ESTIMATION OF OZONE EXPOSURES EXPERIENCED BY URBAN RESIDENTS USING A PROBABILISTIC VERSION OF NEM AND 1990 POPULATION DATA

by

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ACKNOWLEDGMENT

This report describes a probabilistic version of NEM applicable to ozone (pNEM/03). The model consists of two principal parts: 1) the "cohort exposure program" which estimates the sequence of ozone exposures experienced by defined population groups and 2) the "exposure extrapolation program" which estimates the number of persons within a particular study that are represented by each cohort and then combines this information with the cohort exposure sequences to determine the distribution of exposures over a defined population-of-interest. Supplementary programs are used to process air quality, population, and meteorological data for input into each program.

All programs used in pNEM/O3 were developed by IT Air Quality Services (ITAQS) under the direction of the Ambient Standards Branch of the U.S. Environmental Protection Agency (EPA). Mr. Ted Johnson of ITAQS developed the general methodology for the model as described in Section 2 of this report. He also developed the algorithms used to estimate outdoor ozone concentration, equivalent ventilation rate, window status, and air exchange rate. In addition, Mr. Johnson developed the algorithm used to sequence activity diary data and the algorithm used to adjust air quality data to simulate attainment of specified ozone standards. Mr. Johnson was the principal author of Sections 1 through 5 and Section 8 of this report.

Mr. Roy Paul served as project manager for the ITAQS effort. Mr. Paul and Ms. Jill Warnasch were the principal authors of Section 6.

Dr. Louis Wijnberg of ITAQS developed the hourly-average mass balance model used in the cohort exposure program. He also assisted in developing the window status algorithm. Mr. Jim Capel wrote the cohort exposure program and a majority of the supplementary programs. He also developed the algorithm used to estimate cohort populations. Mr. Capel conducted the validation study described in Section 7 and was the principal author of that section. Mr. John Carroll conducted a review of the scientific literature concerning air exchange rates. Mr. Michael McCoy implemented the air quality adjustment algorithm and was responsible for assembling the population data required by the exposure extrapolation program. He also developed the meteorological data files required by the cohort exposure program.

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SECTION 1

INTRODUCTION

Within the U.S. Environmental Protection Agency (EPA), the Office of Air Quality Planning and Standards (OAQPS) has responsibility for establishing and revising National Ambient Air Quality Standards (NAAQS). In evaluating alternative NAAQS proposed for a particular pollutant, OAQPS assesses the risks to human health of air quality meeting each of the standards under consideration.[1] This assessment of risk requires estimates of the number of persons exposed at various pollutant concentrations for specified periods of time. The estimates may be specific to an urbanized area such as Los Angeles or apply to the entire nation.

Several researchers[2,3] have recommended that such estimates be obtained by simulating the movements of people through zones of varying air quality so as to approximate the actual exposure patterns of people living within a defined area. OAQPS has implemented this approach through an evolving methodology referred to as the NAAQS Exposure Model (NEM). An early overview of the NEM methodology is provided in a paper by Biller et al.[4] From 1979 to 1988, IT Air Quality Services (formerly PEI Associates, Inc.) assisted OAQPS in developing and applying pollutant-specific versions of NEM to ozone,[5] particulate matter,[6] and CO.[7] These versions of NEM are referred to as "deterministic" versions in that no attempt was made to model random processes within the exposure simulation.

The deterministic versions of NEM were similar in that each was capable of simulating the movements of selected segments of an urban population through a set of environmental settings. Each environmental setting was defined by a geographic area and a microenvironment. The size and distribution of the geographic areas were determined according to the ambient characteristics of the pollutant. Ambient (outdoor) pollutant levels in each geographic area were estimated from either fixed-site monitoring data or dispersion model estimates. To better utilize fixed-site monitoring data, researchers developed special time series techniques to fill in missing values and special roll-back techniques to adjust the monitoring data to simulate conditions under attainment of a particular NAAQS.

The population of interest in each study area was divided into an exhaustive set of cohorts, and an activity pattern was developed for each cohort. The activity pattern assigned the cohort to a geographic location and a microenvironment for each time interval of a defined exposure period. In early NEM analyses, the time interval was 1 hour; in later NEM analyses, the time interval was reduced to 10 minutes. Exposure periods varied from three months to one year. The activity patterns were based on reviews of time use surveys. Researchers estimated the number of persons represented by each cohort by accessing census and commuting data at the census-tract level.

The pollutant concentration in a particular microenvironment was estimated by a linear model which included terms relating to the ambient pollutant level and to emission sources within the microenvironment. Researchers developed both point estimates and distributions for the parameter values of these linear models by conducting comprehensive reviews of the scientific literature associated with each pollutant.

Additional details concerning the evolution of the deterministic version of NEM are provided by Paul et al.[8] Critiques of deterministic NEM are included in surveys of exposure models by Pandian[9] and Ryan.[10] Two staff papers[11,12] prepared by EPA discuss the use of NEM in evaluating proposed NAAQS for CO and ozone.

In 1988, OAQPS began to incorporate probabilistic elements into the NEM methodology and to apply the resulting model (pNEM) to the criteria pollutants. The initial result of this work was an early version of pNEM applicable to ozone (pNEM/O3). This model used a regression-based relationship to estimate indoor ozone concentrations from outdoor concentrations. A report by Johnson et al. describes this model and its application to Houston, Texas[13].

An advanced version of pNEM applicable to carbon monoxide (pNEM/CO) was developed in 1991. This model marked the first time in the evolution of NEM that a mass balance model was used to estimate indoor pollutant concentrations. The application of pNEM/CO to Denver, Colorado, has been described by Johnson et al[14].

A new version of pNEM/O3 was developed in early 1992. Unlike the earlier version of pNEM/O3, the new model uses a mass balance model to estimate indoor ozone concentrations. A report by Johnson et al. (February 1993)[15] describes the new version of pNEM/O3 and summarizes the results of an initial application of the model to 10 cities.

Subsequent to the February 1993 report, ITAQS made the following enhancements to pNEM/O3 and its input data bases.

- Use of more recent (1990-91) fixed-site monitoring data for estimating ambient ozone concentrations. The earlier analysis was based on 1981-84 monitoring data.
- An increase in the number of fixed-site monitors used to represent each urban area.
- Use of more recent (1990) census data for estimating cohort populations. The earlier analysis used 1980 census data.
- A new methodology for adjusting ambient ozone data to simulate attainment of one-hour and eight-hour NAAQS.
- Revision of the algorithm used to determine limiting values for equivalent ventilation rate.
- Development of origin/destination tables through the use of a new commuting algorithm.

This report describes these enhancements and summarizes the results of applying the enhanced model to nine of the ten cities included in the previous exposure assessment. Tacoma, Washington, was excluded from the analysis because of insufficient monitoring data.

The report is divided into seven sections. Section 2 provides an overview of the pNEM/O3 methodology and describes in detail how the model was applied to a specific city (Houston). Section 3 describes the mass balance model incorporated into pNEM/O3. Section 4 describes the process by which ambient ozone data sets were selected for use in pNEM/O3. It also describes the methods used to fill in missing values in these data sets. Section 5 presents the method used to adjust ambient ozone data to simulate the attainment of proposed air quality standards. Section 6 provides ozone exposure estimates for each of the nine cities. Section 7 presents the results of initial efforts to validate the new version of pNEM/O3. The principal limitations of the model are discussed in Section 8.

SECTION 2

OVERVIEW OF THE METHODOLOGY

The general NEM methodology consists of five steps.

1. Define a study area, a population-of-interest, appropriate subdivisions of the study area, and an exposure period.
2. Divide the population-of-interest into an exhaustive set of cohorts.
3. Develop an exposure event sequence for each cohort for the exposure period.
4. Estimate the pollutant concentration, ventilation rate, and physiological indicator (if applicable) associated with each exposure event.
5. Extrapolate the cohort exposures to the population-of-interest and to individual sensitive groups.

This approach has been followed in developing a probabilistic version of NEM applicable to ozone (pNEM/03). The remainder of this section provides an overview of the pNEM/O3 methodology. The application of pNEM/O3 to Houston is used as a means of demonstrating various features of the methodology.

2.1 Define Study Area, Population-of-Interest, Subdivisions of Study Area, and Exposure Period

The pNEM/O3 methodology provides estimates of the distribution of ozone exposures within a defined population (the population-of-interest) for a specified exposure period. The population-of-interest is typically defined as 1) all residents of a defined study area or 2) the residents of the study area which belong to a specific sensitive population. The study area is defined as an aggregation of exposure districts. Each exposure district is defined as a contiguous set of census tracts or block numbering areas (jointly referred to as "census units") as defined by the Bureau of Census for the 1990 U.S. census.

All census units assigned to a particular exposure district were located within a specified radius of a fixed-site ozone monitor. The pNEM/O3 methodology is based on the assumption that the ambient ozone concentration throughout each exposure district can be estimated by ozone data provided by the associated fixed-site monitor.

Table 1 lists the nine study areas defined for the exposure analyses. Each study area is associated with a major urban area. The table lists the number of exposure districts and the exposure period for each study area. In each case, the exposure period is defined as a series of months within a particular calendar year. The specified months conform to the "ozone season" specified for the urban area by EPA. The ozone season is the annual period when high ambient ozone levels are likely to occur. Three ozone seasons appear in Table 1: January through December, March through September, and April through October. The specified calendar year is either 1990 or 1991, the selected year being the higher year with respect to reported ambient ozone concentrations.

In the application of pNEM/O3 to Houston, eleven fixed-site monitors were selected to represent ambient ozone concentrations (see Section 4). An exposure district was constructed around each monitor through the use of a special computer program ("DIST90"). This program identified all census units having population centroids located within 15 km of the monitor. When a census unit was paired with more than one monitor, the program assigned it to the nearest monitor.

The sum of all census units assigned to the eleven exposure districts defined the Houston study area. The residents of this area were designated as the principal population-of-interest. In 1990, the study area consisted of 532 census units and contained 2,370,512 residents[16].

The Houston ozone season spans the entire calendar year. Consequently, the Houston exposure period was defined as calendar year 1990.

TABLE 1. CHARACTERISTICS OF STUDY AREAS

Study area	Number of exposure districts	1990 population[a]	Exposure period	
			Year	Months
Chicago	12	6,175,121	1991	Apr-Oct
Denver	7	1,484,798	1990	Mar-Sep
Houston	11	2,370,512	1990	Jan-Dec
Los Angeles	16	10,371,115	1991	Jan-Dec
Miami	6	1,941,994	1991	Jan-Dec
New York	12	10,657,873	1991	Apr-Oct
Philadelphia	10	3,785,810	1991	Apr-Oct
St. Louis	11	1,706,778	1990	Apr-Oct
Washington	11	3,085,419	1991	Apr-Oct

[a]Specific to exposure districts which comprise the study area.

2.2 Divide the Population-of-Interest Into an Exhaustive Set of Cohorts

In a pNEM analysis, the population-of-interest is divided into a set of cohorts such that each person is assigned to one and only one cohort. Each cohort is assumed to contain persons with identical exposures during the specified exposure period. Cohort exposure is typically assumed to be a function of demographic group, location of residence, and location of work place. Specifying the home and work district of each cohort provides a means of linking cohort exposure to ambient pollutant concentrations. Specifying the demographic group provides a means of linking cohort exposure to activity patterns that vary with age, work status, and other demographic variables. In some analyses, cohorts are further distinguished according to factors relating to characteristics of the residence, proximity to emission sources, or to time spent in particular microenvironments.

In the pNEM/03 analyses, each cohort was identified as a distinct combination of 1) home district, 2) demographic group, 3) work district (if applicable), and 4) residential air conditioning system. The home district and work district of each cohort were identified according to the exposure districts defined for the study area. Table 2 lists nine demographic groups defined for the pNEM/03 analyses. Three of the demographic groups are identified as workers. Each cohort associated with one of these groups was identified by both home and work district. The remaining cohorts were identified only by home district.

The decision to identify cohorts with respect to the residential air conditioning system was based on the results of two supplemental analyses by ITAQS. An analysis[17] of data on window openings provided by the Cincinnati Activity Diary Study[18] suggested that the time per day that windows are open in a residence is a function of outdoor temperature and air conditioning system, when the later is characterized as 1) no air conditioning, 2) room units, or 3) central air. An analysis[19] of data collected by Stock[20] during a study of asthmatics in Houston suggested that indoor ozone levels are significantly higher when windows are open than when windows are closed. For example, the median ratio of indoor ozone to outdoor ozone for residences in the Sunnyside section of Houston was 0.886 when windows were open and 0.088 when windows were closed. The importance of outdoor ozone concentrations in determining indoor ozone concentrations has also been reported by Weschler et al.[21]

Table 2 lists the number of cohorts in the Houston analyses that were associated with each demographic group. Each of the six nonworking demographic groups is associated with 33 cohorts, one for each combination of home district and residential air conditioning system. Each of the three working demographic groups is associated with 363 cohorts, one for each combination of home district, work district, and residential air conditioning system. The total number of cohorts is thus (6 x 33) + (3 x 363) or 1287.

TABLE 2. DEMOGRAPHIC GROUPS DEFINED FOR PNEM/03 ANALYSIS

Demographic group	Number of Houston cohorts associated with demographic group
1. Children 0 to 5 years	33
2. Children 6 to 13 years	33
3. Children 14 to 18 years	33
4. Workers with low probability of outdoor work	363
5. Workers with moderate probability of outdoor work	363
6. Workers with high probability of outdoor work	363
7. Nonworking adults under 35 years	33
8. Nonworking adults 35 to 54 years	33
9. Nonworking adults 55+ years	33
Total	1287

2.3 Develop an Exposure Event Sequence for Each Cohort for the Exposure Period

In the pNEM/03 methodology, the exposure of each cohort is determined by an exposure event sequence (EES) specific to the cohort. Each EES consists of a series of events with durations from 1 to 60 minutes. To permit the analyst to determine average exposures for specific clock hours, the exposure events are defined such that no event falls within more than one clock hour. Each exposure event assigns the cohort to a particular combination of geographic area and microenvironment. Each event also provides an indication of respiration rate. In typical applications, this indicator is a classification of slow - sleeping, slow - awake, medium, or fast.

The EESs are determined by assembling activity diary records relating to individual 24-hour periods into a series of records spanning the ozone season of the associated study area. Because each subject of a typical activity diary study provides data for only a few days, the construction of a multi-month EES requires either the repetition of data from one subject or the use of data from multiple subjects. The latter approach is used in pNEM analyses to better represent the variability of exposure that is expected to occur among the persons included in each cohort.

The activity diary data used in the pNEM/O3 analysis were obtained from the Cincinnati Activity Diary Study (CADS)[18]. During this study over 900 subjects completed three-day activity diaries and detailed background questionnaires. Figure 1 presents a page from the Cincinnati diary. Each subject was instructed to complete a new diary page whenever he or she changed location or began a new activity.

The CADS data were assembled into a special data base organized by study subject and 24-hour (midnight-to-midnight) time period. The diary records for one subject for one 24-hour period were designated a "person-day." The CADS data base contained 2649 person-days, each of which was indexed by the following factors:

1. Demographic group
2. Season: summer or winter
3. Temperature classification: cool or warm
4. Day type: weekday or weekend.

The demographic group index was determined by the demographic group to which the subject filling out the diary belonged. The season and day type indices were based on the calendar date of the person-day. The temperature classification was based on the daily maximum temperature in Cincinnati on that date. The cool range was defined as daily maximum temperatures below 55°F in winter and temperatures below 84°F in summer.

A distinct EES was developed for each cohort in each of the nine study areas by applying a computerized sampling algorithm to the CADS data base. The algorithm was provided with the sequence of daily maximum temperatures reported for the associated study area and exposure period (Table 1) and with the list of cohorts

TIME [| | |] * AM [ ] PM [ ]

A. ACTIVITY (please specify)

____

____

____

B. LOCATION

In transit, car 01

In transit, other vehicle . . 02

Specify ____________________

Indoors, your residence . . . 03

Indoors, other residence. . . 04

Indoors, office 05

Indoors, manufacturing facility. 06

Indoors, school 07

Indoors, store. 08

Indoors, other. 09

Specify ____________________

Outdoors, within 10 yards of road or street. 10

Outdoors, other 11

Specify ____________________

Uncertain 12

C. BREATHING RATE

Slow (e.g., sitting) 13

Medium (e.g., brisk walk). . . 14

Fast (e.g., running) 15

Breathing problem. 16

Specify ____________________

D. SMOKING

I am smoking 17

Others are smoking 18

No one is smoking. 19

E. ONLY IF INDOORS

(1) Fireplace in use?

Yes. 20

No 21

(2) Woodstove in use?

Yes. 22

No 23

(3) Windows open?

Yes. 24

No 25

Uncertain. 26

*Enter MIDN for midnight and NOON for noon. Otherwise enter four-digit time (e.g., 0930 for 9:30 and 1217 for 12:17) and check a.m. or p.m.

Figure 1. Page from the activity diary used in the Cincinnati study.

defined for the study area. The temperature data were used to assign each calendar day in the exposure period to one of the temperature ranges used in classifying the CADS data. To construct the EES for a particular cohort, the algorithm selected a person-day from the CADS data base for each calendar day in the specified exposure period according to the demographic group of the cohort and the season, day type, and temperature classification associated with the calendar day.

Each exposure event within an EES was defined by 1) district, 2) microenvironment, and 3) breathing rate category. The district was either the home or the work district associated with the cohort. The home/work determination was based on a decision rule which was applied to the activity diary data associated with the exposure event.

Seven microenvironments were defined:

1. Indoors - residence - central air conditioning system
2. Indoors - residence - window air conditioning units
3. Indoors - residence - no air conditioning system
4. Indoors - nonresidential locations
5. Outdoors - near road
6. Outdoors - other
7. In vehicle.

As indicated in Table 3, location codes appearing in the Cincinnati activity diary data base were used to determine the primary microenvironment location of each exposure event (indoors - residence, indoors - nonresidential locations, outdoors- near road, outdoors - other, or in vehicle). The indoors - residence location was subdivided into three microenvironments according to air conditioning (AC) system: central system, window unit(s), or none. This classification was based on the AC system specified for the cohort's residence. For example, a cohort designated as residing in a home with central AC would always be assigned to the microenvironment defined as "indoors - residence - central AC" when activity diary data indicated the cohort was inside a residence.

TABLE 3. MICROENVIRONMENTS DEFINED FOR PNEM/03 ANALYSIS

Microenvironment	Activity diary locations assigned to microenvironment
Indoors - residence a) Central air conditioning system b) Window air conditioning units c) No air conditioning	Subject's residence Other residence
Indoors - other	Office Manufacturing facility School Store Service station/repair facility Other repair shop Physical exercise facility Auditorium Sports arena Museum or exhibition hall Movie theater Restaurant or cafeteria Church Shopping mall Health care facility Bowling alley Bar Other public building Other indoor location Indoors - not specified Uncertain
Outdoor - near road	Within 10 yards of road Motorcycle Other vehicle

(continued)

Table 3 (continued)

Microenvironment	Activity diary locations assigned to microenvironment
Outdoors - other	Residential garage Public garage Parking lot Outdoors - service station Construction site Residential grounds School grounds Playground Sports arena or amphitheater Park or golf course Motorized boat Nonmotorized boat Other outdoor location Outdoors - not specified
In vehicle	Car Truck Bus Van Train Airplane In transit - not specified

Four breathing rate categories were defined according to codes appearing in the CADS data base: slow - sleeping, slow - awake, medium, and fast. Each exposure event was assigned to one of these categories.

2.4 Estimate the Pollutant Concentration and Ventilation Rate Associated With Each Exposure Event

In the general pNEM methodology, the EES defined for each cohort is used to determine a corresponding sequence of exposures, event by event. Each exposure is defined by a pollutant concentration and a ventilation rate indicator.

2.4.1 *Estimation of Pollutant Concentration*

In the pNEM/03 analysis, the pollutant concentration during each exposure event was assumed to be a function of the microenvironment and district associated with the event. Consequently a continuous year-long sequence of hourly average ozone concentrations was developed for each combination of microenvironment and district. When an exposure event assigned a cohort to a particular combination of microenvironment and district, the cohort was assigned the ozone concentration specified for the corresponding clock hour in the appropriate microenvironment/district sequence.

Each year-long sequence of hourly average ozone values for the indoor and in-vehicle microenvironments was generated by the mass-balance algorithm described in Section 3. Briefly, this algorithm estimated the hourly average indoor ozone concentrations during hour h as a function of the indoor ozone concentration at the end of the preceding hour (i.e., hour h - 1), the ozone concentration outdoors during hour h, the air exchange rate during hour h (v), and an ozone decay factor (F_d). Values for the air exchange rate and the ozone decay factor were sampled from appropriate distributions on a daily basis (Subsections 3.1 and 3.3). Air exchange rate was permitted to change hourly in the three residential microenvironments depending on whether windows were assigned a status of "open" or "closed". This assignment was determined through the use of a probabilistic model (Subsection 3.4) in which the status during each clock hour was assumed to be a function of AC system, temperature range, and window status during the previous clock hour.

The outdoor ozone concentration associated with microenvironment m in district d during hour h was determined by an expression having the general form

$$C_{out}(m,d,t,s) = b(m) \times C_{mon}(d,t,s) + e(t), \qquad (1)$$

where $C_{out}(m,d,t,s)$ is the outdoor (or ambient) ozone concentration in microenvironment m in district d at time t under regulatory scenario s, $C_{mon}(d,t,s)$ is the ozone concentration estimated to occur at the monitor representing district d at time t under regulatory scenario s, b(m) is a constant specific to microenvironment m, and

$e(t)$ is a random normal variable with mean = 0 and standard deviation = $\sigma(m)$. A value for $e(t)$ was selected from a normal distribution with mean = 0 and standard deviation = $\sigma(m)$ every hour. The value of $C_{mon}(d,t,s)$ was constant over each clock hour.

In the application of pNEM/O3 described in this report, $b(m)$ was set equal to 1.056 for all microenvironments. A value of 5.3 ppb (0.0053 ppm) was used as the value of $\sigma(m)$ for all microenvironments (Table 4). Consequently, each sequence of hourly ozone values was generated by the expression

$$C_{out}(m,d,t,s) = 1.056 \times C_{mon}(d,t,s) + e(t), \qquad (2)$$

where $e(t)$ is a random normal variate with mean = 0 and standard deviation = 5.3 ppb.

The expression is based on the results of regression analyses performed by ITAQS researchers on personal exposure data collected by T. Stock during the Houston Asthmatic Study[20]. In these analyses, the dependent variable was five-minute ozone concentration measured outdoors by a personal exposure monitor (PEM). The independent variable was the simultaneous ozone concentration (hourly average value) reported by the nearest fixed-site monitor.

An initial regression analysis of 327 paired values yielded an intercept of 0.81 ppb, a slope of 1.042, and set of regression residuals with a standard deviation of 18.5 ppb. The R-squared value was 0.544. Because the regression intercept value was found to be non-significant ($p = 0.76$), a second regression analysis was performed in which the regression line was forced through the origin (i.e., intercept = 0). This analysis yielded a slope of 1.056 and a set of regression residuals with a standard deviation of 18.5 ppb. The residuals were found to be approximately normal (skewness = -0.32, kurtosis = 0.87).

Attempts were made to fit more complex regression models to the Stock data. These models included regression equations using logarithmic transformations of the variables and regression equations which included the previous PEM value as an

TABLE 4. PARAMETERS ASSOCIATED WITH ALGORITHMS USED TO ESTIMATE OZONE CONCENTRATIONS IN MICROENVIRONMENTS

Parameter	Equation(s) containing parameter	Microenvironment[a]	Parameter value
b(m)	1	All	1.056
σ(m)	1	All	5.3 ppb
Air exchange rate	38	1 - 4, 7	See Table 10
Ozone decay factor	38	1 - 4	Normal distribution · Arith. mean = 4.04 h^{-1} · Std. dev. = 1.35 h^{-1} · Minimum = 1.44 h^{-1} · Maximum = 8.09 h^{-1}
		7	72.0 h^{-1} ??

[a]Microenvironments:

1 = Indoors - residence - central air conditioning
2 = Indoors - residence - window units
3 = Indoors - residence - none
4 = Indoors - nonresidential locations
5 = Outdoors - near road
6 = Outdoors - other
7 = In vehicle

independent variable. These alternative models were found to offer no significant improvement in performance over the model specified above. Some of the alternative models were found to be unstable.

The results of this analysis suggested that Equation 2 could be used as a means of generating five-minute values of $C_{out}(d,t,s)$, given that e(t) values were selected every five minutes from a normal distribution with mean equal to 0 and standard deviation equal to 18.5 ppb. A procedure based on this expression was used in a previous version of pNEM/O3 to generate five-minute ozone concentrations for the outdoor microenvironment[13].

As the new version of pNEM/O3 required hourly-average outdoor ozone concentrations rather than five-minute values, the procedure used in the earlier model was modified so that an hourly-average value of e(t) was selected for each hour from a normal distribution with mean equal to 0 and standard deviation equal to 5.3 ppb. The use of a smaller standard deviation (5.3 ppb versus 18.5 ppb) for the hourly-average e(t) terms was based on the statistical principle that the standard deviation of the average of n values drawn from a distribution with standard deviation equal to σ will tend to have a standard deviation equal to σ/m, where m is the square root of n. As there are 12 five-minute values in one hour, the value of n is 12. The corresponding value of m is 3.5, and 18.5 ppb/3.5 = 5.3 ppb.

The current version of pNEM/O3 provides for two outdoor microenvironments: No. 5 (outdoors - near road) and No. 6 (outdoors - other). In the pNEM/O3 analyses described in this report, these microenvironments were treated identically; that is, Equation 2 was used to determine the hourly ozone concentrations in each outdoor microenvironment. This approach is likely to over-estimate ozone concentrations in microenvironment No. 5 (outdoors - near road) because it does not account for potential ozone scavenging by nitric oxides emitted from motor vehicles. The magnitude of this bias is difficult to quantify because of the scarcity of research in this area and the inconsistency of research findings. For example, a study by Rhodes and Holland[22] of a single freeway in San Diego found that downwind ozone concentrations measured near the roadway were less than 28 percent of the ozone concentrations measured simultaneously at more distant outdoor locations judged to be unaffected by the roadway. However, an analysis[19] of outdoor personal exposure data obtained from the Stock study found that the average ratio of personal ozone concentration to fixed-site ozone concentration was approximately 1.0 in areas of both low and high traffic density.

2.4.2 *The Air Quality Adjustment Model*

In Equation 1, $C_{mon}(d,t,s)$ is the monitor-derived value for district d at time t under scenario s. The value for this variable was determined by adjusting monitoring data representing existing ("as is") conditions according to the equation

$$C_{mon}(d, t, s) = (a) [C_{mon}(d, t, e)]^b \qquad (3)$$

where $C_{mon}(d,t,e)$ is the monitor-derived value for district d under existing conditions. The multiplicative factor a and the exponent b are specific to district and scenario. Section 5 describes the derivation of Equation 3 and provides examples of its application to Philadelphia monitoring data.

Equation 3 requires a complete (gapless) year of hourly average $C_{mon}(d,t,e)$ values for each district. These data sets were prepared by applying a special interpolation program to the hourly average ozone data reported by each fixed-site monitor. The interpolation program provided an estimate of each missing value. The resulting filled-in data sets were assumed to represent existing conditions at each monitor.

The interpolation program provides estimates of missing values through the use of a time series model developed by Johnson and Wijnberg[23]. The time series model is based on the assumption that hourly average air quality values can be represented by a combination of cyclical, autoregressive, and noise processes. The parameter values of these processes are determined by a statistical analysis of the reported data.

2.4.3 *Equivalent Ventilation Rate*

In addition to ozone concentration, an equivalent ventilation rate (EVR) value was estimated for each exposure event. EVR is defined as ventilation rate divided by body surface area (BSA). Clinical research by EPA suggests that EVR exhibits less inter-person variability than ventilation rate for a given level of exertion.[24]

The algorithm used to estimate EVR was employed previously in applications of the pNEM methodology to ozone[13] and carbon monoxide.[14] This algorithm is based on an analysis[25] of activity diary data provided by Dr. Jack Hackney. The data were obtained from 36 subjects in Los Angeles who completed activity diaries identical to those used in the Cincinnati study. The heart rate of each subject was monitored during the period reported in the diary. Separate clinical trials were conducted to determine a relationship between ventilation rate and heart rate for each subject. These relationships and subject-specific BSA values were used to convert the one-minute heart rate data associated with each diary activity to an average EVR value for the activity. The resulting EVR estimates were then grouped by breathing rate category (slow - sleeping, slow - awake, medium, fast). Statistical analysis indicated that a two-parameter lognormal distribution provided a good fit to the EVR values in each group. Table 5 lists the geometric mean and standard deviation of each fitted distribution.

The appropriate distribution was randomly sampled to provide an EVR value for each exposure event in the pNEM/03 simulation. EVR values were not permitted to exceed an upper limit (EVRLIM) which varied with demographic group and event duration. In all cases, the value of EVRLIM was set at a level estimated to be achievable by members of the cohort who 1) exercised regularly, 2) were motivated to attain high exertion levels, and 3) were not professional athletes. Joggers would be included in this group; professional basketball players would not be included.

Table 6 presents the algorithm used to determine EVRLIM. The algorithm accounts for the following research findings.

1. Ventilation rate (V_E), oxygen uptake rate (VO_2), and the ratio of V_E to VO_2 increase with increasing work rate.

2. A person's maximum V_E is determined by his or her maximum oxygen uptake rate (VO_{2MAX}) and the V_E/VO_2 ratio in effect under maximum oxygen uptake conditions (MAXRATIO) such that

$$V_{Emax} = (VO_{2max})(MAXRATIO).$$

3. VO_{2max} and MAXRATIO are functions of age, gender, and training, among other factors.

TABLE 5. PARAMETER VALUES OF LOGNORMAL DISTRIBUTIONS USED TO CHARACTERIZE EQUIVALENT VENTILATION RATE

Age group	Breathing rate	Parameter values of fitted lognormal distribution	
		Geometric mean[a]	Geometric standard deviation
Children	Slow-sleeping	8.1	1.60
	Slow-awake	10.0	1.46
	Medium	12.3	1.44
	Fast	14.8	1.62
Adults	Slow-sleeping	5.4	1.22
	Slow-awake	7.1	1.36
	Medium	8.6	1.34
	Fast	18.9	1.92

[a]Liters/min per m^2.

4. Individuals cannot maintain oxygen uptake rates equal to VO_{2max} for more than about five minutes.

5. For activity durations greater than five minutes (i.e., t > 5 min), the percentage of VO_{2max} that can be maintained continuously ($PCTVO_{2max}$) decreases as the natural logarithm of the activity duration [ln(t)] increases.

Research findings supporting these assumptions have been presented by Erb[26], by Astrand and Rodahl[27], and by McArdle, Katch, and Katch.[28] The algorithm itself is a variation of "Algorithm B" proposed by Johnson and Adams.[29]

In determining the EVRLIM value applicable to a particular combination of cohort and event duration, the algorithm uses estimates of VO_{2max}, MAXRATIO, SUBRATIO, and BSA specific to the demographic group associated with the cohort (Table 7). The demographic group estimates provided in Table 7 were based on estimates originally developed by Johnson and Adams[29] for groups defined by age and gender. Analysts defined each of the pNEM/O3 demographic groups as a collection

TABLE 6. ALGORITHM FOR DETERMINING UPPER LIMIT FOR EVR

1. Determine the demographic group of the cohort being simulated.

2. Obtain values for the following quantities from Table 7 according to demographic group.

   VO_{2max}: maximum oxygen uptake rate

   MAXRATIO: maximum ratio of ventilation rate to oxygen uptake rate

   SUBRATIO: submaximal ratio of ventilation rate to oxygen uptake rate

   BSA: body surface area

3. Determine duration of event (t).

4. If t <= 5 minutes, determine the upper limit for EVR (EVRLIM) by the expression

$$EVRLIM = (1.2)(VO_{2max})(MAXRATIO)/BSA.$$

5. If 5 minutes < t <= 162 minutes, determine the percentage of maximum oxygen uptake rate that can be maintained for duration t by the expression

$$PCTVO_{2max} = 116.19 - (10.06)[\ln(t)].$$

   Next determine the ratio of ventilation rate to oxygen uptake rate by the expression

$$RATIO = SUBRATIO + (MAXRATIO-SUBRATIO)(PCTVO_{2max} - 65)/35.$$

   Finally determine EVRLIM by the expression

$$EVRLIM = (1.2)(VO_{2max})(PCTVO_{2max})(RATIO)/(100)(BSA).$$

6. If t > 162 minutes, determine $PCTVO_{2max}$ by the expression presented in Step 5 and EVRLIM by the expression

$$EVRLIM = (1.2)(VO_{2max})(PCTVO_{2max})(SUBRATIO)/(100)(BSA).$$

TABLE 7. PARAMETER VALUES FOR ALGORITHM USED TO DETERMINE LIMITS FOR EQUIVALENT VENTILATION RATE

	Subgroup with largest 5-min EVRLIM			Subgroup characteristics			
Demographic group	Sex	Age	5-min EVRLIM	BSA	VO_{2max}	MAXRATIO	SUBRATIO
1. Children 0 to 5 years	M	5	61.81	0.79	0.99	41.1	35.0
2. Children 6 to 13 years	M	11	77.41	1.23	2.30	34.5	26.0
3. Children 14 to 18 years	M	15	78.83	1.70	3.49	32.0	22.5
4. Workers with low probability of outdoor work	M	18-24	75.74	1.90	3.69	32.5	21.0
5. Workers with moderate probability of outdoor work	M	18-24	75.74	1.90	3.69	32.5	21.0
6. Workers with high probability of outdoor work	M	18-24	75.74	1.90	3.69	32.5	21.0
7. Nonworking adults under 35 years	M	18-24	75.74	1.90	3.69	32.5	21.0
8. Nonworking adults 35 to 54 years	M	35-44	62.09	1.97	3.07	33.2	22.3
9. Nonworking adults 55+ years	M	55-64	49.04	1.93	2.52	31.3	23.5

of the Johnson/Adams age-gender groups. Five-minute EVRLIM values were then calculated for each of the age-gender groups included within each demographic group. Table 7 lists the age-gender group associated with the largest EVRLIM value within each demographic group. The parameter values associated with the identified age-gender group were used to determine the EVRLIM values for the entire demographic group.

The algorithm in Table 6 differs substantially from the EVR limit algorithm employed in the February 1993 pNEM/O3 analysis described by Johnson et al.[15] The new algorithm generally permits higher EVR values than the February 1993 algorithm.

2.4.5 Hourly Average Exposure Sequences

Algorithms within pNEM/03 provided three estimates for each exposure event: average ozone concentration, average EVR, and the product of average ozone concentration and EVR (ozone x EVR). These estimates were processed to produce time-weighted estimates of ozone concentration, EVR, and ozone x EVR for each clock hour. The result was a year-long sequence of hourly values for each of three exposure indicators for each cohort. These sequences can be further processed to determine cohort-specific values for various multihour exposure indicators. Examples of such indicators include the largest eight-hour daily maximum ozone concentration and the number of times the hourly-average ozone concentration exceeds 0.12 ppm.

2.5 Extrapolate the Cohort Exposures to the Population-of-Interest and to Individual Sensitive Groups

The cohort-specific exposure estimates developed in Step 4 of the pNEM methodology (Subsection 2.4) were extrapolated to the general population of each study area by estimating the population size of each cohort. Cohort populations were estimated by the following four-step procedure. In Step 1, the number of persons associated with each demographic group was estimated by census unit. In Step 2, the fraction of homes falling into each of the three air conditioning categories was estimated by census unit. The fractions associated with each census unit were determined using 1980 census data, as the 1990 census did not collect air conditioning data. In cases where the boundaries of a 1990 census unit did not coincide with 1980 census units, analysts used the fractions associated with the 1980 census unit located nearest to the 1990 census unit. In Step 3, the demographic group populations were multiplied by the air conditioning fractions to provide an estimate of the number of persons in each combination of demographic group and air conditioning category. The estimation equation was

$$Pop(d,c,a) = F(c,a) \times Pop(d,c), \tag{4}$$

where Pop(d,c,a) is the population of a group associated with demographic group d, census unit c, and air conditioning system a. F(c,a) is the fraction of housing units in census unit c with air conditioning system a, and Pop(d,c) is the number of persons associated with demographic group d in census unit c.

The values of Pop(d,c,a) were summed over each home district to yield estimates of Pop(d,h,a), the number of persons in demographic group d within home district h assigned to air conditioning category a.

The Pop(d,h,a) values provided an estimate of the population of each non-commuting cohort residing within home district h. In Step 4, the populations of the commuting cohorts (assumed to include all working cohorts) were determined by the expression

$$Com(d,h,a,w) = Pop(d,h,a) \times Com(h,w)/Work(h). \tag{5}$$

Com(d,h,a,w) is the number of persons in the commuting cohort associated with demographic group d, home district h, AC system a, and work district w; Com(h,w) is the number of workers in all demographic groups that commute from home district h to work district w; and Work(h) is the total number of workers in home district h. Estimates of Work(h) were developed from census data specific to each district. Estimates of Com(h,w) were obtained from origin-destination (O-D) produced by a special commuting model.

The pNEM/O3 commuting model is an enhanced version of a model developed by Johnson et al.[30] Briefly, the commuting model uses a trip duration model to develop an O-D table. Trip duration data are collected during each census year for all areas of the U.S. The data for 1990 are reported as the number of persons in each census unit with one-way commute times that fall into each of the following twelve commute duration ranges:

1. Less than 5 minutes
2. 5 to 9 minutes
3. 10 to 14 minutes
4. 15 to 19 minutes
5. 20 to 24 minutes
6. 25 to 29 minutes
7. 30 to 34 minutes
8. 35 to 39 minutes
9. 40 to 44 minutes
10. 45 to 59 minutes
11. 60 to 89 minutes
12. 90+ minutes.

The model assumes that each commute duration range can be converted into a corresponding range of geodesic distances. Geodesic distance is defined here as the shortest distance between two points on the globe, i.e., the distance "as the crow files."

For example, a commuter in a large urbanized area may report that her commute takes between 20 and 24 minutes. If the average geodesic commute speed in the area is 0.3 kilometers per minute (km/min), the commute duration range of 20 to 24 minutes is equivalent to a geodesic distance range (GDR) of 6 to 7.2 km.

In a similar manner, each of the twelve commute distance ranges is converted to a GDR indexed as i = 1, 2, ..., 12. The location of each census unit is represented by its geographic centroid. If the census unit is an origin location for commuters (i.e., a "home" location), one can delineate twelve concentric rings centered on the centroid, one for each GDR. The i-th GDR centered on home location h is identified as GDR(h,i). Other useful terms are defined below.

COM(h): Number of commuters residing in home location h

COM(h,i): Number of commuters residing in home location h who commute to a work location in GDR(h,i)

COM(h,i,w): Number of commuters residing in home location h who commute to work location w where work location w is in GDR(h,i)

N(h,i): Number of work locations in GDR(h,i)

Tot(h,i,w): Total number of commuters who work in work location w in GDR(h,i)

Tot(h,i): Total number of commuters that work in GDR(h,i) (includes commuters from all home locations).

The following method is employed to develop an O-D table.

1. Com(h,i) and N(h,i) are known. Make an initial estimate of Com(h,i,w) using the expression

$$Com(h,i,w) = [Com(h,i)]/[N(h,i)] \tag{6}$$

2. Calculate Tot(h,i,w) by summing Com(h,i,w) values associated with specified w value

3. Calculate Tot(h,i) by summing Tot(h,i,w) values for all work locations in GDR(h,i)

4. Make a new estimate of Com(h,i,w) using the expression

$$Com(h,i,w) = [Com(h,i)][Tot(h,i,w))]/[Tot(h,i)] \tag{7}$$

5. Go to Step 2.

In Step 1, commuters associated with a particular combination of home location and GDR are evenly distributed across the work locations in the GDR. This step is Iteration O. Steps 2 through 4 are repeated n times where n is determined by the user. In each iteration of Steps 2 through 4, the commuters are redistributed across the work locations in the GDR in proportion to the number of workers assigned to each work location during the last iteration.

In applying the commuting model to Houston, analysts first identified all counties which were located within 50 km of the center of Houston. The 819 census units located within these counties were assigned to a commute modeling zone. Each census unit within the modeling zone was assumed to be both a potential home location and a potential work location. Using commuting data from the 1990 census, analysts applied the commuting model to the census units included in the modeling zone and developed an origin-destination table. This table listed the number of persons associated with each of the 670,761 (819 x 819) possible pairings of home and work locations.

Analysts next defined 12 subdivisions of the commute modeling zone -- one for each of the 11 Houston exposure districts and an additional district (District #12) containing all leftover census units. The 670,761 pairings of home and work census units were aggregated into an origin-destination table listing the number of persons associated with each of the 144 possible pairings of the 12 districts. This table was used to estimate values of COM(h,w)/Work(h) -- the fraction of workers residing in exposure district h who commuted to exposure district w. Only persons who lived and worked in one of the 11 Houston exposure districts were included in the exposure assessment. Persons who lived or worked in the remaining district (i.e., District #12) were excluded from the exposure analysis. These persons were assumed to spend a significant part of each week in an area not included in one of the 11 Houston exposure districts. The pNEM/O3 methodology does not provide a means for estimating the exposures of people during periods when they are not within the boundaries of an exposure district.

