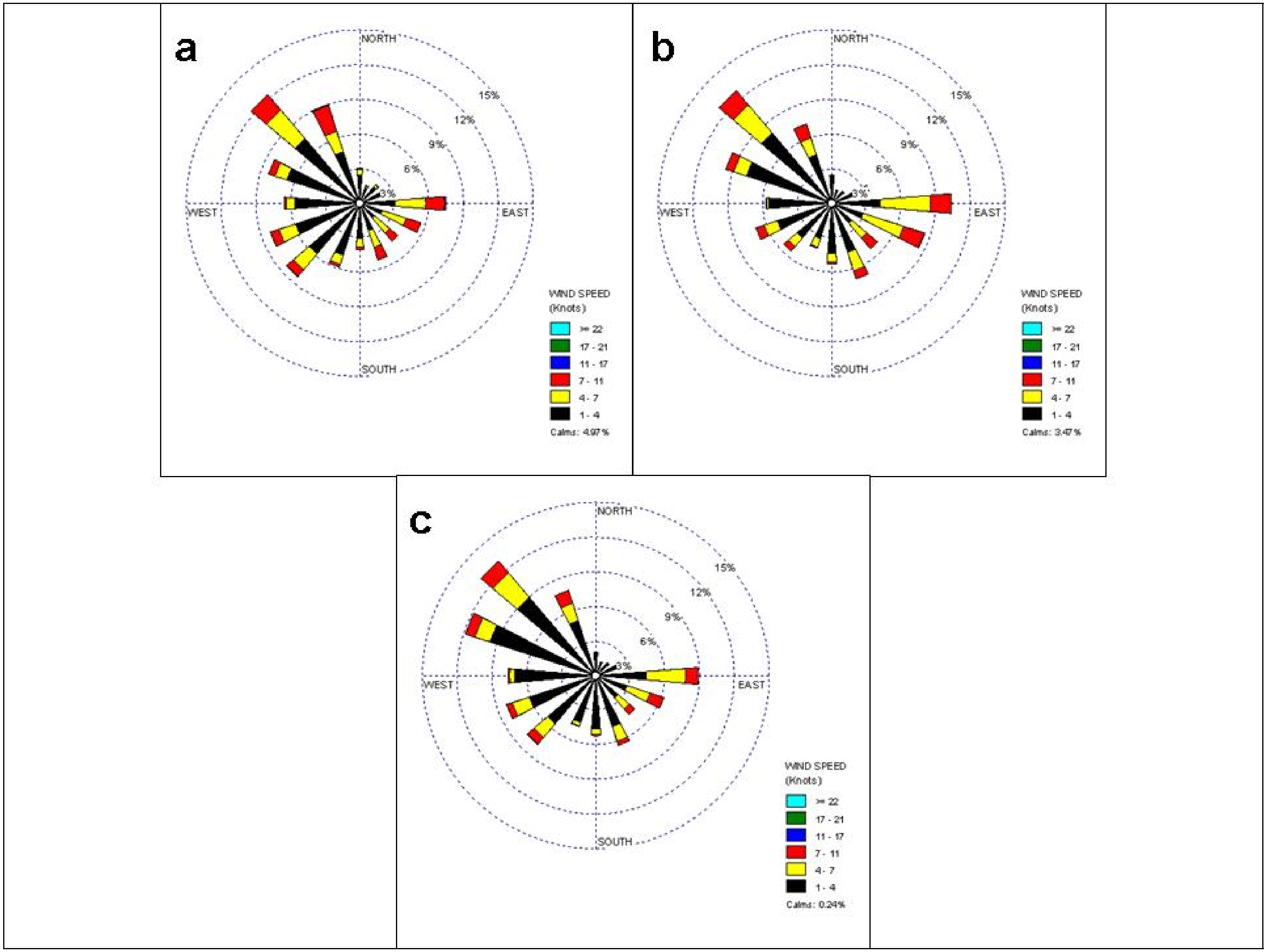

Figure 4. Annual wind roses for JST for a) 2001, b) 2002, and c) 2003.

3. Surface airport data

Surface data from an NWS site was needed to supplement the data from the SEARCH site. For AERMOD, the most representative data for an NWS site should be used, most often the nearest location. For Atlanta, Atlanta Hartsfield Airport (ATL) was chosen as the site. Integrated Surface Hourly (ISH) data was downloaded from the National Climatic Data Center (NCDC) for 2001, 2002, and 2003.

Surface data from NWS locations often contain a large number of calms and variable winds. This is due to the METAR reporting method used for NWS observations. Currently, the wind speed and direction used to represent the hour in AERMOD is 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, 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. For daily or annual averages, this can result in underestimated concentrations. 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. 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 ATL were used to calculate hourly average winds for 2001 through 2003. These winds would be 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:

One minute data files are monthly, so each month for 2001 through 2003 was downloaded. The program used to calculate hourly average winds is executed for each year.

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 ATL prior to April 2007). So a reported wind speed of 0 knots may not necessarily be a calm wind. This also 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 minutes 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 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 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 V_x and V_y 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

$$\text{CORR} = \begin{cases} 180 \text{ for } V_x > 0 \text{ and } V_y > 0 \text{ or } V_x < 0 \text{ and } V_y > 0 \\ 0 \text{ for } V_x < 0 \text{ and } V_y < 0 \\ 360 \text{ for } V_x \geq 0 \text{ and } V_y < 0 \end{cases}$$

4. Upper air data

For AERMET processing, an upper air station must be paired with the surface station. For both JST and ATL, the Peachtree City upper air station, FFC, was chosen as the most representative upper air site. Upper air data in the Forecast System Laboratory (FSL) format was downloaded from the FSL, (now Global Systems Division) website, http://www.fsl.noaa.gov/. The data period chosen was January 1, 2001 through December 31, 2003 for all times and all levels. The selected wind speed units were chosen as tenths of a meter per second. The data was downloaded as one file for all three years.

