

An Assessment of pNEM: a Computer Package for Assessing Population Level Exposures to Air Pollution

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Abstract

This report summarizes the results of a year long study carried out at the University of British Columbia on a probabilistic version of NEM (pNEM), a collection of computer programs for estimating population level exposures to a variety of air pollutants. In Chapter 1, we concern on ourselves with externalities such as file transfers and computing infrastructures. We describe and review pNEM's approach in a general way. And we look at pNEM's central processor in considerable detail, showing control flows and generally how the package carries out population exposure estimation by simulating human interaction with the environment.

In Chapter 2 we turn to pNEM's inputs and outputs together with its capacity for scenario analysis. As well, we provide detailed information on changes needed to run pNEM on UBC's system. Section 2 of Chapter 2 gives that information.

On the inputs side, we give in Appendix B.1, detailed descriptions of all the data files needed to make pNEM generate exposure estimates, in particular, for Toronto, 1991. Outputs appear in Appendix B.2. That Appendix shows all the reports which pNEM outputs at the end of a complete run. Section 3 of Chapter 2 summarizes the results from runs of pNEM modified for use on UBC's Unix operating system. The study area was Toronto, the exposure period, 1991.

The first output runs reported in Chapter 2 were made without turning on pNEM's scenario analysis module. Thus in Section 4 we were able to compare our version of pNEM with that used by International Technology Air Quality Services (ITAQS) for their earlier runs. Where the UBC and ITAQS runs were compared, no qualitative difference between them could be seen.

In Section 5 of Chapter 2, we show the results of using pNEM for scenario analysis. In particular, we adopt the 13ppm AQO for 8 hr daily maximum exposure to CO and show the hypothetical result of implementing that standard in Toronto, 1991.

In Section 6, we turn to a version of pNEM for estimating exposure to ozone, pNEM/O3,

and run it to obtain exposure estimates for Vancouver's population in 1988. The formatted outputs for this run appear in the Appendix.

In Chapter 3 of this report, we consider possible refinement and present an analysis of pNEM/CO's sensitivity to the various models and methods used by the simulator. Our strategy involved looking at gross changes (on the order of 50% or greater) and fine changes (of about 10%). The former might better have been called "insensitivity analysis," its aim being the determination of elements of the program which could be eliminated or replaced by deterministic alternatives. In the latter we were looking for the parameters whose estimation seemed critically important. Only one parameter appeared in this category following our analysis, the slope of the linear model used to carry ambient CO levels down to the level of the individual microenvironments. Our findings thus suggests the need to reassess the suitability for Canada of the values currently being used in pNEM analysis.

Much of the work leading to the results in Section 2 of Chapter 3 consisted of developing statistical tests for comparing pNEM outputs for alternative scenarios under sensitivity testing. We develop appropriate statistical methods for doing this analysis.

To enable us to reduce pNEM's running times, thereby making multiple runs feasible, we selected just 3 out of the 408 possible cohorts, one of children, one of seniors and one of commuting workers. We selected home districts with generally high levels of CO. Finally we ran pNEM for just a single hour to get 365 independent values from the output for our tests. We could then run pNEM ten times for each scenario to investigate the variability of p-values for our formal significance tests of differences between the 365 value series obtained for each scenario. These p-values prove to be quite variable. By combining them using Fisher's formula, we see which of the parameters led to significant changes in outputs for the combined test results. At the same time, we see the risks of basing the analysis on just a single run even though we are using a large number of replicates in each run (365).

In Section 3 we address the problem of imputing missing ambient pollutant levels. The approach used by ITAQS is not well-defined in their earlier publications, forcing us to develop our own alternative to their method. At the same time we discover difficulties with the ITAQS approach in that one of the assumptions underlying the time series portion of their methodology (following the regression step) cannot hold. Nevertheless we can use the method to complete datasets with missing values. And we do a sensitivity analysis which indicates that the method used does not matter much. Even a naive approach in the time series portion

of the method seems adequate since so few missing values remain after the regression step has been completed. We used the method to complete the ambient CO dataset for Toronto, 1990.

In the last section, we present the results of an extensive series of empirical tests done during the past summer on a spatial interpolator for possible use with pNEM. One dataset used in our tests involved daily and monthly values of SO_2 , SO_4 , O_3 , NO_2 and NO_3 . These data were readily available and multivariate in nature. Additional testing was done with acidic deposition data from the NADP/NTN network in the USA. The results suggested our interpolator was quite accurate in practice. However, the activity pools as currently constructed do not provide sufficiently accurate information on where events took place to enable direct use of the interpolator. Additional programming and data refinement would be needed. Alternatively we need to model-in our uncertainty about event locations.

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Chapter 1

Externalities and Broad Views

1.1 Introduction and Summary

This part of the report presents the preliminary findings of a research team employed to implement and adapt for possible use of regulators in Canada, computer software for simulating the personal exposure of a human population to various airborne pollutants. Although the project team concerned itself with carbon monoxide (CO) and ozone (O₃), Chapter 1 emphasizes the software for CO.

NEM (NAAQS Exposure Model) and its probabilistic successor, pNEM were developed over nearly a decade through the collective efforts of a number of individuals, notably from International Technology Air Quality Services (ITAQS) and in particular, Ted Johnson. Since Johnson et al (1992a,b) describe the conceptual model underlying pNEM in detail, we give only a brief summary. We provide that summary in Section 2 to make comprehensible, our description in Section 3 of pNEM's computer implementation.

That implementation has led to the creation of a large collection of computer files stored in the NTIS/NCC facility. We describe the nature of those facilities in Section 4, along with technical considerations about their use in running pNEM. We describe in that section the program requirements needed to run pNEM and factors which might influence the move to another system.

Section 3, the principal section in this chapter, describes pNEM itself. We flow chart the main files and modules used by pNEM and in the following section, describe the associated programs in considerable detail. For example, we provide overviews of their source codes with

flows from inputs to outputs. The important variables are described. So are the common blocks in the code. We give a detailed list of all the basic inputs required to initiate a pNEM run.

Thoughts on the strengths and limitations of the methodology appear in Section 5. Also given in that section are some improvements which could be made to that code. Of particular importance in this last section, is a list of changes needed to adapt pNEM for use with urban areas in Canada.

1.2 pNEM: A Brief Overview

1.2.1 Background

pNEM simulates the impact on exposure of a user-specified population or subpopulation over a user-specified exposure period to a specified pollutant. In particular, it enables decision-makers to test proposed regulatory scenarios and so assist them in comparing and choosing among competing alternatives.

pNEM foregoes simplistic analytic solutions to the problem of forecasting the actual impact of exposure. Instead, it ambitiously tries to incorporate all the principal elements of the source-to-receptor pathways. Those pathways include random elements so that any given run yields a single stochastic path over the hours of the days in the exposure period. In the case of CO for example, such elements will include the period of random length during which a gas stove was in operation for any given hour.

Faithfulness to reality through the inclusion of micromodels for such things as gas stove operation comes at high cost: lots of elapsed mainframe time.

The outcome shows for a subpopulation “cohort” defined below, how many days a “typical” person in that cohort will sustain concentration levels above any given level, say 40ppm, for example in the case of CO. A second run would yield a different number of days for the same analysis. However, because of the large computational times needed for a run, population estimates are found by using implicitly, a kind of quasi-ergodicity. pNEM simply multiplies the outcome for the typical individual by the size of h/her cohort. From cohorts one can proceed in an obvious way to any given subpopulation of interest.

Investigators, notably those from the ITAQS, have implemented the basic methodology for a variety of pollutants. While these implementations vary in detail and data requirements,

they do so by adapting the same conceptual model and core simulation algorithm.

The general approach involves the five steps stated in Johnson et al (1992b):

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 a 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 associated with each exposure event; and
5. extrapolate the cohort exposures to the population of interest and to individual sensitive groups.

The first two steps define pNEM's domain of analysis. The exposure periods are the years 1989-91. We concern ourselves with the populations and the associated geographical areas of greater Toronto. However in Chapter 2 we do present results on ozone for Vancouver. Toronto will serve in this part to help explain the basic pNEM methodology.

The exposure districts are Census Subdivisions (CSD's). Each exposure district has an associated ambient pollution monitoring site (or sites where averages are taken). That site provides the hourly ambient pollutant concentration levels which represent fundamental inputs into the model.

To subdivide the populations-of-interest requires the definition of appropriate demographic groups (DGRP's). We used the DGRP's given in Table 1.1.

pNEM uses the DGRP's to create "cohorts", a fundamental building block. A cohort is a homogeneous subpopulation treated as having a common history of exposure to the pollutant over the exposure period. Each cohort is indexed by (d, hd, wd, f) . Here d represents the DGRP to which members belong. The members share common home districts, hd 's. For DGRP's with working members, wd represents the working district. Each home and work district comes from the collection of exposure districts described above.

We base the calculation of the number of cohorts in Table 1.1 on the working assumption of 6 exposure districts, the same number of home districts used earlier in a study of Denver. It leads to 12 cohorts for nonworking groups because we assume 6 home districts and 2 types

Demographic group	Includes commuting cohorts?	Number of cohorts associated with demographic group
#1. Children, 0 to 5	No	12
#2. Children, 5 to 10	No	12
#3. Children, 10 to 15	No	12
#4. Children, 15 to 20	No	12
#5. Males, 20 to 45 working	Yes	72
#6. Males, 20 to 45 nonworking	No	12
#7. Males, 45 to 65 working	Yes	72
#8. Males, 45 to 65 nonworking	No	12
#9. Males, above 65	No	12
#10. Females, 20 to 45 working	Yes	72
#11. Females, 20 to 45 nonworking	No	12
#12. Females, 45 to 65 working	Yes	72
#13. Females, 45 to 65 nonworking	No	12
#14. Females, above 65	No	12

Table 1.1: Demographic Groups and Hypothetical Number of Associated Cohorts Defined in the Canadian Implementation of pNEM/CO

of residential cooking fuel (gas or not gas). We find the number of working group cohorts by multiplying the 12 just obtained by the additional factor of 6 for work districts.

Select and fix a cohort. Starting with that cohort, pNEM/CO estimates the CO concentrations to which a typical cohort member is exposed during the period of interest. The program also estimates the impact of those exposures through associated carboxyhemoglobin (COHb) levels.

Three data sources serve as the main inputs to the program. The first consists of hourly readings of ambient air pollution levels from fixed site monitors. They are key since the NEM methodology was developed to evaluate the effects of outdoor pollution on individual health. The “rollback” component of pNEM, for example, estimates the impact of lower

ambient air pollution levels on personal exposure by adjusting these data series according to the regulatory scenario proposed. Where missing values appeared within the pollution time series, interpolation was used to fill in the gaps.

The second source is a population file. Information about the population need not be available at the individual level but must at least be known at the level of the cohort.

Daily activity diaries provide the third data source. The database is organized by study subject and 24-hour time intervals starting at 7 p.m. The diaries are linked to each cohort to get an event exposure sequence which ought to represent exposure for all people in that cohort.

The description that follows gives the intent of each of the five broad components of the pNEM methodology. These components represent one or more computer programs which we describe in detail in the next section. Each component is described by its intended purpose, the method used to achieve that purpose, the input, the output and key identifiers for that component. We start with a description of the most important variables and then focus on the components of the main program. All references to Tables, Figures, Appendices and so on refer to Johnson et al (1992b) unless otherwise stated.

1.2.2 Components of the Program

For brevity, the data will be summarized by a one word description of contents. For example, in the Denver study ‘demographics’ represents age, sex and working status. Below we list the most common variables and indicate their source (pollution, population or diary). The variable is constructed from the original data sources where no source is indicated.

‘demographics’ (population) – age, sex and working status.

‘home’ (population and diary) – geographic location of residence.

‘work’ (population and diary) – geographic location of the workplace.

‘district’ – geographic location of the cohort at one point in time.

‘microenvironment’ – general location (indoors/outdoors) and specific location.

‘smokers’ (diary) – presence or absence of smokers.

‘respiration rate’ – slow (sleeping), slow (awake), medium or fast.

Component: Construct the Exposure Event Sequence

Description: Uses computer sampling of diary information to compose an event sequence for each cohort. Two time intervals must be distinguished in this component: event and day. The diary data is arranged by events falling within a day. The program selects all days which match on cohort demographics, season (summer or winter), temperature (warm or cool) and day type (weekday or weekend). From this subset, days are randomly selected until a year long exposure event sequence is constructed. The events within each day can range from five minutes to one hour but all events must fall within the hour intervals defined by the ambient air pollution data.

Input: Prior to running this component, daily temperature highs for the city of interest are appended to the cohort file. to allow for matching with the diary records. The idea is to create a subset of variables common to the cohort and diary files for matching. Besides the matching variables, the variables district, microenvironment, smokers and respiration rate are taken from the diary file.

Output: An event exposure sequence is created for each cohort. The file should contain records with cohort identifier, district (home or work), microenvironment (see Table 4 of Johnson et al 1992a), breathing rate (see their Appendix B) and passive smoking status. Where diary data like breathing rate was lacking, stochastic values were algorithmically imputed.

Component: Estimate CO Concentration, Ventilation Rate and COHb Levels

Description: The component takes one cohort at a time. After enumerating all combinations of microenvironment and district, the program estimates hourly CO average concentrations for the whole year. Since information on all combinations of microenvironment and district become available for a cohort, the CO concentrations can be read off from the event exposure sequence associated with that cohort.

Input: The cohort exposure event sequence and ambient air pollution files.

Calls: The pollutant concentration, rollback, equivalent ventilation and carboxyhemoglobin components are called from this central component.

Output: This component constructs an hourly sequence of values for each cohort. Along with cohort identifier, we should see the following four estimates: carbon monoxide (CO) concentration, equivalent ventilation rate (EVR), $\text{CO} \times \text{EVR}$ and carboxyhemoglobin (COHb). We call this completed cohort file.

Component: Extrapolate Cohort Exposures

Description: The completed cohort file contains hourly exposure estimates for each cohort. This module provides an estimate of the population size of each cohort. With the extra information, it is easy to get, for a given concentration, an estimate of the number of person hours experienced at or above that level (for the population of interest).

Key Formulae:

$$Pop(d, h, f) = F(h, f) \times Pop(d, h)(7)$$

$$Com(d, h, f, w) = Pop(d, h, f) \times Com(h, w)/Work(h)(17)$$

Input: The fraction of homes having gas stoves for cooking, the population size for all demographic groups within home district and the number of workers commuting from the home district are needed from the population (e.g census) file. Normally, the estimates of the number of commuters by home and work districts comes from a commuting model which also uses population data.

Calls: The commuting module is implicitly called to calculate $Com(h, w)$ though the output from the module may be computed beforehand.

Output: The complete cohort file with population estimates appended in some way.

SUB-COMPONENT: Estimation of Pollutant Concentration

DESCRIPTION: The simulated CO concentration is based on outdoor CO concentration, indoor CO concentration, air exchange rate, indoor emissions from gas stoves and a passive smoking indicator. Excepting the passive smoking component, the concentration estimate comes from the mass balance algorithm. Each input to the mass balance algorithm is randomly generated. The outdoor CO concentration, for example, includes the fixed site monitoring station readings as only one influencing variable (see pp. 16-21 of Johnson et al 1992a). For the purpose of deriving an outdoor CO concentration, the 13 microenvironments are partitioned into two groups, 'A' and 'B'. Those in 'A' are more important and their associated methods incorporate information taken from personal exposure modelling studies. The information takes the form of empirical distributions (25 for method 'A' environments versus 5 for method 'B' environments).

KEY FORMULAE:

$$cexp(d, m, p, h, t) = CME(d, m, p, h) + SMOKE(m, t)(1)$$

$$C_{in}(h) = a_1 C_{in}(h - 1) + a_2 C_{out}(h) + a_3.(17)$$

CALLED BY: 'Estimation of CO concentration' component.

FURTHER CALLS: Described in detail in Sections 3.2 and 3.6 of Johnson et al 1992a.) Air exchange rate (AER), Window Status (open/close, air conditioning), Gas Stove Use, and Residential Volume.

INPUT: Smoking status from the exposure event sequence, indoor CO concentration for the previous hour, outdoor CO concentration for the hour.

OUTPUT: CO concentration for a given microenvironment and a given hour.

SUB-COMPONENT: Equivalent Ventilation Rate

DESCRIPTION: Equivalent ventilation rate is defined as ventilation rate (slow, fast, etc.) divided by body surface area. Given age category (child/adult) and breathing rate, the algorithm simulates equivalent ventilation rate (EVR) values by sampling from a truncated lognormal distribution (See Table 7 of Johnson et al 1992a for the lognormal parameter values)

CALLED BY: 'Estimate CO concentration' component

INPUT: Age category and breathing rate for an exposure event.

OUTPUT: Equivalent ventilation rate (EVR)

SUB-COMPONENT: Carboxyhemoglobin Level

DESCRIPTION: For simplicity, exposure event sequences are constructed using the day as the smallest time interval. The carboxyhemoglobin (COHb) algorithm creates a new physiological profile for every day in the exposure event sequence. The profile then determines many of the inputs needed to simulate COHb levels.

CALLED BY: 'Estimate the CO concentration' component

INPUT: The algorithm simulating the COHb level, requires eleven inputs (see Johnson et al 1992a, Section 4). A few, namely City Altitude, Haldane constant and Atmospheric Pressure, are treated as constants. The initial COHb level, duration of exposure and average CO concentration are the outputs of previously called subcomponents. The rest are derived from distributions and regression equations which use physical profile information. That information (age, menstrual phase, height, weight and body surface area) is generated from the distributions and parameter values found in Table 14 of Johnson et al 1992a.

OUTPUT: COHb level.

SUB-COMPONENT: Rollback Model

DESCRIPTION: The rollback component evaluates the effect of more stringent outdoor air quality regulations on exposure. The rollback scenario is simulated by generating proportionally lower outdoor CO concentrations and can be split into two parts: a constant background CO concentration and a varying concentration proportional to CO emissions that are permitted under the scenario.

CALLED BY: 'Estimation of CO concentration' component

INPUT: Originally estimated outdoor CO concentration

OUTPUT: Rolled back outdoor CO concentration

SUB-COMPONENT: Commuting Model

DESCRIPTION: Uses a trip duration model to construct an origin-destination table. The main algorithm (see pp. 28-29 of Johnson et al 1992a) was constructed to convert census data to a format compatible with the formula used to estimate the population of the commuting cohorts.

CALLED BY: 'Extrapolation of cohort exposure' component

INPUT: Available trip duration data from the US census giving the number of people in each census tract having one of eight one-way commute time intervals. The distance between census centroids is also assumed to be known.

OUTPUT: The Denver study had 340 census tracts pegged as home districts and 393 as work districts. The origin-destination table contained $340 \times 393 = 133620$ estimates of $Com(h, w)$. The estimates were then aggregated to 6 home and 7 work districts specified for the Denver exposure analysis.

1.3 The pNEM Computer Programs and Data Files

In this section, we lay out in sequential fashion to the maximal feasible extent, the programs which implement the pNEM/CO methodology. As well, important data input files and output files will be described. We give visual flow charts below.

1.3.1 Preliminaries

The software under consideration can hardly be described as “user friendly.” For example, when the number of DRGP’s changes say from those used in the Denver study, reprogramming becomes necessary. Our number will differ from that of Denver because of differences in the age intervals used. Changing the definitions of a DGRP’s necessitates changes to all the “pool” programs. Such changes become necessary in other programs when the number of DGRP’s changes; the DRGP numbers (like #5, 7, 10, 12 in our Table 1) identifying the cohorts of working people changes.

To make things more difficult, no documentary description of the pNEM programs exists.