Table 8 lists the values of the quantity COM(h,w)/Work(h) determined by this method for each of the 144 combinations of home and work district in Houston. Of these, 13 combinations include District 12 as either the home or work location. As indicated above, persons associated with these 13 entries were not included in the exposure assessment.

TABLE 8. ESTIMATED FRACTION OF HOUSTON WORKERS WITHIN EACH HOME DISTRICT THAT COMMUTE TO EACH WORK DISTRICT

District Identifier			District Identifier			District Identifier		
Home	Work	Com (h,w) / Work (h)	Home	Work	Com (h,w) / Work (h)	Home	Work	Com (h,w) / Work (h)
1	1	0.360	3	1	0.190	5	1	0.006
	2	0.004		2	0.000		2	0.001
	3	0.049		3	0.150		3	0.001
	4	0.245		4	0.072		4	0.230
	5	0.013		5	0.015		5	0.476
	6	0.005		6	0.038		6	0.011
	7	0.003		7	0.008		7	0.013
	8	0.005		8	0.015		8	0.002
	9	0.015		9	0.120		9	0.002
	10	0.010		10	0.073		10	0.003
	11	0.145		11	0.244		11	0.181
	12	0.106[a]		12	0.019[a]		12	0.059[a]
2	1	0.027	4	1	0.052	6	1	0.007
	2	0.286		2	0.019		2	0.001
	3	0.000		3	0.002		3	0.016
	4	0.333		4	0.572		4	0.036
	5	0.007		5	0.114		5	0.053
	6	0.000		6	0.002		6	0.186
	7	0.000		7	0.002		7	0.137
	8	0.000		8	0.001		8	0.068
	9	0.000		9	0.001		9	0.047
	10	0.000		10	0.002		10	0.103
	11	0.012		11	0.135		11	0.302
	12	0.257[a]		12	0.078[a]		12	0.009[a]

(continued)

Table 8 (continued)

District Identifier		Com (h,w) / Work (h)	District Identifier		Com (h,w) / Work (h)	District Identifier		Com (h,w) / Work (h)
Home	Work		Home	Work		Home	Work	
7	1	0.002	9	1	0.023	11	1	0.033
	2	0.000		2	0.000		2	0.001
	3	0.003		3	0.088		3	0.015
	4	0.015		4	0.011		4	0.180
	5	0.043		5	0.004		5	0.123
	6	0.124		6	0.059		6	0.041
	7	0.357		7	0.021		7	0.013
	8	0.188		8	0.178		8	0.006
	9	0.026		9	0.363		9	0.008
	10	0.057		10	0.145		10	0.019
	11	0.097		11	0.052		11	0.524
	12	0.058[a]		12	0.029[a]		12	0.009[a]
8	1	0.000	10	1	0.015	12	1	0.041[a]
	2	0.000		2	0.000		2	0.017[a]
	3	0.004		3	0.046		3	0.004[a]
	4	0.001		4	0.027		4	0.098[a]
	5	0.002		5	0.016		5	0.046[a]
	6	0.055		6	0.162		6	0.002[a]
	7	0.150		7	0.107		7	0.018[a]
	8	0.508		8	0.135		8	0.041[a]
	9	0.061		9	0.115		9	0.008[a]
	10	0.057		10	0.143		10	0.001[a]
	11	0.019		11	0.197		11	0.012[a]
	12	0.119[a]		12	0.006[a]		12	0.568[a]

[a]Persons associated with this entry were not included in the exposure assessment.

A special tabulation program in pNEM/03 combined the cohort-specific estimates of exposure and population to produce histograms and cumulative frequency tables for various population exposure indicators and averaging times. Section 6 provides exposure estimates based on existing conditions in each study area, the attainment of the current NAAQS, and the attainment of each of four alternate NAAQS.

SECTION 3

THE MASS-BALANCE MODEL

In the pNEM/O3 simulation, the ozone concentration in a particular microenvironment during a particular clock hour is assumed to be constant. For indoor and in-vehicle microenvironments, this value is determined by using a mass balance model to calculate the average ozone concentration for the clock hour expected under the following conditions:

1. There are no indoor sources of ozone.
2. The indoor ozone concentration at the end of the preceding hour is specified.
3. The outdoor ozone concentration during the clock hour is constant at a specified value.
4. The air exchange rate during the clock hour is constant at a specified value.
5. Ozone decays at a rate that is proportional to the indoor ozone concentration. The proportionality factor is constant at a specified value.

The mass balance model employed in these calculations is based on a generalized mass balance model described by Nagda, Rector, and Koontz[31], hereafter referred to as the Nagda model. As originally proposed, this model assumed that pollutant concentration decays indoors at a constant rate. For use in pNEM/O3, the Nagda model was revised to incorporate the alternative assumption that the indoor decay rate is proportional to the indoor concentration. The Nagda model was further revised to incorporate ozone-specific assumptions concerning various parameter values suggested by Weschler[32] and others.

Subsection 3.1 presents the theoretical basis for the pNEM/O3 mass balance model and the principal model assumptions. Subsection 3.2 describes the algorithms which were used to generate hourly values of ozone for the indoor and in-vehicle microenvironments. Subsection 3.3 presents the procedure used to determine air exchange rate for the mass balance model. An algorithm for simulating the opening and closing of windows is described in Subsection 3.4.

3.1 Theoretical Basis and Assumptions

The Nagda model can be expressed by the differential equation

$$\frac{dC_{in}}{dt} = (1 - F_B)\ \nu C_{out} + \frac{S}{cV} - m\nu C_{in} - \frac{\lambda}{cV} - \frac{qFC_{in}}{cV} \qquad (8)$$

where C_{in} = Indoor concentration (units: mass/volume)

F_B = Fraction of outdoor concentration intercepted by the enclosure (dimensionless fraction)

ν = Air exchange rate (1/time)

C_{out} = Outdoor concentration (mass/volume)

S = Indoor generation rate (mass/time)

cV = Effective indoor volume where c is a dimensionless fraction (volume)

m = Mixing factor (dimensionless fraction)

λ = Decay rate (mass/time)

q = Flow rate through air cleaning device (volume/time)

F = Efficiency of the air cleaning device (dimensionless fraction).

In this model, the pollutant decay rate (λ) is assumed to be constant. Research by Nazaroff and Cass[33] and by Hayes[34] suggests that the decay rate for ozone should be proportional to C_{in}. Consequently, the pNEM/03 mass balance equation substitutes the term $F_d C_{in}$ for the term λ/cV in Equation 8. The coefficient F_d is expressed in units of 1/time.

The following notational changes were made to simplify the equation:

$$F_p = 1 - F_B, \tag{9}$$

$$V_e = cV, \tag{10}$$

F_p is the "penetration factor," and V_e is the "effective volume." The resulting equation is

$$\frac{d}{dt} C_{in} = F_p \nu C_{out} + \frac{S}{V_e} - m\nu C_{in} - F_d C_{in} - \frac{qFC_{in}}{V_e} \tag{11}$$

If the three terms that are proportional to C_{in} are collected into one term, the equation can be expressed as

$$\frac{d}{dt} C_{in} = F_p \nu C_{out} + \frac{S}{V_e} - \nu' C_{in}, \tag{12}$$

where

$$\nu' = m\nu + F_d + \frac{qF}{V_e}. \tag{13}$$

It can be shown that Equation 12 has the following approximate solution:

$$C_{in}(t) = k_1 C_{in}(t-\Delta t) + k_2 \underline{C}_{out} + k_3, \tag{14}$$

where

$$k_1 = e^{-v'\Delta t}, \tag{15}$$

$$k_2 = (F_p v/v')(1-k_1), \tag{16}$$

$$k_3 = (S/v'V_e)(1-k_1), \tag{17}$$

and $\underline{C}_{out}$ is the average value of the outdoor concentration over the interval t to t + Δt. If $\underline{C}_{out}$ is constant over the interval, then Equation 14 is an exact solution.

The average indoor concentration for hour h, $\underline{C}_{in}$ (h), is given by the expression

$$\underline{C}_{in}(h) = a_1 C_{in}(h-1) + a_2 \underline{C}_{out}(h) + a_3 \tag{18}$$

where C_{in}(h-1) is the instantaneous indoor concentration at the end of the preceding hour, $\underline{C}_{out}$ (h) is the average outdoor concentration for hour h,

$$a_1 = z(h), \tag{19}$$

$$a_2 = (F_p \nu / \nu') \, [1 - z(h)] , \tag{20}$$

$$a_3 = \left(\frac{S}{\nu' V_e}\right) [1 - z(h)] , \tag{21}$$

and

$$z(h) = (1 - e^{-\nu'}) / \nu' . \tag{22}$$

A steady-state version of the mass balance model can be developed by solving Equation 12 under the conditions that

$$\frac{d}{dt} C_{in} = 0 \tag{23}$$

and C_{out} is constant. In this case, the mass balance equation is

$$0 = F_p \nu \, C_{out} + \frac{S}{V_e} - \nu' C_{in} , \tag{24}$$

which can be rearranged as

$$C_{in} = (F_p \nu / \nu') \, C_{out} + \frac{S}{\nu' V_e} . \tag{25}$$

The ratio of indoor concentration to outdoor concentration is

$$C_{in}/C_{out} = (F_p v/v') + \frac{S}{v' V_e C_{out}} . \tag{26}$$

Weschler[32] has developed a steady-state equation for the indoor/outdoor ratio which is expressed in his notation as

$$I/O = E_x/[E_x + k_d (A/V)] , \tag{27}$$

where I = indoor concentration, O = outdoor concentration, E_x = air exchange rate, k_d = deposition velocity, A = surface area, and V = volume. With respect to Equation 11, Weschler's model implies that there are no indoor sources (S = zero), no air cleaning devices (F = zero), the penetration factor is unity (F_p = 1), c = 1, and m = 1. Under these conditions, Equation 11 becomes

$$\frac{d}{dt} C_{in} = v\, C_{out} - (v + F_d)\, C_{in} \tag{28}$$

and Equation 26 becomes

$$C_{in}/C_{out} = \frac{v}{v + F_d} . \tag{29}$$

Weschler's model (Equation 27) and Equation 29 are equivalent if the following substitutions are made:

$$C_{in} = I \tag{30}$$

$$C_{out} = O \qquad (31)$$

$$v = E_x \qquad (32)$$

$$F_d = k_d (A/V) \; . \qquad (33)$$

Equation 33 is a particularly useful relationship, as Weschler has identified a number of studies which suggest that $k_d(A/V)$ is relatively constant from building to building. He suggests that 1.0×10^{-3} sec^{-1} is a good general estimate of this quantity.

Weschler et al. present 14 estimates of $k_d(A/V)$ based on data obtained from specific studies. Nine of these values are based on the observed first-order decay of ozone in isolated rooms. The remaining five values are based on reported I/O values and air exchange rates. Table 9 presents means and standard deviations for the first nine estimates, for the last five estimates, and for all 14 estimates. Two-sided 95 percent confidence intervals for the means are also provided.

The values in Table 9 can be converted to units of h^{-1} by multiplying each value by 3600. Expressed in these units, the mean and standard deviation for the 14 estimates are 4.04 h^{-1} and 1.35 h^{-1}, respectively. A normal distribution with these parameters was assumed to represent the distribution of F_d values for the non-vehicle indoor microenvironments. The value of F_d was not permitted to be less than 1.44 h^{-1} or more than 8.09 h^{-1}. The lower bound was based on the smallest value cited by Weschler[32] which was measured in a stainless steel room. The upper bound corresponds to the 99.87 percentile (i.e., z = 3) of a normal distribution with mean equal to 4.04 and standard deviation equal to 1.35. The largest value cited by Weschler was 7.2 h^{-1}.

A point estimate of 72.0 was assumed for the value of F_d for the in-vehicle microenvironment. This value is based on an estimate of F_d for a single vehicle reported by Petersen and Sabersky[35]. Hayes has used this value in applications of the PAQM exposure model[34].

TABLE 9. MEANS, STANDARD DEVIATIONS, AND CONFIDENCE INTERVALS FOR ESTIMATES OF k_d(A/V) PROVIDED BY WESCHLER

Parameter	Source of k_d (A/V) estimate: Observed first-order decay	Reported I/O values	All
Sample size	9	5	14
Mean, sec^{-1}	1.133×10^{-3}	1.098×10^{-3}	1.121×10^{-3}
Standard deviation, sec^{-1}	0.447×10^{-3}	0.143×10^{-3}	0.374×10^{-3}
Two-sided 95% confidence interval, sec^{-1}	$(0.789, 1.477) \times 10^{-3}$	$(0.920, 1.276) \times 10^{-3}$	$(0.906, 1.335) \times 10^{-3}$

3.2 Simulation of Microenvironmental Ozone Concentrations

Consistent with the theoretical considerations discussed in Subsection 3.1, the following equation was used to estimate the hourly average ozone concentration in a particular indoor or in-vehicle microenvironment during hour h:

$$\underline{C}_{in}(h) = a_1 C_{in}(h-1) + a_2 \underline{C}_{out}(h) \qquad (34)$$

where $\underline{C}_{in}$ (h) is the average indoor ozone concentration during hour h, C_{in} (h-1) is the instantaneous ozone concentration at the end of the preceding hour, $\underline{C}_{out}$ (h) is the outdoor ozone concentration during hour h,

$$a_1 = z(h), \tag{35}$$

$$a_2 = (\nu/\nu')\,[1 - z(h)], \tag{36}$$

$$z(h) = (1 - e^{-\nu'})/\nu', \tag{37}$$

and

$$\nu' = \nu + F_d \tag{38}$$

The instantaneous ozone concentration at the end of a particular hour, C_{in} (h), was estimated by the equation

$$C_{in}(h) = k_1 C_{in}(h-1) + k_2 C_{out}(h), \tag{39}$$

where

$$k_1 = e^{-\nu'} \tag{40}$$

$$k_2 = (\nu/\nu')\,(1 - k_1), \tag{41}$$

and ν' is determined by Equation 38.

The following algorithm was used to generate a sequence of hourly-average ozone concentrations for each combination of microenvironment and district.

1. Go to first/next day.

2. Select value of air exchange rate for day from appropriate distribution or use point estimate. If microenvironment is residential, select one air exchange value for hours when windows are open and one for hours when windows are closed. If microenvironment is a nonresidential building or vehicle, then one air exchange rate is used for all hours of the day.

3. Select value of decay rate (F_d) for day from appropriate distribution or use point estimate. If microenvironment is non-vehicular enclosure, select value of F_d from normal distribution with mean = 4.04 h^{-1} and standard deviation = 1.35 h^{-1}. Value is not permitted to be less than 1.44 h^{-1} or more than 8.09 h^{-1}. If microenvironment is "in vehicle", use point estimate of 72.0 h^{-1}.

4. Go to first/next clock hour.

5. If microenvironment is residential, use supplementary window algorithm to determine window status for current hour (open or closed). Window status determines which air exchange rate determined in Step 2 applies to current hour.

6. Use Equation 34 to determine ozone concentration for current hour based on air exchange rate specified for hour, outdoor ozone concentration during hour, and ozone concentration at end of preceding hour.

7. Use Equation 39 to determine instantaneous ozone concentration at end of current hour based on air exchange rate specified for hour, outdoor ozone concentration during hour, and instantaneous ozone concentration at end of preceding hour. This value is saved for input into Equation 34 during the next hour.

8. If end of day, go to Step 1. Otherwise, go to Step 4.

Step 2 requires the random selection of an air exchange rate from a specified distribution. Four enclosure categories were established for this purpose.

- Residential buildings - windows open
- Residential buildings - windows closed
- Nonresidential buildings
- Vehicles.

A survey of the scientific literature determined that there were sufficient data available to define distributions for only two of the four enclosure categories: "residential building - windows closed" or "nonresidential building". In each case, a two-parameter lognormal distribution was found to provide a good fit to the data. Point (single-valued) estimates were developed for the remaining two enclosure categories.

Each of the two lognormal distributions was defined by the expression

$$AER = GM \times GSD^{z} \qquad (42)$$

where AER is the air exchange rate, GM is the geometric mean, and GSD is the geometric standard deviation. The values for GM and GSD were determined by fitting lognormal distributions to representative data sets (Subsection 3.3). A value of AER was selected at random from a particular lognormal distribution by randomly selecting a value of Z from the unit normal distribution [N(0,1)] and substituting it into Equation 42. Table 10 lists the values of GM and GSD for the two lognormal distributions and the values of the point estimates.

The distributions used to determine AER are discussed in more detail in Subsection 3.3. Subsection 3.4 provides a description of the algorithm used to determine window status in the residential microenvironments (Step 4).

3.3 Air Exchange Rate Distributions

A review of the scientific literature relating to air exchange rates identified 31 relevant references (list available on request). Of these, only a few were found to contain sufficient data to construct a distribution of air exchange rates relating to a particular building type such as residence or office. The two most useful studies were conducted by Grimsrud et al.[36] and by Turk et al.[37]

Residential Locations

Grimsrud et al. measured AER's in 312 residences. Reported AER values ranged from 0.08 to 3.24. Researchers with IT Air Quality Services (ITAQS) analyzed these data to determine which of two distributions (normal versus lognormal) better

TABLE 10. DISTRIBUTIONS OF AIR EXCHANGE RATE VALUES USED IN THE pNEM/03 MASS BALANCE MODEL

Enclosure category	Air exchange rate distribution
Residential building-windows closed	Lognormal distribution ° Geometric mean = 0.53 ° Geometric standard deviation = 1.704 ° Lower bound = 0.063 ° Upper bound = 4.47
Residential building-windows open	Point estimate: 6.4
Nonresidential building	Lognormal distribution ° Geometric mean = 1.285 ° Geometric standard deviation = 1.891 ° Lower bound = 0.19 ° Upper bound = 8.69
Vehicle	Point estimate: 36

characterized the data. The lognormal distribution was found to yield a better fit, as the data were highly skewed. The fitted lognormal parameters were geometric mean = 0.53 and geometric standard deviation = 1.704. This distribution was used in pNEM/03 to represent the distribution of AER's in residences with windows closed. Upper and lower limits of 4.47 and 0.063 air changes per hour were established to prevent the selection of unusually extreme values of AER. These limits correspond to the substitution of Z = 4 and Z = -4 in Equation 42 when GM = 0.53 and GSD = 1.704. The upper bound is 38 percent larger than the largest reported AER (3.24). The lower bound is 21 percent smaller than the smallest reported AER (0.08).

No comparable data bases were identified which were considered representative of residences where windows are open. Hayes has used 6.4 as the AER value for open windows in applications of the PAQM model.[34] This value was used in the pNEM/03 analyses presented here. This value will be replaced by a distribution when an appropriate data base becomes available.

Nonresidential Locations

Turk et al. measured AER's in 40 public buildings identified as schools (n = 7), offices (n = 25), libraries (n = 3), and multipurpose buildings (n = 5). The minimum reported AER was 0.3; the maximum was 4.1. Researchers with ITAQS fit normal and lognormal distributions to the data for all 40 buildings and found that the lognormal distribution produced a slightly better fit, although it had a tendency to over-predict high values. The fitted lognormal parameters were geometric mean = 1.285 and geometric standard deviation = 1.891.

The buildings can be grouped as offices (n = 25) and nonoffices (n = 15). Lognormal fits to these data sets yielded geometric means and standard deviations of 1.30 and 1.93 for offices and 1.27 and 1.87 for nonoffices. ITAQS performed a two-sample t test on the two data sets and found no significant difference in the means or standard deviations of the data. Consequently, a single lognormal distribution (geometric mean = 1.285, geometric standard deviation = 1.891) was used in pNEM/03 for all nonresidential buildings. To prevent the over-prediction of high AER values, an upper bound of 8.69 was established. This value results when Z = 3 is substituted into Equation 42 with GM = 1.285 and GSD = 1.891. This value is over twice the largest AER value (4.1) reported for the 40 buildings and corresponds to the 99.87 percentile of the specified lognormal distribution. A lower bound of 0.19 was also established. This value corresponds to a Z value of -3 and represents the 0.13 percentile of the lognormal distribution.

In Vehicle Locations

A point estimate of 36 air changes per hour was used for in-vehicle locations. This value was obtained from Hayes[38] based on his analysis of data presented by Peterson and Sabersky[35].

3.4 Window Status Algorithm

The opening and closing of windows in the three residential microenvironments was simulated by an algorithm which specified a window status (open or closed) for each clock hour. The algorithm consisted of the following eight-step procedure.

1. Identify air conditioning system associated with cohort (central, window units, none).

2. Go to first/next day.

3. Determine average temperature for day from supplementary file. Identify temperature range which contains this value (below 32, 32 to below 63, 63 to 75, above 75).

4. Select random number between zero and 1. Compare random number with probabilities listed in Table 11 for specified air conditioning system and temperature range. Determine window status for day. If day status is "windows open all day" or "windows closed all day", set window status for all clock hours of day as indicated and go to Step 2. If day status is "windows open part of day", go to Step 5.

5. Go to first/next clock hour.

6. Determine window status of preceding clock hour.

7. Select random number between zero and 1. Compare random number with probabilities listed in Table 12, 13, or 14 for specified air conditioning system, clock hour, temperature range, and window status for preceding hour. If the random number is less than the specified probability, the window will be open during the clock hour. Otherwise, the window will be closed.

8. If end of day, go to Step 2. Otherwise, go to Step 5.

This algorithm assigns each day to one of three categories: 1) windows closed all day, 2) windows open all day, and 3) windows open part of day. These assignments are made according to the air conditioning system associated with the cohort and the average temperature of the day. If the day assignment is "windows open part of day", the algorithm assigns window status on an hourly basis for each of the 24 clock hours in the day. These hourly assignments are made according to the 1) cohort's air conditioning system, 2) clock hour, 3) temperature of the day, and 4) window status of the preceding hour. Both the daily and hourly assignments are made probabilistically by comparing random numbers to the probabilities that the specified window status will occur under the stated conditions.

The window status probabilities listed in Tables 11, 12, 13, and 14 were developed through a statistical analysis of data on window openings obtained from the Cincinnati Activity Diary Study (CADS).[18] This analysis indicated that air conditioning system, temperature, clock hour, and window status of preceding hour were statistically significant factors affecting window status.

TABLE 11. PROBABILITY OF WINDOW STATUS FOR DAY BY AIR CONDITIONING SYSTEM AND TEMPERATURE RANGE

Air conditioning system	Temperature range, °F	Probability of window status for day		
		Closed all day	Open all day	Open part of day
Central	Below 32	1.000	0	0
	32 to 62	0.851	0.009	0.140
	63 to 75	0.358	0.343	0.299
	Above 75	0.633	0.167	0.200
Room units	Below 32	1.000	0	0
	32 to 62	0.734	0.028	0.238
	63 to 75	0.114	0.505	0.381
	Above 75	0.160	0.380	0.460
None	Below 32	1.000	0	0
	32 to 62	0.812	0.011	0.177
	63 to 75	0.095	0.672	0.233
	Above 75	0.016	0.823	0.161

TABLE 12. PROBABILITY OF WINDOWS BEING OPEN BY CLOCK HOUR, TEMPERATURE RANGE, AND WINDOW STATUS OF PRECEDING HOUR (PH) FOR RESIDENCES WITH CENTRAL AIR CONDITIONING

Clock hour	Probability of windows being open					
	32°F to 62°F		63°F to 75°F		Above 75°F	
	PH=open	PH=closed	PH=open	PH=closed	PH=open	PH=closed
1-3	1.000	0.000	0.978	0.011	0.986	0.020
4-6	1.000	0.005	0.989	0.000	1.000	0.017
7-9	0.837	0.038	0.932	0.074	0.961	0.094
10-12	0.679	0.126	0.865	0.235	0.860	0.174
13-15	0.857	0.149	0.912	0.240	0.923	0.263
16-18	0.932	0.131	0.935	0.161	0.912	0.000
19-21	0.646	0.043	0.892	0.136	0.893	0.047
22-24	0.811	0.036	0.913	0.101	0.909	0.066

TABLE 13. PROBABILITY OF WINDOWS BEING OPEN BY CLOCK HOUR, TEMPERATURE RANGE, AND WINDOW STATUS OF PRECEDING HOUR (PH) FOR RESIDENCES WITH WINDOW AIR CONDITIONING UNITS

Clock hour	Probability of windows being open					
	32°F to 62°F		63°F to 75°F		Above 75°F	
	PH=open	PH=closed	PH=open	PH=closed	PH=open	PH=closed
1-3	0.970	0.006	0.947	0.007	0.974	0.010
4-6	0.975	0.000	0.994	0.016	0.989	0.017
7-9	0.864	0.040	0.934	0.101	0.989	0.092
10-12	0.929	0.121	0.917	0.303	0.849	0.351
13-15	0.860	0.244	0.969	0.400	0.819	0.152
16-18	0.859	0.103	0.956	0.125	0.930	0.043
19-21	0.684	0.063	0.925	0.176	0.902	0.056
22-24	0.919	0.042	0.851	0.064	0.865	0.121

TABLE 14. PROBABILITY OF WINDOWS BEING OPEN BY CLOCK HOUR, TEMPERATURE RANGE, AND WINDOW STATUS OF PRECEDING HOUR (PH) FOR RESIDENCES WITH NO AIR CONDITIONING SYSTEM

Clock hour	Probability of windows being open					
	32°F to 62°F		63°F to 75°F		Above 75°F	
	PH=open	PH=closed	PH=open	PH=closed	PH=open	PH=closed
1-3	1.000	0.015	0.974	0.031	1.000	0.000
4-6	1.000	0.000	1.000	0.000	1.000	0.000
7-9	0.950	0.000	0.868	0.057	1.000	0.000
10-12	0.889	0.200	0.933	0.400	0.875	0.500
13-15	0.923	0.130	1.000	0.286	0.917	0.000
16-18	0.848	0.200	0.964	0.000	0.818	0.667
19-21	0.609	0.067	0.909	0.500	1.000	0.200
22-24	0.684	0.043	0.800	0.167	0.769	0.500

SECTION 4

PREPARATION OF AIR QUALITY DATA

The pNEM/03 mass balance model requires representative ambient air quality data for each exposure district in the form of a time series containing one value for each hour in the specified ozone season. This section describes the procedures used to select appropriate data sets for the nine study areas. It also describes the procedure used for filling in missing values in these data sets.

4.1 Selection of Representative Data Sets

To simplify the computer simulation, the ambient ozone concentration throughout an exposure district was assumed to be a function of the ozone concentration measured at a single, representative monitoring site located within the district. Based on guidance from EPA, analysts defined the shape of each exposure district by first drawing a circle of radius = 15 km with the monitoring site at the center. If the centroid of a census unit (census tract or block numbering area) was located within this circle, the census unit was assigned to the exposure district. If a centroid was located within more than one circle, the census unit was assigned to the nearest monitor. Note that the monitoring sites selected to represent a city directly determined the location and shape of the city's exposure districts.

Researchers began the selection process by compiling a list of candidate monitoring sites for each of the ten cities used in the February 1993 analysis.[15]

Chicago	New York
Denver	Philadelphia
Houston	St. Louis
Los Angeles	Tacoma (deleted)
Miami	Washington

The monitoring site list included all sites which reported data to EPA of acceptable completeness for the ozone season of 1990 and/or 1991. The list provided an air quality indicator (the second highest daily maximum 1-hour ozone concentration) for each combination of site and ozone season.

A decision was made at this stage to exclude Tacoma from further analysis. Only two ozone monitors operated in Tacoma during 1990 and 1991. These monitors did not provide adequate geographic coverage of the Tacoma study area.

The air quality data complied for each of the remaining nine cities were examined to determine which ozone season (1990 or 1991) was associated with higher ozone levels across the city. The higher ozone season was designated the exposure period for the city (Table 15). Researchers then selected a set of representative monitoring sites to determine the location of the exposure districts for each city (Tables 16 through 24). Sites were selected according to the following general guidelines.

1. Select sites such that the associated exposure districts will provide good geographic coverage of the city. Districts should include both center-city and suburban areas with few large "holes" in the coverage of each metropolitan area. No city should be represented by less than three monitors. Six sites should provide adequate coverage for medium-sized cities; ten sites should provide adequate coverage for all but the largest cities.

2. To prevent excessive pNEM/O3 run times, no more than 16 sites should be selected to represent a particular city. (Program run time varies roughly as the square of the number of sites selected.)

3. Avoid sites which report unusually low ozone levels, as these may be rural or near-road sites. Selected sites should represent typical urban locations and provide a mix of average and high ozone levels.

Reference 39 provides a city-by-city discussion of the site selection process as originally implemented. Researchers later determined that one of the New York monitors was unrepresentative of ambient ozone conditions due to site location. This monitor (identified by EPA as Site No. 36-061-0063) had been selected to represent an exposure district centered on the southern end of Manhattan. Site No.

TABLE 15. CHARACTERISTICS OF OZONE STUDY AREAS AND MONITORING SITES

Study area	Designated exposure period		Number of counties[a] in area	Number of monitoring sites selected	Largest reported second high daily maximum ozone concentration, ppb
	Ozone season	Year			
Chicago	Apr - Oct	1991	7	12	129
Denver	Mar - Sep	1990	6	7	110
Houston	Jan - Dec	1990	5	11	220
Los Angeles	Jan - Dec	1991	4	16	310
Miami	Jan - Dec	1991	2	6	123
New York City	Apr - Oct	1991	18	11[b]	175
Philadelphia	Apr - Oct	1991	13	10	156
St. Louis	Apr - Oct	1990	7	11	125
Washington, D.C.	Apr - Oct	1991	13	11	144

[a]Counties are geographic areas assigned a county code by the Bureau of Census in Summary Tape File 3 (STF3). A county is counted if any portion is within the study area.
[b]Monitor No. 36-061-0010 represents two exposure districts.

36-061-0063 was later judged to be unrepresentative of ground-level ozone concentrations in this area of New York due to the site's high elevation. Consistent with guidance from EPA, researchers selected the next nearest ozone monitor (No. 36-061-0010) to represent the Manhattan exposure district in the pNEM/O3 analysis. Monitor No. 36-061-0010 also represents another exposure district which is centered on the northern end of Manhattan, the actual location of this monitor.

Table 15 lists the number of ozone monitoring sites selected for each study area. The table also indicates the largest value for the second highest daily maximum hourly ozone concentration, reported by the selected monitors for the indicated season. The omission of Monitor No. 36-061-0063 from the New York Study area does not affect the value of this air quality indicator (175 ppb).

TABLE 16. DESCRIPTIVE STATISTICS FOR 1991 DATA SETS CONTAINING HOURLY-AVERAGE OZONE CONCENTRATIONS OBTAINED FROM SELECTED MONITORING SITES IN THE CHICAGO STUDY AREA

Monitor ID	Monitor location	District code	Filled in?	n[a]	Percentiles, ppb					High values, ppb	
					50	90	95	99	99.5	Second	First
17-031-0001	Alsip	1	No	4903	19	51	61	77	83	104	108
			Yes	5136	19	50	61	77	83	104	108
17-031-0032	Chicago	2	No	4985	28	58	69	87	92	116	120
			Yes	5136	28	59	69	87	92	116	120
17-031-1003	Chicago	3	No	4895	19	51	63	81	88	129	134
			Yes	5136	19	50	61	81	87	129	134
17-031-1601	Lemont	4	No	4799	28	61	71	89	98	126	152
			Yes	5136	28	60	71	89	97	126	152
17-031-4002	Cicero	5	No	5033	18	49	60	78	86	120	125
			Yes	5136	18	49	59	78	86	120	125
17-031-4003	Des Plaines	6	No	4936	23	53	63	80	85	105	119
			Yes	5136	23	52	63	80	86	105	119
17-031-7002	Evanston	7	No	4876	30	59	69	90	97	115	123
			Yes	5136	30	58	69	90	96	115	123

(continued)

TABLE 16 (Continued)

Monitor ID	Monitor location	District code	Filled in?	n[a]	Percentiles, ppb					High values, ppb	
					50	90	95	99	99.5	Second	First
17-031-8003	Calumet City	8	No	4856	23	54	64	81	86	97	109
			Yes	5136	24	54	64	81	86	97	109
17-043-6001	Lisle	9	No	5100	19	49	59	78	87	116	118
			Yes	5136	20	50	59	78	87	116	118
17-089-0005	Elgin	10	No	5041	26	54	63	82	91	126	128
			Yes	5136	26	54	63	82	90	126	128
17-097-0001	Deerfield	11	No	5011	26	56	67	85	90	116	124
			Yes	5136	26	56	67	85	90	116	124
17-097-1002	Waukegan	12	No	5038	30	61	71	92	102	119	126
			Yes	5136	30	61	71	92	102	119	126

[a]Number of hourly-average ozone concentrations during designated ozone season.

TABLE 17. DESCRIPTIVE STATISTICS FOR 1990 DATA SETS CONTAINING HOURLY-AVERAGE OZONE CONCENTRATIONS OBTAINED FROM SELECTED MONITORING SITES IN THE DENVER STUDY AREA

Monitor ID	Monitor location	District code	Filled in?	n[a]	Percentiles, ppb					High values, ppb	
					50	90	95	99	99.5	Second	First
08-001-3001	Adams Co.	1	No	4322	26	54	59	69	72	87	99
			Yes	5136	26	53	58	68	72	87	99
08-005-0002	Arapaho Co.	2	No	4047	40	63	70	88	93	109	111
			Yes	5136	39	60	67	86	91	109	110
08-005-0003	Englewood	3	No	5036	23	53	62	76	83	110	111
			Yes	5136	23	54	62	76	83	110	111
08-013-1001	Boulder Co.	4	No	4458	33	55	64	78	83	102	106
			Yes	5136	32	54	63	77	80	102	106
08-031-0002	Denver	5	No	5063	17	40	47	59	64	104	120
			Yes	5136	17	40	46	59	64	104	120
08-031-0014	Denver	6	No	4453	22	54	62	77	83	107	120
			Yes	5136	22	53	61	75	81	107	120
08-059-0002	Arvada	7	No	4908	26	56	64	79	83	115	115
			Yes	5136	26	55	64	79	83	115	115

[a]Number of hourly-average ozone concentrations during designated ozone season.

TABLE 18. DESCRIPTIVE STATISTICS FOR 1990 DATA SETS CONTAINING HOURLY-AVERAGE OZONE CONCENTRATIONS OBTAINED FROM SELECTED MONITORING SITES IN THE HOUSTON STUDY AREA

Monitor ID	Monitor location	District code	Filled in?	n[a]	Percentiles, ppb					High values, ppb	
					50	90	95	99	99.5	Second	First
48-201-0024	Harris Co.	1	No	6865	20	60	80	110	130	220	220
			Yes	8760	20	60	70	110	120	220	220
48-201-0029	Harris Co.	2	No	7689	20	50	70	100	120	160	180
			Yes	8760	20	50	70	100	110	160	180
48-201-0046	Houston	3	No	8138	10	50	60	100	120	200	230
			Yes	8760	10	50	60	100	120	200	230
48-201-0047	Houston	4	No	7970	10	50	60	100	120	210	240
			Yes	8760	10	50	60	100	120	210	240
48-201-0051	Houston	5	No	7999	20	50	70	110	130	200	220
			Yes	8760	20	50	70	110	130	200	220
48-201-0059	Houston	6	No	6941	10	40	50	80	90	140	190
			Yes	8760	10	40	50	70	90	140	190
48-201-0062	Houston	7	No	8072	20	50	60	100	110	180	230
			Yes	8760	20	46	60	90	110	180	230

(continued)

TABLE 18 (Continued)

Monitor ID	Monitor location	District code	Filled in?	n[a]	Percentiles, ppb					High values, ppb	
					50	90	95	99	99.5	Second	First
48-201-1003	Deer Park	8	No	7685	20	50	60	100	110	230	230
			Yes	8760	20	50	60	100	110	230	230
48-201-1034	Houston	9	No	8098	10	50	60	90	120	200	210
			Yes	8760	10	45	60	90	110	200	210
48-201-1035	Houston	10	No	8300	10	50	60	100	120	230	230
			Yes	8760	10	50	60	100	120	230	230
48-201-1037	Houston	11	No	8086	10	40	60	100	120	220	220
			Yes	8760	10	40	60	100	120	220	220

[a]Number of hourly-average ozone concentrations during designated ozone season.

TABLE 19. DESCRIPTIVE STATISTICS FOR 1991 DATA SETS CONTAINING HOURLY-AVERAGE OZONE CONCENTRATIONS OBTAINED FROM SELECTED MONITORING SITES IN THE LOS ANGELES STUDY AREA

Monitor ID	Monitor location	District code	Filled in?	n[a]	Percentiles, ppb					High values, ppb	
					50	90	95	99	99.5	Second	First
06-037-0016	Glendora	1	No	8416	20	80	110	180	200	310	320
			Yes	8760	20	80	110	180	200	310	320
06-037-1103	Los Angeles	2	No	8356	10	50	70	120	130	170	190
			Yes	8760	10	50	70	110	130	170	190
06-037-1301	Lynwood	3	No	8478	10	40	50	80	90	130	160
			Yes	8760	10	40	50	80	90	130	160
06-037-1601	Pico Rivera	4	No	8523	10	60	80	130	160	250	260
			Yes	8760	10	60	80	130	160	250	260
06-037-1902	Santa Monica	5	No	8179	26	65	80	114	131	191	191
			Yes	8760	25	64	79	112	128	191	191
06-037-2005	Pasadena	6	No	8344	10	70	100	160	170	220	230
			Yes	8760	10	70	100	160	170	220	230
06-037-4002	Long Beach	7	No	8377	20	40	50	70	80	100	110
			Yes	8760	20	40	50	70	80	100	110
06-037-5001	Hawthorne	8	No	8465	20	50	60	80	90	110	110
			Yes	8760	20	50	60	80	90	110	115

(continued)

TABLE 19 (Continued)

Monitor ID	Monitor location	District code	Filled in?	n[a]	Percentiles, ppb					High values, ppb	
					50	90	95	99	99.5	Second	First
06-059-0001	Anaheim	9	No	8473	10	50	60	100	110	200	250
			Yes	8760	10	50	60	100	110	200	250
06-059-1003	Costa Mesa	10	No	8358	30	50	60	80	90	140	170
			Yes	8760	30	50	60	80	90	140	170
06-059-3002	Los Alamitos	11	No	8442	20	50	60	90	100	150	170
			Yes	8760	20	50	60	90	100	150	170
06-059-5001	La Habra	12	No	8492	20	60	70	110	130	190	210
			Yes	8760	15	53	70	110	130	190	210
06-065-8001	Rubidoux	13	No	8521	20	90	110	160	180	240	240
			Yes	8760	20	80	110	160	180	240	240
06-071-1004	Upland	14	No	8408	10	70	100	160	180	240	270
			Yes	8760	10	70	90	160	180	240	270
06-071-4003	Redlands	15	No	8374	30	90	120	180	190	250	250
			Yes	8760	30	90	120	180	190	250	250
06-071-9004	San Bernardino	16	No	8514	20	80	110	160	170	240	250
			Yes	8760	13	80	110	160	170	240	250

[a]Number of hourly-average ozone concentrations during designated ozone season.

TABLE 20. DESCRIPTIVE STATISTICS FOR 1991 DATA SETS CONTAINING HOURLY-AVERAGE OZONE CONCENTRATIONS OBTAINED FROM SELECTED MONITORING SITES IN THE MIAMI STUDY AREA

Monitor ID	Monitor location	District code	Filled in?	n[a]	Percentiles, ppb					High values, ppb	
					50	90	95	99	99.5	Second	First
12-011-0003	Broward Co.	1	No	8624	22	42	48	59	63	93	94
			Yes	8760	22	42	48	59	63	93	94
12-011-2003	Pompano Beach	2	No	8664	23	41	46	58	64	91	96
			Yes	8760	23	41	46	58	63	91	96
12-011-8002	Dania	3	No	8732	26	43	49	61	64	95	100
			Yes	8760	26	43	49	61	64	95	100
12-025-0021	Dade Co.	4	No	8470	21	41	46	57	64	123	124
			Yes	8760	21	41	46	57	63	123	124
12-025-0027	Dade Co.	5	No	8486	28	44	49	58	65	90	95
			Yes	8760	28	44	49	57	64	90	95
12-025-0029	Dade Co.	6	No	8576	21	39	45	54	58	85	90
			Yes	8760	21	39	44	54	58	85	90

[a]Number of hourly-average ozone concentrations during designated ozone season.