Analysis of the data revealed 31 occurrences of missing 1200 UTC soundings for the three years, mostly in 2001. The AERMOD processor requires a 1200 UTC sounding in order to calculate the convective mixing height for the day. As a result, if the 1200 UTC sounding is missing, all of the daytime convective hours for that day will be considered as missing by the AERMOD model. In order to minimize missing data as much as possible, these gaps in the data were filled with data from the Birmingham, AL upper air station, BMX or from the FFC data itself. Table 2 lists the missing dates and method of data substitution. These substitutions should have very limited impact on the Atlanta NO2 modeling since BMX is reasonably representative of Atlanta, and modeling results for low-level releases, such as mobile sources, are not very sensitive to the convective mixing heights in AERMOD.

Table 2. Missing 1200 UTC sounding dates in upper air data with substitution method. Unless specified otherwise, substitution times are the same as the missing date/time.

Date/time	**Substitution**	**Date/time**	**Substitution**
03/11/01	BMX	04/17/02	BMX
03/12/01	BMX	04/18/02	BMX
03/13/01	BMX	04/19/02	BMX
05/06/01	BMX	04/20/02	BMX
06/13/01	BMX	04/21/02	BMX
06/14/01	BMX	04/22/02	BMX
06/15/01	BMX	04/26/02	BMX
08/11/01	BMX	04/27/02	BMX
11/21/01	BMX	06/14/02	BMX
11/22/01	BMX	06/23/02	BMX
11/23/01	BMX	07/21/02	FFC 07/20/02
01/11/02	BMX	09/08/02	BMX
02/19/02	BMX	09/09/02	BMX
03/23/02	BMX	01/22/03	BMX
03/24/02	BMX	03/09/03	BMX
03/25/02	BMX	06/26/03	BMX

5. AERSURFACE

The AERSURFACE tool (U.S. EPA, 2008a) was used to determine surface characteristics (albedo, Bowen ratio, and surface roughness) for input to AERMET. Surface characteristics were calculated for the JST meteorological tower site (33.77753° N, 84.41666° W) and for the ATL meteorological tower (33.63° N 84.44167° W). 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.

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 this modeling period than the 1992 NLCD data supported by the current version of AERSURFACE available on EPA's SCRAM website. Both meteorological data sites were run according to the methodology in Section 3.2.2 of the 1st draft NO_2 risk and exposure assessment technical support document (U.S. EPA, 2008b): both sites were run as non-arid regions, ATL was considered "at an airport" for the low, medium, and high intensity developed categories, default seasonal assignments to each month, and no continuous snow cover. Moisture conditions for Bowen ratio (average, dry, or wet) were assigned to each month based on the analysis shown in Table 30 of the technical support document (U.S. EPA, 2008b). Months with at least twice the normal precipitation level were denoted as wet, those with less than one-half the normal precipitation level were assigned dry and all others were average. This resulted in three AERSURFACE runs for each site with average, dry, or wet conditions because AERSURFACE can not assign moisture conditions to individual months within one AERSURFACE run. Table 3 shows the assignment to each month for each year. Figures 5 and 6 show the sectors used for surface roughness for JST and ATL.

After running AERSURFACE, a year specific set of surface characteristics was generated for each year by merging results for the appropriate moisture condition for each month for the year, i.e. for 2001, the average moisture surface characteristics for January through June were concatenated with the dry July and August surface characteristics, average September surface characteristics, dry October and November surface characteristics, and average December surface characteristics. These merged AERSURFACE results were used in Stage 3 of AERMET.