1.3.2 Definitions

Some definitions will help in reading the flowcharts in the following section. We begin by recalling the demographic groups (DGRP’s) we intend to employ:

Demographic group: one of an exhaustive list of 14 population subgroups, each group being identified by age, sex, and working status:

1. $\text{age} < 5$
2. $5 \leq \text{age} < 10$
3. $10 \leq \text{age} < 15$
4. $15 \leq \text{age} < 20$
5. $20 \leq \text{age} < 45$ & working & male
6. $20 \leq \text{age} < 45$ & not working & male
7. $45 \leq \text{age} < 65$ & working & male
8. $45 \leq \text{age} < 65$ & not working & male

9. age \geq 65 & male
10. $20 \leq$ age $<$ 45 & working & female
11. $20 \leq$ age $<$ 45 & not working & female
12. $45 \leq$ age $<$ 65 & working & female
13. $45 \leq$ age $<$ 65 & not working & female
14. age \geq 65 & female.

Pool: one of 8 possible divisions of a demographic group, each being identified by the demographic group, season, day type, and temperature range:

season: winter or summer

day type: weekday or weekend

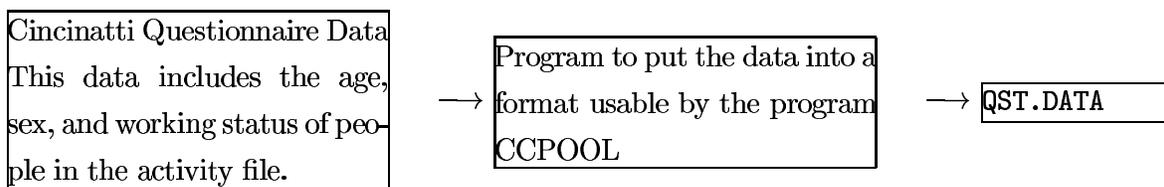
temperature range: 'high' or 'low', 'high' meaning a temperature \geq 55 for winter and \geq 84 for summer.

1.3.3 Flow Charts

In this subsection, we chart the principal pNEM program blocks. We do not include the superficial report writing block (Phase III). The aggregation of the run of hourly concentration and impact values generated by pNEM could be done in a variety of ways and need not in fact use pNEM itself for that purpose.

PHASE I

This phase of the pNEM system generates the input data required. Generally, this takes data, census, meteorological, air quality and so on, and creates data files in a usable format.



Cincinnati Activity Data.
This data contains all the activities of the 968 people in the survey. Up to 111 events were recorded for each respondent for each day

→ Program to put the data into a format usable by the program
CCPOOL

→ CPREP.DATA

Denver Activity Data.
Another survey was done in Denver and this file is the result. A file similar to QST is not necessary as that information was coded directly into this file.

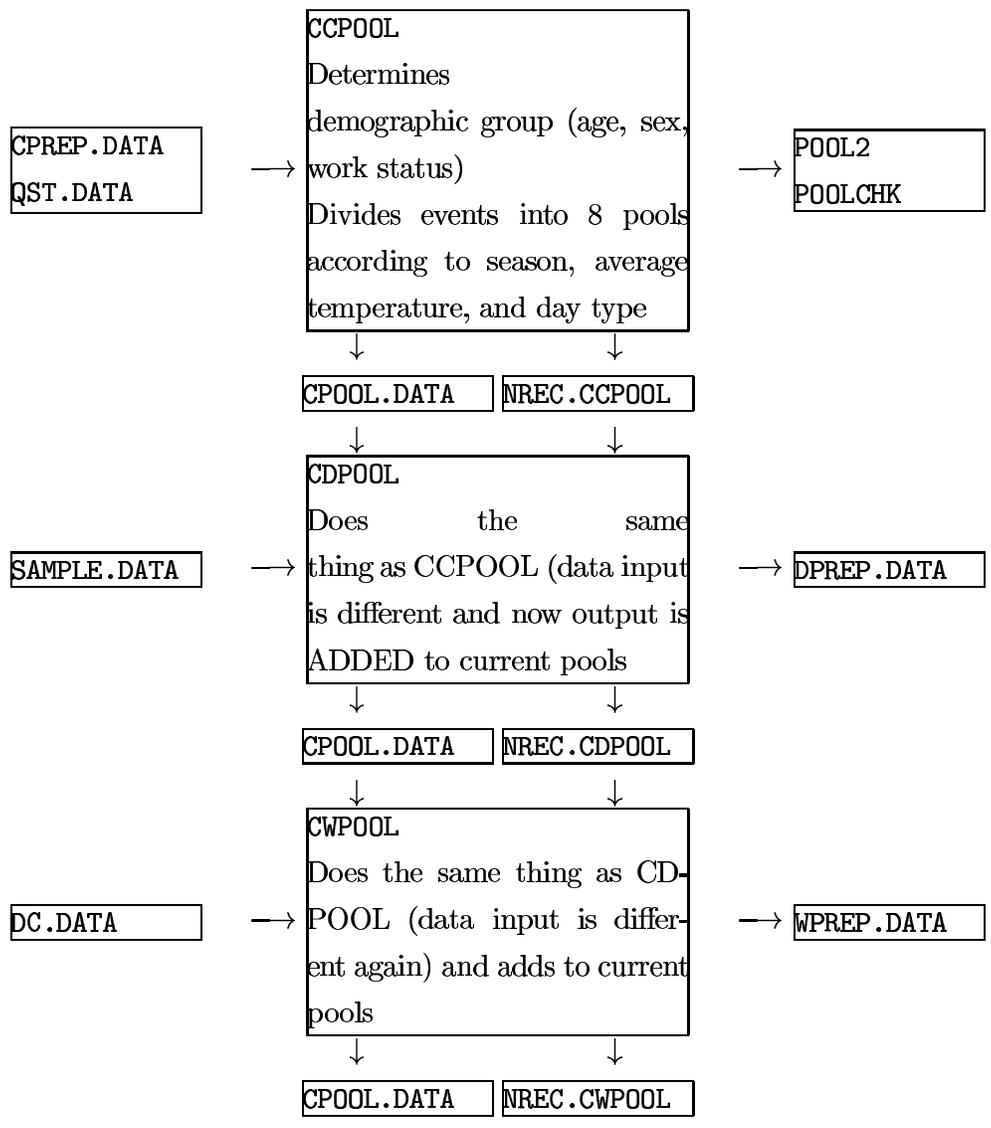
→ Program to put the data into a format usable by the program
CDPOOL

→ SAMPLE.DATA

Washington, DC Activity Data.
This data contains all the activities from the Washington, DC survey.

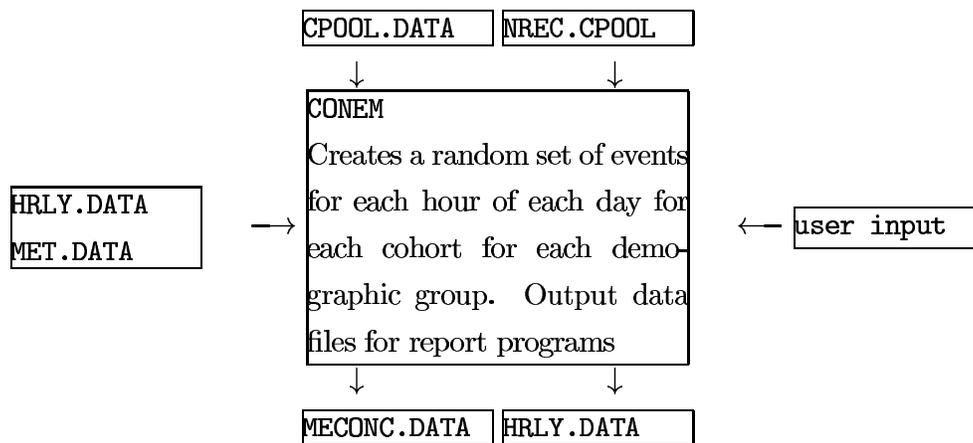
→ Program to put the data into a format usable by the program
CWPOOL

→ DC.DATA



PHASE II

This phase takes the input data described above and produces two data files containing information about Carbon Monoxide emissions, COHb levels, and ventilation rates for all cohorts for all days of the test period.



This leaves us at the end of the pNEM run (except for processing the output data in conjunction with population files) and report generation.

1.3.4 The Computation Process

CONEM, a control file lies at the heart of pNEM/CO. Using gathered questionnaire and activity diary data, CONEM executes a succession of programs. Two output files ordered by cohort emerge and these are then used by various programs to produce relevant reports. Since output is generated using random events, each run of CONEM will produce different results. For any given study area, CONEM requires:

activity data which provides the input for creating a random person year of activities.

census data for the district and time period in a file called POP.DATA (needed only in the last phase, for preparing population level reports).

meteorological data for the district and time period including daily average and maximum temperatures in MET.DATA.

hourly air quality data from air monitoring stations including for each station, hourly concentration levels for the specified pollutant with missing values filled-in. Initially we adopt the methodology described by Johnson et al (1992a) but the final approach is under active investigation by the team. These data go into the file called HRLY.DATA.

user input which identifies the test and other data particular to this test.

PHASE 1

QST and CPREP.DATA. All programs rely on results of a survey of 968 people in Cincinnati which identified various activities related to pollutant exposure. In fact two sets of survey data are required as basic input. Currently, we are using data collected not only from Cincinnati but from Denver, and Washington, DC as well. The QST file contains the survey questionnaire data which identifies the people. The CPREP.DATA file contains the activity diaries of the survey respondents. These diaries give the sequence of activities and their duration, for all the respondents in the surveys. Respondents represented in both QST and CPREP.DATA are labelled so that their records in these two databases can be linked.

Both QST and CPREP.DATA are “wired in” to pNEM. Thus if this data were deemed inadequate or of the wrong type, we would face a major reprogramming effort to create alternatives.

CCPOOL customizes the Cincinnati activity data file and puts it into the form needed by CONEM. CCPOOL uses both QST and CPREP.DATA and assigns to each respondent a demographic group dependent on age range, sex & working status. Records have thus been partitioned by the 14 demographic groups (DGRP’s). The daily records for each respondent in a given DRGP consist of up to 111 “events”. These events are activities and their associated characteristics.

Next, events are “pooled”. DGRP, temperature (high/low), season (summer/winter), and daytype (weekday/weekend) index the pools. The records will thus have been put into an exhaustive and disjoint collection of $112 = 14 \times 2 \times 2 \times 2$ pools. Eventual outputs from this process are:

NREC.CCPOOL containing 112 lines, 1 for each pool, and the count of events in that pool. The output records in NREC.CCPOOL are (DGRP, Season,

DayOfWeek, Numrec, TempRange) although only Numrec seems to be used in succeeding programs.

CPOOL.DATA contains as many lines as there are respondents times events, separated into fixed size pools as described above (each pool having a maximum of 325 items).

To each line in NREC.CCPOOL, CPOOL.DATA associates a pool of records of individuals. The records are all those associated with respondents in the DGRP who responded on days with the characteristics specified in the line, the season, day of the week and right temperature range. Johnson et al (1992a, b) call each record an exposure event sequence (EES).

POOL2 and POOLCHK appear to be outputs from CCPOOL used as checks and not actively used in the programs themselves.

CDPOOL adds the data from the Denver survey to the customized activity database. The Denver questionnaire differs somewhat in format from that of Cincinnati so CDPOOL processes the input data to make its outputs compatible with those of CCPOOL. CDPOOL reads NREC.CCPOOL and SAMPLE.DATA, updates Numrec appropriately to include Denver records and then outputs:

NREC.CDPOOL

DPREP.DATA

CWPOOL Finally, in this phase of processing, the controller runs CWPOOL to repeat for Washington data, the processing done by CDPOOL on Denver data. CWPOOL reads NREC.CDPOOL, updates Numrec (as above) and outputs:

NREC.CWPOOL

WPREP.DATA

We are now ready to go into the time consuming central phase of processing.

PHASE 2

Run the CONEM controller. CONEM reads NREC.CWPOOL, CPOOL.DATA, HRLY.DATA and MET.DATA. It eventually creates as described below in detail, two output files:

MECONC micro-environment exposures for each of 37 micro environments for each cohort;

HRAVG hourly average CO exposures, ventilation rate, and COHb status for each hour of each day in the exposure period for each cohort.

pNEM/CO makes the microenvironment (ME) an important element in exposure calculation. At the finest level there are 37 ME's wherein a respondent can be during an EE (exposure event). For programming simplicity, the routine MICRO clusters these 37 into 13 of ME's of similar type.

We now describe the CONEM controller in more detail. The main program accessed by CONEM is called COCAL (CO calculation).

COCAL is the main program for implementing the pNEM methodology. It reads the user input data, and most of the data required by the program. It then passes control to COHORT to do the work. An overview of the source code appears in Table 1.2.

COHORT is the main subroutine called by COCAL. It defines what a cohort is, calculates the hourly CO concentrations, COHb levels, equivalent ventilation rates and writes the data to disk files for the report phase. Table 1.3 gives an overview of the source code.

We now describe the subroutines called by COHORT.

COHPAR computes the COHb during an exposure event given the DGRP. The AS-PHYX module later uses the data so created. A number of built-in constants in this module will require careful study to determine their relevance to Canadian exposure simulation. Table 1.4 gives an overview of the source code.

MICRO converts an activity diary location into an aggregated ME by converting the 37 input values (NEME's) to 13 (NME's) by grouping similar types. A data statement controls the conversion. This approach allows for easier programming as there will be only 13 rather than 37 types of ME's to check. We do not include here, its simple and straight-forward code. Both COHORT and ALGA call this module.

COEVR is called by COHORT to determine the equivalent ventilation rates (EVR) given breathing rate (BRCAT), demographic group (DGRP), duration of an exposure event (DUR) and wakefulness. Note that DGRP is changed to 1 for number's 1 through 4 and to 2 for the remainder. This value indexes the several built-in constant arrays. Table 1.5 provides an overview of the source code.

ASPHYX, called by COHORT, represents a complex mathematical module for computing COHb levels. Biller and Richmond (1991) describe that module in detail so we won't describe it here.

HRAVG is called by COHORT to compute and output the hourly average statistics into a disk file for further processing. The output consists of information identifying a cohort and the average CO concentration, equivalent ventilation rate, the product of these two, and COHb value. An overview of the source code appears in Table 1.6.

ALGA, called by COHORT, creates the "MOA Array" for both home and work districts and all ME's; that is, for each ME, hour, home district and work district, ALGA computes a CO emission value.

For each home district/work district pair, the module copies the relevant portion of the hourly monitoring data and modifies this data for gas stove operation in residential ME's. Then it does a linear regression using current or last CO value depending on type of ME. An overview of the source code appears in Table 1.7.

The following routines are called by ALGA only.

GASSTOV is called by ALGA for all residential ME's with gas stoves. It creates an array of indoor emissions for each hour. This subroutine uses three other subroutines contained in the same source file. The routine STOVYR appears to have no use since the values it creates are never used. Table 1.8 provides an overview of the source code.

AER1 is called by ALGA just after GASSTOV (under the same circumstances). This module, computes the EVR. AER1 calls AERDAY, TAVG, and ALGB. We describe ALGB below; AERDAY appears in the AER1 file and TAVG is part of COHORT. Table 1.9 gives our overview of the source code.

ALGB is called by AERDAY to find the window status given the type of air conditioning (none, room, central) and average temperature. Specifically, it finds 3 values for window status - open, closed, uncertain. Its code's overview appears in Table 1.10.

GMASSB is called by ALGA just after AER1 (under the same circumstances). The following is quoted directly from the source:

The mass balance determines hourly CO values (indoor) for the microenvironment given the fixed-site monitor values (MON) the hourly air exchange rate values (AER), the hourly indoor emission values (INDOOR).

An overview of the source code appears in Table 1.11.

Table 1.2: Control Flow for Subroutine COCAL

1. read user input data; city, time, districts; rollback
 - a) NOTE: the rollback code has been commented OUT
2. read met data (ALL of it!) creating MXTEMP array saving the average and maximum temperatures. Array indicies:
 - a) day
 - b) year
 - c) city
 - d) max temp, avg temp for that day, year, city
3. Create the DAY array: 1st index from 1 to no. days in sample
2nd index as follows:
 - a) 1: day number of the year
 - b) 2: the season (0 or 1)
 - c) 3: the day type (weekend/weekday?)
 - d) 4: 0 or 1 depending on season value and max temp
 - e) 5: average temp for that day
4. read hourly data into MON array:
 - a) 1st: from 1 to no days in the year
 - b) 2nd: 1 -> 24 (hourly AQ data)
 - c) 3rd: from 1 to no. districts
5. Modify MON array for average across monitors for residual districts: adds to the 3rd index (no check to insure that there is room for these)
 - a) ndist+1 = avg
 - b) ndist+2 = avg
6. adjust times for daylight savings time
7. write to printer important data from DAY, MXTEMP and MON
8. call COHORT
9. stop

Table 1.3: Control Flow for Subroutine COHORT

1. Read user input data
 - a) gas stove data
 - b) air exchange rate data
2. loop from 1 to IDGRP (0..14 in order on NREC)

Read 8 records; Numrec from each from NREC.CWPOOL

 - a) loop from 1 to number of districts (HOME district)

if idgrp=5,7,10,or 12 (ie. groups which work) then
wds=1 wde=ndist

else wds=wde=dist no.

 - 1) loop from wds to wde (WORK district)
 - a> loop from 1 to 2 (GAS)
 - 1> thus var(idgrp,hd,wd,gas)=a cohort
 - 2> call ALGA [create MOA array: for each hour, each microenvironment, calculate CO for HD and WD]
 - 3> get a series of random numbers
 - 4> loop from 1 to number of days
 - a: use the i'th random no + daytyp + n (CWPOOL value)
 - b: use that to read a record from CPOOL (an EVENT)
 - c: copy IDGRP to IDSGRP for COHPAR and modify because idgrps are different and we are using the old COHPAR
 - d: call COHPAR [determines COHB pars given DGRP] like blood, hemoglobin, etc
 - e: loop from 1 to 111 (number of events)
 - 1: call micro [assign microenvironment]
 - 2: call coevr [determine ventilation rates (EVR)]
 - 3: CONC(ie) CO values taken from appropriate part of MOA and modified if smoking
 - 4: set up MECONC values
 - 5: call asphyx [return COHB in CARB(IE)] except for idgrp=1
 - 6: end loop
 - f: call hravg [convert event; compute hourly values for each person day]
 - 5> end loop
 - 6> write microenvironment cohort stats to MECONC.DATA
 - b> end loop
 - 2) end loop
- b) end loop
3. repeat until end of file on CWPOOL

Table 1.4: Control Flow for Subroutine COHPAR

1. Constant data arrays (all of size 11) DGRP has been modified to send in a value based on 1 group for ages 0-20.
 - a) HMN
 - b) HSTD
 - c) A0
 - d) A1
 - e) STDERR
 - f) BLDFAC
 - g) HGMM
 - h) HGSTD
 - i) AGE
 - j) Note also that every calculation in this routine has built-in constants.
2. Get a random number insuring greater than -4
3. $\text{height} = \text{random} * \text{HSTD}(\text{DGRP}) + \text{HMN}(\text{DGRP})$
4. Get a random number insuring greater than -4
5. $\text{weight} = \text{A0}(\text{DGRP}) + \text{A1}(\text{DGRP}) * \text{height} + \text{STDERR}(\text{DGRP}) * \text{random}$
If weight doesn't match certain groups redo the calculation
6. $\text{BSA} = .01009 * (\text{WEIGHT} ** .425) * (\text{HEIGHT} ** .725)$
7. $\text{BLOOD} = \text{WEIGHT} * \text{BLDFAC}(\text{IDGRP}) + .00683 * \text{HEIGHT} ** 3. - 30.$
for DGRP LE 6; for others, .0683 changed to .00678
8. get another random number and calculate HMGLB:
 $\text{HMGLB} = \text{RANDOM} * \text{HGSTD}(\text{IDGRP}) + \text{HGMM}(\text{IDGRP})$
9. get another random number and calculate DIFF and HEMFAC
10. get another random number and calculate ENDGNS
11. return

Table 1.5: Control Flow for Subroutine COEVR

1. Constants defined:
 - a) MU(4,2)
 - b) SIGMA(4,2)
 - c) IGRP(14)
2. IGROUP = IGRP(DGRP) yields 1 for children; 2 for adults
3. get a random number
4. $EVR = \text{EXP}(MU(BRCAT, IGROUP) + \text{RANDOM} * \text{SIGMA}(BRCAT, IGROUP))$
where BRCAT is breathing category. MU and SIGMA are built in constant arrays
5. call upper is used to make sure that the value calculated isn't too large. Comment suggests that this can be removed if desired.
6. if $EVR > \text{EVR LIM}$ then $EVR = \text{MAXEVR}$
7. return
8. SUBROUTINE UPPER
is part of this file; returns EVRLIM
 - a) define a bunch of constant arrays
BSA, VO2MAX, MAXRAT, SUBRAT
 - b) if event duration greater than 5min then
 $\text{EVR LIM} = 1.2 * \text{VO2MAX}(\text{IDGRP}) * \text{MAXRAT}(\text{IDGRP}) / \text{BSA}(\text{IDGRP})$
 - c) other calculations are done for durations:
 - 5 min to 162 min
 - more than 162 min
 - d) return

Table 1.6: Control Flow for Subroutine HRAVG

1. Read TIME (Hr,Min) and DURATION of all events
2. Loop for k for all events
 - a) if duration=-1 skip it
 - b) if this event in same hour as previous
 - 1) save current hour
 - 2) sum co*dur; vent*dur; co*vent*dur;
 - 3) sum duration of events this hour
 - 4) get next event
 - c) else; print warning if sum duration NE 60
 - d) compute hourly averages; ie. the above sums / 60
 - e) cohb value = last cohb value in this hour
3. end loop
4. output to disk HRAVG.DATA
 - a) idgrp hd wd gas daynum, nevent
 - b) for each hour
 - 1) co avg; ventilation avg; co*vent avg; COHb

MASSB, called by ALGA for all ME's, uses the Mass Balance Algorithm. The source code describes its operation.