TABLE 21. DESCRIPTIVE STATISTICS FOR 1991 DATA SETS CONTAINING HOURLY-AVERAGE OZONE CONCENTRATIONS OBTAINED FROM SELECTED MONITORING SITES IN THE NEW YORK STUDY AREA

Monitor ID	Monitor location	District code	Filled in?	n[a]	Percentiles, ppb					High values, ppb	
					50	90	95	99	99.5	Second	First
09-001-0017	Greenwich	1	No	4882	29	61	75	110	120	147	161
			Yes	5136	29	60	74	110	118	147	161
34-013-0011	Newark	2	No	5033	18	52	67	92	97	123	132
			Yes	5136	18	52	67	92	97	123	132
34-017-0006	Bayonne	3	No	4968	24	64	81	109	116	166	167
			Yes	5136	24	64	80	108	116	166	167
34-027-3001	Morris Co.	4	No	4691	39	75	88	111	118	137	139
			Yes	5136	39	73	86	111	118	137	139
34-039-5001	Plainfield	5	No	4986	19	55	69	90	97	115	120
			Yes	5136	20	55	68	90	96	115	120
36-001-0080	Bronx Co.	6	No	4422	12	36	47	68	72	92	94
			Yes	5136	13	36	45	67	72	92	94
36-061-0010	New York City	7,8	No	4893	14	43	58	87	95	151	155
			Yes	5136	14	42	57	87	95	151	155

(continued)

TABLE 21 (Continued)

Monitor ID	Monitor location	District code	Filled in?	n[a]	Percentiles, ppb					High values, ppb	
					50	90	95	99	99.5	Second	First
36-061-0063	New York City	b	No	4912	41	82	96	122	130	175	177
			Yes	5136	41	82	95	122	130	175	177
36-081-0004	Queens Co.	9	No	4912	20	57	72	105	115	162	174
			Yes	5136	20	57	72	105	115	162	174
36-085-0067	Richmond Co.	10	No	4086	28	67	81	106	116	169	178
			Yes	5136	29	62	77	103	111	169	178
36-103-0002	Babylon	11	No	4884	30	67	81	111	121	175	217
			Yes	5136	30	67	80	110	120	175	217
36-119-2004	White Plains	12	No	4975	27	62	78	107	116	145	152
			Yes	5136	27	61	78	107	116	145	152

[a]Number of hourly-average ozone concentrations during designated ozone season.
[b]Originally assigned to District 8. Replaced by Monitor No. 36-061-0010.

TABLE 22. DESCRIPTIVE STATISTICS FOR 1991 DATA SETS CONTAINING HOURLY-AVERAGE OZONE CONCENTRATIONS OBTAINED FROM SELECTED MONITORING SITES IN THE PHILADELPHIA STUDY AREA

Monitor ID	Monitor location	District code	Filled in?	n[a]	Percentiles, ppb					High values, ppb	
					50	90	95	99	99.5	Second	First
34-005-3001	McGuire AFB	1	No	4939	35	72	88	117	126	156	156
			Yes	5136	34	72	88	117	124	156	156
34-007-0003	Camden	2	No	4998	28	70	84	115	120	143	148
			Yes	5136	28	70	84	114	120	143	148
34-007-1001	Camden	3	No	4989	36	76	89	112	117	146	149
			Yes	5136	36	76	89	112	117	146	149
34-015-0002	Gloucester	4	No	5001	33	74	87	115	125	151	151
			Yes	5136	33	73	87	115	125	151	151
42-017-0012	Bristol	5	No	4986	28	70	84	111	119	139	144
			Yes	5136	28	70	84	110	118	139	144
42-045-0002	Chester	6	No	5085	30	67	78	103	108	125	135
			Yes	5136	30	67	78	103	108	125	135
42-091-0013	Norristown	7	No	4907	26	67	78	99	106	125	127
			Yes	5136	26	66	77	98	105	125	127

(continued)

TABLE 22 (Continued)

Monitor ID	Monitor location	Dist-rict code	Filled in?	n[a]	Percentiles, ppb					High values, ppb	
					50	90	95	99	99.5	Second	First
42-101-0014	Philadelphia	8	No	4900	30	70	80	100	110	140	140
			Yes	5136	30	70	80	100	110	140	140
42-101-0023	Philadelphia	9	No	4786	20	50	70	90	100	130	130
			Yes	5136	20	50	70	90	100	130	130
42-101-0024	Philadelphia	10	No	4984	30	70	80	110	110	130	140
			Yes	5136	30	70	80	110	110	130	140

[a]Number of hourly-average ozone concentrations during designated ozone season.

TABLE 23. DESCRIPTIVE STATISTICS FOR 1990 DATA SETS CONTAINING HOURLY-AVERAGE OZONE CONCENTRATIONS OBTAINED FROM SELECTED MONITORING SITES IN THE ST. LOUIS STUDY AREA

Monitor ID	Monitor location	District code	Filled in?	n[a]	Percentiles, ppb					High values, ppb	
					50	90	95	99	99.5	Second	First
17-163-0010	East St. Louis	1	No	4963	19	48	57	73	83	116	124
			Yes	5136	19	48	57	73	82	116	124
29-183-1002	St. Charles	2	No	4587	23	55	66	90	102	125	125
			Yes	5136	27	55	66	90	98	125	125
29-189-0001	Affton	3	No	4218	28	62	75	93	100	120	127
			Yes	5136	29	59	72	90	99	120	127
29-189-0006	St. Louis Co.	4	No	5038	24	48	55	70	75	99	100
			Yes	5136	24	48	55	69	75	99	100
29-189-3001	Clayton	5	No	5042	24	53	65	83	93	125	127
			Yes	5136	24	54	65	83	92	125	127
29-189-5001	Ferguson	6	No	5026	18	42	48	61	64	75	80
			Yes	5136	18	42	47	61	64	75	80
29-189-7001	St. Ann	7	No	5036	29	58	70	92	96	130	135
			Yes	5136	29	58	70	92	96	130	135

(continued)

TABLE 23 (Continued)

Monitor ID	Monitor location	District code	Filled in?	n[a]	Percentiles, ppb					High values, ppb	
					50	90	95	99	99.5	Second	First
29-510-0007	St. Louis	8	No	5008	18	44	52	69	74	96	96
			Yes	5136	18	44	52	69	74	96	96
29-510-0062	St. Louis	9	No	4928	24	53	63	82	89	108	111
			Yes	5136	24	53	63	82	89	108	111
29-510-0072	St. Louis	10	No	4830	18	40	48	64	72	100	110
			Yes	5136	18	40	48	64	72	100	110
29-510-0080	St. Louis	11	No	5044	24	53	64	86	94	117	129
			Yes	5136	24	53	65	86	94	117	129

[a]Number of hourly-average ozone concentrations during designated ozone season.

TABLE 24. DESCRIPTIVE STATISTICS FOR 1991 DATA SETS CONTAINING HOURLY-AVERAGE OZONE CONCENTRATIONS OBTAINED FROM SELECTED MONITORING SITES IN THE WASHINGTON STUDY AREA

Monitor ID	Monitor location	Dist-rict code	Filled in?	n[a]	Percentiles, ppb					High values, ppb	
					50	90	95	99	99.5	Second	First
11-001-0017	Washington	1	No	4928	19	54	64	82	91	137	147
			Yes	5136	19	54	64	82	90	137	147
11-001-0025	Washington	2	No	5031	24	61	72	90	99	144	148
			Yes	5136	24	60	71	90	99	144	148
24-031-3001	Rockville	3	No	4881	29	69	79	100	103	135	137
			Yes	5136	29	68	79	99	103	135	137
24-033-0002	Greenbelt	4	No	5034	30	74	87	110	115	148	153
			Yes	5136	30	74	87	109	114	148	153
24-033-8001	Suitland-Silver	5	No	4997	31	69	81	102	108	139	144
	Hills		Yes	5136	31	68	81	102	108	139	144
51-013-0020	Arlington Co.	6	No	5034	28	68	80	102	107	142	148
			Yes	5136	28	68	79	102	107	142	148
51-059-0018	Mt. Vernon	7	No	4897	30	71	83	106	111	126	142
			Yes	5136	30	71	83	105	111	126	142

(continued)

TABLE 24 (Continued)

Monitor ID	Monitor location	District code	Filled in?	n[a]	Percentiles, ppb					High values, ppb	
					50	90	95	99	99.5	Second	First
51-059-1004	Seven Corners	8	No	4951	33	71	86	110	119	174	178
			Yes	5136	33	71	86	109	116	174	178
51-059-5001	McLean	9	No	5037	27	63	73	95	104	137	138
			Yes	5136	27	63	74	95	101	137	138
51-510-0009	Alexandria	10	No	4916	22	54	65	84	95	131	132
			Yes	5136	22	54	65	84	94	131	132
51-600-0005	Fairfax	11	No	4947	33	66	77	97	107	131	132
			Yes	5136	32	66	76	96	106	131	132

[a]Number of hourly-average ozone concentrations during designated ozone season.

4.2 Treatment of Missing Values and Descriptive Statistics

Hourly average ozone data reported by each site were used to estimate the ambient ozone levels within the associated exposure district. Gaps in the hourly average ozone data sets were filled in by using a time series model developed by Johnson and Wijnberg[23] and previously applied to hourly average ozone data by Johnson et al.[15]. The model contains cyclical, autoregressive, and noise components whose parameters are determined from a statistical analysis of the reported data.

Tables 16 through 24 provide descriptive statistics for each hourly-average data set before and after application of the fill-in program. In general, the fill-in program has little or no effect on the listed percentiles or high values. Whenever there is a difference in the values for a particular percentile, the filled-in value is usually lower.

It should be noted that the data sets differ in terms of concentration resolution. The reported ozone concentration values for all 11 Houston sites and for 15 of the 16 Los Angeles sites are rounded to the nearest 10 ppb. The data for the other seven cities are rounded to the nearest 1 ppb. All other factors being equal, the algorithm used to fill in missing values generally performs better when applied to air quality data of high resolution.

Researchers also constructed a data set for each monitor listing eight-hour running average ozone concentrations based on the filled-in data sets. These data were used to determine each site's status with respect to various eight-hour NAAQS under consideration by EPA. Tables 25 through 33 provide eight-hour descriptive statistics for the monitors selected to represent each city.

TABLE 25. DESCRIPTIVE STATISTICS FOR 1991 DATA SETS CONTAINING EIGHT-HOUR OZONE CONCENTRATIONS OBTAINED FROM SELECTED MONITORING SITES IN THE CHICAGO STUDY AREA

Monitor ID	Monitor location	District code	Percentiles, ppb					High values, ppb	
			50	90	95	99	99.5	Second	First
17-031-0001	Alsip	1	20	46	54	69	75	94	95
17-031-002	Chicago	2	28	54	63	80	84	106	107
17-031-1003	Chicago	3	19	46	55	71	76	101	101
17-031-1601	Lemont	4	28	57	66	82	88	108	109
17-031-4002	Cicero	5	18	45	54	70	75	95	95
17-031-4003	Des Plaines	6	24	48	57	72	77	93	95
17-031-7002	Evanston	7	30	55	64	83	86	101	102
17-031-8003	Calumet City	8	24	49	58	74	78	90	90
17-043-6001	Lisle	9	20	45	53	70	79	98	98
17-089-0005	Elgin	10	26	50	58	74	82	106	106
17-097-0001	Deerfield	11	26	52	61	77	83	101	103
17-097-1002	Waukegan	12	31	58	66	84	88	104	106

TABLE 26. DESCRIPTIVE STATISTICS FOR 1990 DATA SETS CONTAINING EIGHT-HOUR OZONE CONCENTRATIONS OBTAINED FROM SELECTED MONITORING SITES IN THE DENVER STUDY AREA

Monitor ID	Monitor location	District code	Percentiles, ppb					High values, ppb	
			50	90	95	99	99.5	Second	First
08-001-3001	Adams Co.	1	26	47	52	60	63	72	74
08-005-0002	Arapaho Co.	2	38	56	62	76	80	87	87
08-005-0003	Englewood	3	24	48	54	65	70	83	83
08-013-1001	Boulder Co.	4	33	50	57	68	71	83	85
08-031-0002	Denver	5	18	35	41	51	54	84	85
08-031-0014	Denver	6	23	47	52	62	64	77	80
08-059-0002	Arvada	7	26	50	57	68	72	95	96

TABLE 27. DESCRIPTIVE STATISTICS FOR 1990 DATA SETS CONTAINING EIGHT-HOUR OZONE CONCENTRATIONS OBTAINED FROM SELECTED MONITORING SITES IN THE HOUSTON STUDY AREA

Monitor ID	Monitor location	District code	Percentiles, ppb					High values, ppb	
			50	90	95	99	99.5	Second	First
48-201-0024	Harris Co.	1	21	50	64	92	104	149	150
48-201-0029	Harris Co.	2	21	49	61	89	96	124	124
48-201-0046	Houston	3	14	42	53	84	95	151	152
48-201-0047	Houston	4	15	42	55	82	96	156	164
48-201-0051	Houston	5	21	48	61	92	105	167	170
48-201-0059	Houston	6	14	33	41	60	71	110	112
48-201-0062	Houston	7	17	41	52	79	90	154	155
48-201-1003	Deer Park	8	19	46	56	84	92	139	140
48-201-1034	Houston	9	16	41	54	81	90	144	146
48-201-1035	Houston	10	15	42	56	86	97	156	157
48-201-1037	Houston	11	12	39	51	81	92	160	164

TABLE 28. DESCRIPTIVE STATISTICS FOR 1991 DATA SETS CONTAINING EIGHT-HOUR OZONE CONCENTRATIONS OBTAINED FROM SELECTED MONITORING SITES IN THE LOS ANGELES STUDY AREA

Monitor ID	Monitor location	District code	Percentiles, ppb					High values, ppb	
			50	90	95	99	99.5	Second	First
06-037-0016	Glendora	1	24	70	95	135	150	181	182
06-037-1103	Los Angeles	2	14	47	60	85	92	120	120
06-037-1301	Lynwood	3	12	34	41	62	67	86	89
06-037-1601	Pico Rivera	4	12	51	67	97	111	142	146
06-037-1902	Santa Monica	5	27	58	69	93	101	155	155
06-037-2005	Pasadena	6	18	62	84	120	130	165	166
06-037-4002	Long Beach	7	17	35	42	56	61	82	83
06-037-5001	Hawthorne	8	21	46	51	67	76	96	99
06-059-0001	Anaheim	9	17	42	52	77	85	119	119
06-059-1003	Costa Mesa	10	25	47	55	71	76	101	102
06-059-3002	Los Alamitos	11	25	50	59	75	80	97	99
06-059-5001	La Habra	12	17	50	62	90	100	129	132
06-065-8001	Rubidoux	13	24	76	97	139	155	194	196
06-071-1004	Upland	14	16	61	84	124	134	164	165
06-071-4003	Redlands	15	30	86	110	152	162	197	197
06-071-9004	San Bernardino	16	19	74	96	135	146	192	192

TABLE 29. DESCRIPTIVE STATISTICS FOR 1991 DATA SETS CONTAINING EIGHT-HOUR OZONE CONCENTRATIONS OBTAINED FROM SELECTED MONITORING SITES IN THE MIAMI STUDY AREA

Monitor ID	Monitor location	District code	Percentiles, ppb					High values, ppb	
			50	90	95	99	99.5	Second	First
12-011-0003	Broward Co.	1	22	39	44	54	56	76	77
12-011-2003	Pompano Beach	2	22	39	44	52	54	71	72
12-011-8002	Dania	3	25	42	47	56	59	71	72
12-025-0021	Dade Co.	4	21	37	43	52	55	77	79
12-025-0027	Dade Co.	5	27	43	47	55	58	77	80
12-025-0029	Dade Co.	6	21	37	42	51	53	73	73

TABLE 30. DESCRIPTIVE STATISTICS FOR 1991 DATA SETS CONTAINING EIGHT-HOUR OZONE CONCENTRATIONS OBTAINED FROM SELECTED MONITORING SITES IN THE NEW YORK STUDY AREA

Monitor ID	Monitor location	District code	Percentiles, ppb					High values, ppb	
			50	90	95	99	99.5	Second	First
09-001-0017	Grenwich	1	29	57	67	95	103	125	126
34-013-0011	Newark	2	19	46	59	82	89	102	103
34-017-0006	Bayonne	3	25	58	72	95	103	112	112
34-027-3001	Morris Co.	4	39	70	82	100	109	125	125
34-039-5001	Plainfield	5	21	50	61	80	88	109	109
36-001-0080	Bronx Co.	6	14	32	41	56	59	69	71
36-061-0010	New York City	7,8	15	39	50	73	79	102	102
36-061-0063	New York City	a	41	79	90	113	122	133	135
36-081-0004	Queens Co.	9	21	51	64	90	99	119	119
36-085-0067	Richmond Co.	10	29	58	71	95	101	135	136
36-103-0002	Babylon	11	30	62	73	97	104	129	129
36-119-2004	White Plains	12	27	58	70	94	105	125	127

[a]Originally assigned to District 8; represented by Monitor No. 36-061-0010.

TABLE 31. DESCRIPTIVE STATISTICS FOR 1991 DATA SETS CONTAINING EIGHT-HOUR OZONE CONCENTRATIONS OBTAINED FROM SELECTED MONITORING SITES IN THE PHILADELPHIA STUDY AREA

Monitor ID	Monitor location	District code	Percentiles, ppb					High values, ppb	
			50	90	95	99	99.5	Second	First
34-005-3001	McGuire AFB	1	34	67	80	107	114	138	141
34-007-0003	Camden	2	28	64	76	101	109	129	131
34-007-1001	Camden Co.	3	37	71	81	103	107	124	125
34-015-0002	Gloucester	4	33	68	80	105	113	135	135
42-017-0012	Bristol	5	28	64	76	100	104	115	116
42-045-0002	Chester	6	30	62	72	92	98	113	114
42-091-0013	Norristown	7	26	60	70	92	98	118	118
42-101-0014	Philadelphia	8	31	65	76	96	100	125	127
42-101-0023	Philadelphia	9	21	49	60	79	86	112	114
42-101-0024	Philadelphia	10	27	61	72	97	103	116	116

TABLE 32. DESCRIPTIVE STATISTICS FOR 1990 DATA SETS CONTAINING EIGHT-HOUR OZONE CONCENTRATIONS OBTAINED FROM SELECTED MONITORING SITES IN THE ST. LOUIS STUDY AREA

Monitor ID	Monitor location	District code	Percentiles, ppb					High values, ppb	
			50	90	95	99	99.5	Second	First
17-163-0010	East St. Louis	1	20	43	51	66	70	98	99
29-183-1002	St. Charles	2	26	50	59	78	85	110	110
29-189-0001	Affton	3	30	54	64	80	85	100	103
29-189-0006	St. Louis Co.	4	24	44	50	62	67	85	86
29-189-3001	Clayton	5	25	49	58	76	80	93	94
29-189-5001	Ferguson	6	19	39	44	54	56	62	63
29-189-7001	St. Ann	7	29	54	64	81	84	101	104
29-510-0007	St. Louis	8	19	40	48	60	65	76	77
29-510-0062	St. Louis	9	25	48	57	73	77	89	91
29-510-0072	St. Louis	10	19	37	43	56	61	83	85
29-510-0080	St. Louis	11	25	50	60	76	83	99	100

TABLE 33. DESCRIPTIVE STATISTICS FOR 1991 DATA SETS CONTAINING EIGHT-HOUR OZONE CONCENTRATIONS OBTAINED FROM SELECTED MONITORING SITES IN THE WASHINGTON STUDY AREA

Monitor ID	Monitor location	District code	Percentiles, ppb					High values, ppb	
			50	90	95	99	99.5	Second	First
11-001-0017	Washington	1	20	48	58	73	78	120	120
11-001-0025	Washington	2	25	55	64	79	85	114	117
24-031-3001	Rockville	3	30	62	71	88	93	113	113
24-033-0002	Greenbelt	4	31	68	79	96	102	129	131
24-033-8001	Suitland S.H.	5	32	63	73	90	94	124	125
51-013-0020	Arlington Co.	6	29	61	72	91	97	127	128
51-059-0018	Mt. Vernon	7	30	65	75	92	99	110	112
51-059-1004	Seven Corners	8	33	66	77	97	102	147	147
51-059-5001	McLean	9	28	56	65	81	89	115	115
51-510-0009	Alexandria	10	23	50	59	75	82	111	111
51-600-0005	Fairfax	11	33	61	70	88	96	110	111

SECTION 5

ADJUSTMENT OF OZONE DATA TO SIMULATE COMPLIANCE WITH ALTERNATIVE AIR QUALITY STANDARDS

In applying pNEM/O3 to a particular study area, the analyst typically defines the air quality conditions within the area as representing (1) baseline conditions or (2) conditions in which the area just attains a specific National Ambient Air Quality Standard (NAAQS). In the analyses described in this report, fixed-site monitoring data for the years 1990 and 1991 were used to represent baseline conditions for each of the nine study areas. Special air quality adjustment procedures (AQAP's) were used to adjust the baseline data to simulate conditions in which each study area just attains a specific NAAQS.

EPA identified the following NAAQS formulations for assessment:

1. One hour daily maximum - one expected exceedance (1H1EX): the expected number of daily maximum one-hour ozone concentrations exceeding the specified value shall not exceed one.

   Standard level: 120 ppb (the current NAAQS for ozone)

2. Eight-hour daily maximum - one expected exceedance (8H1EX): the expected number of daily maximum eight-hour ozone concentrations exceeding the specified value shall not exceed one.

   Standard levels: 80 ppb, 100 ppb

3. Eight-hour daily maximum - five expected exceedances (8H5EX): the expected number of daily maximum eight-hour ozone concentrations exceeding the specified value shall not exceed five.

   Standard levels: 60 ppb, 80 ppb

A separate AQAP was developed for each of the three classes of NAAQS (1H1EX, 8H1EX, and 8H5EX).

Each AQAP consisted of the following four steps:

1. Specify an air quality indicator (AQI) to be used in evaluating the status of a monitoring site with respect to the NAAQS of interest.

2. Determine the value of the AQI for each site within the study area under baseline conditions.

3. Determine the value of the AQI under conditions in which the air pollution levels within the study area have been reduced until the site with the highest pollution levels just attains a specified NAAQS.

4. Adjust the one-hour values of the baseline data set associated with each site to yield the AQI value determined in Step 3. The adjusted data set should retain the temporal profile of the baseline data set.

Subsection 5.1 discusses the specification of appropriate AQI's (Step 1) and the determination of baseline AQI values (Step 2). Subsection 5.2 presents the methods used to estimate AQI's under attainment conditions (Step 3). Subsection 5.3 describes the procedures used in Step 4 to adjust one-hour data to simulate significant reductions in ozone levels within a study area. More detailed descriptions of these procedures can be found in Appendices A and B. Subsection 5.4 provides examples in which the procedures described in Subsection 5.3 were applied to Philadelphia. Subsection 5.5 presents an alternative procedure which analysts used to adjust one-hour data to simulate small changes (decreases or increases) in ozone levels within a study area. This procedure was applied to Denver, Chicago, and Miami for selected NAAQS formulations.

5.1 Specification of AQI and Estimation of Baseline AQI Values

The following AQI's were selected for evaluating the 1H1EX, 8H1EX, and 8H5EX standards.

1H1EX: the characteristic largest daily maximum one-hour ozone concentration

8H1EX: the characteristic largest daily maximum eight-hour ozone concentration

8H5EX: the observed sixth largest daily maximum eight-hour ozone concentration.

Note that a statistical AQI (the characteristic largest value) was specified for the 1H1EX and 8H1EX standards, whereas a deterministic AQI (the observed sixth largest value) was used for the 8H5EX standards. Analysts elected to use statistical AQI's for the 1H1EX and 8H1EX standards because such indicators are less affected by anomalous high values than the corresponding deterministic AQI (the second highest observed value). A statistical indicator was not considered necessary for the 8H5EX standards, as the sixth highest observed value is relatively unaffected by anomalous high values.

The characteristic largest value (CLV) of a distribution is that value expected to be exceeded once in n observations. If F(x) is the cumulative distribution of x, then

$$F(x) = 1 - \frac{1}{n} \tag{43}$$

when x is the CLV.

Selection of an appropriate cumulative distribution to fit data is important in determining a reasonable CLV. Two distributions that often provide close fits to ambient air quality data are the Weibull and the lognormal. The Weibull distribution is defined as

$$F(x) = 1 - \exp\left[-\left(\frac{x}{\delta}\right)^{k}\right] \tag{44}$$

where δ is the scale parameter and k is the shape parameter. The lognormal distribution is defined as

$$F(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{w} \exp\left(-t^2/2\right)\, dt \tag{45}$$

where

and ln x is distributed normally with mean μ and variance σ^2. As discussed in previous reports, the Weibull distribution generally provides a better fit to hourly

$$w = \frac{\ln x - \mu}{\sigma} \qquad (46)$$

average ozone data.[15]

The hourly average values reported by a single monitoring site during a specified ozone season form a time series x_t (t = 1, 2, 3, ..., n). If the hourly average time series is complete, it will contain n = (24)(N) values, where N is the number of days in the ozone season. From this time series a second time series of daily maximum 1-hour values can be constructed.

Assume that a Weibull distribution with parameters δ and k provides a good fit to the empirical distribution of hourly average values. If one disregards autocorrelation, the value expected to be exceeded once in n = (24)(N) hours can be estimated as

$$CLVOH = \delta\ [\ln(24)(N)]^{1/k}. \qquad (47)$$

This is the characteristic largest one-hour value. If we again disregard autocorrelation, the daily maximum 1-hour value expected to be exceeded once in N days can be estimated as

$$CLVOHDM = \delta\{-\ln[1 - (\frac{N-1}{N})^{1/24}]\}^{1/k}. \qquad (48)$$

This is the characteristic largest daily maximum one-hour value. For 7-month and 12-month ozone seasons, N is equal to 214 and 365, respectively. For these values of N, CLVOH and CLVOHDM are virtually indistinguishable in value over the range in k values typically found in ozone data ($0.6 < k < 2.5$). For example, the following values were calculated using δ = 40 ppb.

N	k	CLVOH	CLVOHDM
214	0.6	1428	1428
	1.4	185	185
	2.5	94	94
365	0.6	1580	1580
	1.4	193	193
	2.5	97	97

The CLVOH and CLVOHDM values match to the nearest ppb. Consequently, the expression

$$CLVOHDM \doteq \delta\ [\ln(24)(N)]^{1/k} \tag{49}$$

can be used as an alternative to Equation 48 for calculating CLVOHDM. The quantity calculated by Equation 49, hearafter denoted by CLV1, was selected as the AQI to be used in evaluating the status of a monitoring site with respect to a particular 1H1EX standard.

A data set containing one-hour concentration values can be processed to determine a corresponding data set containing eight-hour running average values. If a Weibull distribution is fit to the eight-hour data, one can determine a characteristic largest eight-hour value by the equation

$$CLVEH = \delta[\ln(24)N)]^{1/k}, \tag{50}$$

where δ and k are the Weibull parameters for the eight-hour fit. Based on the argument made above for one-hour data, this value should be approximately equal to the characteristic largest daily maximum eight-hour value (CLVEHDM) of the data set. For simplicity, the term CLV8 is hereafter used to refer to the quantity calculated by Equation 50. CLV8 was selected as the AQI to be used in evaluating attainment status with respect to a particular 8H1EX standard.

Table 34 lists the data sets selected to represent baseline conditions in each of the nine cities under analysis. Table 34 also provides estimates of CLV1 and CLV8

TABLE 34. BASELINE AIR QUALITY INDICATORS FOR NINE CITIES

City	Year	District	Ozone concentration, ppb		
			CLV1	CLV8	EH6LDM
Chicago	1991	1	109	94	78
		2	124	107	86
		3	123	106	77
		4	134	114	90
		5	120	99	78
		6	111	97	79
		7	119	106	89
		8	104	92	78
		9	122	106	82
		10	127	111	83
		11	122	106	85
		12	131	111	91
Denver	1990	1	91	74	67
		2	116	94	84
		3	114	85	73
		4	103	86	74
		5	98	79	56
		6	117	78	65
		7	109	94	75
Houston	1990	1	224	162	116
		2	182	137	110
		3	241	161	110
		4	224	171	107
		5	227	179	124
		6	180	131	86
		7	208	165	104
		8	207	143	99
		9	231	154	101
		10	235	171	116
		11	232	167	107

(Continued)

Table 34 (Continued)

City	Year	District	Ozone concentration, ppb		
			CLV1	CLV8	EH6LDM
Los Angeles	1991	1	321	207	170
		2	185	133	109
		3	148	99	75
		4	271	166	129
		5	215	162	115
		6	248	172	146
		7	116	85	64
		8	136	104	84
		9	198	121	94
		10	153	101	81
		11	167	100	87
		12	216	134	110
		13	264	209	167
		14	266	184	146
		15	261	215	180
		16	249	204	165
Miami	1991	1	90	74	60
		2	97	74	60
		3	93	72	64
		4	105	82	59
		5	96	80	65
		6	87	72	57
New York	1991	1	158	135	108
		2	121	112	91
		3	153	133	113
		4	143	134	105
		5	123	113	88
		6	97	75	64
		7	141	108	83
		8[a]	141	108	83
		9	162	131	104
		10	170	143	101
		11	183	140	107
		12	148	137	105

(Continued)

Table 34 (Continued)

City	Year	District	Ozone concentration, ppb		
			CLV1	CLV8	EH6LDM
Philadelphia	1991	1	167	142	116
		2	149	136	113
		3	153	128	111
		4	162	138	115
		5	145	120	107
		6	134	118	101
		7	135	123	102
		8	140	128	104
		9	131	116	90
		10	141	126	102
St. Louis	1990	1	124	100	73
		2	141	116	88
		3	131	106	87
		4	103	87	68
		5	122	97	81
		6	78	65	59
		7	124	103	87
		8	100	79	67
		9	114	91	80
		10	103	84	64
		11	119	104	86
Washington	1991	1	134	110	80
		2	135	113	88
		3	130	113	95
		4	143	128	106
		5	141	119	98
		6	143	123	100
		7	135	118	104
		8	169	143	102
		9	141	120	91
		10	134	112	85
		11	145	123	100

[a]Districts 7 and 8 in New York are represented by the same ozone monitor (Monitor No. 36-061-0010).

based on Weibull fits to the upper two percent of each data set. These values were used as estimates of CLV1 and CLV8 representing baseline conditions.

As previously indicated, the sixth largest daily maximum 8 hour value (denoted EH6LDM) was used to evaluate the status of a monitoring site with respect to a particular 8H5EX standards. Table 34 lists the baseline value of this AQI for each site in the nine cities under analysis.

5.2 Estimation of AQI's Under Attainment Conditions

Tables 35, 36, and 37 provide the step-by-step procedures followed in implementing the AQAP's developed respectively for 1H1EX, 8H1EX, and 8H5EX NAAQS. In general, each AQAP assumed that the i-th ranked site (ranking determined by baseline AQI) will undergo a change in its AQI value proportional to the change required for the highest ranked site to exactly attain the specified standard. The ranking assigned to a particular site under attainment conditions was determined by the site's average ranking over five years, rather than the site's ranking under baseline conditions. Consequently, the site ranked highest under baseline conditions was not necessarily the highest ranked site under attainment conditions. Evaluation of representative ozone data suggested that a site's future ranking could be better predicted from its long-term average rank than from a single year's ranking.

Steps 1 through 4 in each table comprise the procedures used to estimate the value of an attainment AQI value for each site in a particular city. Each attainment AQI was converted to a corresponding characteristic one-hour largest value under attainment (ACLV1). For 1H1EX standards (Table 35), the value of ACLV1 determined by Step 4 was used without further adjustment as the value of ACLV1 required in subsequent steps. For 8H1EX standards (Table 36), the value of ACLV8 determined in Step 4 was converted to the required ACLV1 value through the use of an equivalence relationship (Step 5). The equivalence relationship was

$$ACLV1 = (RATIO1)(ACLV8) \qquad (54)$$

where RATIO1 varied with city (Table 38).

TABLE 35. AIR QUALITY ADJUSTMENT PROCEDURE USED TO SIMULATE ATTAINMENT OF 1H1EX NAAQS (THE EXPECTED NUMBER OF DAILY MAXIMUM ONE-HOUR OZONE CONCENTRATIONS EXCEEDING THE SPECIFIED VALUE SHALL NOT EXCEED ONE)

1. Determine the following quantities.

   CLV1(i,j): the CLV1 of i-th ranked site in City j for the "baseline" or "start" year.

   MAXCLV1(j): the largest CLV1 of all sites in City j for the baseline year.

   AMAXCLV1(j): the largest CLV1 value permitted under the proposed 1-hr NAAQS.

2. Select five years prior to the baseline year and determine the value of CLV1 (or related air quality indicator) at each site m in City j for each year. Rank these values by city and year. Let RANK(m,j,y) indicate the rank of site m in city j in year y. Let MEANRANK(m,j) indicate the mean value of RANK(m,j,y) over the five years. Rank the MEANRANK(m,j) values and let RELRANK(m,j) indicate the relative rank of MEANRANK(m,j).

3. Calculate an adjusted CLV1 for the i-th ranked site in City j by the expression

$$ACLV1(i,j) = [CLV1(i,j)][AMAXCLV1(j)]/[MAXCLV1(j)]. \quad (51)$$

4. If RELRANK(m,j) = i, then m will be the i-th ranked site in City j under attainment. That is,

   ACLV1(m,j) = ACLV1(i,j) if RELRANK(m,j) = i.

5. The 1-hour data at Site m under attainment will be determined by adjusting the 1-hour data at Site m in the baseline year. A Weibull distribution fit to the adjusted data will have a CLV1 equal to ACLV1(i,j) where i = RELRANK(m,j). Subsection 5.3 provides a method for estimating the parameters of this distribution and for making the adjustment.

TABLE 36. AIR QUALITY ADJUSTMENT PROCEDURE USED TO SIMULATE ATTAINMENT OF 8H1EX NAAQS (THE EXPECTED NUMBER OF DAILY MAXIMUM EIGHT-HOUR OZONE CONCENTRATIONS EXCEEDING THE SPECIFIED VALUE SHALL NOT EXCEED ONE)

1. Determine the following quantities.

   CLV8(i,j): the eight-hour CLV of i-th ranked site in City j for the "baseline" or "start" year.

   MAXCLV8(j): the largest CLV8 of all sites in City j for the baseline year.

   AMAXCLV8(j): the largest CLV8 value permitted under the proposed 8-hr NAAQS.

2. Select five years prior to the baseline year and determine the value of CLV8 (or related air quality indicator) at each site m in City j for each year. Rank these values by city and year. Let RANK(m,j,y) indicate the rank of site m in city j in year y. Let MEANRANK(m,j) indicate the mean value of RANK(m,j,y) over the five years. Rank the MEANRANK(m,j) values and let RELRANK(m,j) indicate the relative rank of MEANRANK(m,j).

3. Calculate an adjusted CLV8 for the i-th ranked site in City j by the expression

$$ACLV8(i,j) = [CLV8(i,j)][AMAXCLV8(j)]/[MAXCLV8(j)]. \quad (52)$$

4. If RELRANK(m,j) = i, then m will be the i-th ranked site in City j under attainment. That is,

   ACLV8(m,j) = ACLV8(i,j) if RELRANK(m,j) = i.

5. Using Equation 54, estimate the CLV1 associated with each ACLV8(m,j) value. Denote this value as ACLV1(m,j).

6. The 1-hour data for Site m under attainment of the 8-hr NAAQS will be determined by adjusting the 1-hour data for Site m in the baseline year. A Weibull distribution fit to the adjusted data will have a CLV1 equal to ACLV1(i,j) where i = RELRANK(m,j). Subsection 5.3 provides a method for estimating the parameters of this distribution and for making the adjustment.

TABLE 37. AIR QUALITY ADJUSTMENT PROCEDURE USED TO SIMULATE ATTAINMENT OF 8H5EX NAAQS (THE EXPECTED NUMBER OF DAILY MAXIMUM EIGHT-HOUR OZONE CONCENTRATIONS EXCEEDING THE SPECIFIED VALUE SHALL NOT EXCEED FIVE)

1. Determine the following quantities.

   EH6LDM(i,j): the EH6LDM of the i-th ranked site in City j for the baseline year,

   MAXEH6LDM(j): the largest EH6LDM of all sites in City j for the baseline year.

   AMAXEH6LDM(j): the largest EH6LDM value permitted under the proposed 1-hr NAAQS.

2. Select five years prior to the baseline year and determine the value of EH6LDM (or related air quality indicator) at each site m in City j for each year. Rank these values by city and year. Let RANK(m,j,y) indicate the rank of site m in city j in year y. Let MEANRANK(m,j) indicate the mean value of RANK(m,j,y) over the n years. Rank the MEANRANK(m,j) values and let RELRANK(m,j) indicate the relative rank of MEANRANK(m,j).

3. Calculate an adjusted EH6LDM for the i-th ranked site in City j by the expression

$$AEH6LDM(i,j) = [EH6LDM(i,j)][(AMAXEH6LDM(j)/[MAXEH6LDM(j)]. \quad (53)$$

4. If RELRANK(m,j) = i, then m will be the i-th ranked site in City j under attainment. That is,

$$AEH6LDM(m,j) = AEH6LDM(i,j) \text{ if } RELRANK(m,j) = i.$$

5. Using Equation 55, estimate the CLV1 associated with each AEH6LDM(m,j) value. Denote this value as ACLV1(m,j).

6. The 1-hour data for Site m under attainment of the 8H5EX NAAQS will be determined by adjusting the 1-hour data for Site m in the baseline year. A Weibull distribution fit to the adjusted data will have a CLV1 equal to ACLV1(i,j) where i = RELRANK(m,j). Subsection 5.3 provides a method for estimating the parameters of this distribution and for making the adjustment.

A similar method was employed for 8H5EX standards (Table 37). The value of AEH6LDM determined in Step 4 was converted to the required ACLV1 value through the use of an equivalence relationship (Step 5). In this case, the equivalence relationship was

$$ACLV1 = (RATIO2)(AEH6LDM) \tag{55}$$

where RATIO2 varied with city (Table 38).

Through these procedures, a distinct ACLV1 value was assigned to each site for each standard under evaluation. This ACLV1 value was subsequently used to construct an attainment one-hour data set using the procedures described in Subsection 5.3.

5.3 Adjustment of One-Hour Ozone Data Sets

After a site's attainment ACLV1 value was determined, the baseline one-hour data set associated with the site was adjusted hour-by-hour to create an attainment one-hour data set. A two-stage adjustment procedure was employed. In the first stage, the baseline one-hour data were adjusted to produce an initial attainment data set that had the specified ACLV1 value. In the second stage, the initial data set was "fine-tuned" to produce a final attainment data set having the exact AQI value specified for the site.

5.3.1 Initial Adjustment for All Standards

The initial adjustment equation was

$$y_t = (a)(x_t)^b \tag{56}$$

where x_t was the baseline ozone concentration for hour t and y_t was the attainment ozone concentration for hour t. The terms a and b were "adjustment coefficients" specific to the site and to the standard being attained.

The adjustment equation was based on the general assumption that Weibull distributions would provide good fits to the one-hour data sets under baseline and attainment conditions. A Weibull distribution can be completely characterized through the use of a shape parameter (k) and a scale parameter (δ). The baseline values of k and δ were determined by applying a special maximum likelihood fitting algorithm to each one-hour baseline data set. The attainment value of k (k') was estimated by the empirically-derived equation

$$1/k' = -0.2389 + (0.003367)(ACLV1) + (0.4726)(1/k) \tag{57}$$

where ACLV1 was the estimated value of CLV1 under attainment conditions and k was the baseline k value. The attainment value of δ (δ') was then determined by the identity equation

$$\delta' = (ACLV1)/[\ln(n)]^{1/k'} \tag{58}$$

where n was the number of one-hour values in the exposure period.

The unadjusted data set was treated as a time series where x_t represented the one-hour value at time t. The corresponding adjusted data set was constructed through the use of the expression

$$y_t = (\delta')(x_t/\delta)^{k/k'} \tag{59}$$

where y_t was the adjusted one-hour value at time t. This expression incorporates the assumption that the time series y_t at a site after attainment is related to the original time series x_t in such a way that 1) the rank of the one-hour value at each time t is unchanged, 2) the x_t values follow a Weibull distribution with parameters δ and k, and 3) the y_t values follow a Weibull distribution with parameters δ' and k'. These assumptions are discussed in Appendix A. Equation 59 can be restated as Equation 56 above with the substitutions

$$a = (\delta')/(\delta)^{k/k'} \tag{60}$$

$$b = k/k'. \tag{61}$$

TABLE 38. VALUES FOR EQUIVALENCE RELATIONSHIPS

City	RATIO1[a]	RATIO2[b]
Chicago	1.155	1.441
Denver	1.234	1.453
Houston	1.374	2.091
Los Angeles	1.444	1.846
Miami	1.248	1.513
New York	1.178	1.436
Philadelphia	1.132	1.367
St. Louis	1.226	1.506
Washington	1.179	1.450

[a]RATIO1 = (ACLV1)/(ACLV8).
[b]RATIO2 = (ACLV1)/(EH6LDM).

5.3.2 Final adjustment for Eight-hour Standards

When applied to the 8H1EX standards, the initial adjustment procedure described above produced a one-hour data set with a CLV1 value that exactly matched the specified CLV1. Because the assumed relationship between CLV1 and CLV8 was only an approximation, the CLV8 value of the adjusted data set did not always match the attainment CLV8 value specified for the site. Consequently, analysts made a final "fine-tuning" adjustment to the one-hour data to obtain the exact CLV8 value specified. The following final adjustment equation was used.

$$\text{Adjusted } y_t = (y_t)(\text{Target attainment CLV8})/(\text{Initial attainment CLV8}) \qquad (62)$$

In this equation, y_t is the one-hour value for hour t after the initial adjustment procedure (Equation 56). The "initial attainment CLV8" is the CLV8 value of this data set. The "target attainment CLV8" is the attainment CLV8 value assigned to the site by the procedure summarized in Table 36.