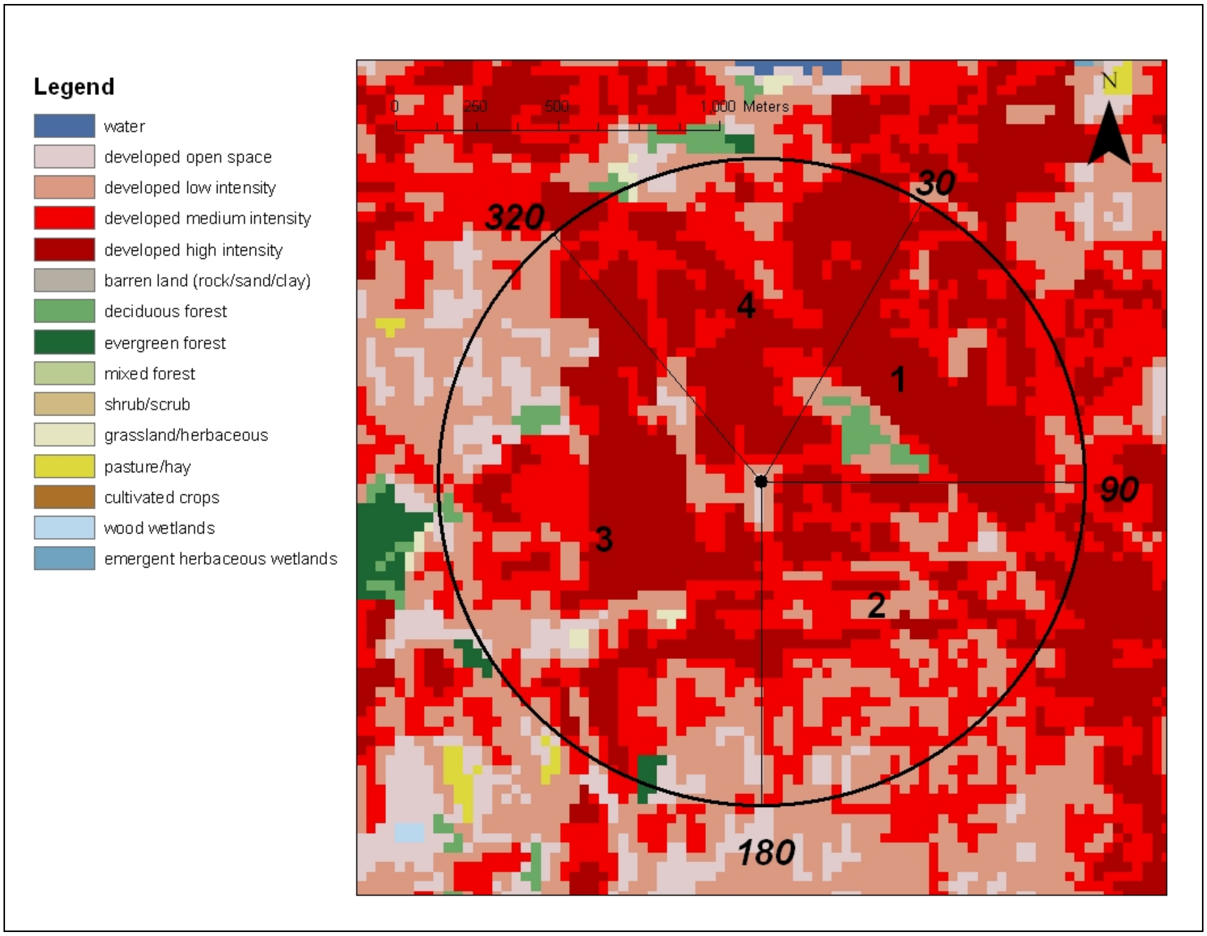

Figure 5. 2001 NLCD for JST with surface roughness 1 km radius and sectors (denoted by numbers 1 through 4). Numbers outside 1 km radius are the starting directions of each sector.

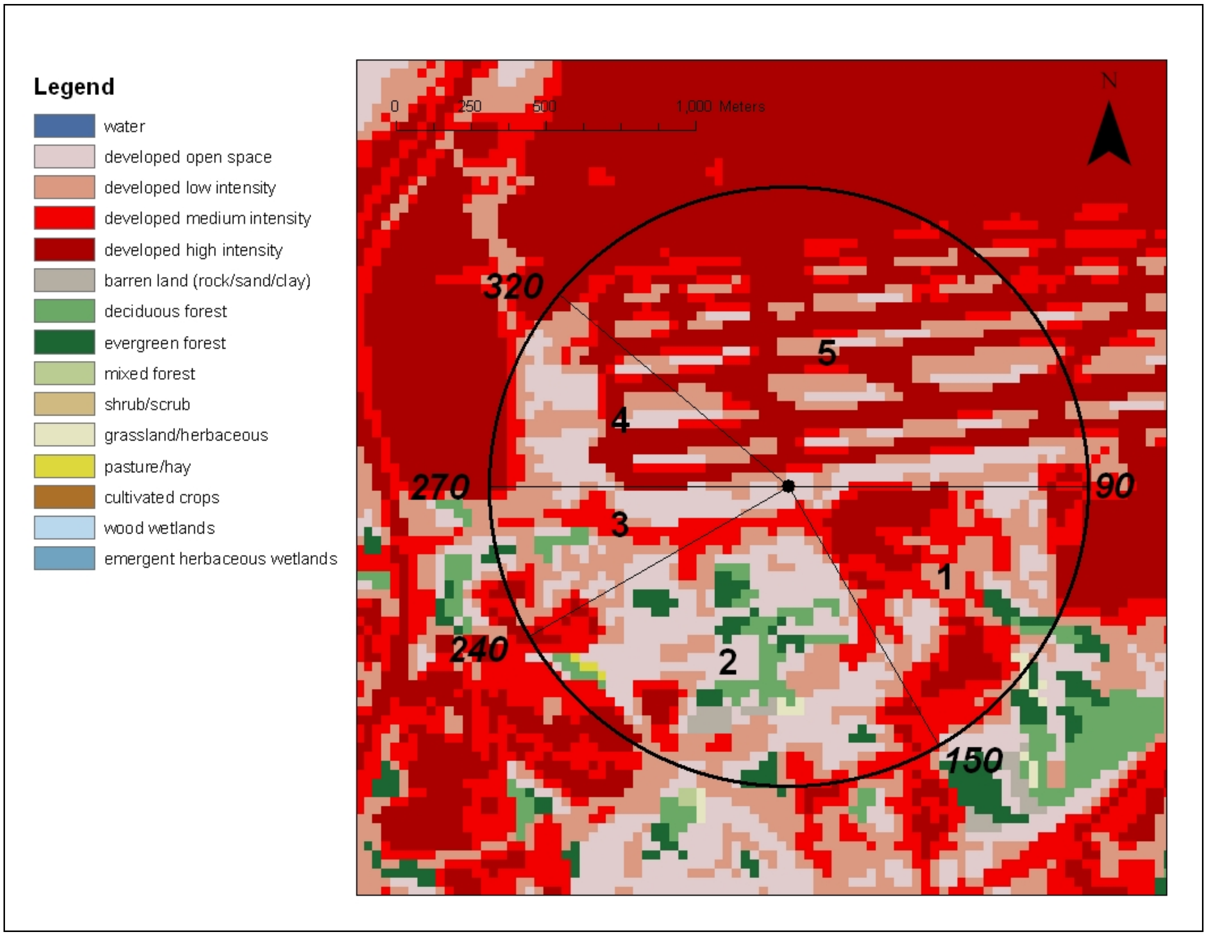

Figure 6. 2001 NLCD for ATL with surface roughness 1 km radius and sectors (denoted by numbers 1 through 5). Numbers outside 1 km radius are the starting directions of each sector.

Table 3. Assignment of average, dry, or wet conditions for each month for ATL and JST for 2001, 2002, and 2003.

Month	**Year**		
	2001	**2002**	**2003**
January	Average	Average	Dry
February	Average	Average	Average
March	Average	Average	Average
April	Average	Average	Average
May	Average	Average	Wet
June	Average	Average	Average
July	Dry	Average	Average
August	Dry	Dry	Average
September	Average	Average	Average
October	Dry	Average	Dry
November	Dry	Average	Average
December	Average	Average	Average

6. AERMET

The meteorological data files (upper air, ATL ISH data, JST surface data, and ATL one minute data) were processed in AERMET, 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 ATL ISH data was processed via the SURFACE pathway, and the JST surface data and ATL one minute hourly average winds were processed via the ONSITE pathway. Winds and temperatures were read into AERMET for the JST data and hourly averaged winds were read into AERMET for the ATL one minute hourly average winds. For JST, the THRESHOLD keyword was set to 0.28 m/s as described in Section 2. For the hourly averaged one minute ATL winds, the threshold was set to 0.01 m/s.