The linear regression type equation calculates hourly CO values (CMB) for the microenvironment given the fixed-site monitor values (MON), the hourly indoor emission values (INDOOR), the slope (a), and intercept (b), and the lag adjustment(LAG).

An overview of the source code is given in Table 1.12.

Important Variables.

Important variables used in the the core calculations described above are:

DGRP Demographic group

NEME number of locations defined in the activity data.

NME aggregated locations. The NEME locations (microenvironments) grouped into similar types to facilitate programming.

MON(366,24,15) hourly air quality input data for each day, for each hour and for each monitoring district.

Table 1.7: Control Flow for Subroutine ALGA

1. loop for 1 (home dist) till 2 (work dist)
 - a) loop for 1 for all microenvioronments
 - 1) call micro
 - 2) kx=0
 - 3) loop for each day in run
 - a> loop for each hour in day
 - 1> kx++
 - 2> district = home or work or if in car, use composite AQ
 - 3> define MON1(kx) from MON(day,hour,district)
[hourly air quality data]
used in call to MASSB
 - 4) end loop
 - 5) if residence ME then
create the indoor hourly CO values
 - a> call gasstov [get emission rates]
 - b> call aer1 [get air exchange rate]
 - c> call gmassb [produce hourly CO]
 - 6) else set indoor=0
 - 7) call massb using INDOOR and MON create CMB (hourly CO values created using regression)
 - 8) loop for each hour
 - a> moa = cmb
 - 9) end loop
 - b) end loop
 2. end loop

Table 1.8: Control Flow for Subroutine GASSTOV

1. call stovyr [sets a value K which is never used]
2. for each day
 - a) call stovday
 - b) for each hour
 - 1) call stovhr
 - 2) $\text{indoor}(j) = \text{epv} / 1.145$ [convert TP PPM]
 $j = 1 \dots 366 * 24$
3. return
4. subroutine stovday
 - a) get 3 random numbers
 - b) calc EFACT using 1st random number and calculation type as defined by user input (normal/lognormal)
 - c) if out of range, get another random number and replace the old one with it and go to step b
 - d) calc AUSE using the 3rd random number and calculation type as defined by user input
 - e) if out of range, get another random number replacing the bad one with the new one and go to step d
 - f) determine contribution from burner and pilot
 - g) calc VOLUME using 2nd random number and calculation type as defined by user input
 - h) if out of range, get a new random number, replacing the 2nd with the new and recalc
 - i) return
5. subroutine stovhr
 - a) using randomness, determine whether stove is off or on and calculate EPV accordingly. If OFF, then only pilot is considered.
 - b) return EPV

Table 1.9: Control Flow for Subroutine AER1

1. for each day in test period
 - a) call aerday to get AER values
 - b) for each ME
 - 1) aerout(day,me) = aer(me)
2. return
3. subroutine aerday
 - a) for each indoor ME
 - 1) if a residence ME
 - a> randomly decide what kind of a/c (if any)
 - b> call algb to determine window status
 - 2) calculate AER depending on user input type of calc
 - 3) check value for appropriate range
 - a> if residence ME & window=3 and out of range, skip it
 - b> else get a new random number and try again

Table 1.10: Control Flow for Subroutine ALGB

1. define RANGE(3,3,2) via constants
2. define WEIGHT(3,3) via constants (looks like these are % of window being open dependent on a/c and avg temp)
3. get a random number
4. if avg temp:
 - a) < 32 window closed; weight=0; return
 - b) LE 62 then IT=1
 - c) > 62 & LE 75 then IT=2
 - d) GT 75 then IT=3
5. if random < range(iac,it,1) IWIND=1, WWF=0 return
6. if random < range(iac,it,2) IWIND=2, WWF=1 return
7. else IWIND=3 WWF=weight(iac,it)

Table 1.11: Control Flow for Subroutine GMASSB

1. for each hour in the test period (loop index is I)
 - a) calculate indoor(hour) from aer(hour,me)
IDAY = (I-1)/24 + 1 day number
J=I-1 last hour
ATERM = EXP(-AER(IDAY,IME))
A1 = (1. - ATERM)/AER(IDAY,IME)
A2 = 1. - A1
A3 = INDOOR(I) * A2 / AER(IDAY,IME)
ISTOVE(I) = ATERM * ISTOVE(J) + INDOOR(I) * (1.- ATERM) /
AER(IDAY,IME)
INDOOR(I) = A1*ISTOVE(J) + A3
 - b) return

Table 1.12: Control Flow for Subroutine MASSB

1. define slope A(37) via constants
2. define intercept B(37) via constants
3. define lag LAG(37) via constants
4. for each hour
 - a) j=hour+lag(ME)
 - b) cmb(i) = (mon(j)*a(ME) + b(ME)*indoor(i)) * pfac

MXTEMP(366,80:92,32,2) daily temperature input data; for each day, for years 1980 to 1992, for all districts in test area store maximum and average temperature.

DAY(366,5) For each day, defines season, day type (weekday or weekend), and average temp (from MXTEMP).

CARB(111) Calculated COHb values for each event in 1 day

CONC(111) Calculated CO values for each event in 1 day

MOA(8784,2,37) from ALGA; for each hour in the test period, for each home and work district, for each input location define CO emission.

MON1(366*24) subset of MON needed in ALGA to create MOA

AER(366,37) Air quality data for each day for each ME

MECONC(37,4) from cohort and output to MECONC.CO91.DATA;

HRAV(24) Calculated hourly CO emissions written to HRAVG.DATA.

ELAVG(24) Calculated equivalent ventilation rate written to HRAVG.DATA.

PROAVG(24) Average product of the previous two values written to HRAVG.DATA.

COHOUT(24) COHb average hourly values written to HRAVG.DATA.

Common Blocks

We have identified the following common blocks.

blank Variable ISEED used in ALGB.FOR, AER1.FOR, COALGA.FOR, COCOH.FOR, COEVR.FOR, GASSTOV2.FOR, GMASSB.FOR

BGAS Variables EMOP,AUOP,VOLOP,EFM,EFSD,EFMAX,EFMIN,AUM,AUSD,AUMAX. Used in COCOH.FOR, GASSTOV2.FOR

BAER Variables AEROP, AERM ,AERSD ,AERMAX ,AERMIN Used in AER1.FOR, COCOH.FOR

BAVG Variables CONC,ELPM,CARB,PROD,EVENT Used in COCOH.FOR, HRAVG.FOR

XPOLL Variables PFAC,POLL Used in COALGA.FOR, COCAL.FOR, COCOH.FOR, MASSB.FOR

ROLLB Variables IROLLB,ROE,XB used in COCAL.FOR

We turn now to the final stages of the pNEM computational process.

FINAL OUTPUTS AND REPORTS

We do not give a control flow of the programs used to produce the various pNEM reports. As noted earlier, this aspect of the pNEM is somewhat peripheral.

MEDISP reads MECONC and POP and produces a report of air quality and time spent in ME's by cohort.

PNEM8HR, relying on CONEM output data, reads HRAVG and POP.DATA and produces tables and CO91.MEAN. In all, it generates 10 tables ordered by cohort. Some are for 1hr maximum exposures and some, for 8hr exposures along with seasonal means in both cases.

COHBHR2 reads POP.DATA, HRAVG and produces the report NEM8HR.DATA (see also CNTL/COHB).

COHBTB2 reads NEM8HR.DATA and produces a report.

BASIC INPUTS.

The following data files need to be provided to pNEM:

QST Cincinnati questionnaire;

CPREP.DATA Cincinnati activity diary;

SAMPLE.DATA Denver activity diary;

DC.DATA Washington, DC activity diary;

HRLY.DATA Hourly monitoring values;

MET.DATA Meteorological data;

POP.DATA Population data.

We now describe user input required in 4 programs:

I. CONEM

1) record 1

a) CITYN, I2, city index (into hourly data)

- b) CITNAM, A17, alphanumeric city name
- c) BEGMO, I2, first month of test period
- d) ENDMO, I3 last month of test period
- e) IYR, I3 year (last 2 digits)
- f) NDIST, I3 number of districts in test area
- g) skip 1
- h) POLL, A3, pollutant ('CO')
- i) PFAC F6.3 P-factor

31TORONTO 01 12 91 6 CO 1.0 <- sample record

2) record 2

- a) IROLLB, I1 rollback
- b) XS, F5.1 ?
- c) XB, F5.1 ?
- d) XMAX F5.1 ?

0 9.0 .53 16.2 ROLLBACK <- sample

NOTE: while the code to read rollback values is active, the code to actually implement it is inactive (ie. commented out).

3) record 3

- a) EMOP, I2 emission distribution
(1=normal 2=lognormal)
- b) AUOP, I2 annual use distribution
(1=normal 2=lognormal)
- c) VOLOP , I2 volume use distribution
(1=normal 2=lognormal)

4) record 4

- a) EFM, F10.5 EF mean
- b) EFSD, F10.5 SD
- c) EFMAX, F10.5 max
- d) EFMIN, F10.5 min

5) record 5

- a) AUM, F10.5 Annual use mean of burners

c) hwtrps(ndist,)

III. PNEM8HR

1) record 1

a) district name A20
b) skip 10x
c) ndist I2 number of districts
d) runind I2 0=all 1=adults

2) records 2...ndist+1

same data as for MEDISP (fraction of trips to work district)

IV. COHBHR2

1) record 1

a) district name A20
b) skip 10x
c) ndist I2 number of districts

2) records 2-ndist+1

same as for MEDISP

3) next record

a) SCENARIO A30 sample hsa 'AS IS'
doesn't actually matter because it isn't used except to write out in one of the tables

4) next record

a) NLVLS I2 number of levels of CO to tabulate

5) next 'nlvls' records - 1 value per record

a) COLVLS F7.3 lower limit of each level

6) next 'nlvls' records - 2 per record

looks like these are read to save having to create them in the program

a) LVLTXT(i,1) A4 lower limit
b) skip 1x
c) LVLTXT(i,2) A4 upper limit

1.4 Computing Environments

1.4.1 Current Situation - NTIS/NCC System

The NTIS/NCC system now includes several IBM mainframes (IBM9021-860's) and VAX machines. PNEM is believed to be run on an IBM ES/9000 series computer (there are two different models and it is unclear as to which one is actually been used to run it).

How to use the NTIS/NCC System

In Appendix A we provide a "friendly" guide to transferring files between a Unix system and the NTIS/NCC. The stepwise approach reflects what the project team has learned in downloading the needed files to UBC.

Characteristics of NTIS/NCC system

The basic characteristics of an ES/9000 computer are currently:

- A basic clock speed of between 7.1 and 9 nanoseconds. generally a vector facility is included, although not at this facility. [Programs can execute much faster if they tend to fit in the vectorizable model.]
- most models include multiple CPUs
- 128 megabytes of real memory

The IBM's at the NTIS/NCC have 512 megabytes of memory and 716 megabytes of expandable memory. One of the two machines runs at 173mips, the other at 203mips.

1.4.2 Program (pNEM) Requirements

The pNEM programs are written in FORTRAN and thus require a reasonable FORTRAN compiler (the more optimization it provides, the better). The system makes use of IBM's IMSL Library for the random number generators. While this isn't a strict requirement, it does reduce the programming effort required in changing to a different random number generator.

The disk storage required for the program, input data, and output data is substantial so a large disk storage system is necessary. More is required if data from previous runs is saved for future comparisons. The main program requests a 200 megabyte region size and a time limit (CPU) of 2 hours.

The main program is very large and requires 200 megabytes of memory. This doesn't imply that the system must have 200 megabytes of REAL memory but that it must be capable of providing it. It is true that the more REAL memory that is available, the less disk paging will be required and thus the program will execute quicker (and the elapsed time will be reduced).

The program also is heavily CPU dependent (ie. it does much calculation as opposed to being heavily I/O dependent). This then requires a reasonably fast CPU to execute the program in a timely fashion.

1.4.3 Factors Influencing the Move to Another Computing System

- Expected CPU time required. Different computers will execute similar programs at different speeds due to many factors; CPU clock speed is one of them. Note that elapsed time usually increases at a greater rate - usually because more system resources are required on the smaller machines.
- Expected elapsed time to run the program. While it is believed that most any Unix system could probably run it (eg. a desktop system), a low-end system will require much more resources and therefore much more time (both CPU and elapsed) to execute. On the other hand, if it doesn't matter that it takes a week to get the results, then the smaller machine will obviously cost less money to acquire.
- Some Comparisons between various machines (IBM ES/9000 model 711 has a single CPU). The numbers represent the computing speed of executing LINPACK (the higher the number the faster the machine):

IBM ES/9000 Mod 711 86

SUN Sparc 10/51 12

SUN Sparc/2 (Desktop) 4

This would tend to suggest that it would take about 7 times as long to execute at UBC as it does at EPA. On a desktop, its over 20. More detail on running times at UBC is given in Part II

1.4.4 The UBC System and Its Characteristics

UBC's Unix Mainframe is currently a Sun Sparc 10/51

The basic characteristics of a Sun Sparc 10/51 are:

- A clock speed of 50 MHz
- No vector facility
- Single CPU
- 256 megabytes real memory

1.4.5 Recommendations

Benchmarks are only guides. To be sure, you have to try it. On the other hand, it isn't likely to be viable on a small system. Possible software changes could reduce the resources required.

1.5 Discussion

Regulators and public policy-makers would question the validity of population exposure estimates generated by the pNEM methodology. A number of specific questions occur. Is pNEM just a fancy random number generator or do its outputs simulate real world exposure levels under various regulatory scenarios? Are all important sources of variability from individual-to-individual represented in the random pathway? Can a single run, albeit for a composite cohort member with greater day-to-day variations in activity patterns than a typical cohort member, really summarize the overall experience of the cohort?

Answers to such questions lie well beyond the scope of this report. Indeed answers could not be found without extensive and costly empirical assessment and in some cases, for hypothetical regulatory scenarios, perhaps not at all.

The results from limited experiments carried out in Denver by Johnson and described by McCurdy et al (1993) seem somewhat inconclusive. Perhaps as noted by these authors,

In one respect the question is not of major concern. The EPA uses NEM modelling results more in a relative model (*sic*) than in an absolute mode.

The idea seems to be that decision makers would use the methodology to see the relative change in exposure impact, which any given change-scenario would seem likely to produce. However, that observation even if valid still leaves uncertainty, here about how well pNEM will estimate changes under a hypothetical scenario.

We could go further than McCurdy et al (1993) and argue that issues of absolute validity are irrelevant in that pNEM constitutes a paradigm rather than model for decision-makers. The computer model offers a small world, thought to be at least somewhat similar to ours, in which the potential value of prospective scenarios might be explored. In this view, we find an analogue of the frequency theory of statistics. Frequentists need not believe the feasibility of the repetitions of an experiment (infinitely often to justify large sample theory!) to believe in this paradigm for testing a proposed statistical procedure.

It must be emphasized that while concerns about pNEM remain, we know of no competitor which might be used in its place to generate estimates at its extremely fine levels of temporal resolution. We favour continued investigation of its potential and where possible, empirical assessment.

1.5.1 Changes in requirements of the program

1. Changing the demographic group definition requires changes to nearly all the routines. For example, code exists in several places to identify a working demographic group and the group numbers are hard coded.
2. Questionnaire and Activity Data. If new data is required then programs would have to be written to process and enter the new data.
3. Subroutine AER1 (Air Exchange Rate algorithm) needs data on the fractions air conditioning types.
4. Subroutine COHPAR has several DATA statements which may or may not need adjusting for any particular area.

5. Subroutine ASPHYX needs hard-wired data for: a) elevation of the test area; and b) some hard-coded constants which need evaluation.
6. Subroutine MASSB SOPE, INTERCEPT, LAG constants *may* need to be adjusted
7. Subroutine COEVR has hard-coded data dependent on age groups so if these change then this subroutine must change; and constant arrays MU and SIGMA are hard-coded constants which *may* need changing for certain situations.
8. PNEM8HR. Changes are required to change the definitions of demographic groups.
9. COHBHR2. Changes are required if the number or type of tables required differ from those used by the EPA.
10. COHBTB2 Similar comments to those about COHBHR2 apply here also.

1.5.2 Suggestions for Improvement of Current Code

1. All of the data read or written to data files is done using formatted I/O. Files intended for human reading, require such formatting. However, the remainder for input to other parts of the program, need not be so formatted. Changing large files like the activity file CPREP, the resulting CPOOL file and the HRLY and MET data files to UNFORMATTED input and output would yield considerable CPU savings:
 - Converting between “human readable” and “machine readable” REAL numbers consumes time, especially since conversion must be done twice: once to write it and then again to read it back in.
 - In some cases, the size of the data file will shrink. Unformatted integer or real data takes 4 bytes no matter how big the number is. Thus, any I or F format specifying a field width greater than 4 will take unnecessary disk space. However, gaining disk space is less important than CPU savings. Of course, programming changes are necessary and while they are not trivial, they are straight-forward.
2. Most data initialization is done in a DATA statement, some of which is for large arrays. This:
 - increases the compilation time, sometimes substantially

- increases the resulting load module size linearly as a function of the array size.

A better way is to include code to initialize the arrays. This adds some CPU time to the final execution but usually is insignificant to the total. One can insure that the entire array is initialized (without having to calculate the total number of bytes to be initialized)

Chapter 2

Running pNEM

2.1 Introduction

In Chapter 1, we concerned ourselves with externalities such as file transfers and computing infrastructures. We described and reviewed pNEM's approach in a general way. And we looked at pNEM's central processor in considerable detail, showing control flows and generally how the package carries out population exposure estimation.

Chapter 2 turns to pNEM's inputs and outputs together with its capacity for scenario analysis. As well, we provide detailed information on changes needed to run pNEM on UBC's system. That information including computation times are provided in Section 2.

On the inputs side, we give in Appendix B, detailed descriptions of all the data files needed to make pNEM generate exposure estimates, in particular, for Toronto, 1991. Outputs appear in Appendix B. That appendix shows all the reports which pNEM outputs at the end of a complete run.

Section 3 summarizes the results from runs of pNEM modified for use on UBC's Unix operating system. Our study area is Toronto, our exposure period, 1991.

Our first runs are made without turning on pNEM's rollback module. We run in both the 'source on' and the 'source off' modes. Thus we can compare our version of pNEM with that used by the International Technology Air Quality Services (ITAQS)..