A similar fine-tuning procedure was employed for the 8H5EX standards. The final adjustment equation was

$$\text{Adjusted } y_t = (y_t)(\text{Target attainment EH6LDM})/(\text{Initial attainment EH6LDM}) \qquad (63)$$

The "initial attainment EH6LDM" is the EH6LDM value of the site after the initial adjustment (Equation 56). The "target attainment EH6LDM" is the attainment EH6LDM value assigned to the site by the procedure summarized in Table 37.

5.4 Application of the AQAP's to Philadelphia

To test the reasonableness of the AQAP's described above, each was initially applied to Philadelphia. Three attainment scenarios were evaluated:

1H1EX-120: One-hour daily maximum, one expected exceedance of 120 ppb

8H1EX-80: Eight-hour daily maximum, one expected exceedance of 80 ppm

8H5EX-80: Eight-hour daily maximum, five expected exceedances of 80 ppb.

In each case, baseline conditions were represented by filled-in 1991 ozone data obtained from the 10 monitoring sites listed in Table 22.

5.4.1 Attainment of 1H1EX-120 Standard

The AQAP summarized in Table 35 was applied to Philadelphia for the purpose of simulating the attainment of the 1H1EX-120 ppb standard. Table 39 presents the results of each step. In this example, baseline conditions in Philadelphia were assumed to be represented by 1991 ozone data as reported by the 10 monitoring sites listed for Philadelphia in Table 22.

Analysts initiated the AQAP by fitting a Weibull distribution to the filled-in 1991 one-hour data set associated with each Philadelphia monitoring site. Each fit produced estimates of the Weibull parameters (k and δ) and the CLV1. The largest CLV1 for 1991 was associated with District 1 (167 ppb).

To exactly attain the specified NAAQS, the largest CLV1 must equal 120 ppb. Consequently, Equation 51 (Step 3, Table 35) was implemented as

TABLE 39. DETERMINATION OF ADJUSTMENT COEFFICIENTS FOR ONE-HOUR NAAQS ATTAINMENT (1H1EX-120) IN PHILADELPHIA

	Weibull fit to 1991 1-hr data			1-hr NAAQS attainment parameters[a]				Adjustment coefficients	
District	k	δ	CLV1	Adjusted CLV1	Reassigned CLV1	k′	δ′	a	b
1	1.69	46.9	167	120	107	2.494	45.27	3.336	0.678
2	2.21	56.4	149	107	110	2.896	52.44	2.417	0.763
3	1.96	51.0	153	110	116	2.546	49.95	2.420	0.770
4	1.81	49.3	162	116	120	2.346	48.09	2.377	0.772
5	2.28	56.6	145	104	104	3.139	52.51	2.800	0.726
6	2.23	51.2	134	96	101	3.194	51.60	3.305	0.698
7	1.93	44.3	135	97	94	3.101	47.06	4.447	0.622
8	2.14	51.2	140	101	101	3.106	50.62	3.361	0.689
9	1.74	38.1	131	94	96	2.809	44.74	4.694	0.619
10	2.26	54.5	141	101	97	3.369	51.31	3.511	0.671

[a]Assumes maximum CLV1 equals 120 ppb.

$$ACLV1(i,j) = [CLV1(i,j)](120/167) = [CLV(i,j)](0.719). \quad (64)$$

Applying this expression to each 1991 CLV1 produced 10 ACLV1's representing attainment conditions. These values are listed in the column labeled "adjusted CLV1." These values were then reassigned to the Philadelphia districts according to the five-year ranking determined for each district. Thus, the largest adjusted CLV1 (120 ppb) was assigned to District 4 because District 4 had the highest five-year ranking. Similarly, the second largest adjusted CLV1 (116 ppb) was assigned to District 3 because District 3 had the second highest five-year ranking.

In this example, the five-year ranking of each site was determined by analyzing second-high daily maximum one-hour ozone concentrations reported by the site over a recent five-year period. Second-high daily maximum values were used in this step rather than CLV1's because they were easier to obtain from standard EPA reports.

Analysts next used Equations 57 and 58 to estimate site-specific values for k' and δ', the values of the Weibull parameters under attainment conditions. For District 1, the substitution of k = 1.69, ACLV1 = 107 ppb, and n = 5136 produced the estimates k' = 2.494 and δ' = 45.27 ppb. These values were substituted into Equations 60 and 61 to produce the values of the adjustment coefficients listed in Table 39 for District 1 (a = 3.336 and b = 0.678).

A one-hour ozone data set representing attainment conditions was constructed for each site by applying Equation 56 to the baseline one-hour data set for the site. Table 40 provides descriptive statistics for the baseline and attainment data sets associated with District 1.

5.4.2 Attainment of 8H1EX-80 Standard

To evaluate the AQAP for 8H1EX standards, the procedure summarized in Table 36 was applied to Philadelphia for the purpose of simulating the attainment of the 8H1EX-80 standard. The results are presented in Table 41. As in the previous example, baseline conditions for Philadelphia were represented by 1991 ozone data.

TABLE 40. DESCRIPTIVE STATISTICS FOR HOURLY-HOUR DATA (PPB) FOR SITE 34-005-3001 (DISTRICT 1, PHILADELPHIA): BASELINE AND ATTAINMENT OF THREE OZONE STANDARDS

Statistic	Baseline	Attainment of indicated standard		
		1H1EX-120	8H1EX-80	8H5EX-80
Number of values	5136	5136	5136	5136
Mean	38	37	36	34
Standard deviation	25	18	14	16
Minimum	0	0	0	0
5th percentile	4	9	12	7
10th percentile	8	14	17	13
25th percentile	19	25	27	23
50th percentile	34	36	36	34
75th percentile	51	48	45	43
90th percentile	72	61	54	54
95th percentile	87	69	60	61
99th percentile	117	84	71	74
99.5 percentile	124	88	73	77
99.8 percentile	137	94	77	82
99.9 percentile	143	97	78	84
Maximum	156	102	82	89

Analysts initiated the AQAP by fitting a Weibull distribution to the filled-in 1991 one-hour data set associated with each Philadelphia monitoring site. Each fit produced estimates of the Weibull parameters (k and δ) and the CLV1. As in the previous example, the largest CLV1 for 1991 was associated with District 1 (167 ppb).

Analysts next estimated a baseline CLV8 for each site by fitting a Weibull distribution to the running-average eight-hour data associated with each Philadelphia monitoring site. The largest CLV8 was 142 ppb (District 1).

To exactly attain the specified NAAQS, the largest CLV8 must equal 80 ppb. Consequently, Equation 52 (Step 3, Table 36) was implemented as

$$ACLV8(i,j) = [CLV8(i,j)](80/142) = [CLV(i,j)](0.563). \qquad (65)$$

TABLE 41. DETERMINATION OF ADJUSTMENT COEFFICIENTS FOR EIGHT-HOUR NAAQS ATTAINMENT (8H1EX-80) IN PHILADELPHIA

District	Weibull fits to 1991 data				8-hr NAAQS attainment parameters[a]			1-h Weibull parameters		Adjustment coefficients	
	1-h k	1-h δ	CLV1	CLV8	Adjusted CLV8	Reassigned CLV8	Equivalent CLV1	k′	δ′	a	b
1	1.69	46.9	167	142	80	72	82	3.173	41.45	5.339	0.533
2	2.21	56.4	149	136	77	77	87	3.725	49.01	4.481	0.593
3	1.96	51.0	153	128	72	78	88	3.339	46.44	4.618	0.587
4	1.81	49.3	162	138	78	80	91	3.057	44.89	4.465	0.592
5	2.28	56.6	145	120	68	72	82	4.119	48.41	5.183	0.554
6	2.23	51.2	134	118	66	69	78	4.237	47.08	5.932	0.526
7	1.93	44.3	135	123	69	65	74	3.941	42.70	6.671	0.490
8	2.14	51.2	140	128	72	71	80	3.960	46.75	5.572	0.540
9	1.74	38.1	131	116	65	66	75	3.518	40.60	6.708	0.495
10	2.26	54.5	141	126	71	68	77	4.359	47.06	5.922	0.518

[a]Assumes maximum CLV8 equals 80 ppb.

Analysts applied this expression to each 1991 CLV8 to obtain 10 ACLV8's representing attainment conditions. These values are listed in the column labeled "adjusted CLV8." These values were then reassigned to the Philadelphia districts according to the five-year ranking determined for each district. The resulting assignments are listed in Table 41 under the heading "reassigned CLV8."

Each reassigned CLV8 was then converted into an equivalent attainment CLV1 using Equation 54 with the RATIO1 value for Philadelphia (1.132). For example, the reassigned CLV8 for District 1 (72 ppb) was multiplied by 1.132 to produce an equivalent attainment CLV1 of 82 ppb.

Analysts next used Equations 57 and 58 to estimate site-specific values for k' and δ', the values of the Weibull parameters for one-hour data under attainment conditions. For District 1, the substitution of k = 1.69, ACLV1 = 82 ppb, and n = 5136 produced the estimates k' = 3.173 and δ' = 41.45 ppb. These values were substituted into Equations 60 and 61 to produce the values of the adjustment coefficients listed in Table 41 for District 1 (a = 5.339 and b = 0.533). These coefficients were then substituted into Equation 56 to produce an initial one-hour data set approximating attainment conditions.

The one-hour data were processed to produce a corresponding 8-hour running average data set. A Weibull distribution was next fit to the adjusted eight-hour data for the site to determine an initial attainment CLV8. Analysts then used Equation 62 to make the final "fine-tuning" adjustment to the one-hour data necessary to achieve the target CLV8 specified for the site (72 ppb). The resulting one-hour data set was assumed to represent attainment conditions for District 1. Table 40 provides descriptive statistics for this data set. Attainment data sets were developed in a similar manner for each of the other Philadelphia monitoring sites.

5.4.3 Attainment of 8H5EX-80 Standard

The AQAP for 8H5EX standards (Table 37) was applied to Philadelphia for the purpose of simulating the attainment of the 8H5EX-80 standard. The results are presented in Table 42.

As in the two previous examples, baseline conditions for Philadelphia were represented by 1991 ozone data. Analysts began the AQAP by fitting a Weibull distribution to the filled-in 1991 one-hour data set associated with each Philadelphia monitoring site. Each fit produced estimates of the Weibull parameters (k and δ) and the CLV1. The largest CLV1 for 1991 was associated with District 1 (167 ppb).

Analysts next determined a baseline EH6LDM value for each site by first calculating all eight-hour daily maximum concentrations in the associated one-hour data set and then identifying the sixth largest value. The largest EH6LDM was 116 ppb (District 1).

The largest EH6LDM value permitted under the 8H5EX-80 standard is 80 ppb. As the largest baseline EH6LDM was 116 ppb, Equation 53 (Table 37) was expressed as

$$AEH6LDM(i,j) = [EH6LDM(i,j)](80/116) = [EH6LDM(i,j)](0.563) \qquad (66)$$

Analysts applied this expression to each 1991 EH6LDM to obtain 10 AEH6LDM's representing attainment conditions. These values are listed in the Table 42 column labeled "adjusted EH6LDM." Analysts next reassigned the values to the Philadelphia districts according to the five-year ranking determined for each district. The resulting assignments are listed in Table 42 under the heading "reassigned EH6LDM."

Each reassigned EH6LDM was then converted into an equivalent attainment CLV1 using Equation 55 with the RATIO2 value for Philadelphia (1.367). In the case of District 1, the reassigned EH6LDM (74 ppb) was multiplied by 1.367 to produce an equivalent attainment CLV1 of 101 ppb.

Analysts next used Equations 57 and 58 to estimate site-specific values for k' and δ', the values of the Weibull parameters for one-hour data under attainment

TABLE 42. DETERMINATION OF ADJUSTMENT COEFFICIENTS FOR EIGHT-HOUR NAAQS ATTAINMENT (EH6LDM = 80 ppb) IN PHILADELPHIA

District	Parameters of 1991 data				8-hour NAAQS attainment parameters				1-hour Weibull parameters		Adjustment coefficients	
	1-h k	1-h δ	CLV1	EH6LDM	Adjusted EH6LDM	Rank	Reassigned EH6LDM	Equivalent CLV1	k'	δ'	a	b
1	1.69	46.9	167	116	80	5	74	101	2.626	44.62	3.750	0.644
2	2.21	56.4	149	113	78	2	79	108	2.954	52.24	2.556	0.748
3	1.96	51.0	153	111	77	1	80	109	2.708	49.37	2.869	0.724
4	1.81	49.3	162	115	79	3	78	107	2.615	47.10	3.171	0.692
5	2.28	56.6	145	107	74	4	77	105	3.106	52.64	2.721	0.734
6	2.23	51.2	134	101	70	6	72	98	3.300	51.16	3.581	0.676
7	1.93	44.3	135	102	70	8	70	96	3.038	47.38	4.261	0.635
8	2.14	51.2	140	104	72	9	70	96	3.277	49.88	3.817	0.653
9	1.74	38.1	131	90	62	10	62	85	3.136	42.89	5.689	0.555
10	2.26	54.5	141	102	70	7	70	96	3.408	51.15	3.608	0.663

[a]Assumes maximum EH6LDM equals 80 ppb.

conditions. For District 1, the substitution of k = 1.69, ACLV1 = 101 ppb, and n = 5136 produced the estimates k' = 2.626 and δ' = 44.62 ppb. These values were substituted into Equations 60 and 61 to produce the values of the adjustment coefficients listed in Table 42 for District 1 (a = 3.750 and b = 0.644). These coefficients were then substituted into Equation 56 to produce an initial one-hour data set approximating attainment conditions.

The one-hour data were processed to produce a corresponding 8-hour running average data set. These data were analyzed to determine an initial attainment EH6LDM. Analysts then employed Equation 63 to make the final "fine-tuning" adjustment to the one-hour data necessary to achieve the target attainment EH6LDM specified for the district (101 ppb). The resulting tuned data set was assumed to represent attainment conditions for District 1. Table 40 presents descriptive statistics for this data set. Attainment data sets were developed in a similar manner for each of the other Philadelphia monitoring sites.

5.5 Special Adjustment Procedures Applied in Selected Attainment Scenarios

The AQAP's described above were developed by comparing the ozone data reported by a site in a high ozone year with ozone data reported by the same site in a low ozone year. Consequently, the AQAP's are expected to perform best when used to simulate a significant reduction in the ozone levels at a site. The results of an analysis of AQAP performance by ITAQS suggested that the AQAP's described above may produce unrealistic data sets for Denver, Chicago, and Miami when used to simulate a small reduction in ozone levels or when used to simulate an increase in ozone levels. For this reason, ITAQS used a different set of AQAP's for the following combinations of study areas and attainment scenarios:

Study area	Attainment scenarios
Denver	1H1EX-120 and 8H1EX-100
Chicago	1H1EX-120 and 8H1EX-100
Miami	all (1H1EX-120, 8H1EX-80, 8H1EX-100, 8H5EX-60, and 8H5EX-80)

The Denver scenarios listed above required slight increases in ozone levels to exactly meet the specified attainment conditions. The Chicago scenarios required small increases in ozone levels. The Miami scenarios required small changes in both directions.

In the alternative AQAP for 1H1EX-120, the procedures summarized in Table 35 were followed to the point in Step 5 where the reader is directed to Section 5.3. The procedures in Section 5.3 were not employed to adjust the one-hour data; instead, each value of the adjusted data set was estimated by the expression

$$y_t = (c)(x_t) \tag{67}$$

where x_t was the baseline ozone concentration for hour t and y_t was the attainment ozone concentration for hour t. The value of c was determined by the expression

$$c = (ACLV1)/(CLV1) \tag{68}$$

where ACLV1 is the characteristic largest one-hour value of the site before adjustment and ACLV1 is the characteristic largest one-hour value assigned to the site in Step 4 to represent attainment conditions.

In a similar manner, the alternative AQAP's for 8H1EX-80 and 8H1EX-100 followed the procedures summarized in Table 36 to the point in Step 6 where the reader is directed to Section 5.3. Again, the procedures in Section 5.3 were not employed to adjust the one-hour data. Instead, an initial estimate of each value of the adjusted data set was estimated according to Equations 67 and 68. In this case, ACLV1 was the characteristic largest one-hour value assigned to the site in Step 5 of Table 36. The adjustment procedure was completed by applying Equation 61 to the data to make a final "fine-tuning" adjustment.

The alternative AQAP's for 8H5EX-60 and 8H5EX-80 followed the steps listed in Table 37 to the point in Step 6 where the reader is directed to Section 5.3. The applicable procedures in Section 5.3 were again omitted; instead, Equations 67 and 68 were employed to make an initial estimate of each value of the adjusted data set. In this procedure, ACV1 was the characteristic largest one-hour value assigned to the site in Step 5 of Table 37. The adjustment procedure was completed by using Equation 62 to make the final fine tuning adjustment.

SECTION 6

OZONE EXPOSURE ESTIMATES FOR NINE URBAN AREAS

To illustrate the capabilities of the updated pNEM/O3 methodology described in this report, the program was applied to the nine urban areas listed earlier in Table 1. The result of each application was a set of 36 exposure summary tables for each regulatory scenario under evaluation. This section describes the scenarios that were analyzed, provides a guide to the interpretation of output tables, and summarizes the principal results of each exposure assessment.

6.1 Regulatory Scenarios

The following regulatory scenarios were examined in applying pNEM/O3 to each study area.

Baseline: Ambient ozone conditions were represented by unadjusted fixed-site monitoring data as reported for the exposure period listed in Table 1. These data were assumed to represent ambient (outdoor) ozone levels typical of "as is" air quality conditions unaffected by nearby sources.

1H1EX-120: The baseline monitoring data were adjusted to simulate the attainment of a 1H1EX standard (see Section 5) permitting one expected exceedance of 120 ppb (0.12 ppm). This standard is identical to the current NAAQS for ozone.

8H1EX-100 The baseline monitoring data were adjusted to simulate attainment of an 8H1EX standard (see Section 5) permitting one expected exceedance of 100 ppb (0.10 ppm).

8H1EX-80 The baseline monitoring data were adjusted to simulate attainment of an 8H1EX standard permitting one expected exceedance of 80 ppb (0.08 ppm).

8H5EX-80 The baseline monitoring data were adjusted to simulate attainment of an 8H5EX standard permitting five expected exceedances of 80 ppb (0.08 ppm).

8H5EX-60 The baseline monitoring data were adjusted to simulate attainment of an 8H5EX standard permitting five expected exceedances of 60 ppb (0.06 ppm).

Section 5 describes the procedures used to adjust baseline data to simulate attainment of 1H1EX, 8H1EX, and 8H5EX standards.

6.2 Formats of the Exposure Summary Tables

The application of pNEM/O3 to a study area produced two sets of 18 exposure summary tables -- one set listing exposure estimates for the general population and one set listing exposure estimates for children only. The general population included all cohorts, regardless of demographic group. Children were defined as the population subgroup containing all cohorts associated with Demographic Groups 1, 2, and 3 (Table 2).

Appendix C contains exposure summary tables for the general population and for children obtained from an sample application of pNEM/O3 to Houston. Each set contains one or more tables organized according to the following table formats. (Note that the table numbers listed under each format refer to the tables in Appendix C.)

Number of people -- cumulative exposures (or doses) by EVR range

These tables list estimates by ozone concentration and EVR range. Each table entry lists the number of people who experienced one or more ozone exposures (or doses) during which the ozone concentration was at or above the level indicated by the row label and the average EVR was within the range indicated by the column heading. Separate tables provide estimates for one-hour exposures (Table 1 in Appendix C), one-hour daily maximum exposures (Table 1A), one-hour daily maximum doses (Table 1B), eight-hour daily maximum exposures (Table 4), and eight-hour daily maximum doses (Table 4A).

Number of people -- cumulative seasonal mean exposures

Table 7 in Appendix C lists estimates by ozone concentration only. Each entry lists the number of people who were associated with a seasonal mean exposure at or above the ozone level indicated by the row label. The seasonal mean is calculated as the average of the eight-hour daily maximum ozone exposures occurring from April to October, inclusive.

Number of occurrences -- exposures (or doses) by EVR range

These tables list estimates arranged by ozone concentration range and EVR range. Each table entry lists the number of times a person experienced an ozone exposure during which the ozone concentration was within the range indicated by the row label and the average EVR was within the range indicated by the column heading. There are separate tables for one-hour exposures (Table 2 in Appendix C), one-hour daily maximum exposures (Table 2A), one-hour daily maximum doses (Table 2B), eight-hour daily maximum exposures (Table 5), and eight-hour daily maximum doses (Table 5A).

Number of occurrences -- seasonal mean exposures

Table 8 in Appendix C presents estimates by ozone range only. Each entry lists the number of times a person experienced a seasonal mean exposure at or above the ozone level indicated by the row label. The seasonal mean is calculated as the average of the eight-hour daily maximum ozone exposures occurring from April to October, inclusive.

Number of people -- highest exposures (or doses) by EVR range

Each of these tables lists estimates arranged by ozone concentration and EVR range. Each entry indicates the number of people who experienced their maximum ozone exposure under conditions in which the ozone concentration was at or above the level indicated by the row label and the average EVR was within the range indicated by the column heading. There are separate tables for one-hour daily maximum exposures (Table 3 in Appendix C) and eight-hour daily maximum exposures (Table 6).

Number of people -- cumulative daily maximum doses by number of days

These tables provide estimates arranged by ozone concentration and number of days per year. Each entry lists the number of people who experienced a daily maximum dose at or above the indicated ozone concentration for the specified number of days. Separate tables are provided for daily maximum one-hour doses (Table 9 in Appendix C), daily maximum eight-hour doses (Table 10), daily maximum one-hour doses with EVR of 30 liters x min^{-1} x m^{-2} (Table 11), and daily maximum eight-hour doses with EVR of 15 liters x min^{-1} x m^{-2} (Table 12).

Regardless of format, each table in Appendix C provides footnotes identifying the study area, regulatory scenario, and the population group analyzed. The footnotes also indicate the number of exposure districts in the study area, the first and last days of the ozone season, and the number of days in the ozone season.

6.3 Results of Analyses

Tables 43 and 44 summarize exposure estimates for one run of the model for the total population within each of the nine study areas according to the six regulatory scenarios that were analyzed. Table 43 lists the percentage of each study area population that was estimated to experience one or more daily maximum one-hour exposures above 0.12 ppm at any ventilation rate. This ozone concentration corresponds to the level of the current standard. Exposures above this level may have adverse health effects. The following general statements apply to the results presented in Table 43.

1. Of the nine study areas, Houston has the highest percentage (97.62 percent) of people experiencing one-hour daily maximum ozone exposures above 0.12 ppm under baseline conditions. In the scenario where the current NAAQS is exactly met, this percentage drops to 6.6 percent.

2. Of the nine study areas, Miami has the lowest percentage (0.59 percent) of persons experiencing one-hour daily maximum ozone exposures above 0.12 ppm under baseline conditions. In the scenario where Miami exactly meets the current NAAQS, the number of persons exposed above 0.12 ppm increases to 6.62 percent. Under baseline conditions, the ozone levels in Miami are lower than those permitted by the current NAAQS; consequently, the adjustment of baseline data to exactly meet the current NAAQS produced an increase in ozone exposure.

3. In all study areas except St. Louis, the number of persons exposed to levels above 0.12 ppm is larger under the 8H1EX-100 standard than under the current NAAQS. In general, the 8H1EX-100 standard appears to be less stringent than the current NAAQS with respect to this exposure indicator.

TABLE 43. NUMBER AND PERCENT OF TOTAL STUDY AREA POPULATION EXPERIENCING ONE OR MORE ONE-HOUR DAILY MAXIMUM OZONE EXPOSURES ABOVE 120 PPB AT ANY VENTILATION RATE

Study Area	Number of Persons at Risk	Regulatory Scenario	Number of Persons Exposed	Percent of Total
Chicago	6,175,121	Baseline	1,726,506	27.96
		Current NAAQS	448,269	7.26
		8H1EX-100	1,191,553	19.30
		8H1EX-80	0	0
		8H5EX-80	4,434	0.07
		8H5EX-60	0	0
Denver	1,484,798	Baseline	195,248	13.15
		Current NAAQS	166,543	11.22
		8H1EX-100	733,869	49.43
		8H1EX-80	0	0
		8H5EX-80	0	0
		8H5EX-60	0	0
Houston	2,370,512	Baseline	2,314,143	97.62
		Current NAAQS	156,483	6.60
		8H1EX-100	670,287	28.28
		8H1EX-80	35,718	1.51
		8H5EX-80	165,597	6.99
		8H5EX-60	0	0
Los Angeles	10,371,115	Baseline	8,454,573	81.52
		Current NAAQS	117,998	1.14
		8H1EX-100	1,020,660	9.84
		8H1EX-80	27,620	0.27
		8H5EX-80	173,626	1.67
		8H5EX-60	0	0

TABLE 43 (Continued)

Study Area	Number of Persons at Risk	Regulatory Scenario	Number of Exposed Persons	Percent of Total
Miami	1,941,994	Baseline	11,374	0.59
		Current NAAQS	128,639	6.62
		8H1EX-100	486,708	25.06
		8H1EX-80	16	0
		8H5EX-80	202,889	10.45
		8H5EX-60	5,685	0.29
New York	10,657,873	Baseline	6,284,728	58.97
		Current NAAQS	218,380	2.05
		8H1EX-100	643,330	6.04
		8H1EX-80	0	0
		8H5EX-80	97,403	0.91
		8H5EX-60	0	0
Philadel-phia	3,785,810	Baseline	3,201,816	84.57
		Current NAAQS	78,588	2.08
		8H1EX-100	148,088	3.91
		8H1EX-80	0	0
		8H5EX-80	0	0
		8H5EX-60	0	0
St. Louis	1,706,778	Baseline	271,580	15.91
		Current NAAQS	67,153	3.93
		8H1EX-100	33,980	1.99
		8H1EX-80	0	0
		8H5EX-80	14,585	0.85
		8H5EX-60	0	0

TABLE 43 (Continued)

Study Area	Number of Persons at Risk	Regulatory Scenario	Number of Persons Exposed	Percent of Total
Washington, DC	3,085,419	Baseline	2,251,949	72.99
		Current NAAQS	61,491	1.99
		8H1EX-100	136,125	4.41
		8H1EX-80	0	0
		8H5EX-80	72,516	2.35
		8H5EX-60	0	0

TABLE 44. PERCENT OF TOTAL STUDY AREA POPULATION EXPERIENCING ONE OR MORE 8-HOUR DAILY MAXIMUM OZONE EXPOSURES ABOVE INDICATED EXPOSURE CONCENTRATIONS AT ANY VENTILATION RATE

Study Area	Regulatory Scenario	Number of Persons at Risk	Percentage of Population Experiencing 8-Hour Daily Maximum Ozone Exposure Above Indicated Concentration		
			0.06 ppm	0.08 ppm	0.10 ppm
Chicago	Baseline	6,175,121	96.65	33.01	1.06
	Current NAAQS		82.81	13.35	0
	8H1EX-100		94.09	30.57	0.12
	8H1EX-80		72.40	0.36	0
	8H5EX-80		83.66	4.15	0
	8H5EX-60		4.43	0	0
Denver	Baseline	1,484,798	77.53	9.28	0
	Current NAAQS		80.34	8.81	0.10
	8H1EX-100		96.96	41.05	6.09
	8H1EX-80		68.21	3.40	0
	8H5EX-80		65.72	1.48	0
	8H5EX-60		2.74	0	0
Houston	Baseline	2,370,512	99.40	90.71	52.09
	Current NAAQS		64.34	8.91	0
	8H1EX-100		82.39	26.05	1.08
	8H1EX-80		33.93	1.75	0
	8H5EX-80		59.59	5.90	0.01
	8H5EX-60		4.11	0	0
Los Angeles	Baseline	10,371,115	96.00	69.77	41.06
	Current NAAQS		23.51	0.86	0
	8H1EX-100		32.83	7.87	1.05
	8H1EX-80		16.07	0.17	0
	8H5EX-80		13.05	0.99	0
	8H5EX-60		1.51	0	0

(continued)

TABLE 44 (Continued)

Study Area	Regulatory Scenario	Number of Persons at Risk	Percentage of Population Experiencing 8-Hour Daily Maximum Ozone Exposure Above Indicated Concentration		
			0.06 ppm	0.08 ppm	0.10 ppm
Miami	Baseline	1,941,994	14.39	0.01	0
	Current NAAQS		58.29	0.71	0.03
	8H1EX-100		74.75	18.09	0
	8H1EX-80		32.32	0	0
	8H5EX-80		67.22	4.86	0.04
	8H5EX-60		6.05	0	0
New York	Baseline	10,657,873	85.81	54.57	21.10
	Current NAAQS		53.67	7.67	0
	8H1EX-100		75.58	17.43	0.36
	8H1EX-80		29.87	0.79	0
	8H5EX-80		33.31	2.36	0
	8H5EX-60		1.75	0	0
Philadel-phia	Baseline	3,785,810	99.96	90.98	36.19
	Current NAAQS		97.72	33.28	1.25
	8H1EX-100		99.75	31.69	0.71
	8H1EX-80		57.31	1.02	0
	8H5EX-80		79.97	7.59	0
	8H5EX-60		2.31	0	0
St. Louis	Baseline	1,706,778	73.22	23.54	0.82
	Current NAAQS		86.86	24.89	0.02
	8H1EX-100		80.75	18.58	0.04
	8H1EX-80		34.07	0.21	0
	8H5EX-80		65.27	3.83	0
	8H5EX-60		5.69	0	0

(continued)

TABLE 44 (Continued)

Study Area	Regulatory Scenario	Number of Persons at Risk	Percentage of Population Experiencing 8-Hour Daily Maximum Ozone Exposure Above Indicated Concentration		
			0.06 ppm	0.08 ppm	0.10 ppm
Washington, DC	Baseline	3,085,419	97.67	77.99	21.53
	Current NAAQS		94.14	15.30	0.13
	8H1EX-100		93.33	18.67	0.27
	8H1EX-80		45.08	0.45	0
	8H5EX-80		79.02	7.29	0
	8H5EX-60		6.00	0	0
Composite	Baseline	Not Applicable	96.00	54.57	21.10
	Current NAAQS		80.34	8.91	0.02
	8H1EX-100		82.39	18.67	0.36
	8H1EX-80		34.07	0.45	0
	8H5EX-80		65.72	4.15	0
	8H5EX-60		4.11	0	0

4. In all nine study areas, the number of persons exposed to levels above 0.12 ppm is smaller under the 8H1EX-80 standard than under the current NAAQS. The 8H1EX-80 standard appears to be generally more stringent than the current NAAQS with respect to this exposure indicator.

5. The exposure estimates for five of the nine study areas indicate that the number of persons exposed to ozone levels above 0.12 is smaller under the 8H5EX-80 standard than the current NAAQS. In the other four cities (Houston, Los Angeles, Miami, and Washington, DC) the number of persons exposed under the 8H5EX-80 standard is greater than under the current NAAQS.

6. In eight of the nine study areas, the number of persons exposed to levels above 0.12 ppm is zero under the 8H5EX-60 standard. The one exception is Miami, whose exposed population percentage is only 0.29 percent. This standard appears to be significantly more stringent than the current NAAQS. Between 1.14 percent and 11.22 percent of each study area population is exposed to levels above 0.12 ppm under the current NAAQS.

Table 44 lists the percentage of each study area population that was estimated to experience one or more 8-hour daily maximum exposures above 0.06 ppm, 0.08 ppm, and 0.10 ppm, respectively, at any ventilation rate. These levels of exposure were chosen for the analysis because they are the levels of possible alternative 8-hour standards. Eight-hour exposures above these levels should have greater health effects than 1-hour exposures at the same levels. The following general statements apply to the results presented in Table 44.

1. Under baseline conditions, Philadelphia has the largest percentage of people experiencing 8-hour daily maximum exposures above 0.06 ppm (99.96 percent) and above 0.08 ppm (90.98 percent). When exposures above 0.10 ppm are considered, however, Houston has the largest percentage (52.09). The corresponding estimate for Philadelphia is 36.19 percent. The upper tail of the exposure distribution is more extended for Houston than for Philadelphia.

2. Under the current NAAQS, Philadelphia has the largest percentage of people experiencing 8-hour daily maximum exposures above 0.06 ppm (97.72 percent), above 0.08 ppm (33.28 percent), and above 0.10 ppm (1.25 percent).

3. According to the exposure estimates listed for the 8H1EX-100 standard, Philadelphia has the largest percentage of exposures above 0.06 ppm (99.75 percent). Denver has the largest percentage above 0.08 ppm (41.05 percent) and above 0.10 ppm (6.09 percent).

The estimates in Table 44 labeled "composite" are medians of the corresponding values listed in Table 44 for the nine cities. For example, the composite value listed in the 0.06 ppm column for the current NAAQS (80.34 percent) is the median of the nine city-specific values listed in the 0.06 ppm column for the current NAAQS. The composite estimates may be interpreted as representing the exposure distributions expected in a typical city under each standard. For this typical city, the five standards would be arranged as follows with respect to the percentage of people with eight-hour exposures above 0.06 ppm.

1. 8H1EX-100 (82.39 percent)
2. Current NAAQS (80.34 percent)
3. 8H5EX-80 (65.72 percent)
4. 8H1EX-80 (34.07 percent)
5. 8H5EX-60 (4.11 percent)

The five standards would have the following ordering if arranged according to the percentage of people with eight-hour exposures above 0.08 ppm.

1. 8H1EX-100 (18.67 percent)
2. Current NAAQS (8.91 percent)
3. 8H5EX-80 (4.15 percent)
4. 8H1EX-80 (0.45 percent)
5. 8H5EX-60 (0 percent)

The orderings of these two sets of rankings are identical.

Figures 2, 3, and 4 provide graphical presentations of selected results from Tables 43 and 44. Figure 2 shows the estimated percentage of Houston-area residents who experience one-hour daily maximum ozone exposures above 0.12 ppm (120 ppb) according to each regulatory scenario. Figure 3 compares all nine study areas with respect to the estimated percentage of residents who experience one-hour ozone exposures above 0.12 ppm under each scenario. Figure 4 displays the estimated percentage of Houston residents who experienced eight-hour daily maximum ozone exposures above 0.80 ppm under each regulatory scenario.

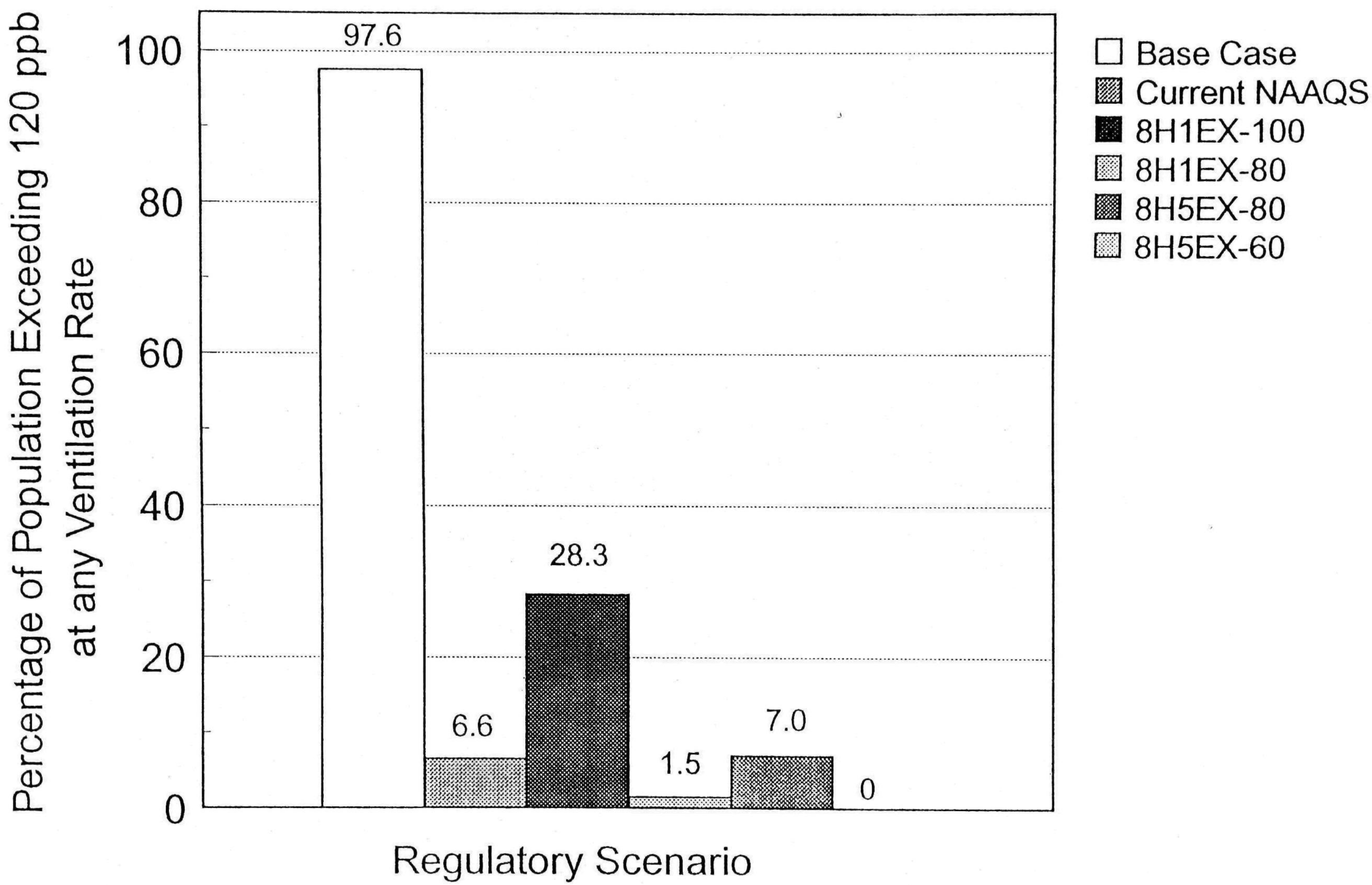

Figure 2. Estimated percentage of residents in Houston study area who experience one-hour daily maximum ozone exposures above 0.12 ppm according to regulatory scenario.

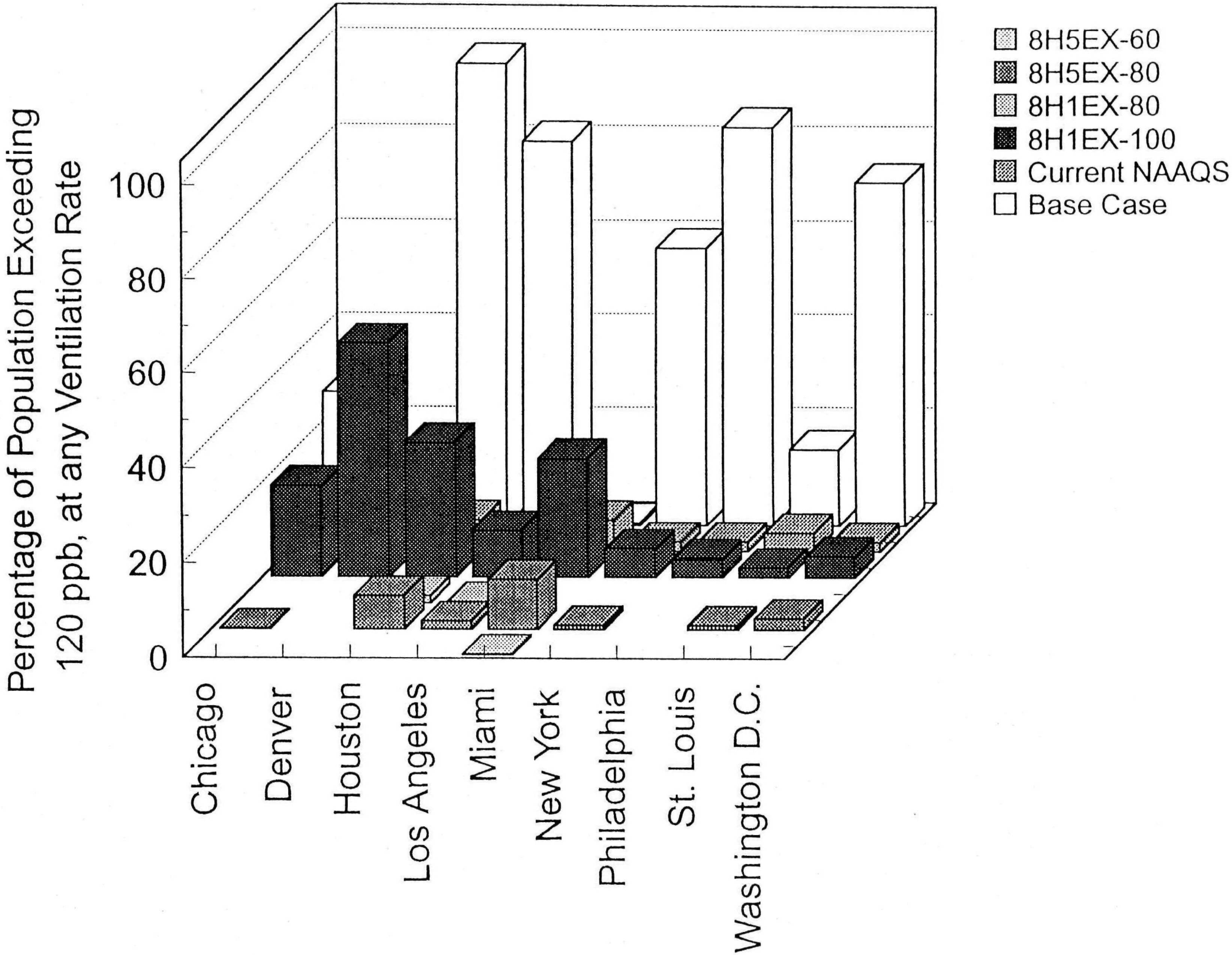

Figure 3. Estimated percentage of residents in each study area who experience one-hour daily maximum ozone exposures above 0.12 ppm according to regulatory scenario.