For each year, there were two separate runs of Stage 2 of AERMET, the merging of surface data and upper air data; one for ATL and one for JST. For ATL, the Stage 1 upper air output, ATL ISH output, and ATL one minute output were merged together via the MERGE pathway. For JST, the upper air output, ATL ISH output, and JST output were merged together.

As with Stage 2, there were two separate Stage 3 runs for each year. First, for ATL, the output from Stage 2 was processed. For each year, the year specific surface characteristics created by concatenating the appropriate surface characteristics for each month were used. The ATL one minute hourly averaged winds would be the primary source of wind data. All other variables would come from the ATL ISH data. ATL ISH winds would be used only when the ATL one minute hourly averaged winds were missing. The substitution was done via the SUBNWS keyword in the Stage 3 input file. The anemometer height was set to 10 m (keyword NWS_HGT).

The second run was for JST. The JST winds and temperature would be the primary source of data. Other variables would come from the ATL ISH data and the ATL winds or temperature would be used only when the values were missing for JST for a particular hour. Surface characteristics were the year specific surface characteristics for JST. For later post-processing, the NWS_HGT keyword was set to 9.9 m. This would allow for identification of hours where the ATL winds were used. For hours with valid data at the JST site, the 10 m height read into AERMET from the JST met file in stage 1 would be used. Note that even for hours using ATL data, surface characteristics for JST were used.

After AERMET processing for each year for JST and ATL, a FORTRAN program was used to substitute the records from the ATL *.SFC and *.PFL files into the JST *.SFC and *.PFL files when ATL data was substituted for missing values in the JST data (anemometer heights of 9.9 m). This substitution was done so that the ATL hours that were substituted into the JST data would have data based on the ATL surface characteristics. The entire record, including anemometer heights, was substituted. The resulting files were a hybrid of JST data and ATL hybrid data. The number of hours substituted with ATL data were 165, 497, and 792 for 2001, 2002, and 2003 respectively.

7. Adjustment of mechanical mixing heights

Preliminary model-to-monitor comparisons using the processed meteorological data for JST should generally good agreement between modeled and observed concentrations. However, several spuriously high 1-hour modeled concentrations were also noted. Examination of the meteorological conditions associated with these high modeled concentrations indicated a consistent pattern of occurring on the first convective hour of the day. This was indicative of an issue with the AERMOD model formulation for the urban option that has been identified, but has not been addressed yet. The urban option in AERMOD currently applies only to nighttime stable hours when the urban heat island effect is expected to increase turbulence relative to the surrounding rural areas. The issue that contributes to these high modeled concentrations for Atlanta is that the urban-enhanced turbulence disappears once the atmosphere becomes convective, with no transitional period to account for residual enhanced turbulence that is likely to occur during the transition from night to day. As a result, low-level releases may be subjected to very limited mixing conditions for the first convective hour of the day, which may lead to unrealistically high concentrations. Every outlier examined was consistent with this pattern, and no such anomalies occurred at other hours of the day. In one case, the 1-hour concentration for the last stable hour was about an order of magnitude lower then the concentration for the first convective hour, with very similar wind speeds and directions.

In order to minimize the impact that these anomalously high 1-hour concentrations may have on the exposure assessment for Atlanta, an adjustment was made to the mechanical mixing heights in the processed meteorological data files for the first convective hour of each day. Morning mechanical mixing heights for both JST and ATL were adjusted for the first convective hour of each day to apply a minimum value of 240 meters. If the mechanical mixing height calculated by AERMET was less than 240 meters, it was reset to 240 meters, and if it was larger than 240 meters then no change was made. This adjustment was intended to account for some limited residual mixing from the urban nighttime boundary layer for the first convective hour. The value of 240 meters is about one half of the urban nighttime boundary layer for a city with the population of Atlanta. Modifying only the mechanical mixing height is considered a reasonable approach to account for residual turbulence since the convective mixing height is driven directly by the daytime solar heating. This adjustment may underestimate the amount of residual mixing that could occur, but is considered to be a reasonable compromise for this application, and subsequent modeling comparisons indicated much better agreement between modeled and monitored concentrations.

8. Analysis of processed meteorology

Table 4 lists the number of hours that were based on one-minute hourly averaged winds for ATL. Table 4 also lists the number of calms and missing winds for the hybrid ATL data and ISH data for ATL. For each year, over 90% of the winds were hourly averaged winds from the one-minute data and the number of calms and missing winds were dramatically reduced.

Table 4. Number of hours using hourly averaged one minute winds and number of calms and missing winds for ATL hybrid data and ATL ISH data.

		One minute		ISH	
Year	**One minute hours**	**calms**	**Missing**	**calms**	**missing**
2001	8028 (92%)	118	48	917	645
2002	7959 (91%)	85	43	856	492
2003	8171 (93%)	123	19	765	277

Wind roses and histograms of wind speed for JST and ATL inputs into AERMOD are shown in Figures 7 through 9 for 2001, 2002, and 2003. Both sites exhibit similar wind roses, with predominant wind directions from the northwest and secondary peaks generally from the east or southwest.

Both the wind roses and histograms show a larger number of lower wind speeds for the JST site than for the ATL site, even with the one minute hourly averaged winds included in the ATL data. This is consistent with expected influence on wind speeds of the higher surface roughness surrounding the JST site as compared to the ATL site.