As noted in Section 4, where the UBC and ITAQS runs are compared, there is no qualitative difference between the two implementations of pNEM. Of course both implementations exhibit run-to-run variation. Those in the ITAQS report, in particular, show substantial

Table 2.1: Differences Between NTIS/NCC and UBC

Items	NTIS/NCC	UBC
Platform:	IBM ES9000	SUN Workstation
Operating System:	MVS	UNIX
Fortran compiler:	IBM Fortran compiler	Sun FORTRAN compiler

differences in some cases (compared to those presented in our report).

In Section 5, we show the results of using pNEM for rollback module. In particular, we adopt the 13ppm AQO for 8 hr daily maximum exposure to CO and show the hypothetical result of implementing that standard in Toronto, 1991.

In the final section we turn to pNEM/O3 and run it to obtain exposure estimates for Vancouver's population in 1988. The formatted outputs for this run appears in the Appendix B.

2.2 Running pNEM/CO at UBC

From the view point of implementation, the pNEM/CO model consists of two major components: source codes and data sets. NTIS/NCC implemented the pNEM/CO model on an IBM ES/9000 running the MVS operating system. We successfully transferred all necessary files from NTIS/NCC. Those files include control files (MVS's files to organize source codes and data sets), Fortran source codes and data files at several stages of development – from raw data files to model output data files. (see Appendix A for details)

Transplanting the pNEM/CO model from NTIS/NCC to UBC required some modifications. Basically, the following differences displayed in Table 1 had to be addressed.

By transplanting we mean making the program run “AS IS” IS”, without any improvement except the modifications dictated by the above differences.

2.2.1 Control Stream to Makefile

On IBM MVS, a control stream drove the program. That control file specifies Fortran's main routine, subroutines and input data files and its execution makes the program run.

On our UNIX system, we replace MVS's control stream with a **make** program. **Make**

includes a specification of interdependencies of the various modules of a program. We place that specification in a file called a **makefile**. Issuing the **make** command on UNIX will automatically compile each source code and link them together to create an executable binary file.

2.2.2 Environment Variable

Instead of explicitly specifying input data files, Sun's FORTRAN compiler f77 needs a subroutine called `ioinit` which will initialize several global parameters in the f77 I/O system, and attach externally defined files to logical units at run time.

For example, if the program `myprogram` has the call:

```
call ioinit ( .true., .false., .false., 'FORT', .false.)
```

then the following sequence

```
% setenv FORT01 mydata
% setenv FORT12 myresults
% myprogram
```

would result in logical unit 1 being opened to file *mydata* and logical unit 12 opened to file *myresults*.

2.2.3 Incompatibilities between Compilers

Not every Fortran source code (file) from NTIS/NCC can be compiled successfully on the UBC system before modification. We pick two examples here:

To define a character type of array, say of length 8 each taking 6 characters, MVS's Fortran compiler uses:

```
CHARACTER SEAS*6(8)
```

which is not legal in the SUN FORTRAN compiler, f77. We have to change it to:

```
CHARACTER SEAS(8)*6
```

Another incompatibility is the use of *entry*. With MVS's Fortran compiler, the variable(s) within *entry* is (are) from the subroutine in which the *entry* program physically resides (in other words, they are in the same file); in contrast with f77, we have to explicitly pass the variable via a parameter or make it a global variable via a COMMON declaration.

2.2.4 Randomness and Library

As we know, random numbers are needed in pNEM. But the ways to generate random numbers are all about the same: a run time seed is obtained by retrieving the current system clock time and then from this a random number with uniform distribution is created by calling Fortran subroutines. If some distribution other than the uniform is needed, for example, lognormal, a transformation can be applied.

On IBM, two stages are used to get a seed. First,

```
CALL DATIM(TIME)
```

TIME being an 8 word integer array. Then

```
ISEED = TIME(1)
```

is used to get the seed ISEED. On SUN-UNIX, only one step is needed:

```
ISEED = TIME()
```

where TIME() is a function which returns an integer that contains the time after 00:00:00 GMT, Jan. 1, 1970, measured in seconds.

After that, the systems use the same method to generate the random number:

```
CALL RNSET(ISEED)
```

```
CALL RNUN(NR,R)
```

```
CALL RNGET(ISEED)
```

On UNIX, the IMSL STAT/LIBRARY provides the subroutines described above.

Table 2.2: Running Time Statistics

program	CPU time	Real time
CCPOOL	00:01:30	00:02:57
CDPOOL	00:00:36	00:01:10
CWPOOL	00:00:27	00:02:02
CONEM	01:03:42	04:13:44
MEDISP	00:00:01	00:00:01
PNEM8HR	00:07:10	00:13:11
COHBHR2	00:07:00	00:50:26
COHBTB2	00:00:01	00:00:01
Total	01:20:27	05:26:32

2.2.5 Running Time Statistics

With the above modifications, the transplantation of pNEM/CO from NTIS/NCC to UBC is complete; the program can run. Some statistics on running times for the programs appear in Table 2.

CCPOOL, CDPOOL and CWPOOL are the pool programs which are used to process diary data for input into the main program, CONEM. MEDISP, PNEM8HR, COHBHR2 and COHBTB2 are the tabulation programs which process the output file from CONEM and population data and then tabulate the exposures and carboxyhemoglobin estimates within a defined population.

2.3 Exposure Estimates for Residents

We used the pNEM/CO methodology to estimate the CO exposure and resulting COHb levels experienced by the Toronto study area population during 1991. We describe the results in this section and format them like Section 6 of the report of Johnson et al (1994) to facilitate comparison of the two sets of results.

Like the study described in this cited last report, ours ran pNEM under two scenarios. Three runs were made under with “indoor sources on” and three with “indoor sources off”. “Indoor sources” means gas stoves and passive smoking only, “on” that pNEM/CO was run

in the standard mode [the CO contributions from gas stoves and passive smoking are handled by the procedures described in Sections 2 and 3 of Johnson's report] and "off" means running pNEM/CO with no CO contribution from these sources.

Table 1 (corresponding to Table 18 on Page 71 of Johnson's report) presents estimates of CO exposure for three averaging times: (i) one-hour daily maximum exposure; (ii) eight-hour daily maximum exposure; (iii) annual mean exposure. By examining Table 1, we can see estimates of the percentage of the population which sustained one or more exposures at or above the indicated CO concentration under the conditions governing the run.

Even with all factors fixed, pNEM runs vary randomly from one to another since the program involves random generation nodes. When factors vary, we can expect even greater variation. Not surprisingly, the three runs with "sources on" yielded markedly different exposure estimates and than those with "sources off".

The run averages suggest 0.2 percent of the Toronto population experienced one-hour daily maximum CO exposures above 25 ppm when indoor sources were on. The corresponding result when sources were off was 0.1 percent. Approximately 0.1 percent experienced eight-hour daily maximum CO exposures above 17.4 ppm with sources on, none when they were off.

By examining Table 2 (corresponding to Table 19 on Page 73 of Johnson's report) we get estimates of the percentage of adults experiencing one or more one-hour daily maximum episodes during which COHb equals or exceeds the specified level.

The results suggest 3.7 % of Toronto adults experienced COHb levels above 2.2 % when sources were on, 0.1 percent when sources were off.

Appendix B.4 (corresponding to Appendix C of Johnson's report) displays a pNEM/CO output array with demographic group (D) codes across the top margin and microenvironment (ME) codes along the side. In each cell of that array we see a vector (A,H,O) of population weighted statistics for the associated (D,ME) pair. Here A=arithmetic mean CO concentration (ppm), H=number of person-hours spent by members of D in ME, and O=number of person-occurrences (exposure events) during which a member of D was in ME. The program calculates A for a specified (D, ME) pair by first finding the average ME concentration for each cohort in D. These values, weighted by the estimated cohort populations, determine the weighted average for D. H was found by dividing the total number of minutes the cohort spent in ME by 60 to get hours. Multiplying the result by the cohort size and summing over

Table 2.4: Percentage of Adults in Toronto Study Area Population Experiencing One or More One-hour Daily Maximum Episodes during which Carboxyhemoglobin Equalled or Exceeded the Specified Level

Carboxyhemoglobin (COHb) level, percent	Estimated value of indicator							
	Indoor source "on"				Indoor source "off"			
	Run 1	Run 2	Run 3	Average	Run 1	Run 2	Run 3	Average
0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
0.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1.0	86.3	81.8	81.3	83.1	62.631	69.997	74.832	69.2
1.5	42.2	36.9	36.9	38.7	28.2	23.4	16.7	22.8
2.0	8.8	2.2	11.8	7.6	2.1	0.2	0.5	0.9
2.1	8.6	0.3	6.3	5.1	2.0	0.2	0.2	0.8
2.2	4.9	0.1	6.1	3.7	0.1	0.2	0.0	0.1

D gives H.

Summing these H values yields (in scientific notation) 1.63×10^{10} person-hours, the product of 1,863,336 (the study area population) and 8760 (the number of hours in 1991). O resembles H; however it treats each exposure event as one occurrence regardless of its duration.

More PNEM/CO output appears in Appendix B.1 (corresponding to Appendix D of Johnson's report). There we see for each cohort defined for the Toronto exposure analysis an estimate of its population, its mean one-hour CO exposure and its mean one-hour daily maximum CO exposure.

2.4 Comparative Assessment of UBC's and NTIS/NCC's pNEM

Overall, we found little difference between our results and those of Johnson et al (1994). As expected, the file NREC.CWPOOL transferred from NTIS/NCC and the one produced by running pNEM at UBC were identical. The version of the HRAVG.DATA file from NTIS/NCC when processed by PNEM8HR at UBC yielded the results identical to those listed in Appendices C and D of the report of Johnson et al (1994).

We present in Appendix B of this report, the reports produced by the tabulation programs. Notice the substantial run-to-run differences in pNEM outputs. For “indoor sources off” in Table 1 we see percentages of 1.9, 7.1 and 2.2 for one or more eight hour daily maximum CO exposures above 11ppm. The implication for policy-makers of the uncertainties arising from run-to-run pNEM percentages needs to be explored and possibly, accounted for.

We cannot formally “test” the equality of Johnson’s reports with ours since we have only, in effect, a sample of size two from an infinite population of pNEM runs. As noted earlier, our results seem comparable, especially in light of the variation seen in the two pNEM runs.

2.5 Rollback Model

The procedure described above generated a sequence of 1-hour outdoor concentrations for each pair (D, ME) given Toronto’s current air quality conditions. pNEM can also generate such sequences under hypothetical regulatory scenarios. Following Johnson et al (1992), we now describe that capability as installed pNEM/CO at UBC.

To represent outdoor air quality under a regulatory scenario, ambient concentrations in each sequence were changed by a “rollback model”:

$$AMB(d, h, s) = BG + \rho(s) \times CAMB(d, h, e), \quad (2.1)$$

where

$$CAMB(d, h, e) = AMB(d, h, e) - BG.$$

$AMB(d, h, s)$ denotes the average ambient pollutant concentration in district d during clock hour h under scenario s , $AMB(d, h, e)$, the expected ambient pollutant levels in district d under scenario e , BG, the assumed background concentration [not affected by the control scenario] and $\rho(s)$, the rollback factor specific to scenario s .

To calculate $\rho(s)$ we need to find $CMAX(s)$, the highest CO concentration permitted under scenario s for a specified air quality indicator (AQI). We also require $CMAX(e)$, the value of this AQI based on 1991 Toronto monitoring data. When $CAMB(d, h, e) > 0$ we find $\rho(s)$ from

$$\rho(s) = (CMAX(s) - BG)/(CMAX(e) - BG) \quad (2.2)$$

If $CAMB(d, h, e) \leq 0$ we use instead

$$\rho(s) = 1. \tag{2.3}$$

The model used above for the rollback additively combines a constant baseline outdoor CO concentration with a variable concentration proportional though $\rho(s)$ to the CO emissions permitted under scenario s . We explored two scenarios described in detail below: (i) attainment of the current 8-hour AQO for CO; (ii) existing conditions.

The current AQO for CO specifies that the second highest 8-hour CO concentration shall not exceed 13 ppm. We define the AQI as the largest value reported by any monitor for the second highest 8-hour CO concentration of the year. In 1991 for Toronto, the value of this AQI was 24.0 ppm. So to simulate attainment of the AQO in Toronto, we let $C_{MAX}(s) = 13.0$ ppm and $C_{MAX}(e) = 24.0$ ppm. We set $BG = 0.72$ ppm, the smallest annual average CO concentration reported by a Toronto monitoring site for 1991. Then equation 2.2 gives us $\rho(s) = 0.52$ for scenario (i) above.

Scenario (ii) (“existing conditions”) requires $AMB(d, h, s) = AMB(d, h, e)$.

Table 3 presents estimates of CO exposure for the Toronto study area population. These estimates come from four runs of the pNEM/CO, two per scenario. We give estimates for three averaging times: (1) one-hour daily maximum exposure; (2) eight-hour daily maximum exposure; (3) annual mean exposure. Each estimate indicates the percentage of the study area population which experienced one or more exposures at or above the indicated CO concentration under the conditions assumed for the model run. Separate sets of estimates are provided for the two indoor source scenarios (“on” and “off”) described above.

Table 3 also presents the averages of each pair of estimates. From these averages we would estimate that 5.3 percent of the Toronto population experienced one-hour daily maximum CO exposures above 13 ppm under the “sources on” scenario. The corresponding estimate under the “sources off” scenario proves to be 0.7 percent. At the same time, about 0.1 percent experienced eight-hour daily maximum CO exposures above 13.0 ppm with sources on. None of the population experienced these exposures with sources off.

Table 4 shows [under rollback conditions] the percentage of adults experiencing one or more one-hour daily maximum episodes during which COHb equals or exceeds various specified levels. Estimates are provided for each of the two runs made under each scenario. The

Table 2.5: Estimates of Carbon Monoxide Exposures among Residents of the Toronto Study Area with Attainment of 8 HR AQO

CO exposure indicator	Estimated value of indicator					
	Indoor source "on"			Indoor source "off"		
	Run 1	Run 2	Average	Run 1	Run 2	Average
Percentage of population with one or more one-hour daily maximum CO exposures at or above the specified concentration						
10.0 ppm	35.2	30.3	32.7	13.0	15.8	14.4
13.0 ppm	5.1	5.7	5.3	1.1	0.3	0.7
20.0 ppm	0.2	0.4	0.3	0.0	0.0	0.0
25.0 ppm	0.1	0.1	0.1	0.0	0.0	0.0
Percentage of population with one or more eight-hour daily maximum CO exposures at or above the specified concentration						
5.0 ppm	59.7	54.5	57.1	32.0	41.0	36.5
11.0 ppm	5.6	5.1	5.3	0.0	0.0	0.0
13.0 ppm	0.2	0.1	0.1	0.0	0.0	0.0
17.4 ppm	0.0	0.0	0.0	0.0	0.0	0.0
20.0 ppm	0.0	0.0	0.0	0.0	0.0	0.0
Percentage of population with annual mean CO exposures at or above the specified concentration						
1.0 ppm	98.9	98.8	98.9	67.42	68.58	68.0
2.0 ppm	0.0	0.0	0.0	0.0	0.0	0.0
3.0 ppm	0.0	0.0	0.0	0.0	0.0	0.0

Table 2.6: Percentage of Adults in Toronto Study Area Population Experiencing One or More One-hour Daily Maximum Episodes during which Carboxyhemoglobin Equalled or Exceeded the Specified Level with Attainment of 8 HR AQO

Carboxyhemoglobin (COHb) level, percent	Estimated value of indicator					
	Indoor source "on"			Indoor source "off"		
	Run 1	Run 2	Average	Run 1	Run 2	Average
0	100.0	100.0	100.0	100.0	100.0	100.0
0.5	100.0	100.0	100.0	100.0	100.0	100.0
1.0	70.5	66.2	68.3	50.3	53.4	51.8
1.5	28.4	32.7	30.6	2.3	11.3	6.8
2.0	0.1	0.3	0.2	0.0	0.0	0.0
2.1	0.0	0.1	0.0	0.0	0.0	0.0
2.2	0.0	0.0	0.0	0.0	0.0	0.0

table also gives the average of each pair. We see that 0.2 percent of Toronto adults experienced COHb levels above 2.0 percent when indoor sources were on, but none 2.0 percent when they were off.

2.6 Running pNEM/O3 at UBC

In addition to pNEM/CO, the UBC team have implemented pNEM/O3 as described by Johnson et al (1993). To check its operation we estimated exposures for Vancouver, 1988. That application produced a set of summary tables indicating the number of people who experienced exposures within specified ranges of ozone concentration and EVR. This section describes our principal results.

Formats of the Exposure Summary Tables

Each pNEM/O3 run for a given study area and year produces 27 summary tables giving exposure estimates for the general population, including all cohorts. Although each such run gives hourly exposure estimates for O3 concentration, EVR, and concentration x EVR, these results are not tabulated by cohort because of the large number of cohorts involved (918 for Vancouver).

The Appendix gives exposure summary tables for Vancouver, 1988 organized according

to the following table formats. (Note that the table numbers listed under each format refer to the tables in the Appendix.)

Cumulative Exposures (Doses) in Population Number-by EVR range

These tables list estimates by ozone concentration and EVR range. Each table entry indicates the number of people experiencing one or more zone 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 the Appendix), one-hour daily maximum exposures (Table 1A), one-hour daily maximum doses (Table 1B), eight-hour daily maximum exposures (Table 4), eight-hour daily maximum doses (Table 4A), six-hour daily maximum exposures (Table 13), and six-hour daily maximum doses (Table 13A).

Cumulative Seasonal Mean Exposures by Population Numbers

Tables 7 and 16 in the Appendix give estimates by ozone concentration only. Each entry indicates the number of people associated with a seasonal mean exposure at or above the ozone level indicated by row label. In Table 7, we present the seasonal mean calculated as the average of the eight-hour daily maximum ozone exposures occurring from May through September, inclusive. In Table 16, we present the seasonal mean calculated as the average of six-hour daily maximum ozone exposures during this period.

Number of Occurrences – Exposures (Doses) by EVR Range

These tables present estimates arranged by ozone concentration and EVR range. Each entry indicates the number of times a member of the population was exposed to an ozone concentration within the range indicated by the row label while the average EVR was within the range indicated by the column heading. The Appendix has separate tables for one-hour exposures (Table 2), one-hour daily maximum exposures (Table 2A), one-hour daily maximum doses (Table 2B), eight-hour daily maximum exposures (Table 5), eight-hour daily maximum doses (Table 5A), six-hour daily maximum exposures (Table 14) and six-hour

daily maximum doses (Table 14A).

Number of Occurrences – Seasonal Mean Exposures

Table 8 and 16 in the Appendix present estimates by ozone range only. Each entry indicates the number of times a person experienced a seasonal mean exposure at or above the ozone level indicated by row label. In Table 8, the seasonal mean is calculated as the average of the eight-hour daily maximum ozone exposures occurring from May through September, inclusive. Corresponding estimates for six-hour daily maximum exposures are presented in Table 16.

Number of People – Highest Exposures (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 average EVR was within the range indicated by column heading. There are separate tables for one-hour daily maximum exposures (Table 3 in the Appendix), eight-hour daily maximum exposures (Table 6), and six-hour daily maximum exposures (Table 15).

Number of People – Cumulative Daily Maximum Doses by Number of Days

These tables give estimates by ozone concentration and number of days per year. Each entry indicates 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 in the Appendix give daily maximum one-hour doses (Table 9), daily maximum eight-hour doses (Table 10), daily maximum one-hour doses with EVR of 30 liters x min^{-1} x min^{-2} (Table 11), daily maximum eight-hour doses with EVR of 15 liters x min^{-1} x min^{-2} (Table 12), daily maximum six-hour doses (Table 18), and daily maximum six-hour doses with EVR of 15 liters x min^{-1} x min^{-2} run in (Table 19).

Regardless of format, each table in the Appendix provides footnotes identifying the study area, the number of exposure districts in the study area, the first and last days of ozone

season, and number of days in the ozone season.