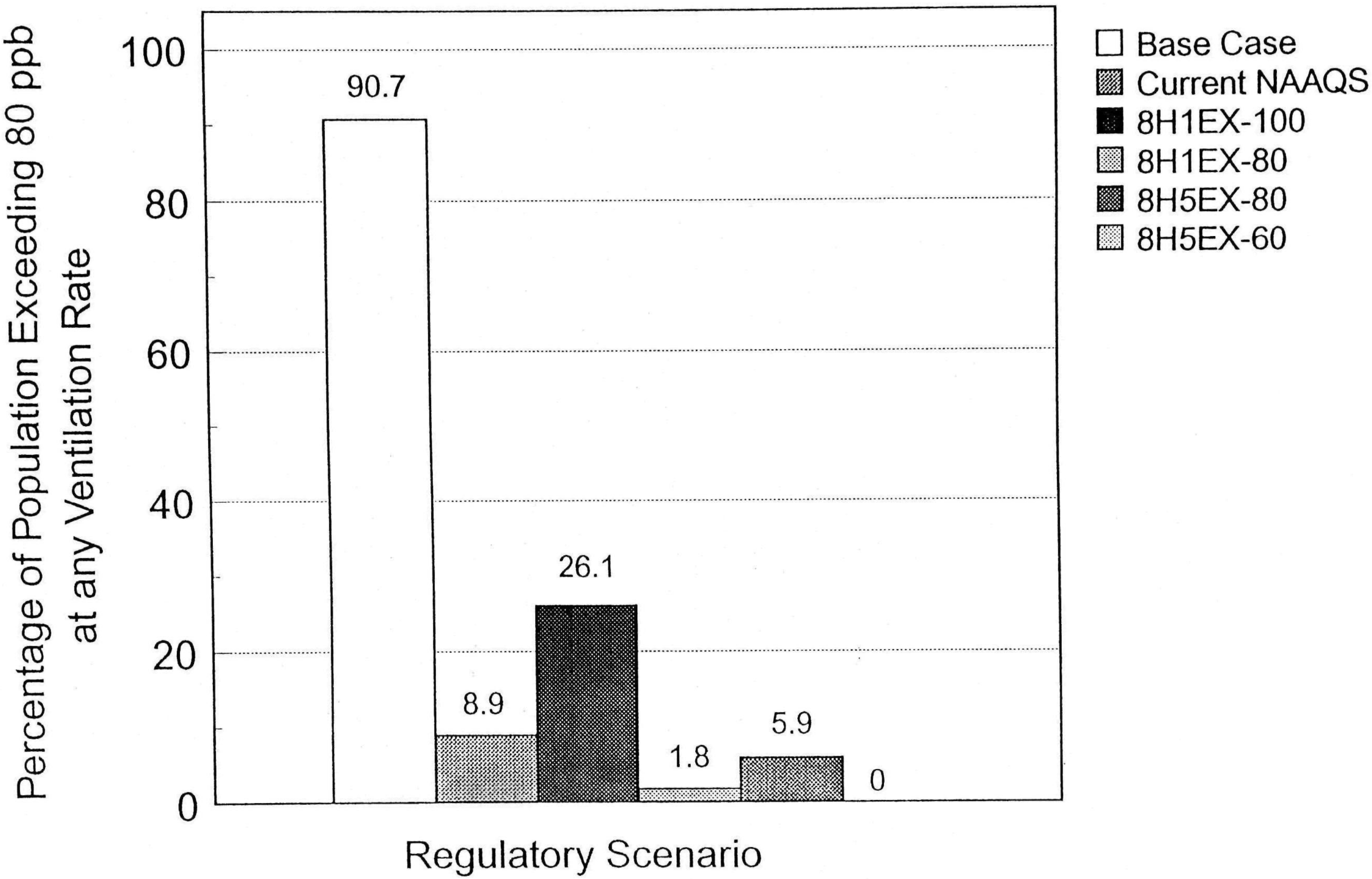

Figure 4. Estimated percentage of residents in Houston study area who experience eight-hour daily maximum ozone exposures above 0.08 ppm according to regulatory scenario.

SECTION 7

INITIAL EFFORTS TO VALIDATE THE EXPOSURE MODEL

The validity of an exposure model such as pNEM/O3 can be best evaluated by comparing model exposure estimates for a variety of urban areas with actual personal exposure measurements collected in the same areas under similar conditions. As the required multi-city personal monitoring data base did not exist at the time of this study, researchers were not able to perform a comprehensive validation effort. Validation was limited to a comparison of pNEM/O3 estimates for Houston, Texas, with personal monitoring data provided by Dr. Thomas Stock. These data were collected in 1981 during the Houston Asthmatic Study (HAS)[20]. This section provides a brief overview of the HAS data file and summarizes the results of initial efforts to validate pNEM/O3.

7.1 The HAS Data

The main HAS data file contains time/activity data and measurements of personal ozone exposure for 30 subjects who resided in two Houston neighborhoods (Clear Lake and Sunnyside). The data for each subject documents one or two daytime periods which typically began when the subject awoke in the morning and ended around 6 pm. Personal ozone measurements were generally recorded at five-minute intervals during this period. Each record in the data file represents a new ozone measurement or a change in the subject's activity or location. Each record contains the following data items:

Subject identification code
Month
Day
Year

Hour of the day
Minute of the hour
Identification code of residence being monitored
Identification code of subject's residence
Microenvironment
Macroenvironment (either "inside study area" or "outside study area")
Air conditioning code
Smoking code
Level of exertion
Cooking code
Cooking fuel
Intensity of traffic

Some of the records contained the following information:

Duration of subject in microenvironment
Ozone concentration recorded by personal monitor
Ozone quality code
One-hour ozone concentration of Clear Lake fixed-site monitor
One-hour ozone concentration of Sunnyside fixed-site monitor

In addition, ITAQS received two data files containing the one-hour fixed-site ozone concentrations for Clear Lake and Sunnyside. Background data were also provided to ITAQS concerning each subject's age, occupation, and residential location.

7.2 The Special Version of pNEM/O3

ITAQS developed a special version of pNEM/O3 (designated pNEM/O3-S) and applied it to Houston in an attempt to simulate the conditions of HAS. In this application, the general modeling approach described in Section 2 was followed with the following exceptions. The exposure period was changed from 1990 to the period of the HAS diary data (June 24 to October 31, 1981). Whenever pNEM/O3-S algorithms required fixed-site ozone concentrations, these values were determined using fixed-site data from this 130-day period. In a similar manner, temperature and calendar data for this period were used whenever these data were required by the model. For example, the exposure event sequence for each cohort was generated using temperature and weekday/weekend calendar data specific to the HAS period.

In applying pNEM/O3-S to Houston, each HAS subject was treated as a distinct cohort. The data available for each subject were reviewed to determined the subject's demographic group, residential air conditioning status, home district, and work district. The study area was assumed to contain three exposure districts: 1) the Clear Lake neighborhood, 2) the Sunnyside neighborhood, and 3) all other areas of Houston. Ambient ozone concentrations for Clear Lake and Sunnyside were determined using ozone data reported by fixed-site monitors in those areas. Ambient ozone concentrations for the remaining district (i.e., all other areas) were determined by averaging ozone data reported by all Houston monitors.

All of the remaining pNEM/O3-S algorithms were identical to the corresponding algorithms in pNEM/O3. In particular, the algorithms used to generate exposure event sequences, EVR values, air exchange rates, and indoor ozone concentrations (the mass balance model) were identical to those described in earlier sections of this report. A run of pNEM/O3-S produced cohort-specific exposure files for the June 24-to-October 31 period which could be compared directly with the HAS data.

7.3 Processing of HAS Data

The HAS data used in the validation effort consisted of the time/activity (diary) data for each subject, personal ozone exposure data for each subject, background data for each subject, and hourly-average ozone data obtained from fixed-site monitors in Clear Lake and Sunnyside. These data were processed by ITAQS to produce a special data file which could be compared directly with pNEM/O3-S exposure estimates.

The time/activity data associated with each subject were transformed from a series of records typically occurring at five-minute intervals to a series containing one record for each discrete exposure event. A discrete exposure event was assumed to begin whenever the diary data for a subject indicated a change in activity, microenvironment, or clock hour.

The personal ozone exposure data associated with each exposure event were averaged to produce an average ozone exposure for the event. If more than 15 minutes of exposure data were missing for a particular event, the ozone exposure was coded as missing. The event-specific exposures were averaged by clock hour (e.g, 2 pm to 3 pm) to produce a file containing one-hour exposures for each subject. Hours with less than 45 minutes of ozone exposure data were coded as missing.

The hourly-average ozone data for the Clear Lake and Sunnyside fixed-site monitors were incomplete in that ozone concentrations were missing for a number of time intervals. Statistical analyses of the existing data for the two sites indicated a strong correlation between the ozone concentrations reported by the sites for the same time interval. Consequently, regression analyses were performed on the two data sets and the resulting regression equations were used to estimate missing values. The regression equations were

$$CL(t) = 10.43 \text{ ppb} + (0.716)[SS(t)] \quad (69)$$

$$SS(t) = 1.22 \text{ ppb} + (0.864)[CL(t)]. \quad (70)$$

In these equations, CL(t) and SS(t) indicate the one-hour ozone concentrations in Clear Lake and Sunnyside, respectively, for time interval t. The R^2 value for each regression equation is 0.618.

Equation 69 was used to estimate missing Clear Lake values; Equation 70 was used for missing Sunnyside values. In a few cases, values were missing in both data sets for the same time interval. The time series procedure discussed in Subsection 4.2 was used to estimate these values.

In the validation process, each HAS subject was modeled as a distinct cohort by pNEM/O3-S. Consequently, each HAS subject had to be classified according to demographic group (Table 2), home district, work district (if applicable), and air conditioning status. Data from the subject's background questionnaire were used to determine demographic group and home district (Clear Lake or Sunnyside). The subject's work district was determined by reviewing his or her diary data. If the subject's activities indicated that he worked at a location coded in the diary as outside the study area (Macroenvironment = 2), then the work district was designated as District 3 (other Houston areas). Otherwise, the work district was assigned to the subject's home neighborhood. The subject's air conditioning status was determined by examining diary entries concerning the type of air conditioning system in use during periods when the subject was in his home microenvironment.

7.4 Comparison of Measured and Estimated Exposures by Person-hour

To evaluate the run-to-run variability in the exposure estimates produced by pNEM/O3-S, researchers executed the program ten times. Each run produced a 130-day exposure sequence for each cohort. As discussed above, each cohort in pNEM/O3-S corresponded to one of the HAS subjects. Consequently, researchers were able to identify a cohort and a time period in each pNEM/O3-S output that corresponded to a subject and a time period in the HAS data set. The hourly-average (one-hour) ozone exposure estimates produced for each designated combination of cohort and time period were placed in a "person-hour" file specific to the pNEM/O3-S run which produced the estimates.

Table 45 presents selected percentiles of the one-hour exposure estimates in the person-hour file produced by each of the 10 runs. The table also presents these percentiles for the file containing the measured one-hour exposures of the HAS subjects. Because of the matchup procedure, each of the 10 pNEM/O3-S files contains the same number of one-hour values (n = 389) as the HAS file.

Table 46 is similar to Table 45 except that it presents percentiles for daily maximum one-hour exposures. The HAS files and each of the 10 pNEM/O3-S files contains 50 daily maximum one-hour exposures.

The run-to-run variability in the pNEM/O3-S estimates is most pronounced in the upper percentiles and maximum values. The 99.5th percentile values in Table 45 vary from 78 ppb to 110 ppb over the 10 runs. The mean 99.5th value is 95.2 ppb. This value is lower than the corresponding 99.5th percentile of the HAS data (120 ppb). In general, the mean pNEM/O3-S percentile values in Table 45 are greater than the corresponding HAS percentile values up to the 95th percentile and less than the corresponding HAS percentile values above the 95th percentile.

TABLE 45. DISTRIBUTIONS OF ONE-HOUR OZONE EXPOSURES (ppb) OBTAINED FROM TEN RUNS OF pNEM/O3-S AND FROM THE HOUSTON ASTHMATIC STUDY

Percentile	pNEM/O3-S Runs											HAS data
	1	2	3	4	5	6	7	8	9	10	Mean	
5	1	1	1	0	1	1	0	1	0	1	0.7	2
10	1	1	1	1	1	1	1	1	1	1	1.0	2
20	3	3	3	2	2	2	3	3	3	2	2.6	2
30	4	4	5	4	4	4	5	4	5	4	4.3	2
40	7	7	7	6	6	6	8	6	8	7	6.8	3
50	10	10	10	9	10	8	11	9	11	10	9.8	5
60	14	14	13	14	15	14	15	16	16	13	14.4	7
70	20	20	19	20	21	19	22	23	21	19	20.4	10
80	28	32	26	29	31	27	31	32	28	26	29.0	16
90	37	40	37	41	42	37	42	50	39	40	40.5	32
95	50	51	53	54	53	50	59	64	51	57	54.2	51
98	67	65	83	71	79	63	72	92	72	80	74.4	78
99	76	79	93	93	88	70	77	96	88	85	84.5	107
99.5	78	89	103	109	104	81	81	103	94	110	95.2	120
Maximum	80	101	130	159	135	117	86	123	135	147	121.3	142

TABLE 46. DISTRIBUTIONS OF ONE-HOUR DAILY MAXIMUM OZONE EXPOSURES (ppb) OBTAINED FROM TEN RUNS OF pNEM/O3-S AND FROM THE HOUSTON ASTHMATIC STUDY

Percentile	pNEM/O3-S Runs											HAS data
	1	2	3	4	5	6	7	8	9	10	Mean	
5	8	5	9	4	4	5	4	6	5	4	5.4	2
10	12	8	11	7	8	9	6	8	9	4	8.2	3
20	17	15	12	13	11	14	10	14	17	12	13.5	6
30	23	18	20	18	18	20	21	22	23	20	20.3	9
40	28	23	22	30	29	27	25	27	27	22	26.0	11
50	33	33	30	38	39	30	34	35	32	30	33.4	15
60	36	42	36	42	45	36	38	48	37	39	39.9	20
70	44	46	38	50	51	45	43	53	45	43	45.8	32
80	59	55	45	56	54	60	56	64	53	57	55.9	47
90	67	65	66	71	79	65	67	67	61	78	68.6	73
95	78	89	103	86	96	81	81	93	91	85	88.3	87
98	79	97	104	109	106	82	81	104	97	110	96.9	120
Maximum	80	101	130	159	135	117	86	123	135	147	121.3	142

The 98th percentile values in Table 46 vary from 79 ppb to 110 ppb. The mean 98th percentile value is 96.9. The corresponding HAS value is 120 ppb. The mean pNEM/O3-S percentile values are greater than the corresponding HAS values up to the 80th percentile and less than the HAS values above the 80th percentile. In general, the results in Tables 45 and 46 suggest that pNEM/O3-S overpredicts the HAS exposures in the range below 70 ppb and underpredicts in the range above 70 ppb.

7.5 Sensitivity of Exposure Estimates to Ozone Decay Rate

A series of exploratory analyses were conducted to identify factors contributing to the observed differences between exposure values obtained from pNEM/O3-S and HAS. The results of these analyses suggested that pNEM/O3-S exposure estimates were particularly sensitive to the distribution of ozone decay rate used in the mass balance algorithm. This effect is demonstrated in Table 47. The table presents average ozone concentrations by microenvironment for each of 12 pNEM/O3-S runs. In each run the mean value (4.04 h^{-1}) used to define the distribution of the ozone decay rate parameter (F_d) for indoor microenvironments in Subsection 3.1 was multiplied by a factor between 0.25 and 4.0, the value of the factor varying with microenvironment and window status (Table 48). The standard deviation of the F_d distribution was held constant at 1.35 h^{-1} in each case, the value specified in Subsection 3.1. Note that the ozone decay rate parameters were not modified for Run No. 1, as the multipliers were set equal to 1.0.

Table 47 also presents average ozone concentrations by microenvironment for the HAS data. Run 12 of pNEM/O3-S was judged to produce the best overall matchup between pNEM/O3-S and HAS microenvironmental ozone concentrations. In this run, one set of multiplicative factors was used for the indoors - residence microenvironment (windows open = 1.0, windows closed = 0.25) and another set (windows open = 2.0, windows closed = 2.0) was used for all other indoor microenvironments.

In reviewing the results in Table 47, it is important to note that the run-to-run variation in average ozone concentrations in the outdoor and in-vehicle microenvironments is not a function of the specified multiplicative factors. A value for ozone decay rate was not required by the algorithm used to estimate outdoor concentrations; all 12 runs used the same point estimate (F_d = 72.0) for the ozone decay rate of the in-vehicle microenvironment. It should also be noted that windows in the indoors - other microenvironment are assumed to be closed at all times. Consequently, the average ozone concentration in this microenvironment varies only as a function of the multiplier applied to the windows closed case.

The results of this initial attempt to validate pNEM/O3 indicate that the use of alternative values for ozone decay rate will produce exposure estimates that more nearly match the HAS data. In interpreting this result, it is important to note that 1) the HAS data base only applies to two Houston neighborhoods, 2) the HAS data base represents only 30 subjects, and 3) the alternative ozone decay rates are not supported by the results of the literature survey discussed in Subsection 3.1. For these reasons, researchers used the decay rate values listed in Subsection 3.1 for the pNEM/O3 runs summarized in Section 6. ITAQS recommends that EPA acquire up-to-date personal monitoring data for a variety of urban areas so that a more definitive validation of pNEM/O3 can be performed.

TABLE 47. MEAN OZONE CONCENTRATIONS IN MICROENVIRONMENTS BASED ON PERSONAL MONITORING DATA FROM THE HOUSTON ASTHMATIC STUDY AND ON EXPOSURE ESTIMATES OBTAINED FROM 12 RUNS OF pNEM/O3-S WITH DIFFERING VALUES OF OZONE DECAY RATE

Microenvironment	Mean ozone conc. based on HAS data	Mean ozone concentration by pNEM/O3-S Run (Table 49), ppb											
		1	2	3	4	5	6	7	8	9	10	11	12[a]
Indoors - residence (all)	7.8	9.9	8.0	6.6	11.8	12.7	9.0	10.9	11.7	8.4	8.2	11.3	9.0
Indoors - residence, no air conditioning	25.0	15.0	12.6	10.8	18.7	20.6	14.7	18.1	21.1	14.8	15.0	21.1	21.3
Indoors - residence, room air conditioning	5.1	11.6	9.1	8.0	14.5	15.3	11.7	13.0	14.2	10.6	11.3	15.0	8.3
Indoors - residence, central air conditioning	4.7	8.1	6.3	5.1	9.3	9.9	6.8	8.3	8.4	6.2	5.7	7.8	5.1
Indoors - other	6.0	13.0	9.7	7.4	13.2	13.5	7.5	7.5	7.4	4.1	4.1	4.0	7.5
Outdoors	37.7	43.2	43.3	43.9	43.2	43.5	43.1	43.1	43.6	43.6	43.0	43.2	43.1
In vehicle	16.2	14.3	14.3	14.4	14.3	14.5	14.4	14.2	14.5	14.4	14.3	14.1	14.3

[a]Run judged to provide exposure estimates most consistent with HAS data.

TABLE 48. MULTIPLICATIVE FACTORS USED TO DETERMINE ALTERNATIVE VALUES FOR MEAN OZONE DECAY RATE

pNEM/O3-S run	Multiplicative factor (m)[a]			
	Indoors-residence, no air conditioning		All other indoor microenvironments	
	Windows closed	Windows open	Windows closed	Windows open
1	1.0	1.0	1.0	1.0
2	1.5	1.5	1.5	1.5
3	2.0	2.0	2.0	2.0
4	1.0	0.5	1.0	0.5
5	1.0	0.25	1.0	0.25
6	2.0	1.0	2.0	1.0
7	2.0	0.5	2.0	0.5
8	2.0	0.25	2.0	0.25
9	4.0	1.0	4.0	1.0
10	4.0	0.5	4.0	0.5
11	4.0	0.25	4.0	0.25
12	1.0	0.25	2.0	2.0

[a]Mean ozone decay rate = (m)(4.04 h^{-1}).

SECTION 8

PRINCIPAL LIMITATIONS OF THE pNEM/O3 METHODOLOGY

The pNEM/O3 methodology was developed specifically to meet the requirements of OAQPS for a computer-based model capable of simulating the ozone exposures of specific population groups under alternative NAAQS. In addition to meeting these needs, the designers of pNEM/O3 have attempted to create a model which is flexible in application and easy to upgrade. The model was deliberately constructed as a collection of stand-alone algorithms organized within a modular framework. For this reason, analysts can revise individual algorithms without the need to make major changes to other parts of the model.

The structure of each algorithm in pNEM/O3 is largely determined by the characteristics of the available input data. For example, the algorithm used to construct a season-long exposure event sequence for each cohort is constrained by the fact that none of the available time/activity studies provides more than three days of diary data for any one subject. To make maximum use of the available diary data, the pNEM/O3 sequencing algorithm constructs each exposure event sequence by sampling data from more than one subject. The other pNEM/O3 algorithms are similarly designed to make best use of available data bases.

In evaluating the exposure estimates presented in this report, the reader should note that the model has a number of limitations which may affect its accuracy. These limitations are usually the result of limitations in the input data bases. The available data were typically collected for purposes other than use in a population exposure model. Consequently, these data frequently represent special sets of conditions which differ from those assumed by pNEM/O3. In these situations, analysts must exercise a certain degree of judgement in adapting the data for use in pNEM/O3.

This section presents a brief discussion of the principal limitations in the pNEM/O3 methodology as applied to 1990 population data. The limitations are organized according to five major components of the model: time/activity patterns, equivalent ventilation rates, air quality adjustment, the mass balance model, and the estimation of cohort populations.

8.1 Time/Activity Patterns

In the general pNEM/O3 methodology, the exposure-related activities of each cohort are represented by a multi-day exposure event sequence which spans a specified ozone season. Each sequence is constructed by an algorithm which selects 24-hour (midnight-to-midnight) activity patterns from a specially prepared database. This database contains data from one or more time/activity studies in which subjects recorded their daily activities in diaries.

In the application of pNEM/O3 described in this report, the time/activity database consisted of diary data obtained from 900 subjects of the Cincinnati Activity Diary Study (CADS). The database contained 2,649 person-days of data, an average of slightly less than three days per subject. All 900 subjects resided in the Cincinnati metropolitan area.

Analysts used time/activity data obtained solely from the CADS subjects to represent the activities of the general population in each of the nine study areas. Although the algorithm which constructs exposure event sequences attempts to account for effects of local climate on activity, it is unlikely that this adjustment procedure corrects for all inter-city differences in people's activities. Time/activity patterns are likely to be affected by a variety of local factors, including topography, land-use, traffic patterns, mass transit systems, and recreational opportunities.

As discussed previously, the average subject provided less than three days of diary data. For this reason, the construction of each season-long exposure event sequence required either the repetition of data from one subject or the use of data from multiple subjects. The latter approach was used in the pNEM/O3 analyses to better represent the variability of exposure expected to occur among the people included in each cohort. The principal deficiency of this approach is that it may not adequately account for the day-to-day repetition of activities common to individuals. Using activities from different subjects may underestimate multiple occurrences of high exertion and/or outdoor exposure for those segments of the population who engage in repetitive outdoor activities.

8.2 Equivalent Ventilation Rates

In the general pNEM/O3 methodology, the EVR associated with each exposure event is determined by an algorithm which randomly selects the value from one of the eight lognormal distributions presented in Table 4. Each distribution is specific to age group (children or adults) and breathing rate category (sleeping, slow, medium, or fast). The distributions are based on EVR data obtained from two diary studies conducted by J. Hackney and associates in Los Angeles.

A total of 36 subjects participated in the Los Angeles studies. Because of the small sample size, the resulting EVR database may not accurately represent the variability of EVR across the population. In addition, the database does not provide sufficient data to adequately characterize age-specific differences in EVR. For example, none of the Los Angeles subjects was below the age of 10 or above the age of 50. The lognormal distributions of EVR developed for children and adults are likely to over-estimate EVR when applied to pre-school children or older adults.

If the resulting EVR estimates are biased, they are likely to be biased high because of the operation of the EVR limiting algorithm. This algorithm determines the maximum EVR that can be maintained for a specified duration by a subject who is (1) male, (2) between the ages of 18 and 24, (3) exercising regularly, and (4) motivated to reach a high ventilation rate. The EVR value assigned by pNEM/O3 to an event of the specified duration is not permitted to exceed this value.

The four conditions assumed by the EVR limiting algorithm do not apply to all members of the population. Consequently, the EVR limiting algorithm may permit more high EVR values to occur in the pNEM/O3 simulation than would occur in the actual population. This potential bias may be corrected in future versions of pNEM/O3 by distinguishing cohorts by gender, age, and physical conditioning. The parameters of the EVR limiting algorithm would be varied according to these factors to yield a reasonable upper EVR limit for each cohort.

8.3 The Air Quality Adjustment Procedures

Section 5 presents a summary of the procedures used to adjust baseline ozone monitoring data to simulate conditions expected when a study area just attains a specified NAAQS. These procedures assume that 1) the Weibull distribution provides a good fit to most ozone data, and 2) the parameters of the Weibull distribution fitting data from a particular monitoring site will change over time in a predictable fashion. The adjustment procedures include equations for predicting the values of the Weibull parameters under future attainment conditions.

The prediction equations were developed through a statistical analysis of ozone data obtained from selected monitoring sites which have experienced moderate reductions in ozone levels during the 1980's. It should be noted that none of the selected monitoring sites reported ozone reductions of the magnitude required to bring Los Angeles into compliance with any one of the NAAQS under evaluation. For this reason, the prediction equations may not produce accurate estimates for the Weibull distribution parameters when applied to Los Angeles ozone data.

The air quality adjustment procedure is based on an assumption that the attainment status of a particular city can be determined by a single year of monitoring data. For example, the current status of Philadelphia is determined by ozone monitoring data for 1991. This single year of monitoring data is then adjusted to exactly meet a specified NAAQS. It should be noted that the pNEM/O3 approach to determining attainment status differs somewhat from the actual method used by EPA to determine attainment status. EPA typically examines three recent years of monitoring data for a particular city and calculates a multi-year air quality indicator (e.g., the fourth highest daily maximum one-hour ozone concentration for the three-year period). The air quality indicator determined by this method is likely to differ from the air quality indicator determined in a pNEM/O3 analysis from a single year of data. As the direction of the difference is random, the degree of adjustment applied to a city by pNEM/O3 may be greater than or less than the adjustment required to bring the city into compliance based on three years of data.

8.4 The Mass Balance Model

The pNEM/O3 methodology uses the mass balance model described in Section 3 to estimate ozone concentrations for the following enclosure categories:

- Residential buildings - windows closed
- Residential buildings - windows open
- Nonresidential buildings
- Vehicles.

The mass balance model provides hourly average ozone concentrations for each enclosure category as a function of outdoor ozone concentration, AER, and ozone decay rate.

In the application of pNEM/O3 described in this report, the outdoor ozone concentration required by the mass balance model was always derived from fixed-site monitoring data. These data were representative of local conditions and were considered to be relatively reliable.

The AER values for residential buildings with closed windows were obtained from a lognormal distribution fit to AER data from 312 residences. These data were considered to be generally representative of housing in urban areas in the U.S.

No comparable databases were identified which were considered representative of residences with open windows. Consequently, analysts represented this enclosure category with a point estimate developed by Hayes[45]. Analysts are uncertain as to the accuracy and general applicability of this estimate.

The AER values for nonresidential buildings were obtained from a lognormal distribution fit to AER data from 40 buildings provided by Turk et al.[44] This sample may be too small to adequately characterize nonresidential buildings in the U.S. It should also be noted that the Turk data are likely to represent only buildings with closed windows. Consequently, the lognormal distribution derived from the Turk data is likely to under-estimate the ozone exposures of people who frequently occupy nonresidential buildings with open windows.

A point estimate of 36 air changes per hour was used for the AER of vehicles. This value was obtained from Hayes[47] based on his analysis of data reported by Peterson and Sabersky[42] for a single vehicle. The use of a point estimate is considered unrealistic as it does not account for varying ventilation conditions within a particular motor vehicle or the variability in AER from vehicle to vehicle.

Analysts also used a point estimate for the ozone decay rate of vehicles. This value was based on data from a single automobile and may be biased.

Ozone decay rates for residential and nonresidential buildings were sampled from a normal distribution. This distribution was based on decay rate data for a relatively small number of buildings assembled by Weschler et al.[39] These data may not adequately represent the variability of ozone decay rates among urban buildings in the U.S.

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APPENDIX A

ADJUSTMENT OF OZONE DATA TO SIMULATE NAAQS ATTAINMENT

INTERNATIONAL
TECHNOLOGY
CORPORATION

April 15, 1993

Mr. Thomas McCurdy
U.S. Environmental Protection Agency
OAQPS, MD-12
Research Triangle Park, North Carolina 27711

Adjustment of Ozone Data to Simulate NAAQS Attainment

Dear Tom:

Under Work Assignment II-5 of EPA Contract No. 68-DO-0062, IT Air Quality Services will be applying a revised version of pNEM/O3 to nine urban areas. Fixed-site monitoring data for the years 1990 and 1991 will be used to represent "as is" ambient concentrations within each exposure district. An air quality adjustment procedure (AQAP) will be used to adjust the "as is" data to simulate various 1-hour and 8-hour National Ambient Air Quality Standards (NAAQS).

Historically, the AQAP's developed for NEM applications have included the following steps:

1. Specify an air quality indicator (AQI) to be used in evaluating the status of a monitoring site with respect to the NAAQS of interest.

2. Determine the value of the AQI for each site within a study area under "as is" conditions.

3. Determine the value of the AQI under conditions in which the air pollution levels within the study area have been reduced until a single site just attains a specified NAAQS.

4. Adjust the one-hour values of the "as is" data set associated with each site to yield the AQI value determined in Step 3. The adjusted data set should retain the temporal profile of the "as is" data set.

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This letter provides recommendations for implementing each of these steps.

STEP 1: SPECIFY AIR QUALITY INDICATOR

To determine compliance with the current one-hour National Ambient Air Quality Standard (NAAQS) for ozone, a "design value" has been determined for each urban area in the United States according to procedures specified by EPA. A common means of determining the design value is to determine the daily maximum hourly average value ranked n+1 when the daily maximum values for n years ($n \leq 3$) are combined and ranked from highest to lowest. Following the directions of AQMD, ITAQS is using an alternative air quality indicator to determine compliance with 1-hr NAAQS: the characteristic largest daily maximum one-hour value determined from a distribution fit to ozone data reported for a single ozone season. A similar quantity, the characteristic largest daily maximum eight-hour value, will be used to determine compliance with proposed 8-hr NAAQS.

The Characteristic Largest Daily Maximum Value

The characteristic largest value of a distribution is that value expected to be exceeded once in n observations. If F(x) is the cumulative distribution of x, then

$$F(CLV) = 1 - \frac{1}{n} \tag{1}$$

if CLV is the characteristic largest value.

Selection of an appropriate cumulative distribution to fit data is important in determining a reasonable characteristic largest value. Two distributions that often provide close fits to ambient air quality data are the Weibull and the lognormal. The Weibull distribution is defined as

$$F(x) = 1 - \exp\left[-\left(\frac{x}{\delta}\right)^k\right] \tag{2}$$

where δ is the scale parameter and k is the shape parameter. The lognormal distribution is defined as

$$F(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{w} \exp\left(-t^2/2\right) dt \tag{3}$$

where

$$w = \frac{\ln x - \mu}{\sigma} \tag{4}$$

and ln x is distributed normally with mean μ and variance σ^2. As discussed in previous reports, the Weibull distribution generally provides a better fit to hourly average ozone data.

The hourly average values reported by a single monitoring site during a specified ozone season form a time series x_t (t = 1, 2, 3, ..., n). If the hourly average time series is complete, it will contain n = (24)(N) values, where N is the number of days in the ozone season. From this time series a second time series of daily maximum 1-hour values can be constructed.

Assume that a Weibull distribution with parameters δ and k provides a good fit to the empirical distribution of hourly average values. If we disregard autocorrelation, the value expected to be exceeded once in n = (24)(N) hours can be estimated as

$$CLVOH = \delta\ [\ln(24)(N)]^{1/k} \tag{5}$$

This is the characteristic largest one-hour value. If we again disregard autocorrelation, the daily maximum 1-hour value expected to be exceeded once in N days can be estimated as

$$CLVOHDM = \delta\{-\ln[1 - (\frac{N-1}{N})^{1/24}]\}^{1/k}. \tag{6}$$

This is the characteristic largest daily maximum 1-hour value. For 7-month and 12-month ozone seasons, N is equal to 214 and 365, respectively. For these values of N, CLVOH and CLVOHDM are virtually indistinguishable in value over the range in k values normally found in ozone data (0.6 < k < 2.5). For example, the following values were calculated using δ = 40 ppb.

N	k	CLVOH	CLVOHDM
214	0.6	1428	1428
	1.4	185	185
	2.5	94	94
365	0.6	1580	1580
	1.4	193	193
	2.5	97	97

The CLVOH and CLVOHDM values match to the nearest ppb. Consequently, we can use the expression

$$CLVOHDM \doteq \delta \, [\ln(24)(N)]^{1/k} \tag{7}$$

as an alternative to Equation 6 for calculating CLVOHDM. This expression is already in place in the computer programs previously developed by ITAQS for fitting Weibull distributions to air quality data.

For simplicity, we will refer to the quantity calculated by Equation 7 as CLV1 throughout the remainder of this letter. CLV1 will be the AQI by which we evaluate the status of a monitoring site with respect to a particular 1-hr NAAQS.

A data set containing one-hour concentration values can be processed to determine a corresponding data set containing eight-hour running average values. If we fit a Weibull distribution to the eight-hour data, we can determine a characteristic largest eight-hour value by the equation

$$CLVEH = \delta[\ln(24)N)]^{1/k}, \tag{8}$$

where δ and k are the Weibull parameters for the eight-hour fit. Based on the argument made above for one-hour data, this value should be approximately equal to the characteristic largest daily maximum eight-hour value (CLVEHDM) of the data set. For simplicity, we will use the term CLV8 to refer to the quantity calculated by Equation 8 throughout the remainder of this letter. CLV8 will serve as the AQI by which we evaluate attainment status with respect to a particular 8-hr NAAQS.

STEP TWO: DETERMINE VALUES OF AQI UNDER "AS IS" CONDITIONS

My letter of February 18, 1993 lists the data sets we have selected to represent "as is" conditions in each of the nine cities under analysis. Tables 22 through 40 in that letter provide estimates of CLV1 and CLV8 based on Weibull fits to the upper two percent of each data set. These values will be our estimates of CLV1 and CLV8 under "as is" conditions.

STEP THREE: ADJUST VALUES OF AQI TO SIMULATE ATTAINMENT

We have developed a new statistical adjustment procedure for implementing this step which does not require the use of EKMA or a similar photochemical model. The procedure is based on patterns identified in a test data base containing multi-year ozone data.

The Test Data Set

Following your guidance, we selected three of the nine urban areas (Houston, Philadelphia, and St. Louis) to be test cities for the purposes of developing a "CLV Adjustment Procedure" (CLVAP). As part of the pNEM/O3 analysis, we had already selected 11 fixed-site monitors to represent Houston, 10 to represent Philadelphia, and 11 to represent St. Louis. We reviewed 1983 - 1992 ozone data reported for the sites associated with each city and selected three years for our test data base. These years represented low, medium, and high ozone levels with respect to the ten year period. To each set of three years we added the year selected for use in the pNEM/O3 analysis (either 1990 or 1991). In this way, we identified 12 city-years (3 cities x 4 years) for use in developing the CLVAP.

A total of 126 site-years of ozone data were associated with these 12 city-years. We collected 1-hour ozone data associated with each site-year, processed the data to produce a complete data set for the specified ozone season, and fit a Weibull distribution to each data set (upper 2 percent fit). The fitted Weibull distribution provided an estimate of CLV1.

We also developed a running 8-hour data set from each 1-hour data set. We then fit a Weibull distribution to each data set and used the results to estimate CLV8 for the data set.

Figures 1, 2, and 3 are printouts listing statistics for Houston, Philadelphia, and St. Louis, respectively, based on the one-hour data sets. Figures 4, 5, and 6 provide corresponding statistics for the eight-hour data sets. In following abbreviations are used in these printouts.

DISTRICT: district associated with monitor

YEAR: last two digits of calendar year

P50: 50th percentile

P90: 90th percentile

P95: 99th percentile

P995: 99.5th percentile

SECHI: second largest value

HIGH: largest value

DISTRICT	YEAR	P50	P90	P95	P99	P995	SECHI	HIGH	CLV	DELTA	K
1	85	20	60	70	110	120	170	180	193	27.2	1.13
1	88	20	60	70	100	120	220	230	204	22.6	1.00
1	90	20	60	70	110	120	220	220	224	22.2	0.95
1	91	20	50	60	100	110	170	170	186	22.8	1.05
2	85	22	50	60	90	110	170	180	200	15.8	0.87
2	88	20	60	70	110	120	220	250	208	24.1	1.02
2	90	20	50	70	100	110	160	180	182	27.3	1.16
2	91	20	40	51	70	80	130	130	122	23.7	1.34
3	85	20	50	66	100	120	210	210	219	17.5	0.87
3	88	20	50	70	100	120	220	220	217	18.7	0.90
3	90	10	50	60	100	120	200	230	241	14.3	0.78
3	91	10	44	60	90	102	160	170	166	22.4	1.10
4	85	17	50	60	100	120	220	230	266	10.7	0.69
4	88	18	50	70	100	110	200	200	214	17.5	0.88
4	90	10	50	60	100	120	210	240	224	16.9	0.85
4	91	10	40	53	80	93	151	158	164	17.5	0.99
5	85	20	50	70	110	130	210	210	224	24.7	1.00
5	88	20	50	70	100	110	190	190	177	27.4	1.18
5	90	20	50	70	110	130	200	220	227	21.0	0.93
5	91	20	50	62	107	120	204	209	219	18.5	0.89
6	85	M	M	M	M	M	M	M	M	M	M
6	88	20	60	70	100	110	190	210	189	24.9	1.09
6	90	10	40	50	70	90	140	190	180	9.5	0.75
6	91	15	40	60	100	110	200	200	214	16.1	0.85
7	85	20	50	61	100	120	190	210	212	21.5	0.96
7	88	20	50	70	100	110	160	170	184	23.2	1.07
7	90	20	46	60	90	110	180	230	208	16.5	0.87
7	91	14	41	56	88	101	158	170	185	16.3	0.91
8	85	20	60	70	110	130	270	290	280	14.7	0.75
8	88	20	60	70	100	110	150	180	170	31.3	1.31
8	90	20	50	60	100	110	230	230	207	17.3	0.89
8	91	15	40	50	80	90	150	150	162	16.5	0.96
9	85	20	50	70	110	120	230	250	240	18.4	0.86
9	88	16	50	70	100	110	190	220	189	23.4	1.06
9	90	10	45	60	90	110	200	210	200	13.0	0.77
9	91	17	47	60	90	100	180	200	177	18.9	0.98
10	85	10	50	60	110	120	250	260	264	13.5	0.74
10	88	20	50	63	90	100	200	210	191	19.2	0.96
10	90	10	50	60	100	120	230	230	235	17.3	0.85
10	91	14	42	60	95	111	180	180	197	18.4	0.93
11	85	10	40	60	100	120	260	260	247	14.7	0.78
11	88	10	50	60	90	110	220	230	238	11.7	0.73
11	90	10	40	60	100	120	220	220	232	14.9	0.80
11	91	10	40	53	87	100	170	175	169	18.9	1.01

Figure 1. Descriptive statistics for one-hour ozone data obtained from monitoring sites associated with Houston exposure districts.