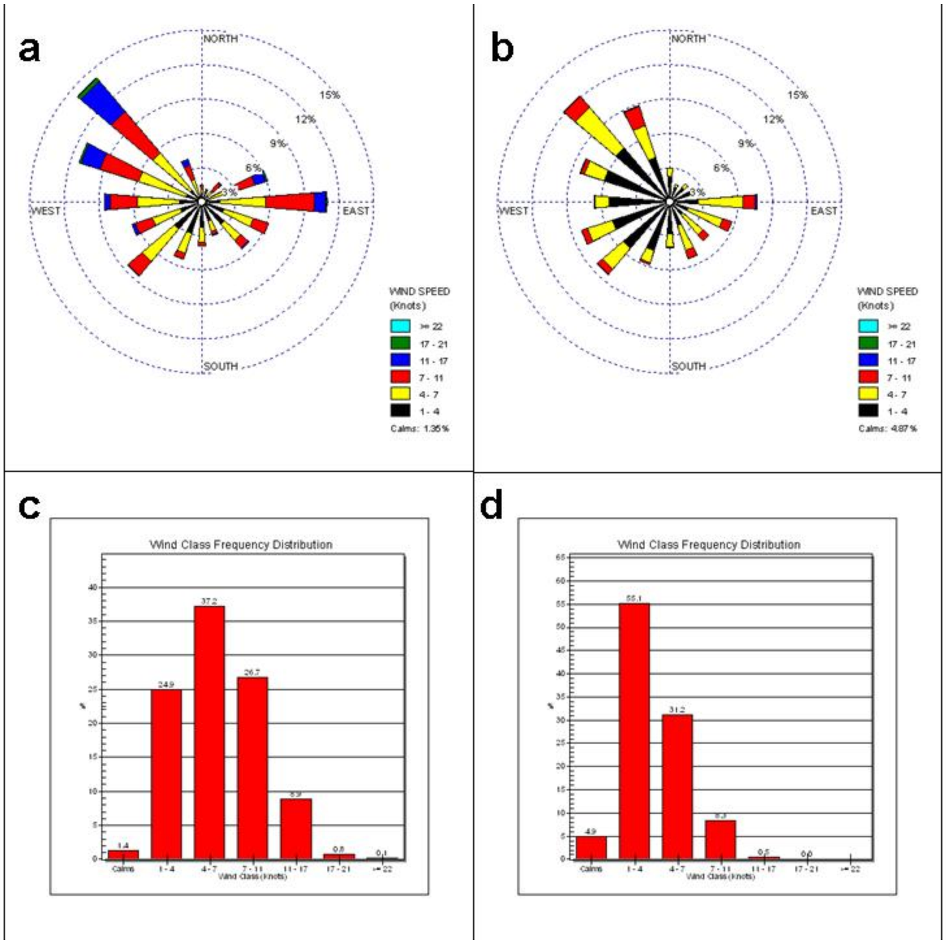

Figure 7. 2001 wind roses and wind speed histograms for a) ATL hybrid, b) JST hybrid, c) ATL hybrid and d) JST hybrid.

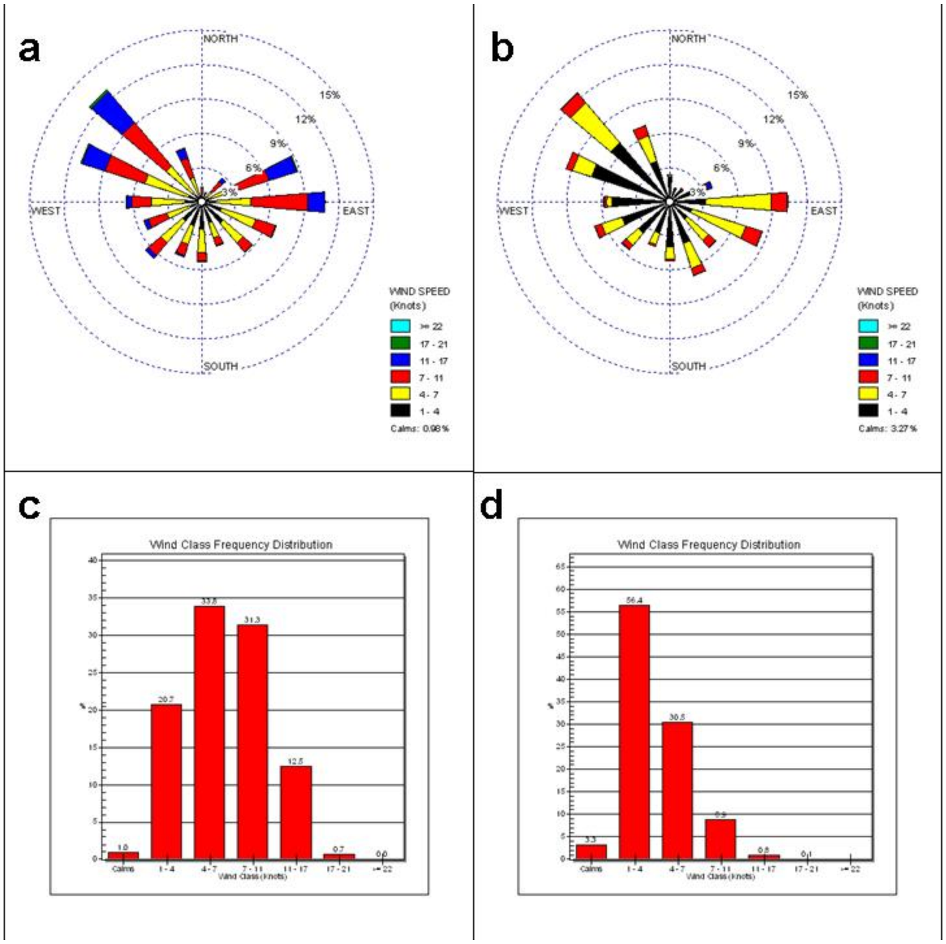

Figure 8. 2002 wind roses and wind speed histograms for a) ATL hybrid, b) JST hybrid, c) ATL hybrid and d) JST hybrid.