Chapter 3

Sensitivities and Refinements

3.1 Introduction

In the previous section we illustrated the use of the pNEM methodology as adapted and installed at UBC, by application to study areas in Canada. In this last part of the report, we investigate some ancillary issues concerning the simulator.

We find in section 2 below, a sensitivity analysis of pNEM/CO outputs to the various models and methods used by the simulator. Our strategy involved looking at gross changes (on the order of 50% or greater) and fine changes (of about 10%). The former might better have been called “insensitivity analysis,” its aim being the determination of elements of the program which could be eliminated or replaced by deterministic alternatives. In the latter we were looking for the parameters whose estimation seemed critically important. Only one appeared in this category following our analysis, the slope of the linear model used to carry ambient CO levels down to the level of the individual micronvironments. Our finding thus suggests the need to reassess the suitability for Canada of the slope parameters currently being used in pNEM analysis.

Much of the work leading to the results in Section 2 consists of developing defensible statistical tests for comparing pNEM outputs for alternative scenarios under sensitivity testing. To give us an adequate number of pNEM runs for our statistical analysis, we selected a representative set of just 3 out of the 408 possible cohorts, one of children, one of seniors and one of commuting workers. We selected home districts with generally high levels of CO. Finally we ran pNEM for just a single hour each day to get 365 independent output

values for our tests. We could then run pNEM ten times for each scenario to investigate the variability of p-values for our formal tests of significance of differences between scenario outputs.

Results in Tables 2 and 3 enable us to analyse the variability in these p-values. In particular, we see the risks involved in basing an analysis on just a single pNEM/CO run even though we are using a large number of replicates in each run (365).

At the same time, we can combine the p-values using Fisher's formula to get an overall estimate of the significance of the differences we have observed. These combined p-values appear in the "sum-p" column. From there, we can determine which parameters lead to significantly different pNEM/CO outputs.

In Section 3 we investigate the problem of filling in missing ambient pollutant levels. The earlier publications emanating from ITAQS do not completely define a procedure for imputing these levels. This lack of definition forced us to develop our own version of the ITAQS method. In doing so we discovered difficulties with that method. In particular, one of the assumptions underlying its time series component following the regression step cannot hold. Further work on this issue seems to be required.

Nevertheless lacking a clear alternative, we used the method to impute missing values. Our sensitivity analysis justifies our decision in that the choice of a method for imputing missing values does not seem to be critical. Even a naive approach in the time series phase of the method seems adequate since so few missing values remain after the regression step has been completed. We used our method to complete the ambient CO dataset for Toronto, 1990.

In Section 6, we present the results of an extensive series of empirical tests done during the past summer on a spatial interpolator intended for eventual use with pNEM. One dataset used in our tests were monthly values of SO_2 , SO_4 , O_3 and NO_2 . These data were readily available and multivariate in nature. Additional testing was done with acidic deposition data from the NADP/NTN network in the USA. While further testing on finer time scales using CO lies ahead, the results suggest our interpolator is quite accurate in practice.

3.2 Sensitivity Analysis

We see at least three general purposes for sensitivity analysis. Such an analysis will firstly identify largely irrelevant parameters; pNEM outputs will not be sensitive to them. We can change them a lot without significantly changing the outputs and future versions of pNEM might be improved by removing the simulation randomization submodules associated with those parameters.

Second, a sensitivity study may reveal parameters to which outputs of pNEM are sensitive. Among them, the supersensitive parameters are of special interest. Those which are susceptible to regulation can be the focus of policy-making. Regulators may control air pollution levels by regulating the sources associated with these parameters.

Third, additional data may need to be obtained to fit those parameters exactly. That issue has particular importance since some of the standard (default) parameter values of pNEM/CO come from studies carried out some time ago in US cities. The sensitivity analysis shows which pNEM parameters need to be refitted with Canadian data for application in Canada.

pNEM/CO generates CO concentration levels, average EVR, as well as the product of average CO concentration and EVR. pNEM/CO also gives COHB levels for adults. Among these four outputs, we deem CO exposure to be most important. That choice seems dictated by the use of this output in finding such things as “the percentage of population with annual mean CO exposure at or above the specified concentration.” Thus, at this stage we limit our sensitivity analysis to the influence of pNEM/CO parameters on the CO concentration.

In this section, we first briefly review how pNEM/CO creates its CO outputs. That knowledge leads us to the parameters pNEM/CO uses to generate the simulated CO exposure levels for each cohort. From there we can go into the sensitivity analysis, present our results, and draw conclusions.

3.2.1 Parameters for Sensitivity Analysis

pNEM: divides the population of interest in each study area into an exhaustive set of cohorts; generates estimated CO exposure levels for each cohort; and extrapolates these levels to the whole population of interest. pNEM then : generates the CO exposures for each cohort from a yearly exposure event sequence (EES) specific to that cohort; and samples each EES for a

cohort from a pool obtained from field studies. For any given hour, h , demographic group d , microenvironment m , person day p and start time t , the CO exposure associated with the event in the EES at time t is determined by

$$CEXP(d, m, p, h, t) = INFIL(d, m, p, h) + SMOKE(d, m, ph, h, t) + STOVE(m, p, h). \quad (3.1)$$

$INFIL(d, m, p, h)$ represents the contribution from ambient CO levels at hour h and district d . pNEM uses a line model to infer this value. Model coefficients are specific to microenvironment (ME). For pNEM/CO, they obtain from the Denver Personal Monitoring Study. More precisely, these values are:

SLOPE

.96, 1.65, 1.14, .96, .59, .57, .85, 1.03, .87, 0.0,
 .78, 1.32, .39, .40, .32, .42, .38, .41, .71, .47,
 .45, .28, 2.11, .12, .31, .35, .79, .79, .96, .55,
 .96, .28, .28, .60, .96, .96, 0.0

INTERCEPT

3.6, 2.5, 2.6, 3.6, 8.3, 2.0, 1.2, 6.9, 4.9, 7.1,
 0.0, 0.0, 0.0, 0.0, 1.0, 1.0, 0.0, 2.4, 0.0, 0.0,
 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
 0.0, 0.0, 0.0, 0.0, 0.0, 3.6, 0.0 .

Each (slope, intercept) pair comes from linearly regressing the values associated with any one of the 37 microenvironments on the ambient levels.

$SMOKE(d, m, p, h, t)$ is a threshold term. This term depends on two event descriptors, passive smoking status and ME. If the passive smoking status for an indoor event indicates the presence of smokers, $SMOKE(d, m, p, h, t)$ is set to 1.6ppm, otherwise 0. The value 1.6 is based on the average increase in CO exposure observed in subjects of the Denver study during indoor periods when smokers were present.

The last term $STOVE(m, p, h)$ is nonzero only when the fuel type of that cohort is gas (coded as 2). $STOVE(m, p, h)$ represents the CO contribution from gas stoves when the cohort is assigned to an indoor residence ME. pNEM employs a complex “mass balance model”, to estimate CO concentrations from gas stoves. The parameters related to this term

appear below where kj represents kilojoules:

1. Probability of stove in operation P(I) (I=1,24)

0.025, 0.023, 0.023, 0.023, 0.023, 0.026, 0.049 0.058,
0.081, 0.073, 0.062, 0.075, 0.085, 0.071, 0.067, 0.064,
0.107, 0.130, 0.091, 0.058, 0.052, 0.047, 0.040, 0.035.

[Note: the data are from Denver housing stock.]

2. Gas Stove Emission Rate

2.1 Annual fuel usage of the burner:

distribution	1 (normal)
mean	3,420,000 (kj)
SD	1,140,000 (kj)
max	28,000,000 (kj)
min	0 (kj).

[Note: data from 46 homes in California.]

2.2 Annual fuel usage by all pilot lights 1820000 kj
(gasstov2.for)

[Note: data from Denver Study.]

2.3 Burner emission factor (mg CO per kj)

distribution	2 (lognormal)
geometric mean	0.0294
geometric sd	2.77
max	0.4
min	0.0

[Note: these values come from North Carolina and
represent well-adjusted stove.]

2.4 Residential Volume

distribution	2 (lognormal)
--------------	---------------

geometric mean	321.0	cubic meters
geometric sd	1.6420	
max	1200	
min	100	

[Notes 1: above values come from Denver

(rationale: all types of housing stock).

2: geometric mean for Toronto is 362, the geometric sd, 1.2763, but only for single detached dwellings; no minimum available.]

3. Air Exchange Rate:

mean	6.4
sd	1.0
max	6.4
min	6.4

[Notes 1: the above values are only for an open window, exactly the case of interest, given our lack of information about the distribution of values.

2: the above values come not from Denver or Toronto but an article by Grimsyud, refer Johnson (1991).]

In 1 above, $P(I)$ gives the chance of a stove being in use during hour I . Items 2 to 4 are needed in the algorithm outlined below.

For ME m and day p , the equations

$$STOVE(h) = \frac{1 - e^{-v}}{v} ISTOVE(h - 1) + \frac{S}{vV} (1 - \frac{1 - e^{-v}}{v}),$$

$$ISTOVE(h) = ISTOVE(h - 1)e^{-v} + S(1 - e^{-v})/V$$

determine the value of $STOVE(h)$ at hour h . In the above, V denotes the “residential volume”, v the “air exchange rate” and S , the “indoor generation rate”. In turn, S is estimated by equations,

$$S(h) = (AUB/365.2) * EFBURN * M(h)/60 + (AUP/8760) * EFBURN,$$

where AUB is the “annual fuel usage of burners”, $EFBURN$, the “burner emission factor” and AUP , the “annual fuel usage by all pilot lights”. $M(h)$ is the duration of burner use during hour h expressed in minutes.

For each CO run, pNEM randomly selects AUP , AUB , v and $EFBURN$ from normal or lognormal distributions. The mean, standard deviation (sd), maximum and minimum values of these distributions are listed above with the parameters. For example, for each run with a given cohort, pNEM randomly generates a number from normal distribution with mean 3,420,000 (kj) and sd 1,140,000 (kj) as the “annual fuel usage of a burner”. However, this random number must not exceed the maximum value, 28,000,000 (kj) or be below 0; otherwise a new random number will be generated. Our scenario analysis in report 2 demonstrates clearly the difference in pNEM outputs corresponding to “gas on” and “gas off”. So we confine our analysis to more subtle issues.

3.2.2 Initial Sensitivity Analysis

We do our sensitivity analysis by comparing the hourly CO exposure levels for each cohort obtained from a run with a set of standard pNEM default parameter values to those from a set of scenario values. We set scenario values with pNEM/CO’s eventual purpose in view, to control or reduce CO levels. Thus, we set a scenario value by either increasing or decreasing the standard value by 10% (for a small change) or 50% (for a big change) in the direction which would if anything, reduce CO levels. That means reducing values except for “Residential Volume”. For it, we increase the standard values by either 10% or 50% since an increase in house volume will result in a reduction of in-door CO concentration levels. The 10% increase or decrease is a small change for finding the parameters to which the CO outputs for a cohort are supersensitive. The 50% increase or decrease is for finding the parameters to which the CO outputs for a cohort are insensitive.

From the previous subsection, we see that pNEM involves two approaches to determining its default parameter values: fixing values such as slopes, intercepts, and smoking; generating random values for things like residential volume and burner emission factor. For the first approach, implementing 10%, 50% changes is straightforward. For the second type, we chose to increase or decrease the mean of the normal or lognormal distributions, from which the default parameter parameters are randomly generated.

In a pNEM/CO run for Toronto, year long hourly CO exposures are generated for each

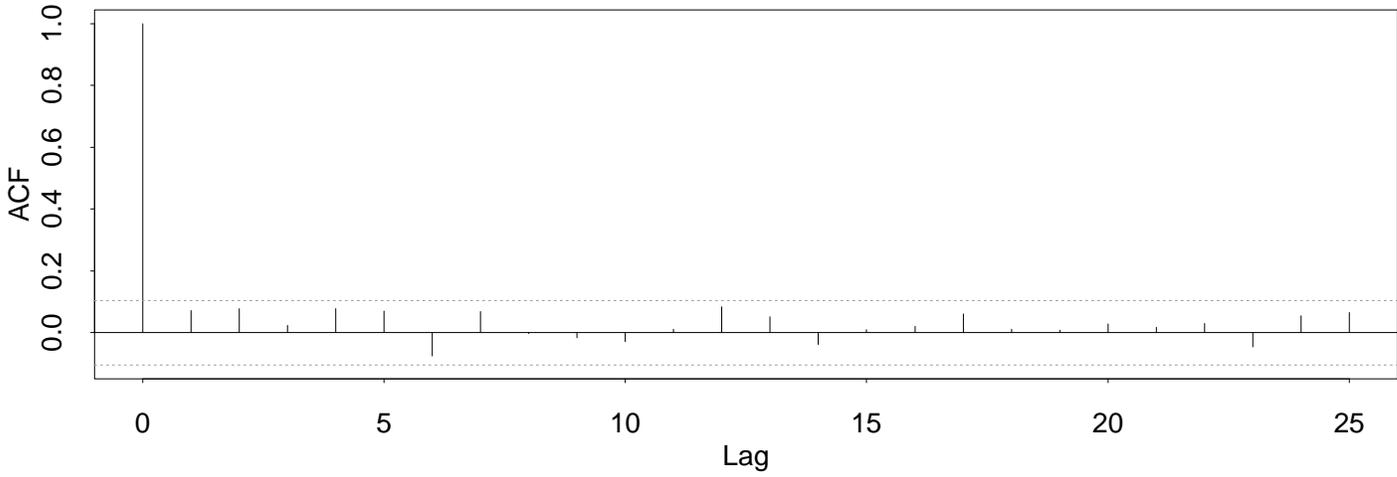
of 408 cohorts . Each cohort is uniquely defined by its demographic group (1-14), a home district (1-6), a working district (1-6) and fuel type (1-2). A complete pNEM/CO run for all 408 cohorts takes 2 computer connection hours on a dedicated Sparc 10 Sun workstation. From a previous subsection, we know that there are in all $2^{10} = 1024$ possible increase-decrease combinations for the entire set of parameters. Thus a complete factorial analysis of all possible combinations would not be computationally feasible. Clearly, some compromise is dictated.

We chose three cohorts to reduce our sensitivity analysis to manageable levels. We changed just one parameter each time. The codes of the cohorts chosen initially are: 3222, 7222 and 13222. The digit(s), 3, 7 and 13 in codes 3222, 7222 and 13222 respectively represent the demographic groups, “Children, 10 to 14”, “Males, 45 to 64, working” and “Females, 45 to 64, nonworking.” The last three digits, 222, represent the population in home district 2, work district 2 using gas stoves.

An hourly CO output time series for a cohort consists of 8760 successive values. However, values from successive hours in any one day are statistically dependent leading to severe difficulties for statistical analysis. We chose to sidestep this problem by considering data for a particular hour, say 6:00 pm when CO levels are appreciable. That still leaves 365 data values for our analysis and these are independent (conditional on the fixed ambient series) since records are independently drawn on successive days. Because of seasonal and other factors influencing the ambient levels, these 365 values will not represent a stationary sequence. To remove that temporal or “day effect” we subtracted the 365 hourly values generated by the default parameters from those generated by the scenario values. We expected these differences to be stationary and independent because of the mechanism pNEM program uses to generate the time series for each cohort. The autocorrelation and partial autocorrelation plots in Figure 3.1 support our view.

Thus, the 365 differences can be treated as independent and identically distributed observations which justifies (with the central limit theorem) the use of the paired t-test. The null hypothesis: the scenario and standard runs come from the same population of values. The alternative: the mean of a scenario run is less than that of the standard run. Table 3.1 shows the p-values of the paired t-tests. In that table, Column 1 lists the code names of scenario values of input parameters, columns 2, 3 and 4, p-values for different cohorts. The rows marked with double stars mean “significance at level $\alpha = 0.05$ ”. Their meanings are

Series : Dt



Series : Dt

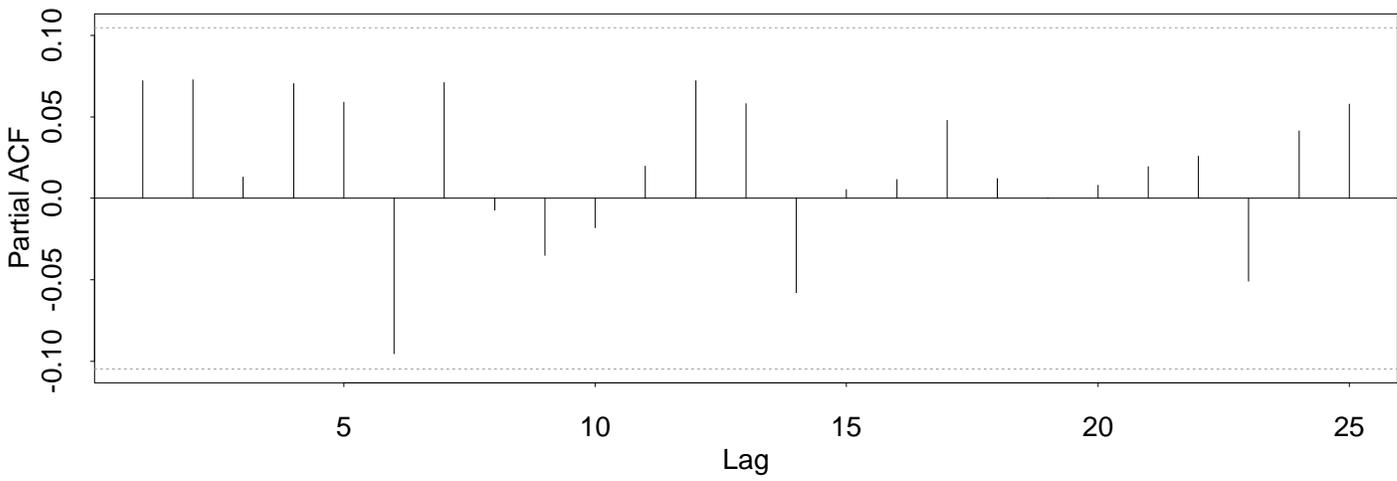


Figure 3.1: Autocorrelation and Partial Autocorrelation Plots for Differenced Hourly CO Levels

further explained below.

Variable: Description

SL0P09 :regression slopes for 37 microenvironments reduced by 10%
SL0P05 :regression slopes for 37 microenvironments reduced by 50%
SMOKE09 :reduced the threshold value 1.6ppm by 10%
SMOKE05 :reduced the threshold value 1.6ppm by 50%
P2400 :stove operation probability set to 0, no gas
EF09 :mean burner emission factor reduced by 10%
EF05 :mean burner emission factor reduced by 50%
BU09 :mean burner annual fuel usage reduced by 10%
BU05 :mean burner annual fuel usage reduced by 50%
VOL11 :mean residential volume increased by 10%
VOL15 :mean residential volume increased by 50%
AER09 :mean open window air exchange rate reduced by 10%
AER05 :mean open window air exchange rate reduced by 50%
PILOT09 :mean pilot light annul usage reduced by 10%
PILOT05 :mean pilot light annul usage reduced by 50%

3.2.3 Further Sensitivity Analyses

In our initial sensitivity analysis, we looked only at the p-value computed from a single pNEM run. We wondered about the level of uncertainty we should attach to them as they are random quantities after all. We had also looked at just one particular hour (6:00pm). We included no cohorts from the population age group aged 64 and up. Finally members of each one of the three cohorts lived and worked in the same district. To test the analysis of the last subsection and expand its domain, we chose more cohorts and repeated the analysis for for different hours.