DISTRICT	YEAR	P50	P90	P95	P99	P995	SECHI	HIGH	CLV	DELTA	K
1	83	32	74	91	123	132	149	152	163	59.0	2.11
1	84	33	66	80	111	123	156	163	172	37.2	1.40
1	86	29	63	75	98	109	145	152	152	33.3	1.41
1	91	34	72	88	117	124	156	156	167	46.9	1.69
2	83	30	77	96	122	132	166	184	170	54.0	1.87
2	84	25	65	80	115	131	160	163	180	36.4	1.34
2	86	26	70	84	113	124	155	161	164	45.5	1.68
2	91	28	70	84	114	120	143	148	149	56.4	2.21
3	83	28	68	81	105	119	154	162	163	37.6	1.46
3	84	31	70	83	107	114	152	152	146	48.4	1.95
3	86	38	73	85	111	119	162	169	160	44.7	1.68
3	91	36	76	89	112	117	146	149	153	51.0	1.96
4	83	33	79	95	127	141	186	205	207	38.6	1.28
4	84	30	70	84	111	120	149	153	153	49.8	1.91
4	86	28	67	81	104	112	138	139	144	46.2	1.89
4	91	33	73	87	115	125	151	151	162	49.3	1.81
5	83	25	69	88	121	133	196	196	186	41.5	1.43
5	84	22	60	74	105	117	203	230	214	18.6	0.88
5	86	25	66	79	101	111	143	148	150	38.8	1.58
5	91	28	70	84	110	118	139	144	145	56.6	2.28
6	83	31	70	86	112	121	192	197	177	38.0	1.40
6	84	27	60	72	96	108	143	146	147	33.9	1.46
6	86	29	65	77	102	108	144	167	147	40.1	1.66
6	91	30	67	78	103	108	125	135	134	51.2	2.23
7	83	24	63	75	101	110	134	135	151	35.6	1.49
7	84	20	53	65	82	87	157	174	147	20.5	1.09
7	86	23	61	73	94	101	117	118	125	45.9	2.14
7	91	26	66	77	98	105	125	127	135	44.3	1.93
8	83	30	70	90	120	130	160	170	170	48.2	1.70
8	84	30	60	80	100	110	150	160	154	32.9	1.39
8	86	30	70	80	100	110	140	150	143	42.1	1.76
8	91	30	70	80	100	110	140	140	140	51.2	2.14
9	83	20	53	70	100	110	150	160	159	30.4	1.30
9	84	20	50	60	80	100	120	150	152	18.8	1.03
9	86	20	49	60	80	90	120	160	131	22.2	1.21
9	91	20	50	70	90	100	130	130	131	38.1	1.74
10	83	30	70	90	120	130	160	170	179	44.4	1.54
10	84	30	60	80	100	110	180	180	175	28.2	1.18
10	86	30	67	80	100	110	140	140	139	50.1	2.11
10	91	30	70	80	110	110	130	140	141	54.5	2.26

Figure 2. Descriptive statistics for one-hour ozone data obtained from monitoring sites associated with Philadelphia exposure districts.

DISTRICT	YEAR	P50	P90	P95	P99	P995	SECHI	HIGH	CLV	DELTA	K
1	83	24	62	76	99	110	138	149	149	36.6	1.53
1	85	22	54	63	79	87	108	111	115	31.7	1.66
1	90	19	48	57	73	82	116	124	124	21.3	1.22
1	91	17	48	59	75	80	102	104	103	33.8	1.93
2	83	10	36	47	67	78	95	104	113	17.8	1.16
2	85	19	46	54	69	76	120	124	115	19.9	1.23
2	90	27	55	66	90	98	125	125	141	29.6	1.38
2	91	27	60	75	94	99	114	118	118	51.2	2.57
3	83	26	66	83	111	125	171	195	187	31.3	1.20
3	85	23	53	63	86	94	132	136	145	23.7	1.19
3	90	29	59	72	90	99	120	127	131	36.8	1.68
3	91	29	64	77	101	106	124	135	132	50.7	2.24
4	83	31	67	81	108	116	184	195	178	31.3	1.23
4	85	31	61	69	95	106	157	164	164	23.7	1.11
4	90	24	48	55	69	75	99	100	103	26.9	1.60
4	91	26	54	64	82	88	106	112	110	37.7	2.01
5	83	27	72	88	120	130	210	212	188	38.8	1.36
5	85	23	57	66	86	96	144	150	159	19.3	1.02
5	90	24	54	65	83	92	125	127	122	33.7	1.66
5	91	24	63	75	97	104	120	123	125	51.5	2.43
6	83	29	72	87	120	133	184	188	192	37.2	1.31
6	85	27	62	72	93	103	144	151	149	29.3	1.32
6	90	18	42	47	61	64	75	80	78	32.9	2.48
6	91	26	58	67	85	93	114	115	121	36.4	1.79
7	83	28	71	88	123	133	224	243	201	35.0	1.23
7	85	23	55	63	87	96	136	137	146	24.7	1.21
7	90	29	58	70	92	96	130	135	124	43.7	2.06
7	91	30	63	74	96	100	119	121	123	52.3	2.52
8	83	14	34	44	64	69	89	93	96	22.2	1.46
8	85	18	45	53	69	77	120	123	121	17.3	1.10
8	90	18	44	52	69	74	96	96	100	27.1	1.65
8	91	18	42	51	68	73	84	85	90	34.1	2.22
9	83	6	37	53	103	112	177	183	187	20.9	0.98
9	85	19	46	54	74	78	125	129	132	15.7	1.01
9	90	24	53	63	82	89	108	111	114	37.7	1.94
9	91	24	53	63	82	85	102	107	105	42.4	2.36
10	83	M	M	M	M	M	M	M	M	M	M
10	85	23	50	60	75	87	110	110	121	24.0	1.33
10	90	18	40	48	64	72	100	110	103	20.5	1.33
10	91	17	42	51	66	70	88	88	88	32.9	2.19
11	83	16	46	60	90	99	145	148	145	27.2	1.28
11	85	17	48	55	71	79	98	106	111	25.2	1.45
11	90	24	53	65	86	94	117	129	119	39.7	1.96
11	91	22	50	59	76	80	95	97	99	38.7	2.30

Figure 3. Descriptive statistics for one-hour ozone data obtained from monitoring sites associated with St. Louis exposure districts.

DISTRICT	YEAR	P50	P90	P95	P99	P995	SECHI	HIGH	CLV	DELTA	K
1	85	20	51	62	89	99	136	140	145	29.6	1.39
1	88	21	50	61	89	96	176	179	155	24.5	1.20
1	90	21	50	64	92	104	149	150	162	26.4	1.22
1	91	19	44	55	80	91	142	144	149	20.2	1.10
2	85	24	45	55	80	92	134	134	149	19.9	1.10
2	88	25	55	67	91	102	164	165	164	25.5	1.18
2	90	21	49	61	89	96	124	124	137	32.2	1.53
2	91	18	39	48	62	67	85	85	93	25.7	1.72
3	85	18	46	74	84	96	164	166	167	18.1	0.99
3	88	17	47	60	88	96	169	171	150	25.5	1.25
3	90	14	42	53	84	95	151	152	161	18.5	1.02
3	91	15	39	50	71	82	119	121	127	20.2	1.20
4	85	17	41	55	86	102	209	210	199	13.3	0.81
4	88	16	46	57	84	94	149	150	150	23.0	1.18
4	90	15	42	55	82	96	156	164	171	17.0	0.96
4	91	13	36	46	69	76	110	111	116	20.4	1.27
5	85	22	50	65	97	107	162	164	170	27.8	1.22
5	88	22	49	60	87	99	129	130	140	29.9	1.43
5	90	21	48	61	92	105	167	170	179	22.1	1.06
5	91	20	45	57	88	100	158	160	162	21.1	1.08
6	85	M	M	M	M	M	M	M	M	M	M
6	88	24	51	62	89	96	131	135	135	32.8	1.56
6	90	14	33	41	60	71	110	112	131	11.3	0.90
6	91	16	39	51	81	91	146	149	153	20.0	1.09
7	85	21	46	59	93	106	135	135	155	28.5	1.30
7	88	19	47	58	84	94	132	134	140	26.4	1.32
7	90	17	41	52	79	90	154	155	165	15.6	0.94
7	91	16	39	50	77	89	109	110	134	20.5	1.17
8	85	22	52	66	100	111	225	227	208	18.8	0.92
8	88	24	52	64	87	97	124	127	134	33.5	1.59
8	90	19	46	56	84	92	139	140	143	25.5	1.28
8	91	15	38	47	71	82	101	103	120	20.8	1.26
9	85	20	49	62	92	102	192	196	179	20.9	1.03
9	88	16	47	60	86	92	146	151	138	29.1	1.42
9	90	16	41	54	81	90	144	146	154	19.0	1.05
9	91	17	40	51	72	81	124	126	133	19.4	1.15
10	85	15	42	56	87	102	202	206	205	13.3	0.81
10	88	17	46	57	80	87	130	131	136	24.7	1.29
10	90	15	42	56	86	97	156	157	171	19.1	1.01
10	91	16	40	52	79	89	127	127	136	23.1	1.24
11	85	15	40	54	87	97	220	226	186	16.2	0.90
11	88	14	42	52	80	95	136	139	162	16.8	0.97
11	90	12	39	51	81	92	160	164	167	16.8	0.96
11	91	11	35	46	70	78	116	116	120	20.8	1.26

Figure 4. Descriptive statistics for eight-hour ozone data obtained from monitoring sites associated with Houston exposure districts.

DISTRICT	YEAR	P50	P90	P95	P99	P995	SECHI	HIGH	CLV	DELTA	K
1	83	33	70	85	106	112	129	129	135	58.4	2.57
1	84	33	64	75	98	106	129	129	139	41.9	1.79
1	86	29	59	68	91	101	113	113	123	43.2	2.05
1	91	34	67	80	107	114	138	141	142	50.7	2.08
2	83	31	71	87	109	113	130	131	133	64.0	2.94
2	84	26	60	73	102	114	132	133	150	36.7	1.52
2	86	27	64	77	101	112	129	131	144	42.7	1.76
2	91	28	64	76	101	109	129	131	136	47.9	2.05
3	83	29	63	74	97	107	126	127	136	41.6	1.81
3	84	32	66	76	99	103	114	114	123	53.6	2.57
3	86	38	69	80	102	107	144	146	140	45.9	1.92
3	91	37	71	81	103	107	124	125	128	57.7	2.70
4	83	34	73	87	114	128	174	177	189	32.8	1.23
4	84	31	65	77	100	107	120	120	130	50.0	2.24
4	86	29	62	75	93	99	119	120	122	46.2	2.20
4	91	33	68	80	105	113	135	135	138	50.9	2.15
5	83	25	63	78	106	112	134	135	143	49.8	2.04
5	84	23	55	69	93	106	159	161	166	22.8	1.08
5	86	25	60	71	89	97	132	132	132	35.2	1.62
5	91	28	64	76	100	104	115	116	120	61.0	3.16
6	83	31	65	79	101	107	140	142	141	44.9	1.88
6	84	28	56	66	86	92	117	120	120	38.1	1.87
6	86	29	61	71	92	97	113	115	119	47.4	2.34
6	91	30	62	72	92	98	113	114	118	49.4	2.47
7	83	25	57	67	88	96	120	123	123	36.8	1.78
7	84	22	49	58	73	78	125	126	117	23.3	1.33
7	86	24	55	66	84	88	102	104	109	43.6	2.34
7	91	26	60	70	92	98	118	118	123	42.2	2.01
8	83	31	66	80	104	111	132	137	140	48.9	2.04
8	84	32	58	69	87	92	119	119	121	38.5	1.88
8	86	27	61	71	89	94	111	113	116	46.2	2.33
8	91	31	65	76	96	100	125	127	128	45.1	2.05
9	83	19	51	61	86	95	106	106	119	36.7	1.82
9	84	19	43	54	72	81	101	104	112	24.4	1.41
9	86	17	42	52	69	76	101	102	106	23.1	1.41
9	91	21	49	60	79	86	112	114	116	30.1	1.59
10	83	27	65	80	105	115	127	129	139	53.1	2.24
10	84	27	59	71	91	100	131	131	136	33.9	1.55
10	86	27	60	71	93	96	115	115	120	48.1	2.34
10	91	27	61	72	97	103	116	116	126	51.2	2.39

Figure 5. Descriptive statistics for eight-hour ozone data obtained from monitoring sites associated with Philadelphia exposure districts.

DISTRICT	YEAR	P50	P90	P95	P99	P995	SECHI	HIGH	CLV	DELTA	K
1	83	25	56	67	87	93	111	112	120	39.4	1.93
1	85	24	49	57	69	74	93	95	99	28.1	1.70
1	90	20	43	51	66	70	98	99	100	23.1	1.47
1	91	18	43	51	66	71	89	90	91	29.3	1.90
2	83	12	34	41	55	61	77	78	86	17.8	1.36
2	85	19	41	48	63	66	94	97	96	21.2	1.42
2	90	26	50	59	78	85	110	110	116	29.4	1.56
2	91	27	55	66	81	87	102	104	106	43.2	2.39
3	83	27	60	72	98	109	142	145	147	36.5	1.54
3	85	25	49	57	78	84	115	116	116	28.2	1.52
3	90	30	54	64	80	85	100	103	106	41.4	2.28
3	91	29	58	70	89	95	109	110	116	46.4	2.35
4	83	31	62	73	95	105	141	143	143	35.5	1.54
4	85	33	57	63	84	97	123	123	139	25.0	1.25
4	90	24	44	50	62	67	85	86	87	27.7	1.88
4	91	27	50	58	72	77	86	87	94	36.5	2.27
5	83	28	64	77	104	113	150	153	155	39.4	1.57
5	85	25	51	59	77	84	122	122	123	24.2	1.32
5	90	25	49	58	76	80	93	94	97	39.4	2.37
5	91	25	56	66	84	89	101	103	107	45.5	2.50
6	83	30	65	78	105	113	138	138	153	40.5	1.61
6	85	29	57	66	81	88	120	122	126	27.5	1.41
6	90	19	39	44	54	56	62	63	65	34.3	3.38
6	91	27	52	60	75	82	94	95	100	37.5	2.19
7	83	29	64	77	106	115	170	171	164	35.4	1.40
7	85	24	49	57	76	83	109	110	117	26.3	1.44
7	90	29	54	64	81	84	101	104	103	44.1	2.53
7	91	30	57	66	85	90	101	102	106	48.9	2.78
8	83	15	30	39	56	59	75	75	76	24.5	1.90
8	85	20	41	47	61	66	100	102	97	20.0	1.36
8	90	19	40	48	60	65	76	77	79	31.2	2.31
8	91	18	38	45	59	63	74	74	78	29.7	2.22
9	83	9	35	49	88	101	137	139	156	19.5	1.03
9	85	20	40	48	61	68	97	99	103	17.6	1.22
9	90	25	48	57	73	77	89	91	91	42.5	2.80
9	91	24	49	57	73	77	88	88	93	39.4	2.51
10	83	M	M	M	M	M	M	M	M	M	M
10	85	24	46	54	66	72	101	103	103	22.7	1.42
10	90	19	37	43	56	61	83	85	84	20.7	1.53
10	91	18	39	45	59	61	73	74	76	30.0	2.31
11	83	17	42	54	79	85	113	113	116	31.1	1.63
11	85	18	42	50	63	69	92	93	95	22.3	1.48
11	90	25	50	60	76	83	99	100	104	34.9	1.96
11	91	23	45	53	67	72	80	81	86	35.9	2.45

Figure 6. Descriptive statistics for eight-hour ozone data obtained from monitoring sites associated with St. Louis exposure districts.

CLV: characteristic largest value

DELTA: δ value of fitted Weibull distribution

K: k value of fitted Weibull distribution.

M: missing value.

The statistics listed in Figures 1 through 6 were the primary source of data used in developing the CLVAP's discussed below.

Descriptive Statistics for CLV1 by City-Year

The CLV1 values associated with a particular city-year form an empirical distribution. We attempted to characterize these distributions by fitting normal and lognormal distributions to each empirical distribution. Table 1 lists (1) the arithmetic mean (AM) and standard deviation (ASD) associated with each normal distribution and (2) the geometric mean (GM) and standard deviation (GSD) associated with each lognormal distribution. Note that the results listed for St. Louis, 1983, were determined after the removal of two outliers (the two lowest values). If these outliers had been retained, the AM and ASD would have been 163.6 ppb and 36.2 ppb, respectively. The GM and GSD would have been 159.3 ppb and 1.286, respectively.

In the listing for each city-year, Table 1 also provides the median CLV1 value, the maximum CLV1 value (MAXCLV1), the normal z value of the MAXCLV1, and the lognormal z value of the MAXCLV1. The normal z value was calculated as follows:

$$\textit{normal z of MAXCLV1} = [(\textit{MAXCLV1}) - (\textit{AM})]/\textit{ASD}. \quad (9)$$

The lognormal z value was calculated by the expression

$$\textit{lognormal z of MAXCLV1} = [\ln(\textit{MAXCLV1})-\ln(\textit{GM})]/\ln(\textit{GSD}). \quad (10)$$

Table 1 also lists the relative standard deviation (RSD), the ratio of MAXCLV1 to AM, and the ratio of MAXCLV1 to GM.

Observed Patterns in CLV1 Data

We examined Table 1 to determine whether there were any patterns in the year-to-year listings for each city. The following patterns were noted:

Table 1
Descriptive Statistics for Characteristic Largest One-Hour Values Associated with Ozone Monitoring Sites in Houston, Philadelphia, and St. Louis

City	Year	n	Characteristic largest values, ppb						Relative std. dev.	Ratio of MAXCLV to AM	Ratio of MAXCLV to GM	Z value of maximum	
			Arithmetic		Geometric		Median	Maxi-mum				Arith.	Geom.
			Mean	S.D.	Mean	S.D.[a]							
Houston	1985	10	234.5	29.61	232.8	1.135	232.0	280	0.126	1.19	1.20	1.54	1.46
	1988	11	198.3	19.96	197.4	1.104	191.0	238	0.101	1.20	1.21	1.99	1.89
	1990	11	214.5	20.79	213.6	1.105	224.0	241	0.097	1.12	1.13	1.27	1.21
	1991	11	178.3	26.75	176.3	1.173	177.0	219	0.150	1.23	1.24	1.52	1.36
	Mean					1.129			0.119	1.19	1.20		
Philadelphia	1983	10	172.5	15.89	171.9	1.094	170.0	207	0.092	1.20	1.20	2.17	2.07
	1984	10	164.0	21.62	162.9	1.132	153.5	214	0.132	1.30	1.31	2.31	2.20
	1986	10	145.2	12.01	145.0	1.087	145.5	164	0.083	1.13	1.13	1.57	1.48
	1991	10	145.7	12.05	145.3	1.085	143.0	167	0.083	1.15	1.15	1.77	1.71
	Mean					1.100			0.098	1.20	1.20		
St. Louis	1983	8[b]	178.4	20.41	177.3	1.128	182.5	201	0.114	1.13	1.13	1.11	1.04
	1985	11	134.4	18.99	133.2	1.151	132.0	164	0.141	1.22	1.23	1.56	1.48
	1990	11	114.5	17.43	113.2	1.177	119.0	141	0.152	1.23	1.25	1.52	1.35
	1991	11	110.4	14.63	109.5	1.145	110.0	132	0.133	1.20	1.21	1.48	1.38
	Mean					1.150			0.135	1.20	1.21		

[a]Dimensionless quantity.
[b]Omits two site-years.

1. The ASD is moderately correlated with AM (R squared = 0.474).

2. The GSD (a dimensionless quantity) is not correlated with GM (R squared = 0.029) and is relatively constant within each city. The four-year mean GSD for each city is listed below.

   Houston: 1.129

   Philadelphia: 1.100

   St. Louis: 1.150

3. The RSD is not correlated with AM (R squared = 0.065) and is relatively constant within each city. The four-year mean RSD for each city is listed below.

   Houston: 0.119

   Philadelphia: 0.098

   St. Louis: 0.135

4. The MAXCLV1 is highly correlated with AM (R squared = 0.960). The regression equation (n = 12) is

   MAXCLV1 = 7.57 ppb + (1.14)(AM).

   The intercept is not significant.

5. The MAXCLV1 is highly correlated with GM (R squared = 0.958). The regression equation (N = 12) is

   MAXCLV1 = 8.29 ppb + (1.14)(GM).

   The intercept is not significant.

6. The MAXCLV1 is highly correlated with the median (R squared = 0.903). The regression equation (n = 12) is

   MAXCLV1 = 16.16 ppb + (1.10)(median).

   The intercept is not significant.

7. The ratio of MAXCLV1 to AM is relatively constant within and between cities. The four-year mean ratios are listed below.

   Houston: 1.19

   Philadelphia: 1.20

   St. Louis: 1.20

8. The ratio of MAXCLV1 to GM is relatively constant within and between cities. The four-year mean ratios are listed below

   Houston: 1.20

   Philadelphia: 1.20

   St. Louis: 1.21

Two Candidate Models for Adjusting CLV1's

We have developed two general models for adjusting CLV1's which are consistent with these patterns. Model A assumes that

a) the CLV1's for a given city-year follow a lognormal distribution,

b) the GSD of the lognormal distribution is constant from year-to-year, and

c) the z value associated with the CLV1 of the r-th ranked site is constant from year-to-year.

Model B assumes that

a) the one-hour CLV1's for a given city-year follow a normal distribution,

b) the RSD of the normal distribution is constant from year-to-year, and

c) the z value associated with the CLV1 of the r-th ranked site is constant from year-to-year.

Evaluation of Model A With Respect to the Observed Patterns

To evaluate Model A, we have defined ZMAXA as the z value of the MAXCLV1 with respect to the lognormal distribution. The relationship between MAXCLV1 and GM is expressed by the lognormal equation

$$MAXCLV1 = (GM)(GSD)^{ZMAXA}. \tag{11}$$

If GSD and ZXAXA are constant from year to year as assumed, then the ratio of MAXCLV1 to GM is constant and equal to GSD^{ZMAXA}. This relationship is consistent with Patterns 5 and 8.

The relationship between GM and AM for a lognormal distribution is

$$AM = (GM)[\exp(\sigma^2)]^{0.5}, \tag{12}$$

where $\sigma = \ln(GSD)$. Note that GM is being multiplied by a term that is determined solely by the value of GSD. If GSD is constant year-to-year, then the ratio of AM to GM is constant. Consequently, the ratio of MAXCLV1 to AM is constant. This relationship is consistent with Patterns 4 and 7 noted above.

The median of a lognormal distribution is equal to the GM. This relationship supports Pattern 6.

The RSD of a lognormal distribution can be expressed as

$$ASD/AM = RSD = [\exp(\sigma^2) - 1]^{0.5}, \tag{13}$$

where $\sigma = \ln(GSD)$. Note that RSD is determined solely by GSD. If GSD is constant year-to-year, RSD will be constant year-to-year and ASD will be correlated with AM (Patterns 3 and 2). The average GSD for the 12 city-years is 1.126. Inserting this value in the equation above yields an RSD value of 0.119. The average of the 12 RSD values in Table 7 is 0.117, a difference of less than 2 percent.

These results suggest that Model A is consistent with all eight patterns noted in Table 7.

Evaluation of Model B With Respect to the Observed Patterns

Model B assumes that the CLV1 values are normally distributed and that RSD is constant year-to-year. To evaluate Model B, we have defined ZMAXB as the z value of the MAXCLV1 with respect to the normal distribution. The relationship between MAXCLV1 and AM is expressed by the normal equation

$$MAXCLV1 = AM + (ASD)(ZMAXB). \qquad (14)$$

Because ASD = (RSD)(AM), this expression is equivalent to

$$MAXCLV1 = (AM)[1 + (RSD)(ZMAXB)]. \qquad (15)$$

If RSD and ZXAXB are constant from year to year as assumed, then the ratio of MAXCLV1 to AM is constant and equal to the far-right term [1 + (RSD)(ZMAXB)]. This relationship is consistent with Patterns 5 and 8.

The relationships among GM, AM, and the median for a normal distribution can be expressed by the simple identity

$$AM = GM = median. \qquad (16)$$

If the ratio of MAXCLV1 to AM is constant year-to-year, then the ratio of MAXCLV1 to GM and the ratio of MAXCLV1 to median are also constant year-to-year. This behavior is consistent with Patterns 6 and 8.

Although CLV1's are by definition positive values, a normal distribution fit to these values will always extend below zero, at least in theory. As GSD's cannot be determined for theoretical distributions containing negative values, there is no formula for determining GSD from the parameters of a normal distribution. Consequently, we cannot predict the behavior of GSD from the assumptions concerning AM and ASD. There is no way that we can evaluate Model B according to Pattern 2 (i.e., GSD is constant year-to-year).

We recommend that Model A be incorporated into the adjustment procedure. Model A does not have the theoretical problem of negative values and is consistent with all eight patterns.

Year-to-Year Variability in Identity of Highest Ranked Site

MAXCLV1 is defined as the maximum CLV1 of a particular city for a specific year. Associated with MAXCLV1 is a value for ZMAXA. Under Model A, ZMAXA is assumed to remain constant from year to year, although GM may change. It should be noted that we have not assumed that ZMAXA is associated with the same site each year. The data in Figures 1, 2, and 3 demonstrate that the identity of the "MAXCLV1 site" can change from year to year. For example, the MAXCLV1 site in Houston is associated with the District 8 site in 1985, the District 11 site in 1988, the District 10 site in 1990, and the District 5 site in 1991.

Ideally, we would like to assume that the ranking of all sites in a city with respect to CLV1 is constant from year to year. The validity of this assumption varies with city. Table 2 lists the ranking of the sites associated with each city in each of the four years selected for analysis. (Note that the site with the largest value of CLV1 is assigned a rank of 1.) The table also shows the highest and lowest rank assigned to each site over the four years included in the analysis. The mean rank is also provided.

The rankings associated with Houston display the most random behavior. Site 8 is ranked No. 1 and No. 11. Site 5 is ranked No. 1 and No. 10. Site 6 is ranked No. 2 and No. 11. The rankings in any one year do not provide a good indication of the rankings in another year. For example, the Spearman rank correlation between the CLV1 values of Year A (1985) -- the year with the largest CLV1 (280 ppb) -- and the CLV1 values of Years B, C, and D is -0.1394 for Year B (1988), 0.1398 for Year C (1990), and -0.1879 for Year D (1991). The ranks in Years B, C, and D are better predicted by the mean rank of the other three years than by Year A alone. The Spearman rank coefficient between the rank in each of these years and the mean of the ranks of the other three years is 0.1216 for Year B, 0.7853 for Year C, and -0.0547 for Year D.

The least random behavior is displayed by the rankings associated with Philadelphia. For example, the Spearman rank correlation between the CLV1 values of Year B -- the year with the highest CLV1 (214 ppb) -- and the CLV1 values of Years A, C, and D is 0.4893 for Year A, 0.2553 for Year C, and 0.2918 for Year D. Although these correlations are stronger than those associated with Houston, but they are still relatively weak in an absolute sense. The ranks in Years A, C, and D are better predicted by the mean rank of the other three years than by Year B alone. The Spearman rank coefficient between the rank in each of these years and the mean of the ranks of the other three years is 0.4268 for Year A, 0.4909 for Year C, and 0.5289 for Year D.

A Procedure for Predicting Future CLV1's Under One-Hour NAAQS Attainment

At this point, the evidence suggests that the future ranking of a site under a particular one-hour NAAQS scenario is better predicted by the average ranking of that site over a multi-year period than by the ranking of the site in a randomly selected year. The following procedure for predicting future CLV1 values under 1-hr NAAQS attainment conditions is based on combining this assumption with Model A above.

1. Determine the following quantities.

   CLV1(i,j): the CLV1 of i-th ranked site in City j for the "baseline" or "start" year.

Table 2
Ranks of Characteristic Largest One-Hour Values Associated with Ozone Monitoring Sites Representing Exposure Districts in Houston, Philadelphia, and St. Louis

City	District	Rank by year[a]				Ranks over 4 years		
		A	B	C	D	High	Low	Mean
Houston	1	10	5	6	4	4	10	6.3
	2	9	4	10	11	4	11	8.5
	3	7	2	1	8	1	8	4.5
	4	2	3	5	9	2	9	4.8
	5	6	10	4	1	1	10	5.3
	6	b	7	11	2	2	11	6.7
	7	8	9	7	5	5	9	7.3
	8	1[c]	11	8	10	1	11	7.5
	9	5	8	9	6	5	9	7.0
	10	3	6	2	3	2	6	3.5
	11	4	1	3	7	1	7	3.8
Philadelphia	1	7	4	3	1	1	7	3.8
	2	6	2	1	4	1	6	3.3
	3	8	10	2	3	2	10	5.8
	4	1	6	6	2	1	6	3.8
	5	2	1[c]	4	5	1	5	3.0
	6	4	8	5	9	4	9	6.5
	7	10	9	10	8	8	10	9.3
	8	5	5	7	7	5	7	6.0
	9	7	7	9	10	7	10	8.3
	10	3	3	8	6	3	8	5.0
St. Louis	1	7	9	3	8	3	9	6.8
	2	9	10	1	5	1	10	4.0
	3	4	5	2	1	1	5	3.0
	4	6	1	8	6	1	8	5.3
	5	3	2	5	2	2	5	3.0
	6	2	3	11	4	2	11	5.0
	7	1[c]	4	4	3	1	4	3.0
	8	10	7	10	10	7	10	9.3
	9	5	6	7	7	5	7	6.3
	10	a	8	9	11	8	11	9.3
	11	8	11	6	9	6	11	8.5

[a]Houston: A = 1985, B = 1988, C = 1990, D = 1991
Philadelphia: A = 1983, B = 1984, C = 1986, D = 1991
St. Louis: A = 1983, B = 1985, C = 1990, D = 1991.
[b]Insufficient data to determine rank.
[c]Site-year associated with largest ACLV for indicated city.

MAXCLV1(j): the largest CLV1 of all sites in City j for the baseline year.

AMAXCLV1(j): the largest CLV1 value permitted under the proposed 1-hr NAAQS.

2. Select five years prior to the baseline year and determine the value of CLV1 (or related air quality indicator) at each site m in City j for each year. Rank these values by city and year. Let RANK(m,j,y) indicate the rank of site m in city j in year y. Let MEANRANK(m,j) indicate the mean value of RANK(m,j,y) over the n years. Rank the MEANRANK(m,j) values and let RELRANK(m,j) indicate the relative rank of MEANRANK(m,j).

3. Calculate an adjusted CLV1 for the i-th ranked site in City j by the expression

$$ACLV1(i,j) = [CLV1(i,j)][AMAXCLV1(j)]/[MAXCLV1(j)]. \quad (17)$$

4. If RELRANK(m,j) = i, then m will be the i-th ranked site in City j under attainment. That is,

ACLV1(m,j) = ACLV1(i,j) if RELRANK(m,j) = i.

5. The 1-hour data at Site m under attainment will be determined by adjusting the 1-hour data at Site m in the baseline year. A Weibull distribution fit to the adjusted data will have a CLV1 equal to ACLV1(i,j) where i = RELRANK(m,j). (A method for estimating the parameters of this Weibull distribution will be discussed later in this letter.)

The procedure assumes that the CLV1's of City j are lognormally distributed with GSD = GSD(j) in both the baseline and attainment years. Equation 17 in Step 3 follows directly from the Model A assumptions that the z value of the i-th ranked CLV1 is constant. We will allow the identity of the site associated with the i-th ranked CLV1 to change, however. We identify the i-th ranked site under attainment by first averaging the ranks of each site for five years near to and including the baseline year. These ranks can be determined by CLV1 or by a related air quality indicator (e.g., the observed second highest daily maximum one-hour concentration). The site with the i-th ranked average will be assigned the i-th ranked CLV1 determined for the attainment year.

Application of the CLV1 Adjustment Procedure to Philadelphia

We have applied the CLV1 adjustment procedure to Philadelphia. Table 3 presents the results. The baseline year is 1991. The five-year ranking of each site is based on second-high daily maximum one-hour concentrations, as these values are easier to obtain than CLV1's. District 1 has the largest CLV1 for 1991 (156 ppb). The largest CLV1 must be reduced to 120 ppb for Philadelphia to meet the current 1-hour NAAQS. Equation 17 is thus

$$ACLV1(i,j) = [CLV1(i,j)](120/156) = [CLV1(i,j)](0.769).$$

Applying this expression to each 1991 CLV1, we determine 10 CLV1's for the attainment year. These values are listed in the column labeled "adjusted CLV1". We then assign these values to the districts according to the five-year ranking determined for each district. Thus, the largest adjusted CLV1 (120 ppb) is assigned to District 4 because District 4 has the highest five-year ranking. Similarly, the second largest adjusted CLV1 (116 ppb) is assigned to District 3 because District 3 has the second highest five-year ranking.

A Procedure for Predicting Future CLV8's Under Eight-Hour NAAQS Attainment

Table 4 follows the same format as Table 1 to present descriptive statistics for the eight-hour data listed in Figures 4, 5, and 6. We examined Table 4 to determine whether there were any patterns in the year-to-year listings for each city. The following patterns were noted:

1. The ASD is weakly correlated with AM (R squared = 0.253).

2. The GSD (a dimensionless quantity) is not correlated with GM (R squared = 0.125) and is relatively constant within each city. The four-year mean GSD for each city is listed below.

   Houston: 1.122

   Philadelphia: 1.109

   St. Louis: 1.149

   Note that these city means are almost identical to the corresponding city means listed in Table 1 for CLV1's.

Table 3
Application of Adjustment/Reassignment Procedure to Characteristic Largest One-Hour Values Associated with Monitoring Sites Representing Exposure Districts in Philadelphia

District	1991 CLV1, ppb	1991 ranking	Five-year ranking	Adjusted CLV1, ppb	Reassigned attainment CLV1, ppb
1	167	1	4.5	120	107
2	149	4	3.0	107	110
3	153	3	2.0	110	116
4	162	2	1.0	116	120
5	145	5	4.5	104	104
6	134	9	7.0	96	101
7	135	8	10.0	97	94
8	140	7	6.0	101	101
9	131	10	9.0	94	96
10	141	6	8.0	101	97

Table 4
Descriptive Statistics for Characteristic Largest Eight-Hour Values Associated with Ozone Monitoring Sites in Houston, Philadelphia, and St. Louis

City	Year	n	Characteristic largest values, ppb						Relative std. dev.	Ratio of MAXCLV to AM	Ratio of MAXCLV to GM	Z value of maximum	
			Arithmetic		Geometric		Median	Maxi-mum					
			Mean	S.D.	Mean	S.D.[a]						Arith.	Geom.
Houston	1985	10	176.3	22.97	174.9	1.140	174.5	208	0.130	1.18	1.19	1.38	1.32
	1988	11	145.8	10.93	145.5	1.077	140.0	164	0.075	1.12	1.13	1.67	1.61
	1990	11	158.3	15.31	157.6	1.105	162.0	179	0.097	1.13	1.14	1.35	1.28
	1991	11	131.2	19.32	129.8	1.166	133.0	162	0.147	1.23	1.25	1.59	1.44
	Mean					1.122			0.112	1.17	1.18		
Philadelphia	1983	10	139.8	18.95	138.8	1.132	137.5	189	0.136	1.35	1.36	2.60	2.49
	1984	10	131.4	16.72	130.5	1.130	126.5	166	0.127	1.26	1.27	2.07	1.97
	1986	10	123.1	12.34	122.6	1.104	121.0	144	0.100	1.17	1.17	1.69	1.63
	1991	10	127.5	8.78	127.2	1.071	127.0	142	0.069	1.11	1.12	1.65	1.60
	Mean					1.109			0.108	1.22	1.23		
St. Louis	1983	8[b]	144.2	17.38	143.3	1.135	150.0	164	0.121	1.14	1.15	1.14	1.07
	1985	11	110.4	14.69	109.5	1.138	103.0	139	0.133	1.26	1.27	1.95	1.85
	1990	11	93.8	14.41	92.8	1.177	97.0	116	0.154	1.24	1.25	1.54	1.37
	1991	11	95.7	12.64	94.9	1.144	94.0	116	0.132	1.21	1.22	1.61	1.49
	Mean					1.149			0.135	1.21	1.22		

[a]Dimensionless quantity.
[b]Omits two site-years.

3. The RSD is not correlated with AM (R squared = 0.101) and is relatively constant within each city. The four-year mean RSD for each city is listed below.

Houston: 0.112

Philadelphia: 0.108

St. Louis: 0.135

Note that these city means are almost identical to the corresponding city means listed in Table 1 for CLV1's.

4. The MAXCLV8 is highly correlated with AM (R squared = 0.885). The regression equation (n = 12) is

$$MAXCLV8 = 15.8 \text{ ppb} + (1.08)(AM).$$

The intercept is not significant.

5. The MAXCLV8 is highly correlated with GM (R squared = 0.879). The regression equation (N = 12) is

$$MAXCLV8 = 16.8 \text{ ppb} + (1.08)(GM).$$

The intercept is not significant.

6. The MAXCLV8 is highly correlated with the median (R squared = 0.832). The regression equation (n = 12) is

$$MAXCLV8 = 25.1 \text{ ppb} + (1.01)(\text{median}).$$

The intercept is not significant.

7. The ratio of MAXCLV8 to AM is relatively constant within and between cities. The four-year mean ratios are listed below.

Houston: 1.17

Philadelphia: 1.22

St. Louis: 1.21

Note that these city means are almost identical to the corresponding city means listed in Table 1 for CLV1's.

8. The ratio of MAXCLV8 to GM is relatively constant within and between cities. The four-year mean ratios are listed below

Houston: 1.18

Philadelphia: 1.23

St. Louis: 1.22

Note that these city means are almost identical to the corresponding city means listed in Table 1 for CLV1's.

These patterns are similar to those identified for the CLV1 statistics in Table 1. Consequently, these patterns support eight-hour versions of Models A and B. We recommend that the CLV8 adjustment procedure incorporate Model A, as this was the model selected for the CLV1 adjustment procedure.

Because CLV1 and CLV8 are highly correlated, we can expect the year-to-year rankings of CLV8's to behave in a similar manner to those of CLV1's; that is, the future ranking of a site under a particular eight-hour NAAQS scenario is better predicted by the average ranking of that site over a multi-year period than by the ranking of the site in a randomly-selected year. The rankings can be determined by either one-hour or eight-hour data, as we expect the rankings to be essentially the same by either method.

The following procedure for predicting future CLV8 values under <u>8-hr NAAQS attainment</u> conditions follows the procedure outlined above for 1-hr NAAQS attainment.

1. Determine the following quantities.

CLV8(i,j):	the eight-hour CLV of i-th ranked site in City j for the "baseline" or "start" year.
MAXCLV8(j):	the largest CLV8 of all sites in City j for the baseline year.
AMAXCLV8(j):	the largest CLV8 value permitted under the proposed 8-hr NAAQS.

2. Select five years prior to the baseline year and determine the value of CLV8 (or related air quality indicator) at each site m in City j for each year. Rank these values by city and year. Let RANK(m,j,y) indicate the rank of site m in city j in year y. Let MEANRANK(m,j) indicate the mean value of RANK(m,j,y) over the n years. Rank

the MEANRANK(m,j) values and let RELRANK(m,j) indicate the relative rank of MEANRANK(m,j). Note: this ranking can be performed using CLV1's or related air quality indicators.

3. Calculate an adjusted CLV8 for the i-th ranked site in City j by the expression

$$ACLV8(i,j) = [CLV8(i,j)][AMAXCLV8(j)]/[MAXCLV8(j)]. \quad (18)$$

4. If RELRANK(m,j) = i, then m will be the i-th ranked site in City j under attainment. That is,

$$ACLV8(m,j) = ACLV8(i,j) \text{ if } RELRANK(m,j) = i.$$

5. Using a suitable equivalence relationship, estimate the CLV1 associated with each ACLV8(m,j) value. Denote this value as ACLV1(m,j). (A recommended equivalence relationship is provided later in this letter.)

6. The 1-hour data for Site m under attainment of the 8-hr NAAQS will be determined by adjusting the 1-hour data for Site m in the baseline year. A Weibull distribution fit to the adjusted data will have a CLV1 equal to ACLV1(i,j) where i = RELRANK(m,j). (A method for estimating the parameters of this Weibull distribution will be discussed later in this letter.)

Application of the CLV8 Adjustment Procedure to Philadelphia

We have applied the procedure to Philadelphia with the assumption that an 8-hour NAAQS of 80 ppb has been attained. Table 5 presents the results using the same format as Table 3. As in the one-hour example, the baseline year is 1991. The five-year ranking of each site is based on second-high daily maximum one-hour concentrations, as these values were easier to obtain than CLV8's. District 1 has the largest CLV8 for 1991 (142 ppb). The largest CLV8 must be reduced to 80 ppb for Philadelphia to meet a proposed 8-hour NAAQS. Equation 18 is thus

Table 5
Application of Adjustment/Reassignment Procedure to Characteristic Largest Eight-Hour Values Associated with Monitoring Sites Representing Exposure Districts in St. Louis

District	1991 CLV8, ppb	1991 ranking	Five-year ranking	Adjusted CLV8, ppb	Reassigned attainment CLV8, ppb
1	142	1	4.5	80	72
2	136	3	3	77	77
3	128	4.5	2	72	78
4	138	2	1	78	80
5	120	8	4.5	68	72
6	118	9	7	66	69
7	123	7	10	69	65
8	128	4.5	6	72	71
9	116	10	9	65	66
10	126	6	8	71	68

$$ACLV8(i,j) = [CLV8(i,j)](80/142) = [CLV8(i,j)](0.563).$$

Applying this expression to each 1991 CLV8, we determine 10 CLV8's for the attainment year. These values are listed in the column labeled "adjusted CLV8". We then assign these values to the districts according to the five-year ranking determined for each district. Thus, the largest adjusted CLV8 (80 ppb) is assigned to District 4 because District 4 has the highest five-year ranking. Similarly, the second largest adjusted CLV8 (72 ppb) is assigned to District 3 because District 3 has the second highest five-year ranking.