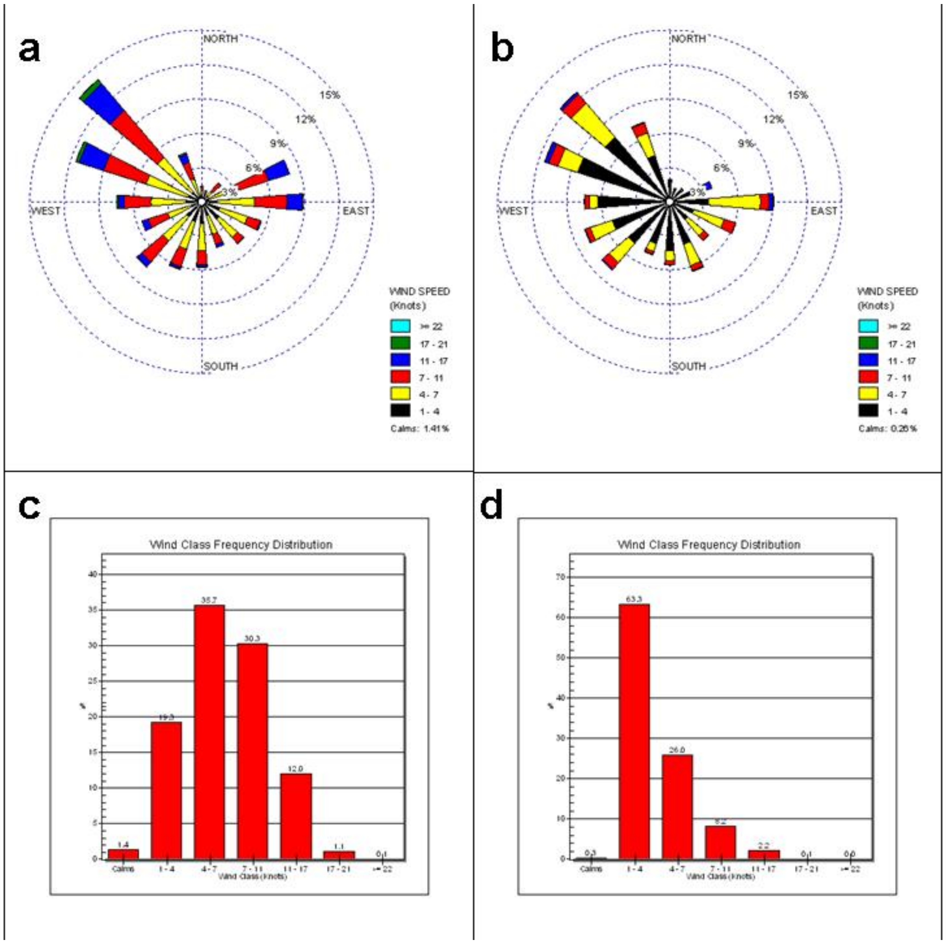

Figure 9. 2002 wind roses and wind speed histograms for a) ATL hybrid, b) JST hybrid, c) ATL hybrid and d) JST hybrid.

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Attachment 2: Technical Memorandum on Longitudinal Diary Construction Approach

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.

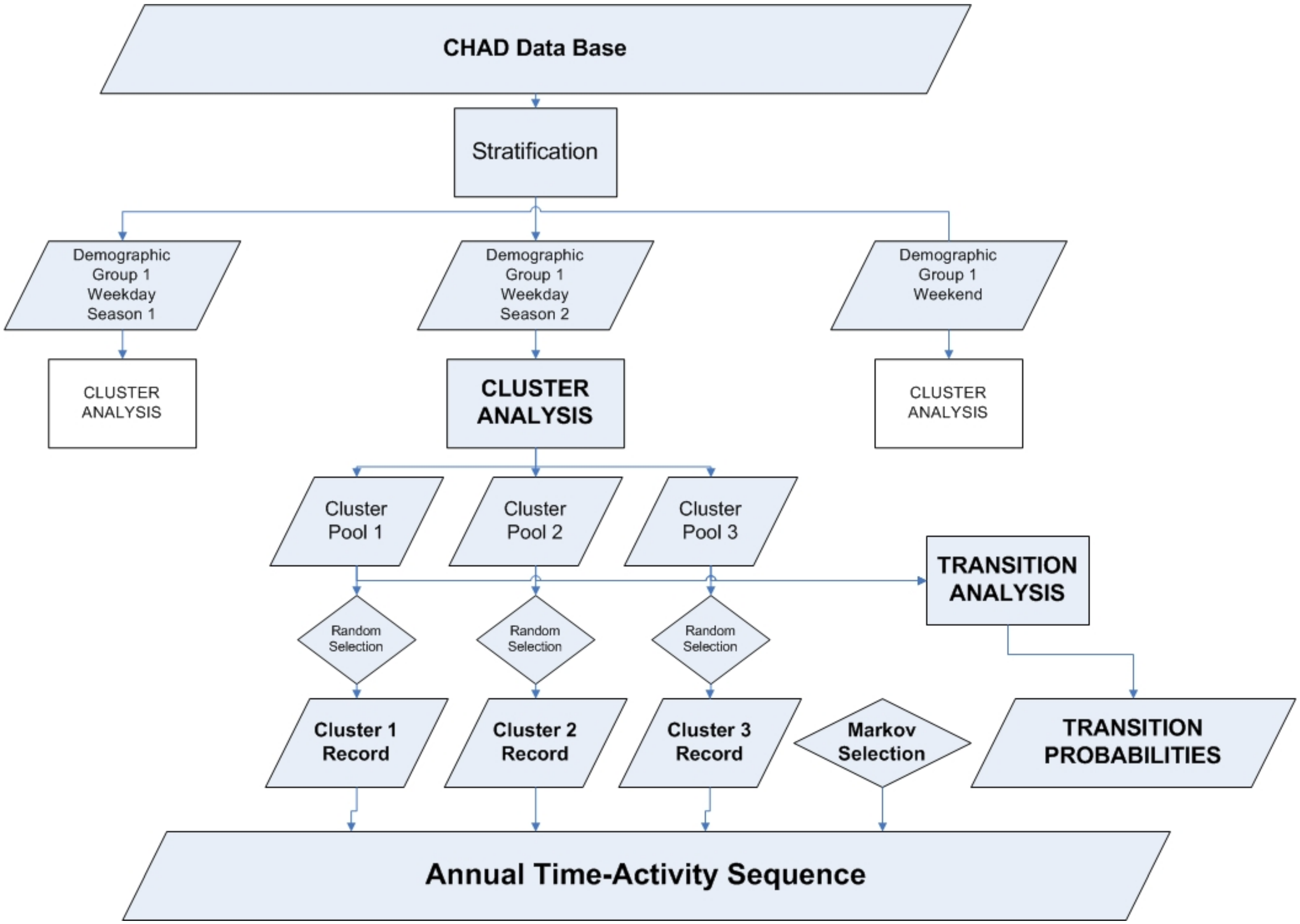

Figure 1. Flow chart of Cluster-Markov algorithm used for constructing longitudinal time-activity diaries.