The codes of new the cohorts are: 1222; 7232; 14222. Demographic group 1 represents “Children, 0 to 4” and 14, “Females, aged 64 and above”. The hour 7:00pm, is chosen for all three of the new cohorts. We repeated the analysis done above. For each cohort, we made 10 runs. Table 3.2 displays their p-values; Column 1 lists the codes for the scenario parameter values, Column 2, the codes for cohorts, Column 3, the selected hour, Columns 4-13 the p-values for each of 10 runs and the last column, the summarized p-values of the 10 runs obtained from Fisher’s formula for combining p-values. The summarized p-value

Table 3.1: P-values of Pairwise t Tests for a Single Run

Vari	cohort 3222	cohort 7222	cohort 13222
SLOP09	0.232	0.366	0.075
SLOP05	0.000**	0.000**	0.000**
SMOKE09	0.186	0.365	0.211
SMOKE05	0.033**	0.200	0.081
P2400	0.003**	0.109	0.000**
BU09	0.238	0.128	0.462
BU05	0.348	0.372	0.095
EF09	0.478	0.630	0.514
EF05	0.074	0.190	0.002**
VOL11	0.027**	0.059	0.739
VOL15	0.011**	0.339	0.154
AER09	0.390	0.237	0.399
AER05	0.035**	0.432	0.554
PILOT09	0.317	0.240	0.213
PILOT05	0.111	0.656	0.254

derives from the fact that under our null hypothesis, $-2\sum_{i=1}^n \log(p_i)$, where p_i is the p-value for the i^{th} run, has a χ^2 distribution with $2n$ degrees of freedom.

To see if changing the hour yields significantly different results, we reran our analysis using new hours, 6:00pm, 2:00pm, and 12:00pm and cohorts 1222, 7232 and 14222. We then repeated the tests and present the results in Table 3.3.

Our test results show clear patterns for some of the parameters. For example, smoke (with/out a smoker at the presence), slopes for the 37 microenvironment2 linear models and gas stove (on/off) are (super)sensitive parameters for most of the cohorts discussed here. These results agree with our earlier rollback analysis.

We also see a large variation in p-values for the same cohort and hour, implying the need for caution in assessing results from any single pNEM run.

Having identified parameters to which pNEM outputs are sensitive, we then went on to check whether the overall outputs from pNEM would be sensitive to those same parameters. Our results (see Table 3.4) reveal little sensitivity at that level to BU, EF, and VOL. Combining outputs across cohorts and time in forming the eventual population level estimates seems to smooth out the discontinuities we have induced through our parameter level

Table 3.2: P-values For Ten Runs At Same Hour

P-VALUES *100 FOR RUN:

Variable	Cohort	Hour (pm)	1	2	3	4	5	6	7	8	9	10	Sum-p
SLOP09	1222	7	0	16	27	0	2	31	61	2	24	0	0
SLOP09	7232	7	12	37	4	7	1	14	26	9	3	30	0
SLOP09	14222	7	2	0	56	30	66	17	7	3	24	0	0
SLOP05	1222	7	0	0	0	0	0	0	0	0	0	0	0
SLOP05	7232	7	0	0	0	0	0	0	0	0	0	0	0
SLOP05	14222	7	0	0	0	0	0	0	0	0	0	0	0
SMOKE09	1222	7	41	62	13	3	48	74	68	19	50	41	27
SMOKE09	7232	7	12	45	73	9	64	79	55	19	13	64	32
SMOKE09	14222	7	85	29	7	12	98	70	43	76	47	38	27
SMOKE05	1222	7	6	13	15	4	0	27	53	6	0	7	0
SMOKE05	7232	7	2	14	1	0	1	2	16	2	2	20	0
SMOKE05	14222	7	10	2	9	16	24	48	24	20	66	16	0
P2400	1222	7	3	0	0	1	2	1	1	18	46	2	0
P2400	7232	7	49	36	16	88	99	78	32	1	1	7	2
P2400	14222	7	11	15	21	1	53	38	28	30	67	40	6
BU09	1222	7	14	71	59	6	24	48	64	38	61	23	32
BU09	7232	7	10	96	48	30	54	46	31	48	33	77	59
BU09	14222	7	69	58	93	87	56	56	45	71	89	92	100
BU05	1222	7	11	9	16	48	2	18	41	24	25	59	7
BU05	7232	7	2	36	4	1	5	6	25	20	39	7	0
BU05	14222	7	29	8	14	1	48	23	21	3	15	8	0
EF09	1222	7	45	73	42	37	91	47	99	37	2	1	15
EF09	7232	7	45	83	5	2	75	32	35	93	9	22	22
EF09	14222	7	56	23	15	84	66	50	7	33	32	11	29
EF05	1222	7	0	3	7	3	21	6	61	2	6	34	0
EF05	7232	7	8	44	6	15	16	5	7	44	10	61	1
EF05	14222	7	23	1	17	6	69	2	0	3	32	0	0
VOL11	1222	7	48	87	86	15	51	29	97	45	24	71	79
VOL11	7232	7	42	49	33	49	78	37	49	43	25	91	75
VOL11	14222	7	36	5	26	25	67	63	77	46	29	58	41
VOL15	1222	7	14	29	19	3	2	46	20	23	12	3	0
VOL15	7232	7	23	46	1	4	67	61	30	28	18	34	4
VOL15	14222	7	55	0	30	10	45	44	54	6	23	20	1
AER09	1222	7	23	9	74	36	8	39	88	22	96	46	62
AER09	7232	7	22	96	1	13	10	72	8	38	52	73	6
AER09	14222	7	85	14	61	50	82	83	26	22	67	43	73
AER05	1222	7	12	58	62	2	44	53	95	37	80	15	24
AER05	7232	7	51	90	32	32	68	53	80	47	55	73	92
AER05	14222	7	82	84	55	94	55	61	52	40	99	44	98
PILOT09	1222	7	29	43	52	17	52	31	89	8	16	42	28
PILOT09	7232	7	52	85	46	58	55	40	69	58	13	38	76
PILOT09	14222	7	80	53	75	97	92	73	88	53	60	41	100
PILOT05	1222	7	14	13	30	8	16	43	84	3	34	3	1
PILOT05	7232	7	54	59	9	25	69	31	58	24	23	49	38
PILOT05	14222	7	20	72	43	42	75	6	86	44	63	77	67

Table 3.3: P-values For Ten Runs At Different Hour

P-VALUES *100 FOR RUN:

Variable	Cohort	Hour(pm)	1	2	3	4	5	6	7	8	9	10	Sum-p
SLOP09	1222	6	0	7	8	54	10	1	29	11	63	55	0
SLOP09	7232	2	4	18	66	23	33	7	26	33	59	18	6
SLOP09	14222	12	4	11	52	1	43	22	29	37	1	0	0
SLOP05	1222	6	0	0	0	0	0	0	0	0	0	0	0
SLOP05	7232	2	1	1	0	0	1	0	0	0	7	0	0
SLOP05	14222	12	0	0	0	0	0	0	0	0	0	0	0
SMOKE09	1222	6	19	62	2	98	68	11	48	56	77	64	36
SMOKE09	7232	2	63	85	15	3	29	4	32	2	43	11	1
SMOKE09	14222	12	16	1	94	35	85	55	89	41	9	93	26
SMOKE05	1222	6	0	54	7	21	3	7	13	40	7	6	0
SMOKE05	7232	2	0	0	0	0	4	0	1	0	2	0	0
SMOKE05	14222	12	5	0	21	16	31	38	30	79	0	62	0
P2400	1222	6	0	1	0	1	0	1	5	12	11	2	0
P2400	7232	2	22	1	67	14	52	66	57	31	15	8	4
P2400	14222	12	2	0	0	0	0	0	0	2	0	0	0
BU09	1222	6	43	36	81	74	4	74	16	97	16	94	49
BU09	7232	2	46	28	24	75	95	29	38	35	100	6	47
BU09	14222	12	60	18	22	4	99	60	80	69	78	16	43
BU05	1222	6	2	11	6	37	7	1	2	72	34	44	0
BU05	7232	2	74	13	65	60	40	11	87	80	98	32	73
BU05	14222	12	27	44	24	25	93	87	87	44	45	24	68
EF09	1222	6	7	57	34	49	36	30	27	50	66	46	40
EF09	7232	2	10	16	41	45	87	63	92	72	91	14	60
EF09	14222	12	79	30	40	60	67	32	87	77	16	59	81
EF05	1222	6	40	13	16	62	2	24	13	3	44	18	1
EF05	7232	2	65	35	63	48	25	20	93	26	86	16	57
EF05	14222	12	23	13	57	1	45	49	70	30	5	35	4
VOL11	1222	6	13	86	60	96	17	2	38	32	78	65	3
VOL11	7232	2	36	7	25	30	74	23	98	62	94	6	29
VOL11	14222	12	45	61	77	63	49	68	59	84	12	47	86
VOL15	1222	6	19	80	49	72	10	6	24	67	34	22	21
VOL15	7232	2	60	42	14	35	45	54	42	11	69	16	32
VOL15	14222	12	50	19	76	0	76	84	66	46	18	13	14
AER09	1222	6	27	75	43	88	28	69	13	80	72	92	4
AER09	7232	2	53	51	74	75	90	22	73	36	78	9	77
AER09	14222	12	63	10	71	13	79	93	96	97	2	48	45
AER05	1222	6	84	98	51	96	63	59	23	98	92	72	99
AER05	7232	2	94	95	45	64	31	7	37	73	100	4	80
AER05	14222	12	26	22	81	74	72	83	85	76	50	50	93
PILOT09	1222	6	84	37	30	82	5	51	29	93	24	59	52
PILOT09	7232	2	98	53	61	35	52	37	24	46	82	18	71
PILOT09	14222	12	46	34	56	3	67	67	85	27	17	13	24
PILOT05	1222	6	59	21	39	62	39	66	31	77	35	53	72
PILOT05	7232	2	86	35	58	43	45	17	76	74	64	15	71
PILOT05	14222	12	18	27	83	13	65	92	77	67	50	83	79

scenario analysis for those parameters. pNEM population level estimates appear to be insensitive to changes in those parameters. That finding suggests pNEM can be simplified to run faster without changing its outputs.

Table 3.4 gives estimates of CO exposure for the Toronto study area population (1,863,336 people) based on four runs of the pNEM/CO, corresponding to each scenario. Estimates are provided for three averaging times: one-hour daily maximum exposure, eight-hour daily maximum exposure, and annual mean exposure. Each exposure estimate indicates the percentage of the study area population which experienced one or more exposures at or above the indicated CO concentration under the conditions assumed for the model run. Separate sets of estimates are provided for the four sensitive analysis scenarios described above.

3.3 Estimating Missing Values

When pNEM/CO estimates the CO exposure of a cohort, it requires complete hourly observations from the ambient monitoring sites. Thus we must fill in any missing values in the dataset before running the pNEM/CO. In this section, we briefly review the fill-in method used by ITAQS and describe our implementation of this method.

ITAQS uses a two-step procedure to impute missing values. First, it uses a step-wise regression approach to impute part of the missing data. It then applies a time series approach to impute the still missing values. The next subsection summarizes the step-wise regression approach. After that we present the results of applying the method to the 1990 CO dataset for Toronto. Subsection 3 describes the time series fill-in method and its implementation. The last subsection reports what we found on implementing the method.

3.3.1 General Approach to Estimating Missing Values

The 1990 data we have for six Toronto monitoring sites exhibited varying degrees of completeness, ranging from 96.4 to 99.3 percent complete. An exploratory analysis by ITAQS had indicated that the one-hour CO concentrations at each site were highly correlated with CO concentrations measured simultaneously at other sites within Toronto, Johnson et al (1994). The hourly values at each site were also found to be highly correlated with the hourly values from the previous hour (the “one-hour lag value”) and 24 hours earlier (the “24 hour lag value”) at the same site. A large one hour lag correlation indicates that CO

Table 3.4: Estimates of Carbon Monoxide Exposures Among Residents of the Toronto Study Area

CO exposure indicator	Estimated value of indicator			
	AS IS	BU05	EF05	VOL15
Percentage of population with one or more one-hour daily maximum CO exposures at or above the specified concentration				
10.0 ppm	46.59	51.82	50.73	51.62
13.0 ppm	22.22	19.33	25.97	31.27
20.0 ppm	9.05	3.19	7.44	7.81
25.0 ppm	3.52	0.18	0.11	2.40
Percentage of population with one or more eight-hour daily maximum CO exposures at or above the specified concentration				
5.0 ppm	72.74	68.00	66.04	67.49
11.0 ppm	6.04	2.68	12.48	12.69
13.0 ppm	1.63	0.19	5.65	2.09
17.4 ppm	0.00	0.00	0.00	0.01
20.0 ppm	0.00	0.00	0.00	0.00
Percentage of population with annual mean CO exposures at or above the specified concentration				
1.0 ppm	100.0	100.0	100.0	100.0
2.0 ppm	0.60	0.32	0.40	0.40
3.0 ppm	0.00	0.00	0.00	0.00

concentration does not change rapidly from hour to hour. A large 24-hour lag correlation indicates the presence of periodic diurnal patterns in the one-hour data.

The ITAQS method for filling in missing values employs the observed lag and inter-site correlations through stepwise regression. For each site, a series of stepwise regressions takes the CO concentration at time t as the dependent variable. The independent variables were one-hour and 24-hour lagged values at that site and the CO concentrations for time t reported at other Toronto sites.

The resulting regression equations had the form

$$Y = b_0 + b_1X_1 + b_2X_2 + \dots + b_mX_m + e \quad (3.2)$$

In this equation, Y represents the hourly CO concentration at time t ; b_0, \dots, b_m are constants; and X_1, \dots, X_m are the independent variables. The e term represents random “noise” which is uncorrelated with the CO concentrations X_1, \dots, X_m .

The fill-in procedure was performed in two steps. In step 1, a stepwise linear regression analysis was performed on each site to determine an initial R^2 value for the site. This value indicated the fraction of total variation in the dependent variable (i.e. the one-hour CO concentrations reported at that site) which could be explained by the independent variables selected as predictor variables. The sites were ranked high to low according to their R^2 values.

In Step 2, the dataset for each site was filled in using Equation (3.2) according to the ranking the site received in Step 1; that is, the site with the highest R^2 value was filled in first, and the site with lowest value was filled in last. A stepwise linear regression analysis was performed on the first site (Site 1) to determine the coefficient of each term of Equation (3.2). This site-specific version of Equation (3.2) was then used to estimate missing values in the site’s dataset. Then another stepwise linear regression analysis was performed on the dataset associated with Site 2. When the regression analysis required a value for Site 1, the value was taken from the filled-in data set for Site 1. This procedure was continued for all of the sites. In each case, previously filled-in data sets were used in the regression analysis where appropriate. When completed, the procedure produced a partially filled-in data set for each of six Toronto sites.

Table 3.5 presents the results of the stepwise linear regression analysis for each of the six selected sites. For each monitoring site, the table indicates the dependent variable site

(Y), lists the selected predictor variables (X_m), and indicates the b_m coefficient associated with each predictor variable. The table also presents the R^2 value of the regression equation. The sites appear in the table in the order that they were filled-in, from highest to lowest R^2 value. In addition, the table lists the number of values in each dataset before and after application of the stepwise linear regression fill-in procedure.

3.3.2 Example

The UBC team developed a C-program to implement the method described above. Table 3.5 shows the results using that program..

Site 6 reported 8699 hourly CO values for 1990. The first set of linear regression analyses determined that Site 6 had the sixth highest R^2 value, and hence should be filled-in after the five other sites with higher R^2 values (appearing before it in the table). The regression R^2 value was 0.5847.

The fill-in equation was

$$\begin{aligned}
 Y = & 0.0702 + 0.5930 * (1 - hrlagvalue) + 0.0746 * (24 - hrlagvalue) \\
 & + 0.0636 * (filled - insite60415) + 0.0448 * (filled - insite60402) \\
 & + 0.0067 * (filled - insite60416) + 0.0220 * (filled - insite60413) \\
 & + 0.1736 * (filled - insite60403)
 \end{aligned} \tag{3.3}$$

The value of Y for hour No. 395 (the first hour with a missing datum for Site 6) was determined by substituting the following hourly CO concentrations for each predictor variable into Equation (3.3):

```

1-hour lag value      = 3.00 ppm
24-hour lag value     = 3.00 ppm
Filled-in Site 60415 = 2.00 ppm
Filled-in Site 60402 = 2.00 ppm
Filled-in Site 60416 = 2.00 ppm
Filled-in Site 60413 = 1.00 ppm
Filled-in Site 60403 = 2.00 ppm

```

Table 3.5: Results of Stepwise Regression Analyses for Six Selected Sites

Dependent variable	Number of values before fill-in	Fill-in regression equation			Number complete after fill-in	Percent after fill-in
		Predictor sites (X_m)	Coefficient (b_m)	of values R^2		
Site 60415 (Site 1)	8449	constant 1-hr lag 24-hr lag site 60402 site 60416 site 60413 site 60403 site 60410	-0.0932 0.6941 0.1176 -0.0435 -0.0174 0.0701 0.1816 0.1037	0.7171	8469	96.6
site 60402 (Site 2)	8685	constant 1-hr lag 24-hr lag Filled-in site 60415 site 60416 site 60413 site 60403 site 60410	-0.0344 0.7164 0.0619 0.0164 0.0133 0.0449 0.0591 0.0998	0.7164	8702	99.3
site 60416 (Site 3)	8676	constant 1-hr lag 24-hr lag site 60413 site 60403 site 60410	-0.1442 0.7219 0.0930 0.1955 0.1651 0.1409	0.6927	8698	99.3
site 60413 (Site 4)	8621	constant 1-hr lag 24-hr lag filled-in site 60415 filled-in site 60416 site 60403 site 60410	-0.1067 0.6334 0.1012 0.0569 0.0291 0.1416 0.0444	0.6603	8658	98.8
site 60403 (Site 5)	8621	constant 1-hr lag 24-hr lag filled-in site 60415 filled-in site 60402 filled-in site 60416 filled-in site 60413 site 60410	0.0582 0.5099 0.0642 0.0977 0.0245 0.0191 0.0929 0.1273	0.6062	8646	98.6
site 60410 (Site 6)	8699	constant 1-hr lag	0.0702 0.5930	0.5847	8714	99.4

The values listed for filled-in Sites 1, 2, 3, 4 and 5 are specific to hour No. 395. The value listed for the one-hour lag is the CO value reported for Site 6 for hour No. 395; and the value listed for the 24-hour lag is the reported CO value for Site 60410 for hour No. 371. Using (3.3), the calculated value for Y turned out to be 2.6724 ppm.

3.3.3 The Time Series Approach

At stage two, a time series approach is used to fill in the still missing values. The method can be outlined as follows: fill in the missing data with a linear interpolator; fit the (filled) “complete” series with a Fourier series; keep the most influential terms from the Fourier series and model the remaining (residuals) with an AR(2) model. Finally use the sum of the m most influential terms and a random number generated from the AR(2) process as a “tuned-up” value to replace the raw values filled in by the linear interpolator. The details are given next.

If a gap between values x_a and x_{a+b} contains $b-1$ missing values, they can be filled in by using the linear equation

$$x_t = x_a + \frac{1}{b}(t - a)(x_{a+b} - x_a), \quad t \in (a, b). \quad (3.4)$$

Linear interpolation may not yield reasonable estimates of the missing one-hour values for large gaps, especially if they are bounded by extreme values. In these cases, the arithmetic mean \bar{x} may be a better estimate of each missing value.

With all missing data filled in, the “complete” year of hourly average data takes the form of a time series x_1, \dots, x_n where $n = 8760$. We can fit this series exactly by the model

$$x_t = \bar{x} + \sum_{j=1}^{4380} R_j \cos(\omega_j t + \theta_j) \quad (3.5)$$

where \bar{x} is the arithmetic mean of the series, R_j and θ_j are the amplitude and phase angle values determined by Fourier analysis, and $\omega_j = 2\pi j/8760$. Omission of one or more of the 4380 Fourier cosine terms will yield an approximate fit. Because Fourier cosine functions are orthogonal and because the contribution of each cosine function to the representation of the original time series is proportional to its amplitude R_j , we can provide a least squares fit to the original time series with m cosine terms by using the cosine terms with the m largest

amplitudes. We denote each term of this estimated time series as \bar{x}_t where

$$\bar{x}_t = \bar{x} + \sum_{i=1}^m R_i \cos(\omega_i t + \theta_i) \quad (3.6)$$

while R_i, ω_i , and θ_i are the parameters of the Fourier term having the i^{th} largest amplitude. We refer to the m Fourier terms in Equation (3.5) as the essential cyclical component (ECC).