STEP 4: ADJUST ONE-HOUR DATA

Simulation of One-Hour NAAQS

The CLV1 adjustment procedure discussed above provides an estimate of the CLV1 associated with each site under attainment conditions. To complete the adjustment process, the one-hour values associated with the site must be adjusted to produce the designated CLV1. If we assume that the adjusted data can be fit by a Weibull distribution, then we must develop a method for estimating the parameters of this distribution.

Let δ and k indicate the parameters of the Weibull distribution fitting the unadjusted 1-hour data associated with a particular site. These parameters are related to the UCLV1 -- the CLV1 of the unadjusted data -- by the expression

$$UCLV1 = \delta[\ln(n)]^{1/k}. \qquad (19)$$

Let δ′ and k′ indicate the parameters of the Weibull distribution fitting the adjusted 1-hour data. These parameters are related to the adjusted CLV1 (ACLV1) by the expression

$$ACLV1 = \delta'[\ln(n)]^{1/k'}. \qquad (20)$$

We would like to find an prediction equation incorporating UCLV1, ACLV1, δ, and/or k which can be used to estimate either δ′ or k′. Given an estimate of δ′, Equation 20 can be used to estimate k′. Similarly, Equation 20 can be used to estimate δ′ given an estimate of k′.

To assist in developing the required prediction equation, we reviewed the 128 site-years of one-hour data listed in Figures 1, 2, and 3. (As discussed above, we had previously fit a Weibull distribution to each of the data sets.) We identified a pair of data sets associated with each of 30 monitors such that the pair contained the highest and lowest year with respect to CLV1. We assumed the high CLV1 year represented an unadjusted data set and the low year represented an adjusted data set.

We performed a series of regression analyses in which the dependent variable was either the δ or k value associated with the adjusted data set (i.e., δ′ or k′). The independent variables included various functions of the three parameters associated with the unadjusted data set (δ, k, and UCLV1) and various functions of ACLV1 -- the CLV1 of the adjusted data set. Based on the results of these analyses, we are recommending that the following regression equation be used to estimate k′:

$$1/k' = -0.2389 + (0.003367)(ACLV1) + (0.4726)(1/k). \qquad (21)$$

Each coefficient of this equation was found to be statistically significant at the p = 0.10 level; the over-all R squared value was 0.6993. Note that the equation assumes that ACLV1 will be in units of ppb.

Given the ACLV1 and an estimate of k′, we can estimate the corresponding δ′ value by the equation

$$\delta' = (ACLV1)/[\ln(n)]^{1/k'}. \qquad (22)$$

We now have values for δ, k, UCLV1, δ′, k′, and ACLV1. If we treat the unadjusted data set as a time series in which x_t is the one-hour value at time t, we can construct a corresponding adjusted data set by the expression

$$y_t = (\delta')(x_t/\delta)^{k/k'}. \qquad (23)$$

where y_t is the adjusted value at time t. This expression is based on the assumptions that the time series y_t at a site after attainment is related to the original time series x_t in such a way that (1) the rank of the one-hour value at each time t is unchanged, (2) the x_t values follow a Weibull distribution with parameters δ and k, and (3) the y_t values follow a Weibull distribution with parameters δ′ and k′. The latter two assumptions have already been discussed.

The first assumption is made primarily as a means of incorporating the general seasonal and diurnal patterns of the x_t series into the y_t series. We are assuming that the time series "profile" of the x_t series reflects the interactions of meteorology, precursors, and decay mechanisms as they currently occur. In the absence of reliable information on the magnitude and interactions of these factors under a hypothetical scenario, we are assuming the "profile" will not change. The absolute value of the ozone concentration at each time t may change, but the relative ranking of the values will not change. Peak values will still occur on the same days at the same time of day. In a sense, we are assuming that the basic temporal patterns in meteorology, precursors, and decay mechanisms will not change significantly under any projected regulatory scenario. What does change is shape of the distribution of hourly average values. Equations 21 and 22 determine the parameters of the new distribution.

Equation 23 can be restated as

$$y_t = (c)(x_t)^d \tag{24}$$

$$c = (\delta')/(\delta)^{k/k'} \tag{25}$$

$$d = k/k'$$

We will refer to c and d as "adjustment coefficients."

To illustrate the adjustment procedure for one-hour values, we have applied it to the 1991 Philadelphia data sets listed in Table 6. The table lists the k value associated with the unadjusted data set and the adjusted CLV1 expected under attainment of the current NAAQS (120 ppb). Through the use of Equation 21, we determined a value of k′ for each data set. Through the use of Equation 22, we next determined a value for δ′. These values were then used to determine the adjustment coefficients (c and d). These values are listed in the far-right columns of Table 6.

Simulation of 8-Hour NAAQS

The CLV8 adjustment procedure discussed above provides an estimate of the CLV8 associated with each site under attainment conditions. To complete the adjustment process, the one-hour values associated with the site should be adjusted so that a Weibull distribution fit to the resulting eight-hour values will yield the designated CLV8. We can simplify this process by adjusting the one-hour values so that a Weibull distribution fit to the one-hour values will yield a CLV1 that is equivalent to the desired CLV8. Given this CLV1 and the k value of the Weibull distribution fit to the unadjusted one-hour data, we can use Equations 21 and 22 to determine k′ and δ′ for the adjusted one-hour Weibull distribution. The original one-hour data are then adjusted using Equation 23.

In our letter of March 1, 1993, we provided a series of equivalence expressions relating CLV8 to CLV1 (referred to as EHCLV and OHCLV, respectively, in the letter). The expressions were based on regression analyses performed on the 96 site-years of data we will be using to represent the "as is" (1990-91) air quality for the nine-city pNEM/O3 analysis. The simple expression

$$CLV1 = (CLV8)^{1.0466} \tag{26}$$

Table 6
Determination of Adjustment Coefficients for One-Hour NAAQS Attainment (CLV1 = 120 ppb) in Philadelphia

	Weibull fit to 1991 1-hr data			1-hr NAAQS attainment parameters[a]				Adjustment coefficients	
District	k	δ	CLV1	Adjusted CLV1	Reassigned CLV1	k′	δ′	c	d
1	1.69	46.9	167	120	107	2.494	45.27	3.336	0.678
2	2.21	56.4	149	107	110	2.896	52.44	2.417	0.763
3	1.96	51.0	153	110	116	2.546	49.95	2.420	0.770
4	1.81	49.3	162	116	120	2.346	48.09	2.377	0.772
5	2.28	56.6	145	104	104	3.139	52.51	2.800	0.726
6	2.23	51.2	134	96	101	3.194	51.60	3.305	0.698
7	1.93	44.3	135	97	94	3.101	47.06	4.447	0.622
8	2.14	51.2	140	101	101	3.106	50.62	3.361	0.689
9	1.74	38.1	131	94	96	2.809	44.74	4.694	0.619
10	2.26	54.5	141	101	97	3.369	51.31	3.511	0.671

[a]Assumes maximum CLV1 equals 120 ppb.

performed particularly well (R squared = 0.889). For CLV8 < 110 ppb, this exponential relationship is very closely fit by the linear relationship

$$CLV1 = (1.213)(CLV8). \tag{27}$$

The term 1.2313 is the median ratio of CLV1 to CLV8 for the 96 site-years of data.

We examined the 96 site-specific ratios of CLV1 to CLV8 by city and found that the ratios varied more among cities than among sites within a city. We also examined the CLV1-to-CLV8 ratios in the three-city multiyear data base (Houston, Philadelphia, and St. Louis) described above and found that the average city ratio was either constant year to year or else showed a slight decreasing trend. For example, the median ratio for Houston was relatively constant; the ratio was 1.334 for 1985, 1.370 for 1988, 1.374 for 1990, and 1.352 for 1991. The median ratio for Philadelphia displayed an overall decline; the ratio was 1.240 for 1983, 1.249 for 1984, 1.184 for 1986, and 1.142 for 1992. We recommend that (1) a single average CLV1-to-CLV8 ratio be applied to all sites within a particular city and (2) the ratio be determined by a recent year of data specific to the city.

Table 7 lists the mean and median ratios for each city based on the 1990-91 nine-city data base. The table also lists mean and median ratios for three other years for three of the cities (Houston, Philadelphia, and St. Louis). We recommend that the flagged median ratios in this table be used for the city-specific ratios. Each median is associated with a recent year (1990 or 1991). The medians are preferred to the means, as they are less affected by outliers.

Table 8 demonstrates the application of the adjustment procedure to Philadelphia for an eight-hour NAAQS which permits a maximum CLV8 of 80 ppb. Under "as is" conditions the highest CLV8 is 142 ppb. We are interested in simulating attainment of a NAAQS which permits a CLV8 no higher than 80 ppb. Each CLV8 is first multiplied by 80ppb/142ppb as indicated by Equation 18. These adjusted CLV8's are then reassigned according to the relative rank of each site for the five-year period. The reassigned CLV8's are next multiplied by 1.132, the median CLV1-to-CLV8 ratio listed for Philadelphia in Table 7. This step provides estimates of equivalent CLV1's which are then used to determine adjustment coefficients through the use of Equations 21 through 26.

ADJUSTMENT COEFFICIENTS FOR NINE CITIES

We have developed four sets of adjustment coefficients (c and d) for each of the monitoring sites associated with the nine cities. The coefficients can be used to adjust the "as is" data associated with each site to simulate attainment of the following NAAQS scenarios:

Table 7
Ratios of CLV1 to CLV8 for Nine Cities Based on Recent Ozone Data

			CLV1-to-CLV8 ratio		
City	Data year	Number of sites	Mean	Std. dev.	Median
Chicago	1991	12	1.158	0.024	1.155[a]
Denver	1990	7	1.272	0.115	1.234[a]
Houston	1990	11	1.376	0.082	1.374[a]
Los Angeles	1991	16	1.443	0.152	1.444[a]
Miami	1991	6	1.251	0.048	1.248[a]
New York	1991	12	1.180	0.090	1.178[a]
Philadelphia	1991	10	1.142	0.043	1.132[a]
St. Louis	1990	11	1.221	0.036	1.226[a]
Washington	1991	11	1.173	0.028	1.179[a]
Houston (other years)	1985	10	1.331	0.022	1.334
	1988	11	1.359	0.076	1.370
	1991	11	1.359	0.058	1.352
Philadelphia (other years)	1983	10	1.240	0.068	1.241
	1984	10	1.249	0.055	1.247
	1986	10	1.184	0.045	1.169
St. Louis (other years)	1983	10	1.248	0.032	1.247
	1985	11	1.217	0.048	1.198
	1991	11	1.153	0.026	1.154

[a]Recommended ratio for specified city.

Table 8
Determination of Adjustment Coefficients for Eight-Hour NAAQS Attainment (CLV8 = 80 ppb) in Philadelphia

District	Weibull fits to 1991 data				8-hr NAAQS attainment parameters			1-h Weibull parameters		Adjustment coefficients	
	1-h k	1-h δ	CLV1	CLV8	Adjusted CLV8	Reassigned CLV8	Equivalent CLV1	k'	δ'	c	d
1	1.69	46.9	167	142	80	72	82	3.173	41.45	5.339	0.533
2	2.21	56.4	149	136	77	77	87	3.725	49.01	4.481	0.593
3	1.96	51.0	153	128	72	78	88	3.339	46.44	4.618	0.587
4	1.81	49.3	162	138	78	80	91	3.057	44.89	4.465	0.592
5	2.28	56.6	145	120	68	72	82	4.119	48.41	5.183	0.554
6	2.23	51.2	134	118	66	69	78	4.237	47.08	5.932	0.526
7	1.93	44.3	135	123	69	65	74	3.941	42.70	6.671	0.490
8	2.14	51.2	140	128	72	71	80	3.960	46.75	5.572	0.540
9	1.74	38.1	131	116	65	66	75	3.518	40.60	6.708	0.495
10	2.26	54.5	141	126	71	68	77	4.359	47.06	5.922	0.518

[a]Assumes maximum CLV8 equals 80 ppb.

1. 1-hour NAAQS: highest CLV1 in city equals 120 ppb.

2. 8-hour NAAQS: highest CLV8 in city equals 60 ppb.

3. 8-hour NAAQS: highest CLV8 in city equals 80 ppb.

4. 8-hour NAAQS: highest CLV8 in city equals 100 ppb.

With your approval, we will use these coefficients to simulate NAAQS attainment in the next round of pNEM/O3 runs. Tables listing the coefficients will be provided in a future letter. Draft copies of these tables can be obtained from Jim Capel.

I hope this letter is useful in explaining our proposed adjustment procedure for ozone data. Please call me if you have any questions or comments.

Sincerely,

IT AIR QUALITY SERVICES

Ted Johnson

Ted Johnson

TRJ:jda

cc: Bill Biller
Harvey Richmond
Steve Kopp

APPENDIX B

ADJUSTMENT OF OZONE DATA TO SIMULATE 5EXEX 8H NAAQS

INTERNATIONAL
TECHNOLOGY
CORPORATION

June 15, 1993

IT Project No. 830013-26

Mr. Thomas McCurdy
U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Mutual Building, Mail Drop - 12
Research Triangle Park, North Carolina 27711

Adjustment of Ozone Data to Simulate 5exex 8h NAAQS

Dear Tom:

Under Work Assignment II-5 of EPA Contract No. 68-DO-0062, IT Air Quality Services (ITAQS) will be applying a revised version of pNEM/O3 to nine urban areas. Fixed-site monitoring data for the years 1990 and 1993 will be used to represent "as is" ambient concentrations within each exposure district. An air quality adjustment procedure (AQAP) will be used to adjust the "as is" data to simulate various 1-hour and 8-hour National Ambient Air Quality Standards (NAAQS).

In my letter of April 15, 1993, I described AQAP's that could be used to simulate the attainment of 1-hour and 8-hour daily maximum NAAQS which permitted one expected exceedance of a specified ozone concentration. In this letter, I will present a recommendation for an AQAP that can be used to simulate the attainment of 8-hour daily maximum NAAQS that permit five expected exceedances. This letter also provides a recommendation for an extra step to be added to the AQAP previously proposed for simulating attainment of 8-hour daily maximum NAAQS that permit one expected exceedance.

The letter will be organized according to the same step-by-step procedure used in the previous letter. The five steps included in the AQAP are listed below.

1. Specify an air quality indicator (AQI) to be used in evaluating the status of a monitoring site with respect to the NAAQS of interest.

2. Determine the value of the AQI for each site within a study area under "as is" conditions.

3. Determine the value of the AQI under conditions in which the air pollution levels within the study area have been reduced until a single site just attains a specified NAAQS.

4. Adjust the one-hour values of the "as is" data set associated with each site to yield the AQI value determined in Step 3. The adjusted data set should retain the temporal profile of the "as is" data set.

STEP 1: SPECIFY AIR QUALITY INDICATOR

Let "8HDM-5ExEX NAAQS" indicate an 8-hour daily maximum NAAQS which permits 5 expected exceedances. To determine compliance with a 8HDM-5ExEx NAAQS, we must determine an Air Quality Indicator (AQI) for the area of interest. There are at least two ways that we can determine the AQI. Consistent with EPA guidelines, we can (1) determine the sixth largest 8-hour daily maximum concentration associated with each monitoring site in the area and (2) designate the largest of these values as the AQI for the area. An alternative approach would be to (1) fit a Weibull or lognormal distribution to the daily maximum values associated with each site, (2) determine the characteristic fifth largest 8-hour daily maximum concentration associated with each fitted distribution, and (3) designate the largest of these values as the AQI for the area. The latter approach is similar to the approach incorporated into the AQAP's described in my letter of April 15, 1993. Note that the characteristic fifth largest value is statistically equivalent to the value expected to be exceeded five times.

We recommend that the first approach be employed. The observed sixth largest daily maximum 8-hour value should be a relatively robust statistic. We do not believe that there is enough "noise" in the observed sixth largest values to justify the additional effort required to fit distributions and calculate characteristic fifth highest values.

In the remainder of this letter, we will use the term EH6LDM to indicate the sixth largest eight-hour daily maximum value.

STEP TWO: DETERMINE VALUES OF AQI UNDER "AS IS" CONDITIONS

My letter of February 18, 1993 lists the data sets we have selected to represent "as is" conditions in each of the nine cities under analysis. We have determined the EH6LDM for each of these 96 site-years based on the "filled-in" data set. These values are listed in Table 1 of this letter, together with previously determined values for the characteristic largest one-hour value (CLV1) and the characteristic largest eight-hour value (CLV8).

STEP THREE: ADJUST VALUES OF AQI TO SIMULATE ATTAINMENT

We have developed an adjustment procedure for implementing this step which depends on the assumption of a strong relationship between CLV8 and EH6LDM.

Relationship Between CLV8 and EH6LDM

Linear regression analyses of the nine-city data base described above (n = 96) produced the following regression equations.

$$CLV8 = 0.38 \text{ ppb} + (1.267)(EH6LDM) \qquad RSQ = 0.897 \qquad (1)$$

$$LNCLV8 = 0.107 + (1.028)(LNEH6LDM) \qquad RSQ = 0.909 \qquad (2)$$

In Equation 2, LNCLV8 = ln(CLV8) and LNEH6LDM = ln(EH6LDM). Note that both of the R-squared (RSQ) values exceed 0.89, indicating a high degree of correlation between the regressed parameters.

The intercept of each equation was found to be non-significant at the $p = 0.05$ level. Consequently, the analyses were repeated with the regression lines forced through the origin. The resulting regression equations are presented below.

$$CLV8 = (1.270)(EH6LDM) \qquad RSQ = 0.897 \qquad (3)$$

$$LNCLV8 = (1.052)(LNEH6LDM) \qquad RSQ = 0.908 \qquad (4)$$

Both RSQ values exceed 0.89. Note that Equation 3 assumes a constant ratio between CLV8 and EH6LDM, i.e., ratio = CLV8/EH6LDM = 1.270. Equation 4 can be expressed as

$$CLV8 = (EH6LDM)^{1.052} \qquad (5)$$

For EH6LDM values between 40 ppb and 200 ppb, the power curve expressed by Equation 5 is closely fit (within 5 percent) by the linear relationship expressed by Equation 3.

In my letter of April 15, 1993, I presented a recommendation for an AQAP applicable to CLV8. In this procedure, each CLV8 associated with a city under "as is" conditions is adjusted to simulate attainment of a NAAQS through the use of the equation

$$ACLV8(i,j) = [CLV8(i,j)][(AMAXCLV8(j))]/[MAXCLV8(j)]. \qquad (6)$$

TABLE 1

AIR QUALITY INDICATORS FOR NINE CITIES

City	Year	District	Ozone concentration, ppb		
			CLV1	CLV8	EH6LDM
Chicago	1991	1	109	94	78
		2	124	107	86
		3	123	106	77
		4	134	114	90
		5	120	99	78
		6	111	97	79
		7	119	106	89
		8	104	92	78
		9	122	106	82
		10	127	111	83
		11	122	106	85
		12	131	111	91
Denver	1990	1	91	74	67
		2	116	94	84
		3	114	85	73
		4	103	86	74
		5	98	79	56
		6	117	78	65
		7	109	94	75
Houston	1990	1	224	162	116
		2	182	137	110
		3	241	161	110
		4	224	171	107
		5	227	179	124
		6	180	131	86
		7	208	165	104
		8	207	143	99
		9	231	154	101
		10	235	171	116
		11	232	167	107

Table 1 (Continued)

City	Year	District	Ozone concentration, ppb		
			CLV1	CLV8	EH6LDM
Los Angeles	1991	1	321	207	170
		2	185	133	109
		3	148	99	75
		4	271	166	129
		5	215	162	115
		6	248	172	146
		7	116	85	64
		8	136	104	84
		9	198	121	94
		10	153	101	81
		11	167	100	87
		12	216	134	110
		13	264	209	167
		14	266	184	146
		15	261	215	180
		16	249	204	165
Miami	1991	1	90	74	60
		2	97	74	60
		3	93	72	64
		4	105	82	59
		5	96	80	65
		6	87	72	57
New York	1991	1	158	135	108
		2	121	112	91
		3	153	133	113
		4	143	134	105
		5	123	113	88
		6	97	75	64
		7	141	108	83
		8	172	145	126
		9	162	131	104
		10	170	143	101
		11	183	140	107
		12	148	137	105

Table 1 (Continued)

City	Year	District	Ozone concentration, ppb		
			CLV1	CLV8	EH6LDM
Philadelphia	1991	1	167	142	116
		2	149	136	113
		3	153	128	111
		4	162	138	115
		5	145	120	107
		6	134	118	101
		7	135	123	102
		8	140	128	104
		9	131	116	90
		10	141	126	102
St. Louis	1990	1	124	100	73
		2	141	116	88
		3	131	106	87
		4	103	87	68
		5	122	97	81
		6	78	65	59
		7	124	103	87
		8	100	79	67
		9	114	91	80
		10	103	84	64
		11	119	104	86
Washington	1991	1	134	110	80
		2	135	113	88
		3	130	113	95
		4	143	128	106
		5	141	119	98
		6	143	123	100
		7	135	118	104
		8	169	143	102
		9	141	120	91
		10	134	112	85
		11	145	123	100

according to the following definitions.

ACLV8(i,j): the CLV8 of the i-th ranked site in City j under attainment of the proposed NAAQS,

CLV8(i,j): the CLV8 of the i-th ranked site in City j for the baseline year,

MAXCLV8(j): the largest CLV8 of all sites in City j for the baseline year,

AMAXCLV8(j): the largest CLV8 permitted under the proposed NAAQS.

This expression is consistent with Model A, a model for CLV8 which we developed in the April 15 letter. Model A assumes that

a) the CLV8's for a given city-year follow a lognormal distribution,

b) the geometric standard deviation (GSD) of the lognormal distribution is constant from year-to-year, and

c) the z value associated with the CLV8 of the r-th ranked site is constant from year-to-year.

If a constant ratio exists between the values of EH6LDM and CLV8 for a city [i.e., CLV8/EH6LDM = constant), then the following expression should apply to EH6LDM.

AEH6LDM(i,j) = [EH6LDM(i,j)][(AMAXEH6LDM(j)/[MAXEH6LDM(j)]. (7)

The following definitions apply.

AEH6LDM(i,j): the EH6LDM of the i-th ranked site in City j under attainment of the proposed NAAQS,

EH6LDM(i,j): the EH6LDM of the i-th ranked site in City j for the baseline year,

MAXEH6LDM(j): the largest EH6LDM of all sites in City j for the baseline year,

AMAXEH6LDM(j): the largest EH6LDM permitted under the proposed NAAQS.

As a preliminary check of this approach, we applied it to the 1990 data for Houston. Table 2 lists the Houston EH6LDM values ranked from largest to smallest under the heading "1990 observed." The largest value [MAXEH6LDM(j)] is 124 ppb. We used the equation above to predict the EH6LDM values for 1991 under the assumption that the 1991 air quality for Houston will just attain a NAAQS level of 108 ppb. The resulting predictions are listed in Table 2 together with the observed values for 1991. In each case, the predicted value for rank i is equal to 0.87 times the 1990 value for rank i. The multiplier (0.87) is equal to (108 ppb)/(124 ppb), where 108 ppb is the largest EH6LDM permitted in the adjusted data and 124 ppb is the largest EH6LDM in the baseline data. In this example, the predicted values agree well (within 4 ppb or 5 percent) with the observed values.

We repeated the test using 1983 data for Philadelphia as the baseline data set and 1991 Philadelphia data as the data set we were attempting to predict. The results are presented in Table 3. In this case, the predicted value is within 5 ppb of the corresponding observed value for Ranks 1 through 9, the predicted value generally being larger than the observed value. In the worst case (Rank 10), the predicted value differs from the observed value by 10 ppb (89 ppb vs. 79 ppb). Note that the observed value (79 ppb) appears to be an outlier, as it differs from the next lowest observed value (89 ppb) by 10 ppb, whereas the remaining observed values are closely spaced.

In a third test, we used 1983 data for St. Louis as the baseline data base and 1990 St. Louis data as the data set we were attempting to predict. Table 4 presents the results of this test. In this case, each predicted value is within 5 ppb of the corresponding observed value for Ranks 1 through 8, the predicted value generally being smaller than the observed value. In contrast to these relatively good predictions, the differences for Ranks 9 and 10 are 17 ppb and 15 ppb, respectively. Note that in this case, the two lowest 1983 values (68 ppb and 60 ppb) appear to be outliers, as they are widely separated from the remaining values.

TABLE 2

PREDICTION OF 1991 EH6LDM VALUES
FOR HOUSTON GIVEN 1990 EH6LDM VALUES

Rank	EH6LDM, ppb			Difference, ppb	Percent difference
	1990 observed	1991			
		Observed	Predicted[a]		
1	124	108	108	0	0
2	116	104	101	-3	-2.9
3	116	100	101	1	1.0
4	110	99	96	-3	-3.0
5	110	97	96	-1	-1.0
6	107	91	93	2	2.2
7	107	89	93	4	4.5
8	104	89	91	2	2.2
9	101	85	88	3	3.5
10	99	84	86	2	2.4
11	86	74	75	1	1.4
Mean	107.3	92.7	93.5	0.8	0.9

[a]1991 predicted = (108/124) (1990 observed)

TABLE 3

PREDICTION OF 1991 EH6LDM VALUES
FOR PHILADELPHIA GIVEN 1983 EH6LDM VALUES

Rank	EH6LDM, ppb			Difference, ppb	Percent difference
	1983 observed	1991 Observed	1991 Predicted[a]		
1	125	112	112	0	0
2	117	108	105	-3	-2.8
3	116	102	104	2	2.0
4	115	101	103	2	2.0
5	115	101	103	2	2.0
6	115	98	103	5	5.1
7	109	97	98	1	1.0
8	108	95	97	2	2.1
9	99	89	89	0	0
10	99	79	89	10	12.7
Mean	111.8	98.2	100.2	2	2.0

[a]1991 predicted = (112/125)(1983 observed)

TABLE 4

PREDICTION OF 1990 EH6LDM VALUES
FOR ST. LOUIS GIVEN 1983 EH6LDM VALUES

Rank	EH6LDM, ppb 1983 observed	1990 Observed	1990 Predicted[a]	Difference, ppb	Percent difference
1	119	88	88	0	0
2	119	87	88	1	1.1
3	117	87	87	0	0
4	110	86	81	-5	-5.8
5	109	81	81	0	0
6	101	80	75	-5	-6.3
7	96	73	71	-2	-2.7
8	86	68	64	-4	-5.9
9	68	67	50	-17	-25.4
10	60	59	44	-15	-25.4
Mean	98.5	77.6	72.8	-4.8	-6.2

[a]1990 predicted = (88/119)(1983 observed)

The results of these three tests suggest that the adjustment procedure is sensitive to outliers. Because the procedure is keyed on the highest ranked value of the baseline data set, it should perform well in predicting the higher ranked values in the attainment data set. Poor predictions are more likely to occur in the lower ranks. The examples presented here support this assumption, as the differences between predicted and observed attainment values are most pronounced in the lower ranks.

Note that the large differences associated with the lower ranks were positive in Table 3 and negative in Table 4. In the Table 3 analysis, the single outlier (79 ppb) was associated with the attainment data. The two outliers in the Table 4 analysis (60 ppb and 68 ppb) were associated with the baseline data set. Note that any single "universal fix" of the procedure would tend to reduce the differences in one case while increasing the differences in the other. Consequently, I recommend that we use Equation 7 without modification.

Equation 7 provides an estimate of the r-th ranked EH6LDM value. Following the approach described in the April 15 letter, we will rank the monitoring sites associated with a particular study area according to average rank calculated for each site from five recent years of ozone data (including the year -- 1990 or 1991 -- selected for the pNEM/O3 analysis). The r-th ranked site according to the five-year rank will be assigned the r-th ranked EH6LDM value. Per your instructions, we will determine the five year rank through data provided by RADS. Note that the ranking assigned to each site according to EH6LDM may differ from the ranking assigned to the site according to CLV8.

STEP 4: ADJUST ONE-HOUR DATA

The EH6LDM adjustment procedure discussed above provides an estimate of the EH6LDM associated with each site under attainment conditions. To complete the adjustment process, the one-hour values associated with the site should be adjusted so that a Weibull distribution fit to the resulting eight-hour daily maximum values will yield the designated EH6LDM.

We can simplify this process by adjusting the one-hour values so that a Weibull distribution fit to the one-hour values will yield a CLV1 that is equivalent to the desired EH6LDM. This short-cut requires an equivalence expression relating EH6LDM to CLV1.

Linear regression analyses of the nine-city data base described above (n = 96) produced the following regression equations.

$$CLV1 = -14.3 \text{ ppb} + (1.755)(EH6LDM) \qquad RSQ = 0.754 \qquad (8)$$

$$LNCLV1 = 0.110 + (1.077)(LNEH6LDM) \qquad RSQ = 0.776 \qquad (9)$$

In Equation 9, LNCLV1 = ln(CLV1) and LNEH6LDM = ln(EH6LDM). Note that both of the R-squared (RSQ) values exceed 0.75, indicating a relatively high degree of correlation between the regressed parameters.

The intercept of each equation was found to be non-significant at the $p = 0.05$ level. Consequently, the analyses were repeated with the regression lines forced through the origin. The resulting regression equations are presented below.

$$\text{CLV1} = (1.614)(\text{EH6LDM}) \qquad \text{RSQ} = 0.748 \qquad (10)$$

$$\text{LNCLV1} = (1.101)(\text{LNEH6LDM}) \qquad \text{RSQ} = 0.775 \qquad (11)$$

Both RSQ values exceed 0.74. Note that Equation 10 assumes a constant ratio between CLV1 and EH6LDM, i.e., ratio = CLV1/EH6LDM = 1.614. Equation 11 can be expressed as

$$\text{CLV1} = (\text{EH6LDM})^{1.101} \qquad (12)$$

For EH6LDM values between 80 ppb and 190 ppb, the power curve expressed by Equation 12 is closely fit (within 5 percent) by the linear relationship expressed by Equation 10.

We examined the 96 site-specific ratios of CLV1 to EH6LDM by city and found that the ratios varied more among cities than among sites within a city. We also examined the CLV1-to-EH6LDM ratios in the three-city multiyear data base (Houston, Philadelphia, and St. Louis) described above and found that the average city ratio was either constant year to year or else showed a slight decreasing trend. For example, the median ratio for Houston was relatively constant; the ratio was 2.134 for 1985, 1.890 for 1988, 2.091 for 1990, and 1.929 for 1991. The median ratio for Philadelphia displayed an overall decline; the ratio was 1.528 for 1983, 1.622 for 1984, 1.473 for 1986, and 1.373 for 1992. We recommend that (1) a single average CLV1-to-EH6LDM ratio be applied to all sites within a particular city and (2) the ratio be determined by a recent year of data specific to the city.

Table 5 lists the mean and median ratios for each city based on the 1990-91 nine-city data base. The table also lists mean and median ratios for three other years for three of the cities (Houston, Philadelphia, and St. Louis). We recommend that the flagged median ratios in this table be used for the city-specific ratios. Each flagged median is associated with a recent year (1990 or 1991). The medians are preferred to the means, as they are less affected outliers.

Given an estimate of ACLV1, the CLV1 of the adjusted data, we next predict the parameters of the Weibull distribution that will fit the adjusted data. I presented a method for predicting these parameters in my letter of April 15, 1993. For convenience, I have briefly summarized this material below.

TABLE 5

RATIOS OF CLV1 TO EH6LDM FOR NINE CITIES BASED ON RECENT OZONE DATA

City	Data year	Number of Sites	CLV1 to EH6LDM ratio		
			Mean	Std. dev.	Median
Chicago	1991	12	1.453	0.080	1.441[a]
Denver	1990	7	1.528	0.182	1.453[a]
Houston	1990	11	2.033	0.177	2.091[a]
Los Angeles	1991	16	1.806	0.197	1.846[a]
Miami	1991	6	1.559	0.122	1.513[a]
New York	1991	12	1.487	0.144	1.436[a]
Philadelphia	1991	10	1.373	0.049	1.367[a]
St. Louis	1990	11	1.499	0.109	1.506[a]
Washington	1991	11	1.484	0.124	1.450[a]
All Cities	See above	96	1.595	0.246	1.512
Houston (other years)	1985	10	2.129	0.293	2.134
	1988	11	1.891	0.176	1.890
	1991	11	1.915	0.125	1.929
Philadelphia (other years)	1983	10	1.543	0.079	1.528
	1984	10	1.653	0.214	1.622
	1986	10	1.485	0.072	1.473
St. Louis (other years)	1983	10	1.659	0.084	1.640
	1985	11	1.726	0.125	1.704
	1991	11	1.357	0.035	1.344

[a]Recommended ratio for specified city.

Estimation of Weibull Parameters of Adjusted One-Hour Data

Let δ and k indicate the parameters of the Weibull distribution fitting the unadjusted 1-hour data associated with a particular site. These parameters are related to the UCLV1 -- the CLV1 of the unadjusted data -- by the expression.

$$\text{UCLV1} = \delta\ [1\text{n}(\text{n})]^{1/k}. \tag{13}$$

Let δ' and k' indicate the parameters of the Weibull distribution fitting the adjusted 1-hour data. These parameters are related to the adjusted CLV1 (ACLV1) by the expression

$$\text{ACLV1} = \delta'\ [1\text{n}(\text{n})]^{1/k'} \tag{14}$$

Based on the results of a series of regression analyses discussed in the April 15 letter, we are recommending that the following regression equation be used to estimate k':

$$1/k' = -0.2389 + (0.003367)\ (\text{ACLV1}) + (0.4726)\ (1/k). \tag{15}$$

Each coefficient of this equation was found to be statistically significant at the $p = 0.10$ level; the over-all R squared value was 0.6993. Note that the equation assumes that ACLV1 will be in units of ppb.

Given the ACLV1 and an estimate of k', we can estimate the corresponding δ' value by the equation

$$\delta' = (\text{ACLV1})/[1\text{n}(\text{n})]^{1/k'}. \tag{16}$$

We now have values for δ, k, UCLV1, δ', k', and ACLV1. If we treat the unadjusted data set as a time series in which x_t is the one-hour value at time t, we can construct a corresponding adjusted data set by the expression

$$y_t = (\delta')\ (x_t/\delta)^{k/k'}. \tag{17}$$

where y_t is the adjusted value at time t.

Equation 17 can be restated as

$$y_t = (c)\ (x_t)^d \tag{18}$$

$$c = (\delta')/(\delta)^{k/k'} \tag{19}$$

$$d = k/k'$$

We will refer to c and d as "adjustment coefficients."

Table 6 demonstrates the application of the adjustment procedure to Philadelphia for an eight-hour NAAQS which permits a maximum EH6LDM of 80 ppb. Under "as is" conditions the highest EH6LDM is 116 ppb. We are interested in simulating attainment of NAAQS which permits a EH6LDM no higher than 80 ppb. Each EH6LDM is first multiplied by 90 ppb/116 ppb as indicated by Equation 7. These adjusted EH6LDM's are then reassigned according to the relative rank of each site for the five-year period. The reassigned EH6LDM are next multiplied by 1.367, the median CLV1-to-EH6LDM ratio listed for Philadelphia in Table 5. This step provides estimates of equivalent CLV1's which are then used to determine adjustment coefficients through the use of Equations 15 through 19.

Final Adjustment of One-Hour Data

The adjustment procedure described above will produce a one-hour data set with a specified CLV1. Note that the EH6LDM value of this data set may not exactly equal the "target" value, as the assumed relationship between CLV1 and EH6LDM is only an approximation. We recommend that a final "fine-tuning" adjustment be made to the one hour data so that we obtain the exact EH6LDM specified. The following expression would be implemented.

$$\text{Adjusted } y_t = (y_t)(\text{Observed EH6LDM})/(\text{Target EH6LDM}) \qquad (20)$$

In this equation, y_t is the one-hour value for hour t after the Weibull adjustment procedure. The "observed EH6LDM" is the EH6LDM value of the data set after the Weibull adjustment procedure, and the "target EH6LDM" is the EH6LDM value assigned to the site by the rollback procedure.

This procedure can also be used as a final step in the procedure proposed for CLV8 in my letter of April 15, 1993. That is, the following equation would be used to adjust the one-hour data after the Weibull adjustment step.

$$\text{Adjusted } y_t = (y_t)(\text{Observed CLV8})/(\text{Target CLV8}) \qquad (21)$$

TABLE 6

DETERMINATION OF ADJUSTMENT COEFFICIENTS FOR EIGHT-HOUR NAAQS ATTAINMENT (EH6LDM = 80 ppb) IN PHILADELPHIA

District	Parameters of 1991 data				8-hour NAAQS attainment parameters				1-hour Weibull parameters		Adjustment coefficients	
	1-h k	1-h δ	CLV1	EH6LDM	Adjusted EH6LDM	Rank	Reassigned EH6LDM	Equivalent CLV1	k'	δ'	c	d
1	1.69	46.9	167	116	80	5	74	101	2.626	44.62	3.750	0.644
2	2.21	56.4	149	113	78	2	79	108	2.954	52.24	2.556	0.748
3	1.96	51.0	153	111	77	1	80	109	2.708	49.37	2.869	0.724
4	1.81	49.3	162	115	79	3	78	107	2.615	47.10	3.171	0.692
5	2.28	56.6	145	107	74	4	77	105	3.106	52.64	2.721	0.734
6	2.23	51.2	134	101	70	6	72	98	3.300	51.16	3.581	0.676
7	1.93	44.3	135	102	70	8	70	96	3.038	47.38	4.261	0.635
8	2.14	51.2	140	104	72	9	70	96	3.277	49.88	3.817	0.653
9	1.74	38.1	131	90	62	10	62	85	3.136	42.89	5.689	0.555
10	2.26	54.5	141	102	70	7	70	96	3.408	51.15	3.608	0.663

[a]Assumes maximum EH6LDM equals 80 ppb.

With your approval, we will use these equations to make final adjustments to the data sets we prepare for the pNEM/O3 analyses of 8HDM-1ExEx NAAQS and 8HDM-8ExEx NAAQS.

This letter completes our documentation of the proposed adjustment procedures for the 1993 pNEM/O3 exposure assessments. Please call me if you have any questions or comments.

Sincerely,

IT AIR QUALITY SERVICES

Ted Johnson

Ted R. Johnson

TRJ/kdl

cc: S. Kopp
M. McCoy
J. Capel

APPENDIX C

SAMPLE OUTPUT OF pNEM/O3 APPLIED TO 1990 CHILDREN AND ENTIRE POPULATION DATA (HOUSTON, 1-HOUR, DAILY MAXIMUM 0.12 PPM STANDARD [CURRENT NAAQS])

Table 1.
Cumulative Numbers of People at Hourly O3 Exposures
during O3 Season by Equivalent Ventilation Rate

O3 Level Equalled or Exceeded, ppm	Equivalent Ventilation Rate, l/min-m**2 <15	15-24	25-29	30-34	35+	ANY
.401+	0	0	0	0	0	0
.381	0	0	0	0	0	0
.361	0	0	0	0	0	0
.341	0	0	0	0	0	0
.321	0	0	0	0	0	0
.301	0	0	0	0	0	0
.281	0	0	0	0	0	0
.261	0	0	0	0	0	0
.241	0	0	0	0	0	0
.221	0	0	0	0	0	0
.201	0	0	0	0	0	0
.181	0	0	0	0	0	0
.161	0	0	0	0	0	0
.141	0	0	0	0	0	0
.121	81227	7870	7870	0	0	89097
.101	207464	185176	7870	0	4932	339188
.081	488563	372450	22129	0	16348	488563
.061	489899	481979	149948	137131	34385	489899
.041	489899	489899	476490	298988	313330	489899
.021	489899	489899	489899	484709	444173	489899
.001	489899	489899	489899	489899	488509	489899
0.000	489899	489899	489899	489899	489899	489899

Study Area = HOUSTON 1-HR RB   Children
No. exposure districts =   11
First day of O3 season =   1
Last day of O3 season =   365
No. days in O3 season =   365

Table 2.
Occurrences of People at Hourly Exposures
During O3 Season by Equivalent Ventilation Rate

O3 Interval, ppm	Equivalent Ventilation Rate, l/min-m**2 <15	15-24	25-29	30-34	35+	ANY
.401+	0.	0.	0.	0.	0.	0.
.381-.400	0.	0.	0.	0.	0.	0.
.361-.380	0.	0.	0.	0.	0.	0.
.341-.360	0.	0.	0.	0.	0.	0.
.321-.340	0.	0.	0.	0.	0.	0.
.301-.320	0.	0.	0.	0.	0.	0.
.281-.300	0.	0.	0.	0.	0.	0.
.261-.280	0.	0.	0.	0.	0.	0.
.241-.260	0.	0.	0.	0.	0.	0.
.221-.240	0.	0.	0.	0.	0.	0.
.201-.220	0.	0.	0.	0.	0.	0.
.181-.200	0.	0.	0.	0.	0.	0.
.161-.180	0.	0.	0.	0.	0.	0.
.141-.160	0.	0.	0.	0.	0.	0.
.121-.140	141126.	7870.	7870.	0.	0.	156866.
.101-.120	348827.	188311.	0.	0.	4932.	542070.
.081-.100	2939799.	791203.	14259.	0.	11416.	3756677.
.061-.080	15896222.	4049915.	175729.	146245.	23351.	20291462.
.041-.060	83622135.	22236534.	1269978.	359528.	492558.	107980733.
.021-.040	417911084.	76198305.	3818606.	1250975.	982068.	500161038.
.001-.020	2956488880.	361721235.	16871271.	4792889.	2355820.	3342230095.
0.000	281454911.	32139002.	1707503.	711170.	383713.	316396299.
						4291515240.