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 1.

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%)

References

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Xue J, Liu SV, Ozkaynak H, Spengler J. (2005). Parameter evaluation and model validation of ozone exposure assessment using Harvard Southern California Chronic Ozone Exposure Study Data. *J. Air & Waste Manage Assoc.* 55:1508–1515.

Attachment 3: Detailed 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 2)

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.[26]

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.

$$NBIAS = \frac{100}{N}\sum_{1}^{N}\frac{(predicted - observed)}{observed} \ \%$$

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 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

[26] 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.

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, 11-12	Summer	2.2	1.6	-25%
		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, 11-12	Summer	21	18	-15%
		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, 11-12	Summer	10	10	1%
		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%

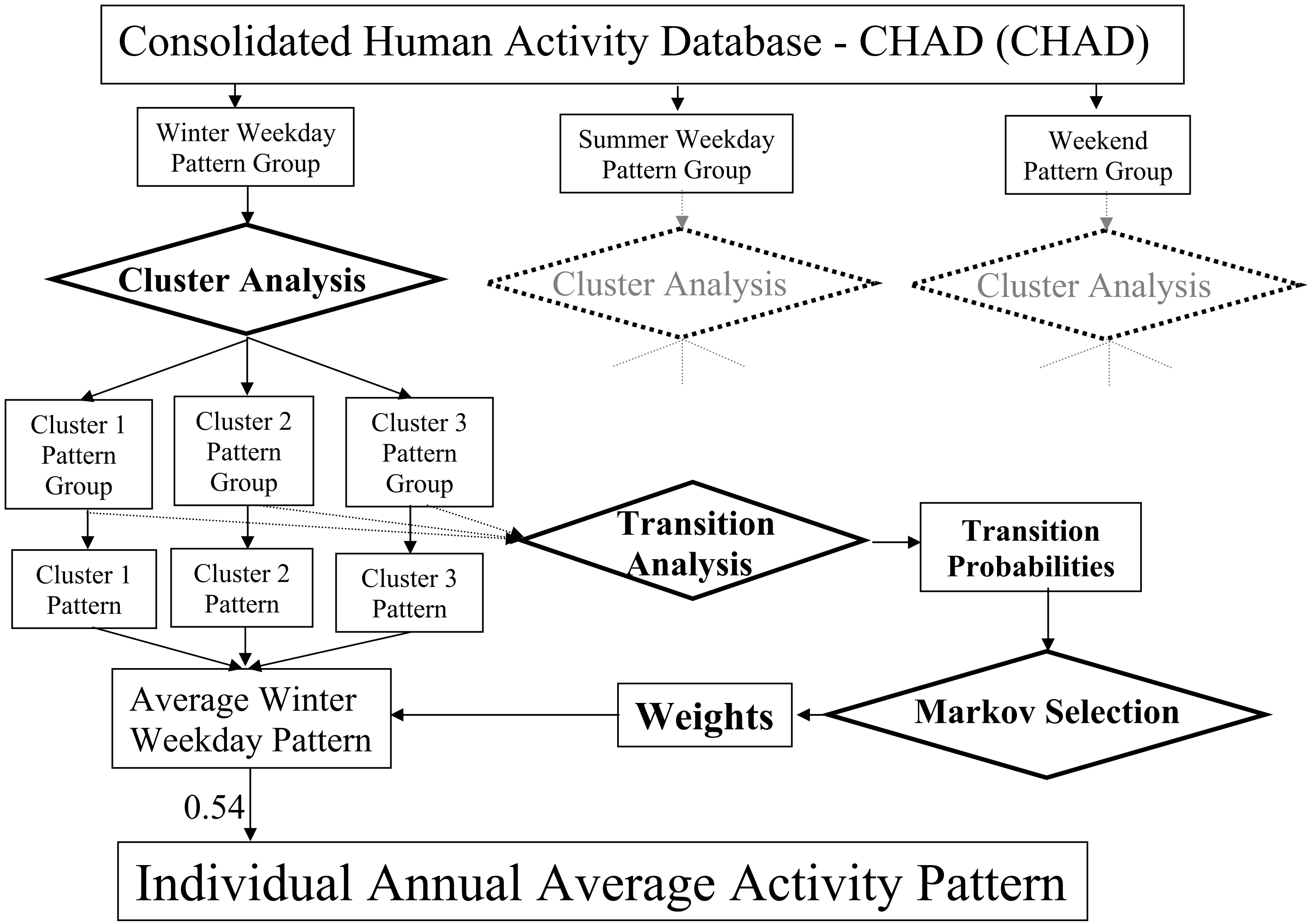

Figure 1. Flow diagram of proposed algorithm for creating annual average activity patterns for HAPEM5.

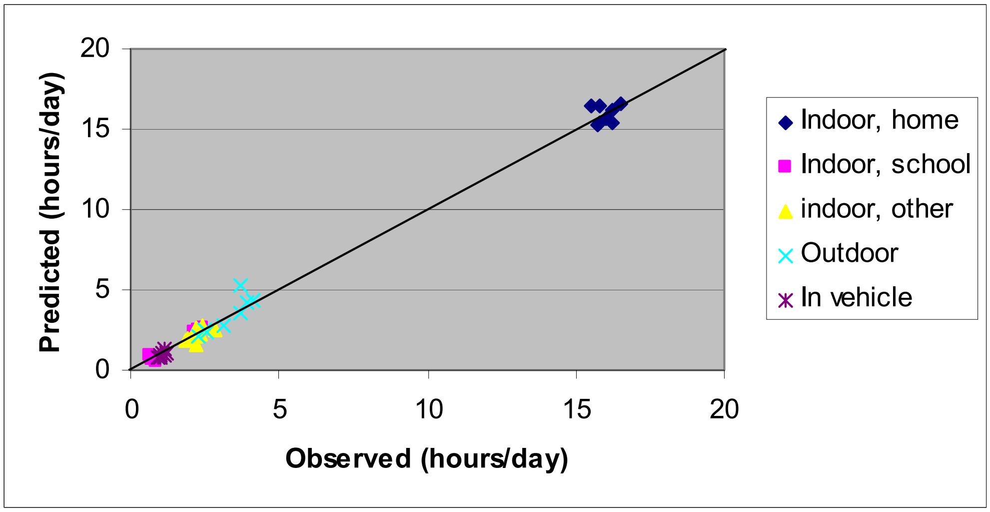

Figure 2. Comparison of predicted and observed average time in each of 5 microenvironments for age/gender groups and seasons.