The differences between the x_t series and the \hat{x}_t series comprise the d_t series, i.e.,

$$d_t = x_t - \hat{x}_t. \quad (3.7)$$

If the x_t series exhibits autocorrelation, the d_t series is likely to exhibit autocorrelation. Each d_t term can be expressed as

$$d_t = a_t + \phi_1 d_{t-1} + \phi_2 d_{t-2} + \dots + \phi_p d_{t-p} \quad (3.8)$$

where a_t is a normally distributed random variate with mean 0 and variance σ_a^2 .

Estimates of $\phi_1, \phi_2, \dots, \phi_p$ can be obtained by first estimating each autocorrelation ρ_k using the relationship $\hat{\rho}_k = r_k$ where

$$r_k = \frac{c_k}{c_0} \quad k = 1, 2, \dots, p \quad (3.9)$$

and

$$c_k = (1/8760) \sum_{k+1}^{8760} (d_t - \bar{d})(d_{t-k} - \bar{d}). \quad (3.10)$$

From these estimates, the Yule-Walker estimates of the autoregressive parameters can be obtained.

Autocorrelation of the d_t series will decrease as m increases since an increasing portion of the x_t series autocorrelation is explained by the cosine functions. The ITAQS method assumes that most of the autocorrelation in the data corresponding to $k \geq 3$ would be contained in the ECC selected and that an AR(2) process would suffice to characterize the d_t series. In that case:

$$\hat{\phi}_1 = \frac{r_1(1 - r_2)}{1 - r_1^2}; \quad (3.11)$$

$$\hat{\phi}_2 = \frac{r_2 - r_1^2}{1 - r_1^2}. \quad (3.12)$$

The autocorrelations at lag- k ($k \leq 3$) of an AR(2) can be computed by the iterative formula:

$$\rho(k) = \phi_1\rho(k-1) + \phi_2\rho(k-2), \quad (3.13)$$

$$\sigma_a^2 = c_0(1 - \hat{\phi}_1r_1 - \hat{\phi}_2r_2). \quad (3.14)$$

However, we cannot discover from published reports, how m has been chosen. So the UBC team developed its own criteria for making that choice.

Note that when d_t is stationary, for fixed h $\hat{\rho}_h = (\hat{\rho}(1), \dots, \hat{\rho}(h))^t$ is asymptotically normal with mean ρ_h and covariance matrix $n^{-1}W$. $\rho_h^t = (\rho_1, \dots, \rho_h)$ denotes the true autocorrelations. W is defined by

$$w_{ij} = \sum_{k=-h}^{k=h} (\rho(k+i)\rho(k+j) + \rho(k-i)\rho(k+j) + 2\rho(i)\rho(j)\rho^2(k) - 2\rho(i)\rho(k)\rho(k+j) - 2\rho(j)\rho(k)\rho(k+i)). \quad (3.15)$$

Let,

$$Y_h = n^{\frac{1}{2}}W^{-1/2}(\hat{\rho}_h - \rho_h) \quad (3.16)$$

then Y_k will be asymptotically normal, $N(\mathbf{0}, \mathbf{I})$. Under the assumption that d_t is AR(2), $Y_h^t Y_h$ goes to zero as m increases. We can choose m such that $Y_h^t Y_h$ is smaller than a pre-determined value.

The above discussion can be summarized in the following algorithm:

1. calculate the mean and standard deviation of each data set;
2. identify gaps of length exceeding 72 hours and/or with boundary values exceeding the arithmetic mean by more than two standard deviations fill them with the arithmetic mean;
3. use linear interpolation to fill in the remaining gaps;
4. use Fourier analysis on the augmented time series created in steps (2) and (3);
5. construct an ECC which contains the smallest number of cosine terms required to produce a d_t series consistent with Equations (3.11) and (3.12).

6. represent the d_t series by an AR(2) process using Equations (3.8), (3.9) and (3.10) to find $\hat{\phi}_1, \hat{\phi}_2$, and $\hat{\sigma}_a$.
7. from an a_t series by dividing each term in a $N(0,1)$ random series by $\hat{\sigma}_a$; [For consistency, the same random series was used in each case.]
8. simulate missing d_t values using the relationships,

$$\hat{d}_t = \hat{\phi}_1 \hat{d}_{t-1} + \hat{\phi}_2 \hat{d}_{t-2} + a_t; \quad (3.17)$$

9. fill-in missing x_t values using the model,

$$\hat{x}_t = \bar{x} + \sum_{i=1}^m R_i \cos(\omega_i t + \hat{d}_t) \quad (3.18)$$

to create the final augmented data set.

3.3.4 Implementing the Time Series Approach

In developing and implementing our codes for the time series approach we found that the 1990 hourly CO data in Toronto do not meet one of the basic requirements of the ITAQS approach: as m increases, d_t should approach an AR(2) process. In Figure 3.2, we plot the partial autocorrelation function of d_t for $m = 1, 100, 500$ and 1000 . The plot shows the departure of d_t from an AR(2) process when m increases.

Thus we are in doubt about the appropriateness of the time series approach used to fill in missing values. However, finding a suitable alternative would be a major undertaking well beyond the scope of our study. Moreover that alternative may not actually be necessary; our sensitivity analysis suggests the method used may not be important since so little data needs to be filled in by the time series method.

3.3.5 A Method of Comparison

The CO levels reported for all six sites in Toronto area are almost complete. We are thus led to expect small difference between various fill-in procedures in terms of pNEM outputs. In this section, using our sensitive analysis, we make a comparison between our variation of

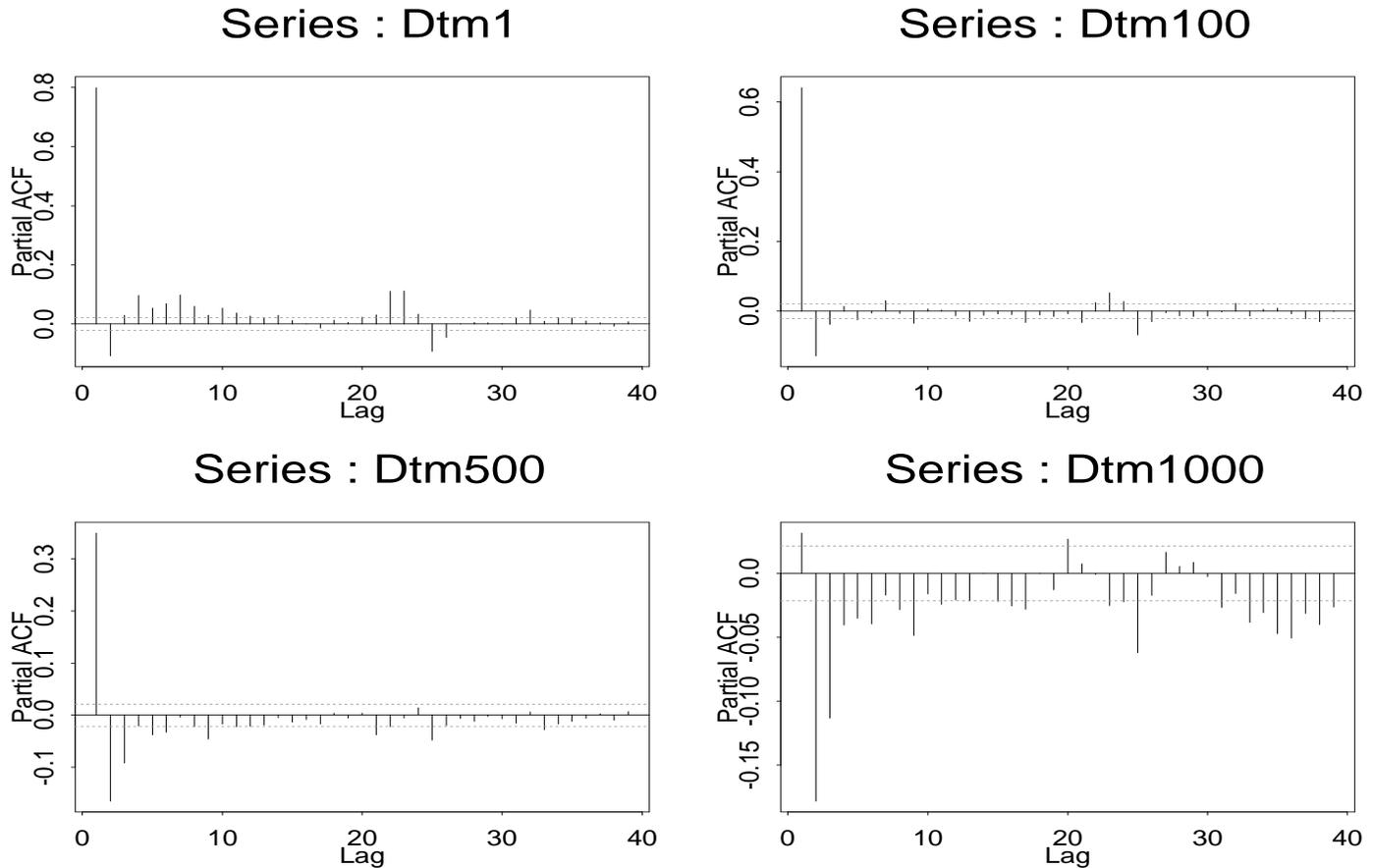


Figure 3.2: Autocorrelation Plots for $m = 1, 100, 500$ And 1000

the ITAQS method and a very crude alternative: fill-in the missing values with the grand mean. In other words, we treat our crude method as another scenario and compare the two methods as we would two scenarios using a paired t-test. The grand means of the two districts, 60416 and 60402 are 2.11 ppm and 0.72 ppm, respectively. Table 3.6 shows no significant differences between the two fill-in methods.

Table 3.6: P-values of Pairwise t Tests when Treating Crude Method as Scenario

P-VALUES *100 FOR RUN:

Cohort	Hour(pm)	1	2	3	4	5	6	7	8	9	10	Sum-p
3222	6	68	97	66	62	85	9	80	97	100	79	99
7232	6	93	61	4	11	43	87	60	50	87	71	64
14222	6	44	81	81	78	51	59	21	38	81	32	87

3.4 The Bayesian Interpolation Theory and Its Empirical Assessment

In this section, we describe an empirical assessment of the interpolation theory proposed by Le, Sun and Zidek (1994, hereafter LSZ). Our empirical analysis uses a southern Ontario air pollution dataset because: (i)it was available long before the files relating to Toronto CO levels became available to the investigators; (ii)its broad geographical domain and multivariate nature were seen as more challenging than those of direct interest in the pNEM study. Our results seem encouraging and further testing will be done subsequently on pNEM's more local space-time context.

Our theory assumes a normal model for the conditional pollutant sampling distribution,

$$X | Z, B, \Sigma \sim N_{sk \times n}(BZ, \Sigma \otimes I_n), \quad (3.19)$$

where: $X = (X_1, \dots, X_n)_{sk \times n}$ is the response matrix, X_t ($t = 1, \dots, n$) being the response vector for all s sites at time t ; $Z = (Z_1, \dots, Z_n)_{h \times n}$ is the matrix of covariates;

$$B = \begin{pmatrix} \beta_{1,1} & \dots & \beta_{1,h} \\ \vdots & & \\ \beta_{sk,1} & \dots & \beta_{sk,h} \end{pmatrix}_{sk \times h}$$

is the coefficient matrix; Σ is the unknown spatial covariance matrix of X_t and I_n is a $n \times n$ identity matrix. The conjugate priors of Σ, B are,

$$B | B^o, \Sigma, F \sim N_{skh}(B^o, \Sigma \otimes F^{-1}) \quad (3.20)$$

and

$$\Sigma \mid \Phi, \delta^* \sim W_{sk}^{-1}(\Phi, \delta^*). \quad (3.21)$$

Among s sites, s_g are gauged (the ambient monitors) and yield observations of pollutant concentrations. The remaining s_u ungauged sites provide no observations. Accordingly we partition X into X^0 and $X^{(1)}$. X^0 is the response matrix at ungauged sites. After appropriate rearrangement of columns, we can further partition $X^{(1)}$ into X^1 and X^2 . The response matrix X^1 represents all unobserved pollutant concentrations and X^2 those observed. The partitions of Σ , B^o , F and Φ are similar. For instance,

$$\Sigma = \begin{pmatrix} \Sigma_{00} & \Sigma_{0(1)} \\ \Sigma_{(1)0} & \Sigma_{(11)} \end{pmatrix},$$

where Σ_{00} and $\Sigma_{(11)}$ are $s_u k \times s_u k$, $s_g k \times s_g k$ matrices, respectively.

To simplify notation, we introduce an indicator matrix R . Suppose the indices of missing values in $X_t^{(1)}$ were i_1, \dots, i_l and the indices of observed values, $i_{l+1}, \dots, i_{s_g k}$. Then we would let $R_1 = (r_{i_1}, \dots, r_{i_l})$ and $R_2 = (r_{i_{l+1}}, \dots, r_{i_{s_g k}})$ where r_j , $j = 1, \dots, s_g k$ is a $s_g k \times 1$ -dimensional vector with the j^{th} element being one and the remainder being zero. Thus, R_1 and R_2 “mark” the position of missing columns. Finally, $R = (R_1, R_2)$, and we let $\Sigma_{ij} = R_i^t \Sigma_{(11)} R_j$, $\Psi_{ij} = R_i^t \Phi_{(11)} R_j$ and $B_i^o = R_i^t B_{(i)}^o$, $i, j = 1, 2$.

For given hyperparameters, LSZ prove that the predictive distribution of $X^0 \mid X^2 = x^2$ follows a matrix T distribution. More precisely,

$$X^0 \mid X^2 = x^2 \sim T \left(\Phi_{0|2}^{-1}, c, B_0^o Z + \Phi_{0(1)} R_2 \Psi_{22}^{-1} (x^2 - B_2^o Z), \delta^* - l + 1 \right)$$

where

$$c = I + Z^t F^{-1} Z + (x^2 - B_2^o Z)^t \Psi_{22}^{-1} (x^2 - B_2^o Z);$$

$$\Phi_{0|2} = \Phi_{00} - \Phi_{0(1)} R_2 \Psi_{22}^{-1} R_2^t \Phi_{(1)0}.$$

In the last result, l is the number of missing pollutant concentrations at gauged sites and time t . If we adopt a squared loss function, the Bayesian interpolator is

$$E(X^0 \mid X^2 = x^2) = B_0^o Z + \Phi_{0(1)} R_2 \Psi_{22}^{-1} (x^2 - B_2^o Z). \quad (3.22)$$

Following Brown, Le and Zidek (1994, hereafter BLZ), LSZ adopt an empirical approach

and estimate hyperparameters. More precisely, LSZ maximize the conditional likelihood function for given $X^2 = x^2$ and also use two unbiased estimators. To reduce the number of parameters, LSZ adopt a Kronecker structure, $\Phi = \Lambda \otimes \Omega$, where Λ is the between-sites-hyperparameters and Ω , between-pollutants. LSZ use the following procedure to estimate all hyperparameters. First, they use the two unbiased estimators to estimate $B_{(1)}^o$, F^{-1} ; second, they apply the EM algorithm to estimate Ω , δ^* and Λ_g , where Λ_g is the between-gauged-sites-hypercovariance-matrix; third, they invoke a procedure of Sampson and Guttorp (1992, hereafter SG) to extend Λ_g to Λ . Finally, LSZ assume an exchangeability structure on B^o to extend $B_{(1)}^o$ to B^o . libby 1979), a two-dimensional representation of the sampling sites is found. In this two dimensional Euclidean space, called the D-plane, a monotonic function of the distance between two points approximates the spatial dispersion between the same two points. The D-plane, has a counterpart in the G-plane comprised of the geographical coordinates of the sampling sites. Step two yields thinplate splines to provide smooth mappings from the G-plane into their the MDS representation. Then the composition of this mapping f and a monotone function g derived from MDS yields a nonparametric estimator of $var(Z(x_a) - Z(x_b, t))$ having the form $g(| f(x_a) - f(x_b) |)$ for any two geographic locations x_a and x_b .

3.4.1 Fitting the Interpolator

The daily maximum hourly levels of nitrogen dioxide (NO_2), ozone (O_3), sulphur dioxide (SO_2) and the daily mean levels of sulfate (SO_4) were recorded from January 1 of 1983 to December 31 of 1988 in Ontario and its surrounding areas. These data come from several monitoring networks in the Province, including the Environment Air Quality Monitoring Network (OME), Air Pollution in Ontario Study (APIOS) and the Canadian Acid and Precipitation Monitoring Network (CAPMON). The reader should see Burnett R. T. et al (1992) for a more detailed description of the data. In all, the network has 37 different monitoring locations (sites) but not all sites monitor all of the five air pollutants. In the application below, we assume that the variation caused by networks to sites is negligible, therefore we can simple pool the observed pollution levels without worrying about that variation.

In general there are two kinds of air pollutants: (i) a primary pollutant, which is directly emitted by identifiable sources; (ii) a secondary pollutant, which is produced by chemical

reactions within the atmosphere between pollutants and other constituents. SO_2 is a primary pollutant and NO_2 , O_3 and SO_4 are secondary pollutants. SO_2 is produced by burning of sulphur contained fuels and its level depends on the local emission sources, like burning fuel oil or smelting.

The secondary pollutants studied here are all produced by oxidation of primary pollutants. This oxidation is driven by ultra-violet radiation from sunlight and comprises chemical reactions that are temperature dependent. Since the chemical reactions proceed while the polluted air is being advected by winds, secondary pollutants are generally more widespread than primary pollutants. We thus refer to secondary pollutants as regional. Because of temperature dependence of the governing chemical reaction, NO_2 , NO_3 and O_3 are high in early afternoon and midsummer, low overnight and in winter. The oxidation of SO_2 to SO_4 is dominated by photochemical processes in dry, warm atmospheres.

Monthly pollutant concentrations at gauged sites are simply computed as the mean of the observed daily levels for that month, January 1983 to December 1988. The time series of observed monthly mean concentrations for each pollutant consists of 72 values.

The series with more than one third missing values are omitted from this analysis. As a result, the number of gauged sites is reduced to 31 from 37. Figure 3.3 depicts the locations of each pollutant measured at a subset of the remained 31 sites. The whole Ontario Province divides into thirty-seven PHUs or districts (Duddek et al 1994). The PHU is similar to a Census Division, the difference being marginal disagreements in boundaries. Some PHUs, for example, are aggregates of two Census Divisions. Figure 3.4 displays the locations of the approximate centroids of these PHU's. Hence, the total number of gauged sites s_g is 31 and the total number of ungauged sites s_u is 37.

Table 3.7: Pollutants Observed at Each of the 31 Gauged Sites.