Study Area = HOUSTON 1-HR RB Children
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 1A.
Cumulative Numbers of People at 1hr Daily Max. Exposure
During O3 Season by Equivalent Ventilation Rate

O3 Level Equalled or Exceeded, ppm	Equivalent Ventilation Rate, l/min-m**2 <15	15-24	25-29	30-34	35+	ANY
.401+	0	0	0	0	0	0
.381	0	0	0	0	0	0
.361	0	0	0	0	0	0
.341	0	0	0	0	0	0
.321	0	0	0	0	0	0
.301	0	0	0	0	0	0
.281	0	0	0	0	0	0
.261	0	0	0	0	0	0
.241	0	0	0	0	0	0
.221	0	0	0	0	0	0
.201	0	0	0	0	0	0
.181	0	0	0	0	0	0
.161	0	0	0	0	0	0
.141	0	0	0	0	0	0
.121	81227	7870	0	0	0	89097
.101	199594	160220	0	0	4932	339188
.081	488563	335504	13859	0	4932	488563
.061	489899	468162	60356	94040	22969	489899
.041	489899	489899	384589	152560	150984	489899
.021	489899	489899	431963	318717	352346	489899
.001	489899	489899	431963	337315	390761	489899
0.000	489899	489899	431963	337315	390761	489899

Study Area = HOUSTON 1-HR RB Children
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 2A.
Occurrences of People at 1hr Daily Max. Exposure
During O3 Season by Equivalent Ventilation Rate

O3 Interval, ppm	Equivalent Ventilation Rate, 1/min-m**2 <15	15-24	25-29	30-34	35+	ANY
.401+	0	0	0	0	0	0
.381-.400	0	0	0	0	0	0
.361-.380	0	0	0	0	0	0
.341-.360	0	0	0	0	0	0
.321-.340	0	0	0	0	0	0
.301-.320	0	0	0	0	0	0
.281-.300	0	0	0	0	0	0
.261-.280	0	0	0	0	0	0
.241-.260	0	0	0	0	0	0
.221-.240	0	0	0	0	0	0
.201-.220	0	0	0	0	0	0
.181-.200	0	0	0	0	0	0
.161-.180	0	0	0	0	0	0
.141-.160	0	0	0	0	0	0
.121-.140	136028	7870	0	0	0	143898
.101-.120	255855	155485	0	0	4932	416272
.081-.100	1785175	442115	13859	0	0	2241149
.061-.080	7084224	2166532	54599	94040	18037	9417432
.041-.060	27442111	8055529	616321	119907	161903	36395771
.021-.040	65976863	14303903	829844	372866	294297	81777773
.001-.020	42400651	5606295	316908	52230	44756	48420840
0.000	0	0	0	0	0	0
						178813135.

Study Area = HOUSTON 1-HR RB Children
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 1B.
Cumulative Numbers of People at 1-Hr Daily Max. Dose
During O3 Season by 1-Hr O3 and EVR.

O3 Level Equalled or Exceeded, ppm	Equivalent Ventilation Rate, l/min-m**2 <15	15-24	25-29	30-34	35+	ANY
.401+	0	0	0	0	0	0
.381	0	0	0	0	0	0
.361	0	0	0	0	0	0
.341	0	0	0	0	0	0
.321	0	0	0	0	0	0
.301	0	0	0	0	0	0
.281	0	0	0	0	0	0
.261	0	0	0	0	0	0
.241	0	0	0	0	0	0
.221	0	0	0	0	0	0
.201	0	0	0	0	0	0
.181	0	0	0	0	0	0
.161	0	0	0	0	0	0
.141	0	0	0	0	0	0
.121	67551	0	7870	0	0	75421
.101	139685	145455	7870	0	4932	272384
.081	402944	367666	21729	0	16348	462746
.061	489899	481979	129306	137131	34385	489899
.041	489899	489899	475182	294094	313330	489899
.021	489899	489899	489899	484709	444173	489899
.001	489899	489899	489899	489899	474833	489899
0.000	489899	489899	489899	489899	474833	489899

Study Area = HOUSTON 1-HR RB Children
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 2B.
Occurrences of People at 1-Hr Daily Max. Dose
During O3 Season by 1-Hr O3 and EVR.

O3 Interval, ppm	Equivalent Ventilation Rate, 1/min-m**2 <15	15-24	25-29	30-34	35+	ANY
.401+	0	0	0	0	0	0
.381-.400	0	0	0	0	0	0
.361-.380	0	0	0	0	0	0
.341-.360	0	0	0	0	0	0
.321-.340	0	0	0	0	0	0
.301-.320	0	0	0	0	0	0
.281-.300	0	0	0	0	0	0
.261-.280	0	0	0	0	0	0
.241-.260	0	0	0	0	0	0
.221-.240	0	0	0	0	0	0
.201-.220	0	0	0	0	0	0
.181-.200	0	0	0	0	0	0
.161-.180	0	0	0	0	0	0
.141-.160	0	0	0	0	0	0
.121-.140	67551	0	7870	0	0	75421
.101-.120	166484	148590	0	0	4932	320006
.081-.100	721625	622525	13859	0	11416	1369425
.061-.080	3449658	2884269	155487	146245	23351	6659010
.041-.060	13899509	13549635	1179709	340361	492558	29461772
.021-.040	38857485	33984139	2938215	1015650	897792	77693281
.001-.020	32066341	26397213	3225854	1004007	540805	63234220
0.000	0	0	0	0	0	0
						178813135.

Study Area = HOUSTON 1-HR RB Children
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 3.
Number of People at Their Highest 1hr Daily Max. Exposure
During O3 Season by Ventilation Rate Categories

O3 Interval, ppm	Equivalent Ventilation Rate, l/min-m**2 <15	15-24	25-29	30-34	35+	ANY
.401+	0	0	0	0	0	0
.381-.400	0	0	0	0	0	0
.361-.380	0	0	0	0	0	0
.341-.360	0	0	0	0	0	0
.321-.340	0	0	0	0	0	0
.301-.320	0	0	0	0	0	0
.281-.300	0	0	0	0	0	0
.261-.280	0	0	0	0	0	0
.241-.260	0	0	0	0	0	0
.221-.240	0	0	0	0	0	0
.201-.220	0	0	0	0	0	0
.181-.200	0	0	0	0	0	0
.161-.180	0	0	0	0	0	0
.141-.160	0	0	0	0	0	0
.121-.140	81227	7870	0	0	0	89097
.101-.120	118367	152350	0	0	4932	250091
.081-.100	288969	175284	13859	0	0	149375
.061-.080	1336	132658	46497	94040	18037	1336
.041-.060	0	21737	324233	58520	128015	0
.021-.040	0	0	47374	166157	201362	0
.001-.020	0	0	0	18598	38415	0
0.000	0	0	0	0	0	0

Study Area = HOUSTON 1-HR RB   Children
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 4.
Cumulative Numbers of People at 8-Hr Daily Max. Exposure
During O3 Season by 8-Hr Equivalent Ventilation Rate

O3 Level Equalled or Exceeded, ppm	8hr Equivalent Ventilation Rate, l/min-m**2 <15	15-24	25-29	30-34	35+	ANY
.201+	0	0	0	0	0	0
.191	0	0	0	0	0	0
.181	0	0	0	0	0	0
.171	0	0	0	0	0	0
.161	0	0	0	0	0	0
.151	0	0	0	0	0	0
.141	0	0	0	0	0	0
.131	0	0	0	0	0	0
.121	0	0	0	0	0	0
.111	0	0	0	0	0	0
.101	0	0	0	0	0	0
.091	0	0	0	0	0	0
.081	91214	0	0	0	0	91214
.071	223911	6129	0	0	0	226905
.061	355762	15461	0	0	0	356162
.041	489899	310180	0	0	0	489899
.021	489899	489899	0	0	0	489899
.001	489899	489899	0	0	0	489899
0.000	489899	489899	0	0	0	489899

Study Area = HOUSTON 1-HR RB Children
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 5.
Occurrences of People at 8-Hr Daily Max. Exposure
During O3 Season by 8-Hr Equivalent Ventilation Rate

O3 Interval, ppm	8hr Equivalent Ventilation Rate, l/min-m**2 <15	15-24	25-29	30-34	35+	ANY
.201+	0.	0.	0.	0.	0.	0.
.191-.200	0.	0.	0.	0.	0.	0.
.181-.190	0.	0.	0.	0.	0.	0.
.171-.180	0.	0.	0.	0.	0.	0.
.161-.170	0.	0.	0.	0.	0.	0.
.151-.160	0.	0.	0.	0.	0.	0.
.141-.150	0.	0.	0.	0.	0.	0.
.131-.140	0.	0.	0.	0.	0.	0.
.121-.130	0.	0.	0.	0.	0.	0.
.111-.120	0.	0.	0.	0.	0.	0.
.101-.110	0.	0.	0.	0.	0.	0.
.091-.100	0.	0.	0.	0.	0.	0.
.081-.090	91214.	0.	0.	0.	0.	91214.
.071-.080	264689.	6129.	0.	0.	0.	270818.
.061-.070	582277.	9332.	0.	0.	0.	591609.
.041-.060	9034532.	437675.	0.	0.	0.	9472207.
.021-.040	58672876.	2305009.	0.	0.	0.	60977885.
.001-.020	105655918.	1711943.	0.	0.	0.	107367866.
0.000	41536.	0.	0.	0.	0.	41536.
						178813135.

Study Area = HOUSTON 1-HR RB Children
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 4A.
Cumulative Numbers of People at 8-Hr Daily Max. Dose
During O3 Season by 8-Hr O3 and 8-Hr EVR.

O3 Level Equalled or Exceeded, ppm	8hr Equivalent Ventilation Rate, l/min-m**2 <15	15-24	25-29	30-34	35+	ANY
.201+	0	0	0	0	0	0
.191	0	0	0	0	0	0
.181	0	0	0	0	0	0
.171	0	0	0	0	0	0
.161	0	0	0	0	0	0
.151	0	0	0	0	0	0
.141	0	0	0	0	0	0
.131	0	0	0	0	0	0
.121	0	0	0	0	0	0
.111	0	0	0	0	0	0
.101	0	0	0	0	0	0
.091	0	0	0	0	0	0
.081	85900	0	0	0	0	85900
.071	192060	13999	0	0	0	195054
.061	352412	23585	0	0	0	353562
.041	489899	335221	0	0	0	489899
.021	489899	489899	0	0	0	489899
.001	489899	489899	0	0	0	489899
0.000	489899	489899	0	0	0	489899

Study Area = HOUSTON 1-HR RB   Children
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 5A.
Occurrences of People at 8-Hr Daily Max. Dose
During O3 Season by 8-Hr O3 and 8-Hr EVR

O3 Interval, ppm	8hr Equivalent Ventilation Rate, l/min-m**2 <15	15-24	25-29	30-34	35+	ANY
.201+	0.	0.	0.	0.	0.	0.
.191-.200	0.	0.	0.	0.	0.	0.
.181-.190	0.	0.	0.	0.	0.	0.
.171-.180	0.	0.	0.	0.	0.	0.
.161-.170	0.	0.	0.	0.	0.	0.
.151-.160	0.	0.	0.	0.	0.	0.
.141-.150	0.	0.	0.	0.	0.	0.
.131-.140	0.	0.	0.	0.	0.	0.
.121-.130	0.	0.	0.	0.	0.	0.
.111-.120	0.	0.	0.	0.	0.	0.
.101-.110	0.	0.	0.	0.	0.	0.
.091-.100	0.	0.	0.	0.	0.	0.
.081-.090	85900.	0.	0.	0.	0.	85900.
.071-.080	152824.	13999.	0.	0.	0.	166823.
.061-.070	551753.	10336.	0.	0.	0.	562089.
.041-.060	8597205.	721039.	0.	0.	0.	9318244.
.021-.040	55177394.	3210520.	0.	0.	0.	58387914.
.001-.020	107362790.	2887839.	0.	0.	0.	110250629.
0.000	41536.	0.	0.	0.	0.	41536.
						178813135.

Study Area = HOUSTON 1-HR RB Children
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Tabla 6.
Number of People at Their Highest 8-Hr Daily Max. Exposure
During O3 Season by 8-Hr Ventilation Rate Categories

O3 Interval, ppm	8hr Equivalent Ventilation Rate, l/min-m**2 <15	15-24	25-29	30-34	35+	ANY
.201+	0	0	0	0	0	0
.191-.200	0	0	0	0	0	0
.181-.190	0	0	0	0	0	0
.171-.180	0	0	0	0	0	0
.161-.170	0	0	0	0	0	0
.151-.160	0	0	0	0	0	0
.141-.150	0	0	0	0	0	0
.131-.140	0	0	0	0	0	0
.121-.130	0	0	0	0	0	0
.111-.120	0	0	0	0	0	0
.101-.110	0	0	0	0	0	0
.091-.100	0	0	0	0	0	0
.081-.090	91214	0	0	0	0	91214
.071-.080	132697	6129	0	0	0	135691
.061-.070	131851	9332	0	0	0	129257
.041-.060	134137	294719	0	0	0	133737
.021-.040	0	179719	0	0	0	0
.001-.020	0	0	0	0	0	0
0.000	0	0	0	0	0	0

Study Area = HOUSTON 1-HR RB   Children
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 7.
Cumulative Numbers of People at 8-Hr Daily Max.
Seasonal Mean (April to October) Exposure

O3 Level Equalled or Exceeded, ppm	
.071+	0
.066	0
.061	0
.056	0
.051	0
.046	0
.041	0
.036	0
.031	3885
.026	102243
.021	427497
.011	489899
.001	489899
0.000	489899

Study Area = HOUSTON 1-HR RB Children
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 8.
Occurrences of People at 8-Hr Daily Max.
Seasonal Mean (April to October) Exposure

O3 Interval, ppm	
.071+	0
.066-.070	0
.061-.065	0
.056-.060	0
.051-.055	0
.046-.050	0
.041-.045	0
.036-.040	0
.031-.035	3885
.026-.030	98358
.021-.025	325254
.011-.020	62402
.001-.010	0
0.000	0

Study Area = HOUSTON 1-HR RB   Children
No. exposure districts =   11
First day of O3 season =   1
Last day of O3 season =   365
No. days in O3 season =   365

Table 9.
Number of People at Daily Max Dose that Exceed
Specified 1-HR O3 Levels 1 or More Times per Year

O3 Level Equalled or Exceeded, ppm	Days / Year 1	2	3	4	5	>5
.401+	0	0	0	0	0	0
.381	0	0	0	0	0	0
.361	0	0	0	0	0	0
.341	0	0	0	0	0	0
.321	0	0	0	0	0	0
.301	0	0	0	0	0	0
.281	0	0	0	0	0	0
.261	0	0	0	0	0	0
.241	0	0	0	0	0	0
.221	0	0	0	0	0	0
.201	0	0	0	0	0	0
.181	0	0	0	0	0	0
.161	0	0	0	0	0	0
.141	0	0	0	0	0	0
.121	75421	0	0	0	0	0
.101	149341	123043	0	0	0	0
.081	81367	34829	136602	84879	58114	66955
.061	0	1336	0	4531	16843	467189
.041	0	0	0	0	0	489899
.021	0	0	0	0	0	489899
.001	0	0	0	0	0	489899
0.000	0	0	0	0	0	489899

Study Area = HOUSTON 1-HR RB Children
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 10.
Number of People at Daily Max 8-HR Dose that Exceed
Specified 8-hr O3 Levels 1 or More Times per Year

O3 Level Equalled or Exceeded, ppm	Days / Year 1	2	3	4	5	>5
.201+	0	0	0	0	0	0
.191	0	0	0	0	0	0
.181	0	0	0	0	0	0
.171	0	0	0	0	0	0
.161	0	0	0	0	0	0
.151	0	0	0	0	0	0
.141	0	0	0	0	0	0
.131	0	0	0	0	0	0
.121	0	0	0	0	0	0
.111	0	0	0	0	0	0
.101	0	0	0	0	0	0
.091	0	0	0	0	0	0
.081	85900	0	0	0	0	0
.071	158238	17984	16811	2021	0	0
.061	97912	142638	52948	36945	19984	3135
.041	0	0	0	0	0	489899
.021	0	0	0	0	0	489899
.001	0	0	0	0	0	489899
0.000	0	0	0	0	0	489899

Study Area = HOUSTON 1-HR RB Children
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 11.
Number of People that Exceed Specified O3 Levels
at 1-HR Daily Max Dose 1 or More Times per Year
with Ventilation Rates of 30 or Higher

O3 Level Equalled or Exceeded, ppm	Days / Year 1	2	3	4	5	>5
.401+	0	0	0	0	0	0
.381	0	0	0	0	0	0
.361	0	0	0	0	0	0
.341	0	0	0	0	0	0
.321	0	0	0	0	0	0
.301	0	0	0	0	0	0
.281	0	0	0	0	0	0
.261	0	0	0	0	0	0
.241	0	0	0	0	0	0
.221	0	0	0	0	0	0
.201	0	0	0	0	0	0
.181	0	0	0	0	0	0
.161	0	0	0	0	0	0
.141	0	0	0	0	0	0
.121	0	0	0	0	0	0
.101	4932	0	0	0	0	0
.081	16348	0	0	0	0	0
.061	118366	33789	0	0	0	0
.041	126980	144606	106537	45147	1394	15917
.021	1390	8683	33718	78188	37753	330167
.001	0	0	0	28270	23154	438475
0.000	0	0	0	28270	23154	438475

Study Area = HOUSTON 1-HR RB Children
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 12.
Number of People that Exceed Specified 8 HR O3 Levels
at Daily Max 8-HR Dose 1 or More Times per Year
with 8 Hour Ventilation Rates of 15 or Higher

O3 Level Equalled or Exceeded, ppm	Days / Year 1	2	3	4	5	>5
.201+	0	0	0	0	0	0
.191	0	0	0	0	0	0
.181	0	0	0	0	0	0
.171	0	0	0	0	0	0
.161	0	0	0	0	0	0
.151	0	0	0	0	0	0
.141	0	0	0	0	0	0
.131	0	0	0	0	0	0
.121	0	0	0	0	0	0
.111	0	0	0	0	0	0
.101	0	0	0	0	0	0
.091	0	0	0	0	0	0
.081	0	0	0	0	0	0
.071	13999	0	0	0	0	0
.061	22835	750	0	0	0	0
.041	74588	147727	79427	30344	3135	0
.021	762	0	0	35850	34670	418617
.001	0	0	0	0	0	489899
0.000	0	0	0	0	0	489899

Study Area = HOUSTON 1-HR RB Children
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 1.
Cumulative Numbers of People at Hourly O3 Exposures
during O3 Season by Equivalent Ventilation Rate

O3 Level Equalled or Exceeded, ppm	Equivalent Ventilation Rate, l/min-m**2 <15	15-24	25-29	30-34	35+	ANY
.401+	0	0	0	0	0	0
.381	0	0	0	0	0	0
.361	0	0	0	0	0	0
.341	0	0	0	0	0	0
.321	0	0	0	0	0	0
.301	0	0	0	0	0	0
.281	0	0	0	0	0	0
.261	0	0	0	0	0	0
.241	0	0	0	0	0	0
.221	0	0	0	0	0	0
.201	0	0	0	0	0	0
.181	0	0	0	0	0	0
.161	0	0	0	0	0	0
.141	0	0	0	0	0	0
.121	147640	8057	8656	0	0	156483
.101	830692	198588	9845	159	7442	965082
.081	2096625	814058	103710	62209	30668	2213976
.061	2370270	1354763	344059	233236	127184	2370270
.041	2370512	2227942	1160975	662850	855980	2370512
.021	2370512	2370512	1821690	1341432	1296710	2370512
.001	2370512	2370512	2199478	1918676	1730735	2370512
0.000	2370512	2370512	2202476	1942763	1740540	2370512

Study Area = HOUSTON 1-HR RB Entire Population
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 2.
Occurrences of People at Hourly Exposures
During O3 Season by Equivalent Ventilation Rate

O3 Interval, ppm	Equivalent Ventilation Rate, l/min-m**2 <15	15-24	25-29	30-34	35+	ANY
.401+	0.	0.	0.	0.	0.	0.
.381-.400	0.	0.	0.	0.	0.	0.
.361-.380	0.	0.	0.	0.	0.	0.
.341-.360	0.	0.	0.	0.	0.	0.
.321-.340	0.	0.	0.	0.	0.	0.
.301-.320	0.	0.	0.	0.	0.	0.
.281-.300	0.	0.	0.	0.	0.	0.
.261-.280	0.	0.	0.	0.	0.	0.
.241-.260	0.	0.	0.	0.	0.	0.
.221-.240	0.	0.	0.	0.	0.	0.
.201-.220	0.	0.	0.	0.	0.	0.
.181-.200	0.	0.	0.	0.	0.	0.
.161-.180	0.	0.	0.	0.	0.	0.
.141-.160	0.	0.	0.	0.	0.	0.
.121-.140	214448.	8057.	8656.	0.	0.	231161.
.101-.120	1235055.	201654.	1189.	159.	7442.	1445499.
.081-.100	10919964.	1379661.	94651.	62845.	23518.	12480639.
.061-.080	60889038.	6289740.	369544.	180689.	108115.	67837126.
.041-.060	345958827.	34320249.	2103150.	832813.	1109426.	384324465.
.021-.040	2051044177.	122913126.	7695255.	2189772.	2274776.	2186117106.
.001-.020	16061980954.	592148896.	29684368.	9204118.	6007192.	16699025528.
0.000	1361261946.	48611571.	2625486.	1045110.	679483.	1414223596.
						20765685120.

Study Area = HOUSTON 1-HR RB Entire Population
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 1A.
Cumulative Numbers of People at 1hr Daily Max. Exposure
During O3 Season by Equivalent Ventilation Rate

O3 Level Equalled or Exceeded, ppm	Equivalent Ventilation Rate, l/min-m**2 <15	15-24	25-29	30-34	35+	ANY
.401+	0	0	0	0	0	0
.381	0	0	0	0	0	0
.361	0	0	0	0	0	0
.341	0	0	0	0	0	0
.321	0	0	0	0	0	0
.301	0	0	0	0	0	0
.281	0	0	0	0	0	0
.261	0	0	0	0	0	0
.241	0	0	0	0	0	0
.221	0	0	0	0	0	0
.201	0	0	0	0	0	0
.181	0	0	0	0	0	0
.161	0	0	0	0	0	0
.141	0	0	0	0	0	0
.121	147640	8057	786	0	0	156483
.101	822733	168994	1975	159	7442	965082
.081	2094975	721822	92928	55384	17954	2213976
.061	2370270	1132916	236411	178146	92471	2370270
.041	2370512	1907127	903374	396825	429994	2370512
.021	2370512	2295531	1454012	827282	951965	2370512
.001	2370512	2343928	1531842	906780	1037304	2370512
0.000	2370512	2343928	1531842	906780	1037304	2370512

Study Area = HOUSTON 1-HR RB   Entire Population
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 2A.
Occurrences of People at 1hr Daily Max. Exposure
During O3 Season by Equivalent Ventilation Rate

O3 Interval, ppm	Equivalent Ventilation Rate, l/min-m**2 <15	15-24	25-29	30-34	35+	ANY
.401+	0	0	0	0	0	0
.381-.400	0	0	0	0	0	0
.361-.380	0	0	0	0	0	0
.341-.360	0	0	0	0	0	0
.321-.340	0	0	0	0	0	0
.301-.320	0	0	0	0	0	0
.281-.300	0	0	0	0	0	0
.261-.280	0	0	0	0	0	0
.241-.260	0	0	0	0	0	0
.221-.240	0	0	0	0	0	0
.201-.220	0	0	0	0	0	0
.181-.200	0	0	0	0	0	0
.161-.180	0	0	0	0	0	0
.141-.160	0	0	0	0	0	0
.121-.140	203299	8057	786	0	0	212142
.101-.120	966555	164072	1189	159	7442	1139417
.081-.100	6703954	887159	91739	55225	10512	7748589
.061-.080	28663197	3142770	162180	123120	74938	32166205
.041-.060	121473044	13495039	1115292	387427	433269	136904071
.021-.040	341851072	23352288	1941939	702887	726738	368574924
.001-.020	306846274	10540713	565873	179458	146095	318278413
0.000	213119	0	0	0	0	213119
						865236880.

Study Area = HOUSTON 1-HR RB   Entire Population
No. exposure districts =   11
First day of O3 season =   1
Last day of O3 season =   365
No. days in O3 season =   365

Table 1B.
Cumulative Numbers of People at 1-Hr Daily Max. Dose
During O3 Season by 1-Hr O3 and EVR.

O3 Level Equalled or Exceeded, ppm	Equivalent Ventilation Rate, l/min-m**2 <15	15-24	25-29	30-34	35+	ANY
.401+	0	0	0	0	0	0
.381	0	0	0	0	0	0
.361	0	0	0	0	0	0
.341	0	0	0	0	0	0
.321	0	0	0	0	0	0
.301	0	0	0	0	0	0
.281	0	0	0	0	0	0
.261	0	0	0	0	0	0
.241	0	0	0	0	0	0
.221	0	0	0	0	0	0
.201	0	0	0	0	0	0
.181	0	0	0	0	0	0
.161	0	0	0	0	0	0
.141	0	0	0	0	0	0
.121	101680	187	8656	0	0	110523
.101	586789	158474	9845	159	7442	726881
.081	1862210	681126	102348	62201	30668	1969564
.061	2365190	1311877	297085	232498	126777	2365190
.041	2370512	2092130	1076701	641882	854632	2370512
.021	2370512	2366671	1773190	1279366	1285825	2370512
.001	2370512	2370512	2071281	1661165	1693059	2370512
0.000	2370512	2370512	2071281	1661165	1693059	2370512

Study Area = HOUSTON 1-HR RB   Entire Population
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 2B.
Occurrences of People at 1-Hr Daily Max. Dose
During O3 Season by 1-Hr O3 and EVR.

O3 Interval, ppm	Equivalent Ventilation Rate, l/min-m**2 <15	15-24	25-29	30-34	35+	ANY
.401+	0	0	0	0	0	0
.381-.400	0	0	0	0	0	0
.361-.380	0	0	0	0	0	0
.341-.360	0	0	0	0	0	0
.321-.340	0	0	0	0	0	0
.301-.320	0	0	0	0	0	0
.281-.300	0	0	0	0	0	0
.261-.280	0	0	0	0	0	0
.241-.260	0	0	0	0	0	0
.221-.240	0	0	0	0	0	0
.201-.220	0	0	0	0	0	0
.181-.200	0	0	0	0	0	0
.161-.180	0	0	0	0	0	0
.141-.160	0	0	0	0	0	0
.121-.140	101776	187	8656	0	0	110619
.101-.120	660165	161422	1189	159	7442	830377
.081-.100	3652933	1075555	93289	62042	23226	4907045
.061-.080	18623289	4452618	305018	179769	102430	23663124
.041-.060	86085760	22291881	1887247	756883	1048656	112070427
.021-.040	275771153	58553853	5913687	1777552	1950034	343966279
.001-.020	313180932	54755841	6918633	2457127	2163357	379475890
0.000	213119	0	0	0	0	213119
						865236880.

Study Area = HOUSTON 1-HR RB Entire Population
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 3.
Number of People at Their Highest 1hr Daily Max. Exposure
During O3 Season by Ventilation Rate Categories

O3 Interval, ppm	Equivalent Ventilation Rate, l/min-m**2 <15	15-24	25-29	30-34	35+	ANY
.401+	0	0	0	0	0	0
.381-.400	0	0	0	0	0	0
.361-.380	0	0	0	0	0	0
.341-.360	0	0	0	0	0	0
.321-.340	0	0	0	0	0	0
.301-.320	0	0	0	0	0	0
.281-.300	0	0	0	0	0	0
.261-.280	0	0	0	0	0	0
.241-.260	0	0	0	0	0	0
.221-.240	0	0	0	0	0	0
.201-.220	0	0	0	0	0	0
.181-.200	0	0	0	0	0	0
.161-.180	0	0	0	0	0	0
.141-.160	0	0	0	0	0	0
.121-.140	147640	8057	786	0	0	156483
.101-.120	675093	160937	1189	159	7442	808599
.081-.100	1272242	552828	90953	55225	10512	1248894
.061-.080	275295	411094	143483	122762	74517	156294
.041-.060	242	774211	666963	218679	337523	242
.021-.040	0	388404	550638	430457	521971	0
.001-.020	0	48397	77830	79498	85339	0
0.000	0	0	0	0	0	0

Study Area = HOUSTON 1-HR RB Entire Population
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 4.
Cumulative Numbers of People at 8-Hr Daily Max. Exposure
During O3 Season by 8-Hr Equivalent Ventilation Rate

O3 Level Equalled or Exceeded, ppm	8hr Equivalent Ventilation Rate, l/min-m**2 <15	15-24	25-29	30-34	35+	ANY
.201+	0	0	0	0	0	0
.191	0	0	0	0	0	0
.181	0	0	0	0	0	0
.171	0	0	0	0	0	0
.161	0	0	0	0	0	0
.151	0	0	0	0	0	0
.141	0	0	0	0	0	0
.131	0	0	0	0	0	0
.121	0	0	0	0	0	0
.111	0	0	0	0	0	0
.101	0	0	0	0	0	0
.091	1467	0	0	0	0	1467
.081	211171	0	0	0	0	211171
.071	600390	6129	0	0	0	603384
.061	1524093	17517	0	0	0	1525115
.041	2365702	461142	8642	0	0	2365702
.021	2370512	1061471	29025	382	1	2370512
.001	2370512	1161075	35600	382	1	2370512
0.000	2370512	1161075	35600	382	1	2370512

Study Area = HOUSTON 1-HR RB   Entire Population
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 5.
Occurrences of People at 8-Hr Daily Max. Exposure
During O3 Season by 8-Hr Equivalent Ventilation Rate

O3 Interval, ppm	8hr Equivalent Ventilation Rate, l/min-m**2 <15	15-24	25-29	30-34	35+	ANY
.201+	0.	0.	0.	0.	0.	0.
.191-.200	0.	0.	0.	0.	0.	0.
.181-.190	0.	0.	0.	0.	0.	0.
.171-.180	0.	0.	0.	0.	0.	0.
.161-.170	0.	0.	0.	0.	0.	0.
.151-.160	0.	0.	0.	0.	0.	0.
.141-.150	0.	0.	0.	0.	0.	0.
.131-.140	0.	0.	0.	0.	0.	0.
.121-.130	0.	0.	0.	0.	0.	0.
.111-.120	0.	0.	0.	0.	0.	0.
.101-.110	0.	0.	0.	0.	0.	0.
.091-.100	1467.	0.	0.	0.	0.	1467.
.081-.090	209729.	0.	0.	0.	0.	209729.
.071-.080	605843.	6129.	0.	0.	0.	611972.
.061-.070	2265535.	11388.	0.	0.	0.	2276923.
.041-.060	32194775.	675509.	8642.	0.	0.	32878926.
.021-.040	254465331.	3501047.	22184.	382.	1.	257988945.
.001-.020	568691373.	2424252.	6786.	0.	0.	571122411.
0.000	146507.	0.	0.	0.	0.	146507.
						865236880.

Study Area = HOUSTON 1-HR RB   Entire Population
No. exposure districts =   11
First day of O3 season =   1
Last day of O3 season =   365
No. days in O3 season =   365

Table 4A.
Cumulative Numbers of People at 8-Hr Daily Max. Dose
During O3 Season by 8-Hr O3 and 8-Hr EVR.

O3 Level Equalled or Exceeded, ppm	8hr Equivalent Ventilation Rate, l/min-m**2 <15	15-24	25-29	30-34	35+	ANY
.201+	0	0	0	0	0	0
.191	0	0	0	0	0	0
.181	0	0	0	0	0	0
.171	0	0	0	0	0	0
.161	0	0	0	0	0	0
.151	0	0	0	0	0	0
.141	0	0	0	0	0	0
.131	0	0	0	0	0	0
.121	0	0	0	0	0	0
.111	0	0	0	0	0	0
.101	0	0	0	0	0	0
.091	1416	0	0	0	0	1416
.081	199893	0	0	0	0	199893
.071	529910	13999	0	0	0	532904
.061	1503914	25394	0	0	0	1505653
.041	2356499	560608	10796	0	0	2356499
.021	2370512	1099214	38292	382	13	2370512
.001	2370512	1222681	47680	382	13	2370512
0.000	2370512	1222681	47680	382	13	2370512

Study Area = HOUSTON 1-HR RB   Entire Population
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 5A.
Occurrences of People at 8-Hr Daily Max. Dose
During O3 Season by 8-Hr O3 and 8-Hr EVR

O3 Interval, ppm	8hr Equivalent Ventilation Rate, 1/min-m**2 <15	15-24	25-29	30-34	35+	ANY
.201+	0.	0.	0.	0.	0.	0.
.191-.200	0.	0.	0.	0.	0.	0.
.181-.190	0.	0.	0.	0.	0.	0.
.171-.180	0.	0.	0.	0.	0.	0.
.161-.170	0.	0.	0.	0.	0.	0.
.151-.160	0.	0.	0.	0.	0.	0.
.141-.150	0.	0.	0.	0.	0.	0.
.131-.140	0.	0.	0.	0.	0.	0.
.121-.130	0.	0.	0.	0.	0.	0.
.111-.120	0.	0.	0.	0.	0.	0.
.101-.110	0.	0.	0.	0.	0.	0.
.091-.100	1416.	0.	0.	0.	0.	1416.
.081-.090	198502.	0.	0.	0.	0.	198502.
.071-.080	461221.	13999.	0.	0.	0.	475220.
.061-.070	2200165.	12145.	0.	0.	0.	2212310.
.041-.060	30672652.	1045991.	10801.	0.	0.	31729444.
.021-.040	244107723.	4802454.	30311.	382.	13.	248940883.
.001-.020	577018505.	4485519.	12846.	0.	0.	581516870.
0.000	161449.	786.	0.	0.	0.	162235.
						865236880.

Study Area = HOUSTON 1-HR RB Entire Population
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 6.
Number of People at Their Highest 8-Hr Daily Max. Exposure
During O3 Season by 8-Hr Ventilation Rate Categories

O3 Interval, ppm	8hr Equivalent Ventilation Rate, l/min-m**2 <15	15-24	25-29	30-34	35+	ANY
.201+	0	0	0	0	0	0
.191-.200	0	0	0	0	0	0
.181-.190	0	0	0	0	0	0
.171-.180	0	0	0	0	0	0
.161-.170	0	0	0	0	0	0
.151-.160	0	0	0	0	0	0
.141-.150	0	0	0	0	0	0
.131-.140	0	0	0	0	0	0
.121-.130	0	0	0	0	0	0
.111-.120	0	0	0	0	0	0
.101-.110	0	0	0	0	0	0
.091-.100	1467	0	0	0	0	1467
.081-.090	209704	0	0	0	0	209704
.071-.080	389219	6129	0	0	0	392213
.061-.070	923703	11388	0	0	0	921731
.041-.060	841609	443625	8642	0	0	840587
.021-.040	4810	600329	20383	382	1	4810
.001-.020	0	99604	6575	0	0	0
0.000	0	0	0	0	0	0

Study Area = HOUSTON 1-HR RB   Entire Population
No. exposure districts =   11
First day of O3 season =   1
Last day of O3 season =   365
No. days in O3 season =   365

Table 7.
Cumulative Numbers of People at 8-Hr Daily Max.
Seasonal Mean (April to October) Exposure

O3 Level Equalled or Exceeded, ppm	
.071+	0
.066	0
.061	0
.056	0
.051	0
.046	0
.041	0
.036	0
.031	6134
.026	219654
.021	1434125
.011	2370512
.001	2370512
0.000	2370512

Study Area = HOUSTON 1-HR RB   Entire Population
No. exposure districts =   11
First day of O3 season =   1
Last day of O3 season =   365
No. days in O3 season =   365

Table 8.
Occurrences of People at 8-Hr Daily Max.
Seasonal Mean (April to October) Exposure

O3 Interval, ppm	
.071+	0
.066-.070	0
.061-.065	0
.056-.060	0
.051-.055	0
.046-.050	0
.041-.045	0
.036-.040	0
.031-.035	6134
.026-.030	213520
.021-.025	1214471
.011-.020	936387
.001-.010	0
0.000	0

Study Area = HOUSTON 1-HR RB   Entire Population
No. exposure districts =   11
First day of O3 season =   1
Last day of O3 season =   365
No. days in O3 season =   365

Table 9.
Number of People at Daily Max Dose that Exceed
Specified 1-HR O3 Levels 1 or More Times per Year

O3 Level Equalled or Exceeded, ppm	Days / Year 1	2	3	4	5	>5
.401+	0	0	0	0	0	0
.381	0	0	0	0	0	0
.361	0	0	0	0	0	0
.341	0	0	0	0	0	0
.321	0	0	0	0	0	0
.301	0	0	0	0	0	0
.281	0	0	0	0	0	0
.261	0	0	0	0	0	0
.241	0	0	0	0	0	0
.221	0	0	0	0	0	0
.201	0	0	0	0	0	0
.181	0	0	0	0	0	0
.161	0	0	0	0	0	0
.141	0	0	0	0	0	0
.121	110427	96	0	0	0	0
.101	527223	185360	14139	159	0	0
.081	507817	424359	391327	307331	144643	194087
.061	9728	25082	20881	40632	120541	2148326
.041	0	0	0	0	0	2370512
.021	0	0	0	0	0	2370512
.001	0	0	0	0	0	2370512
0.000	0	0	0	0	0	2370512

Study Area = HOUSTON 1-HR RB Entire Population
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 10.
Number of People at Daily Max 8-HR Dose that Exceed
Specified 8-hr O3 Levels 1 or More Times per Year

O3 Level Equalled or Exceeded, ppm	Days / Year 1	2	3	4	5	>5
.201+	0	0	0	0	0	0
.191	0	0	0	0	0	0
.181	0	0	0	0	0	0
.171	0	0	0	0	0	0
.161	0	0	0	0	0	0
.151	0	0	0	0	0	0
.141	0	0	0	0	0	0
.131	0	0	0	0	0	0
.121	0	0	0	0	0	0
.111	0	0	0	0	0	0
.101	0	0	0	0	0	0
.091	1416	0	0	0	0	0
.081	199868	25	0	0	0	0
.071	438842	48453	43046	2563	0	0
.061	698881	439091	232740	73090	57884	3967
.041	6149	7859	101795	79995	26662	2134039
.021	0	0	0	0	0	2370512
.001	0	0	0	0	0	2370512
0.000	0	0	0	0	0	2370512

Study Area = HOUSTON 1-HR RB   Entire Population
No. exposure districts =   11
First day of O3 season =   1
Last day of O3 season =   365
No. days in O3 season =   365

Table 11.
Number of People that Exceed Specified O3 Levels
at 1-HR Daily Max Dose 1 or More Times per Year
with Ventilation Rates of 30 or Higher

O3 Level Equalled or Exceeded, ppm	Days / Year 1	2	3	4	5	>5
.401+	0	0	0	0	0	0
.381	0	0	0	0	0	0
.361	0	0	0	0	0	0
.341	0	0	0	0	0	0
.321	0	0	0	0	0	0
.301	0	0	0	0	0	0
.281	0	0	0	0	0	0
.261	0	0	0	0	0	0
.241	0	0	0	0	0	0
.221	0	0	0	0	0	0
.201	0	0	0	0	0	0
.181	0	0	0	0	0	0
.161	0	0	0	0	0	0
.141	0	0	0	0	0	0
.121	0	0	0	0	0	0
.101	7601	0	0	0	0	0
.081	91317	776	0	0	0	0
.061	286699	43613	157	168	0	0
.041	609506	306847	130165	54866	49908	16318
.021	539354	285437	196323	173985	100998	429263
.001	373931	281467	263861	154285	93416	868350
0.000	373931	281467	263861	154285	93416	868350

Study Area = HOUSTON 1-HR RB   Entire Population
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365

Table 12.
Number of People that Exceed Specified 8 HR O3 Levels
at Daily Max 8-HR Dose 1 or More Times per Year
with 8 Hour Ventilation Rates of 15 or Higher

O3 Level Equalled or Exceeded, ppm	Days / Year 1	2	3	4	5	>5
.201+	0	0	0	0	0	0
.191	0	0	0	0	0	0
.181	0	0	0	0	0	0
.171	0	0	0	0	0	0
.161	0	0	0	0	0	0
.151	0	0	0	0	0	0
.141	0	0	0	0	0	0
.131	0	0	0	0	0	0
.121	0	0	0	0	0	0
.111	0	0	0	0	0	0
.101	0	0	0	0	0	0
.091	0	0	0	0	0	0
.081	0	0	0	0	0	0
.071	13999	0	0	0	0	0
.061	24644	750	0	0	0	0
.041	238922	187363	106292	33142	3150	349
.021	183062	77747	85307	154601	88395	510102
.001	101027	86930	79230	85014	113740	756740
0.000	101027	86930	79230	85014	113740	756740

Study Area = HOUSTON 1-HR RB Entire Population
No. exposure districts = 11
First day of O3 season = 1
Last day of O3 season = 365
No. days in O3 season = 365