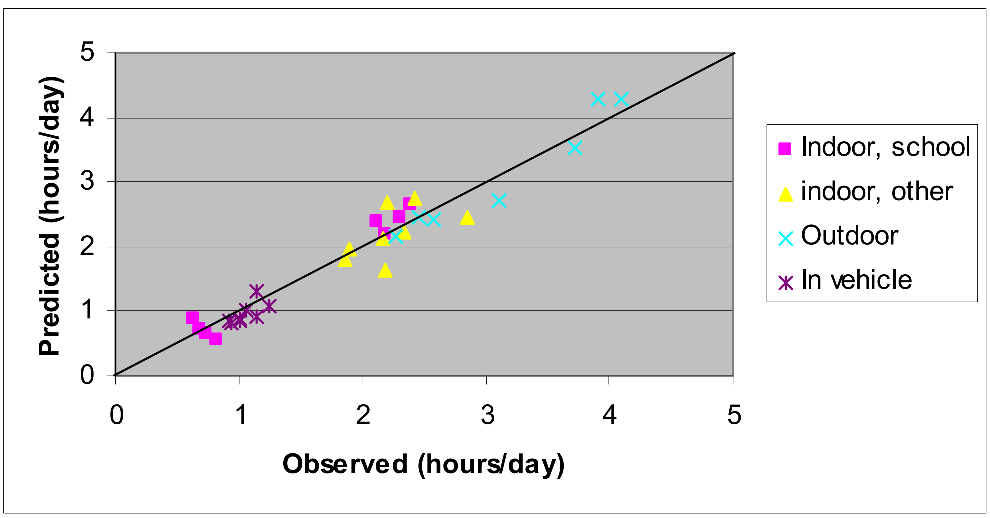

Figure 3. Comparison of predicted and observed average time in each of 4 microenvironments for age/gender groups and seasons.

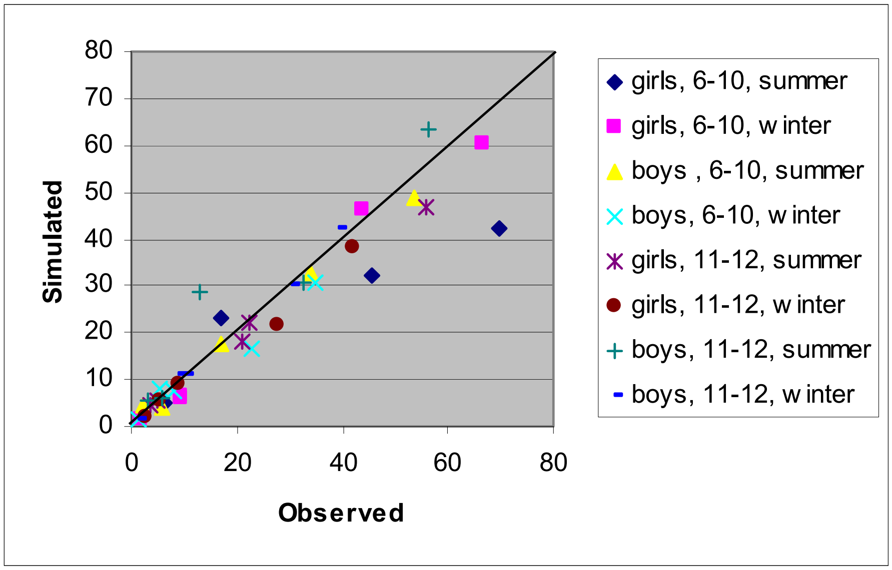

Figure 4. Comparison of predicted and observed variance across persons for time spent in each of 5 microenvironments for age/gender groups and seasons.

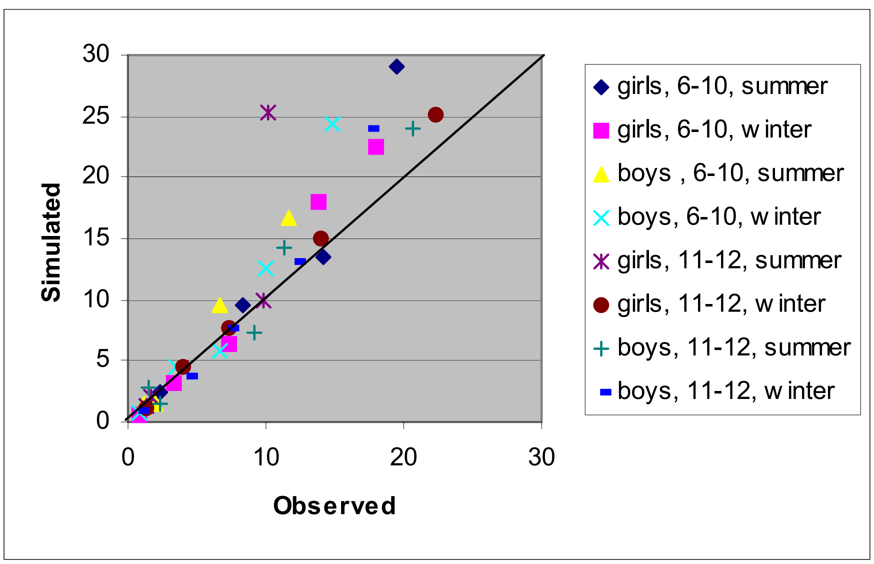

Figure 5. Comparison of predicted and observed the average within-person variance for time spent in each of 5 microenvironments by age/gender groups and seasons.