Sites	1	2	3	4	5	6	7	8	9	10	11	12
Pollutants	b	b	b	b	abde	d	be	ade	d	d	ade	de
Sites	13	14	15	16	17	18	19	20	21	22	23	24
Pollutants	ade	ade	ade	b	abde	b	ade	ade	ade	d	e	ade
Sites	25	26	27	28	29	30	31					
Pollutants	de	ade	ade	de	b	e	de					

Table 3.7 names the pollutants observed at each of the 31 gauged sites, where a , b , d and

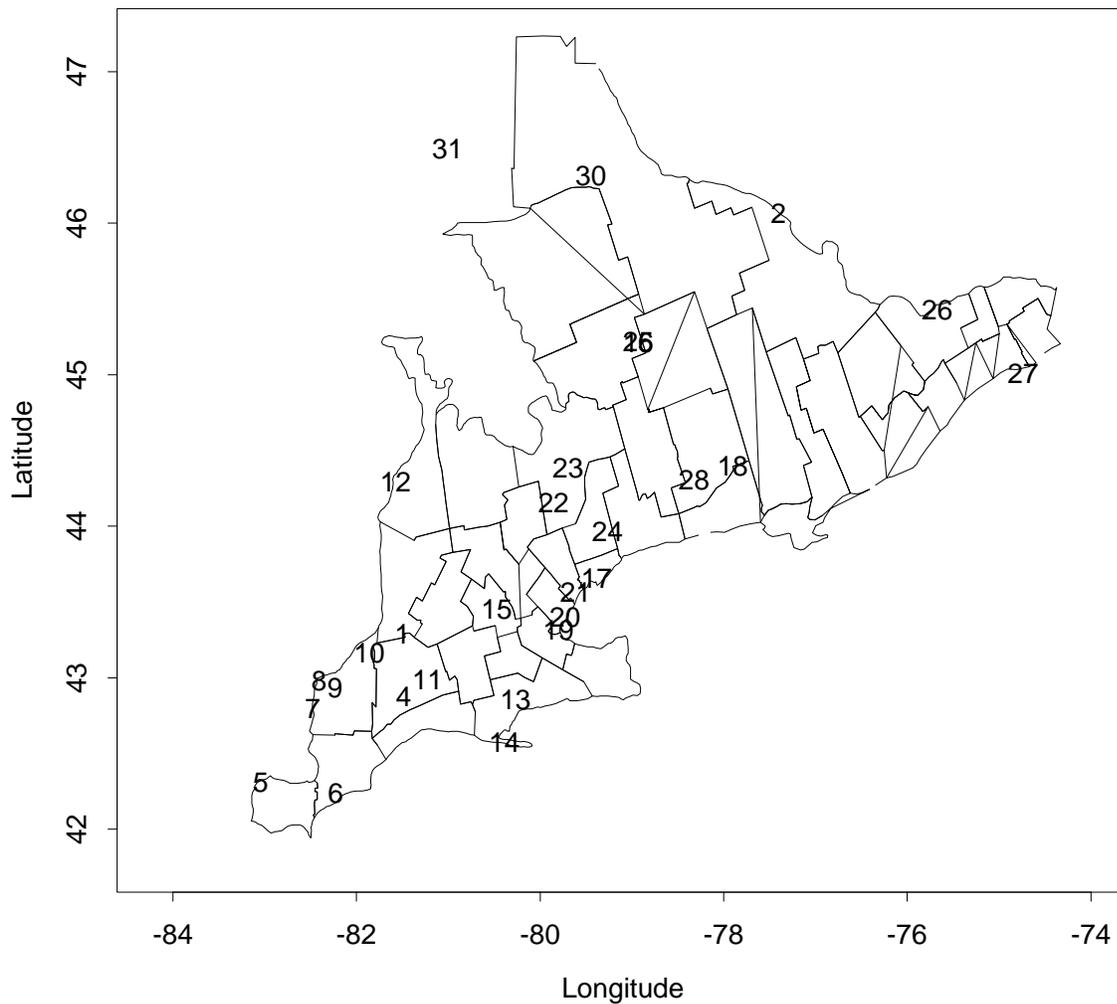


Figure 3.3: Locations of gauged sites in Southern Ontario plotted with Census Subdivision's boundaries, where monthly pollution levels are observed and Sites 3, 29 (outliers) are not plotted.

e represent NO_2 , SO_4 , O_3 and SO_2 respectively.

From Table 3.7, we see that at the 31 gauged sites, there are 64 observed and 60 missing time series. Among the 64 observed time series, about two percent of the values are randomly missing, including those below the detection limit. In this analysis, each of the missing values is replaced by the mean of the monthly observed values of the same pollutant and month in other years. If all six measurements in the same month are missing, the grand mean of observations in the six years will be used. However, no such case exists in the data set. A more delicate method of filling in the randomly missing data may be used here. But with such a low percentage of missing data the extra effort seems unnecessary.

The theory of Bayesian multivariate interpolation with missing-by-design data is developed under two important assumptions of normality and temporal independence (see Equation (3.19)). Checking the multivariate normality assumption is not easy. Here, we only examine the normal quantile plot for each pollutant separately. The normal quantile plots of the residuals of the raw data seem very nonlinear. Therefore, the observed data must be transformed. With a logarithmic transformation of the observed data, the residuals appear to be marginally normal. Figure 3.5 shows a typical example of the normal quantile plots of the data. The plot is based on the measured air pollution levels of SO_4 at gauged Site 4. In the sequel, when we refer to these pollutants we mean their log transformed versions.

The temporal independence assumption is checked with autocorrelation and partial autocorrelation plots. Autocorrelation and partial autocorrelation plots of the temporal residuals of the log-transformed data are shown in Figure 3.7. The plot is based on the measured air pollution levels of SO_4 at gauged Site 1. The correlation plots show no sign of autocorrelation. By repeating the above initial data analysis for the observed pollutant levels at all gauged sites, we conclude that the assumptions of our interpolation theory seem reasonable with the log-transformed data.

The linear trend and seasonal component of the time series are captured with $Z_t = \{1, t, \cos(2\pi t/12), \sin(2\pi t/12)\}$, where $t = 1, \dots, 72$. Here $t = 1$ represents the January of 1983, $t = 2$ represents the February of 1983 and so on, until $t = 72$, which represents December of 1988. The coefficients of the linear trend and seasonal component are estimated with ordinary least squares. In Figure 3.8, the time series plots and the least squares fitted curve of the four observed pollutants at Site 5 are displayed. The fit of the time series for $\log(O_3)$ is far better than that of the other three, because of its periodic nature. The strong yearly pattern of ozone is partially explained by the fact that the creation of ozone is highly related to solar radiation.

In the following, we demonstrate the method with the summer data only. Here “summer” means May 1 to August 31 and “winter” the remainder of the year. Each summer data time series thus has 24 values (24 months). We take as our purpose, the interpolation down to 37 PHU approximate centroids in Southern Ontario, of NO_2 , SO_4 , O_3 and SO_2 levels in the summers of 1983 to 1988.

The interpolation procedure begins by finding the unbiased estimators of F^{-1} and $B_{(1)}^o$; next, the EM algorithm is invoked to estimate δ^* , Λ_g and Ω ; third, the SG method is applied

Table 3.8: The Estimated Between-pollutants-hypercorrelation Matrix of the Log-transformed Monthly Data

	NO_2	SO_4	O_3	SO_2
NO_2	1.00	-0.29	0.03	0.14
SO_4	-0.29	1.00	0.79	-0.34
O_3	0.03	0.79	1.00	-0.15
SO_2	0.14	-0.34	-0.15	1.00

to extend Λ_g to Λ ; then, with the exchangeability assumption on B^o , $B_{(1)}^o$ is extended to B^o ; finally, all hyperparameters having being estimated, the interpolated values are computed by the Bayesian interpolator.

Software to implement the approach has been developed and a working version is now available. Applying the approach to the summer data yields the following result. The prior number of degrees of freedom is estimated at 610. Table 3.8 gives the estimated hypercorrelation matrix of the log transformed NO_2 , SO_4 , O_3 and SO_2 values; the corresponding hyper-variances are 0.66, 1.63, 0.22, 1.85. Among the estimated hyper-variances, that of $\log(O_3)$ is smallest, $\log(SO_2)$, largest. This result indicates that the overall variation of the observed ozone levels is smaller than that of SO_2 . The result confirms our prior knowledge that ozone is a regional pollutant and so more homogeneous. In contrast SO_2 is local and so much less homogeneous. The biggest positive correlation among the four pollutants occurs between O_3 and SO_4 . Again, since both O_3 and SO_4 are regional air pollutants and both are related to sunlight, we expect a higher correlation of O_3 and SO_4 .

Figures 3.9, 3.10 and 3.11 summarize the result of the SG step. The righthand plot in Figure 3.9 is a twisted 30-by-30 checkerboard in the D-plane. The original 30-by-30 checkerboard is in the G-plane and the coordinates of its lower left corner are the minimum latitude and longitude of the gauged sites. The coordinates of its upper right corner are the corresponding maximum latitude and longitude. The lefthand plot in Figure 3.9 shows an exponential fit between dispersion and the D-plane distance. The parameter λ controls the smoothness of the twisted checkerboard. By sacrificing the fit between the dispersion and D-plane distance, we get a smoother checkerboard in the D-plane. Figure 3.10 shows a smoother checkerboard in the D-plane but a rougher fit between the dispersion and D-plane distance when the smoothing parameter value is increased from 0 to 2500. The straight line

in the righthand side of Figure 3.11 shows that the estimated covariance and the observed covariance are conformable.

After applying the GS method, we compute the interpolated air pollutant levels at all PHU approximate centroids over six years by applying Equation (3.22) and using the above estimated hyperparameter values. To check the interpolated values, we plot in Figure 3.12 the overall means of observed ozone levels at each gauged site in summers of 1983 to 1986. Those of interpolated ozone levels at the PHU approximate centroids appear in Figure 3.13. The two plots affirm the value of the interpolation procedure. When a higher mean O_3 level is observed at a gauged site, our Bayesian method interpolates higher O_3 values at the PHU approximate centroids near that site. Analogous results obtain for a lower observed O_3 level.

3.4.2 How Accurate is the Interpolator?

One way of checking the interpolation procedure is to look at the correlation between the observed data and the estimated data by cross validation (CV hereafter). CV successively deletes observed data one at a time and imputes these from the remainder, as if the value were not observed. It is a popular diagnostic tool.

In our CV study, we deleted one gauged site at a time and interpolated the pollutant levels at the same site using the observed levels at other sites. To avoid spuriously high computed correlations between the estimated and the observed levels of pollutants, we removed the trends from both the estimated columns and the observed columns and then calculated the correlations from the residuals.

An overall impression of the quality of the interpolator can be gained by computing the correlation between the estimated and the observed levels of each pollutant aggregating across sites and over time. Those correlations in Table 3.9.

For the two pollutants whose spatial fields are quite homogeneous (SO_4 and O_3), the interpolator does extremely well by this criterion. Table 3.10 gives the correlation between the estimated and observed levels at each gauged site and each observed pollutant. Notice that the correlations of SO_4 and O_3 in both summer and winter are generally higher than those of SO_2 . In other words, predicting SO_4 or O_3 is easier than SO_2 . Figure 3.14 displays the plot residuals of Log-transformed, monthly observed and estimated pollutant levels in both summer and winter. Figure 3.15 shows the scatter plots of log-transformed, estimated

Table 3.9: Correlations Between the Residuals of Log-transformed Observed and Predicted Values of Pollutants

	Summer	Winter
NO_2	0.243	0.242
SO_4	0.494	0.438
O_3	0.534	0.429
SO_2	0.238	0.200

vs. observed pollutant levels for each pollutant both in summer and winter. In the plots, a straight line means accurate interpolation. The plots confirm conclusions suggested by the tables and demonstrate again that O_3 and SO_4 are regional pollutants. They are easier to predict than their nonregional counterparts.

Can a simpler to use, normal distribution be substituted for the multivariate T predictive distribution? That might naively seem possible since the univariate normal approximates its longer tailed relative very well. However, our results suggest this substitution cannot be recommended without additional study. Our initial impression comes from an evaluation we did of the empirical coverage percentage of three-standard-deviation confidence intervals (CI). If the predictive distribution were normal, all the three-standard-deviation CIs would include the true values about 100 percent of the time. As the percentages by pollutants presented in Table 3.11 indicate, this high coverage probability is not achieved here. The heavier tailed predictive matrix T distribution seems to be required.

We also checked the unbiasedness of the residuals. The top plot of Figure 3.16 displays the boxplots of the four pollutants' prediction errors. We define these errors to be the differences of the predicted and observed values. Except for SO_2 , the mean prediction errors of the other three pollutants are almost zero. In another words, the interpolator is unbiased.

The two plots seen at the bottom of Figure 3.16 demonstrate that the boxplots of the predicted values resemble those for the observed values. However, the predicted values have bigger variances.

3.4.3 Multivariate vs. Univariate Interpolation

By interpolating one pollutant at a time, one can apply the earlier LZ theory to the problem studied above. So why a new theory when an old theory exists? The answer lies in the

Table 3.10: Correlations Between the Residuals of Log-transformed Observed and Estimated Pollution Levels at Gauged Sites

Sites	summer				winter			
	NO2	SO4	O3	SO2	NO2	SO4	O3	SO2
1		0.96				0.81		
2		0.96				0.85		
3		0.87				0.74		
4		0.93				0.81		
5	0.39	0.82	0.75	0.57	0.09	0.67	0.70	0.40
6			0.92				0.74	
7		0.90		0.67		0.71		0.14
8	0.42		0.81	0.76	0.56		0.74	0.58
9			0.87				0.78	
10			0.85				0.41	
11	0.57		0.97	0.66	0.61		0.75	0.32
12			0.87	0.65			0.59	0.30
13	0.44		0.75	0.54	0.11		0.57	0.04
14	0.11		0.88	0.53	0.13		0.69	0.33
15	0.66		0.93	0.69	0.52		0.79	0.24
16		0.90				0.87		
17	0.66	0.91	0.80	0.78	0.25	0.68	0.55	0.18
18		0.85				0.75		
19	0.63		0.77	0.80	0.34		0.59	0.38
20	0.36		0.72	0.61	0.57		0.72	0.40
21	0.67		0.80	0.63	0.47		0.63	0.40
22			0.86				0.49	
23				0.78				0.25
24	0.48		0.74	0.68	0.56		0.65	0.56
25			0.80	0.52			0.44	0.26
26	0.71		0.82	0.81	0.24		0.47	0.23
27	0.55		0.77	0.66	0.44		0.59	0.50
28			0.87	0.83			0.40	0.49
29		0.97				0.49		
30				0.78				0.10
31			0.82	0.62			0.23	0.52

Table 3.11: Empirical Percentages of Three SD's Intervals

	Summer	Winter
NO_2	100%	94.2%
SO_4	100%	99.2%
O_3	98.6%	98.8%
SO_2	94.5%	100%

information gained in the new approach with a corresponding increase in the accuracy of interpolation.

With the LZ method, only partial data are used for each interpolation. The new method includes all the available data in the procedure. For example, consider O_3 in the Southern Ontario study. When the levels of O_3 are interpolated down to the ungauged sites by the LZ theory, only the observed O_3 levels at gauged sites are included in the interpolator. By the new method, all observed values of NO_2 , SO_4 , O_3 and SO_2 are included. To distinguish these two methods, we call the LZ method *univariate interpolation* and the new method, *multivariate interpolation*.

Theoretically it can be showed that the multivariate interpolator leads to a smaller mean square error than that of its counterpart. More precisely, let \mathbf{X}_0 , \mathbf{Y}_0 be any two random vectors and X a random variable. Then

$$E(X - E(X | \mathbf{X}_0, \mathbf{Y}_0))^2 \leq E(X - E(X | \mathbf{X}_0))^2. \quad (3.23)$$

The proof can be found in LSZ.

Returning to the O_3 example, we take \mathbf{X}_0 to be the observed levels of O_3 at the gauged sites, \mathbf{Y}_0 , the observed levels of the other pollutants and X , any unobserved pollution level at an ungauged site. Then the univariate Bayesian interpolator, $E(X | \mathbf{X}_0 = x_0)$ and the multivariate Bayesian interpolator is $E(X | \mathbf{X}_0 = x_0, \mathbf{Y}_0 = y_0)$. When the model is correctly specified and all the hyperparameters are known, the theoretical result stated above implies that the multivariate interpolator does at least as well as the univariate one.

The following CV study answers empirically the question addressed above. Again, the monthly air pollution data set from Southern Ontario is used. At each gauged site successively, the observed pollutants are deleted as if they were not observed. Then both

univariate and multivariate Bayesian interpolators are applied to obtain the predicted values of the “deleted” values based on the data at the other gauged sites. When the values are predicted by both methods for all 31 gauged sites, we calculate the mean squared error of prediction for the univariate and the multivariate interpolator, respectively. The results for the monthly summer and winter data are listed below.

Table 10. Mean Squared Error of Prediction for Multivariate and Univariate Interpolator

	<i>Multivariate</i>		<i>Univariate</i>	
	summer	winter	summer	winter
NO_2	0.19	0.14	0.28	0.13
SO_4	0.14	0.21	1.27	0.73
O_3	0.044	0.05	0.13	0.24
SO_2	0.62	0.28	0.76	0.43

The values depicted in Table 10 confirm the theory, except for NO_2 in winter. There the mean squared error of prediction of the univariate interpolator is smaller than that of the multivariate interpolator.

One interesting point is worth mentioning here. The above numbers show that the relative reduction of the mean squared error of prediction from using multivariate interpolation over univariate interpolation is much higher for SO_4 and O_3 than SO_2 . For SO_4 and O_3 , the relative reduction is from 300% to 900%; for SO_2 , just under 50%. This result can be explained by the fact that SO_4 , O_3 are regional pollutants while SO_2 is not. A regional air pollutant has higher correlation with other pollutants, as indicated by the estimated between-pollutants-hypercorrelation. Including the other correlated pollutants in the analysis should enhance the interpolator’s performance relatively more. For a local pollutant, since it has little or no correlation with other pollutants, the inclusion of additional pollutants in the analysis will not improve the interpolator as much. Therefore, we can conclude on heuristics alone that the interpolator with missing-by-design data does better than that of LZ on regional pollutants. It does not do so much better than LZ on local pollutants.

3.5 References

Biller, W. F. and Richmond, H.M. (1991) “COHB module for a probabilistic CO NEM.”
EPA, Research Triangle Park.

- Brown, PJ, Le, ND and Zidek, J.V. (1994). "Multivariate Spatial Interpolation and Exposure to Air Pollutants". Canadian Journal of Statistics. To appear.
- Burnett, RT, Dales RE, Rainenne MD and Krewski D (1992). "The Relationship Between Hospital Admissions and Ambient Air Pollution in Ontario, Canada: A Preliminary Report". Unpublished Report.
- Duddek, C, Le N. D., Sun W, White R, Wong H, Zidek JV (PI) (1994). "Assessing the Impact of Ambient Air Pollution on Hospital Admissions Using Interpolated Exposure Estimates in Both Space and Time: Final Report to Health Canada under DSS Contract h4078-3-C059/01-SS". Unpublished Report.
- Johnson, Ted, Jim Capel, Roy Paul and Luke Wijnberg (1992a). "Estimation of carbon monoxide exposures and associated carboxyhemoglobin levels in Denver residents using a probabilistic version of NEM." EPA, Research Triangle Park, NC, July 1992.
- Johnson, Ted, Jim Capel, Roy Paul and Luke Wijnberg (1992b). "Estimation of carbon monoxide exposures and associated carboxyhemoglobin levels in Denver residents using a probabilistic version of NEM." Paper 91-145.01 presented at the 85th Annual Meeting of Air and Waste Management Association, Kansas City, June 1992.
- Johnson, T, Capel, J, McCoy, M and Warnasch, J (1994). "Estimation of carbon monoxide exposures and associated carboxyhemoglobin levels experienced by residents of Toronto, Ontario using a probabilistic version of nem." Draft Report to Health Canada.
- Le, ND, Sun, W and Zidek, JV (1994). "Bayesian Multivariate Spatial Interpolation with Systematically Missing Data." Submitted.
- Le, ND and Zidek, JV (1992). "Interpolation with Uncertain Spatial Covariance: A Bayesian Alternative to Kriging". *J. Mult. Anal*, 43, 351-74.
- McCurdy, Thomas, Richmond, H. Capel, Johnson, T. and Biller, W. (1993). "Estimating carbon monoxide exposures of denver residents under selected air quality scenarios." Paper 93-RA-116B.06 presented at the 86th Annual Meeting of Air and Waste Management Association, Denver, Colorado, June 1992.
- Sampson, P and Guttorp, P, (1992). "Nonparametric estimation of nonstationary spatial covariance structure". *J. Amer. Statist. Assoc.* Vol.87 No. 417, 108-119.
- Sun, W (1994). "Bayesian Multivariate Interpolation with Missing Data and Its Applications". Unpublished Ph.D. Thesis, Department of Statistics, University of British Columbia, Vancouver, Canada.

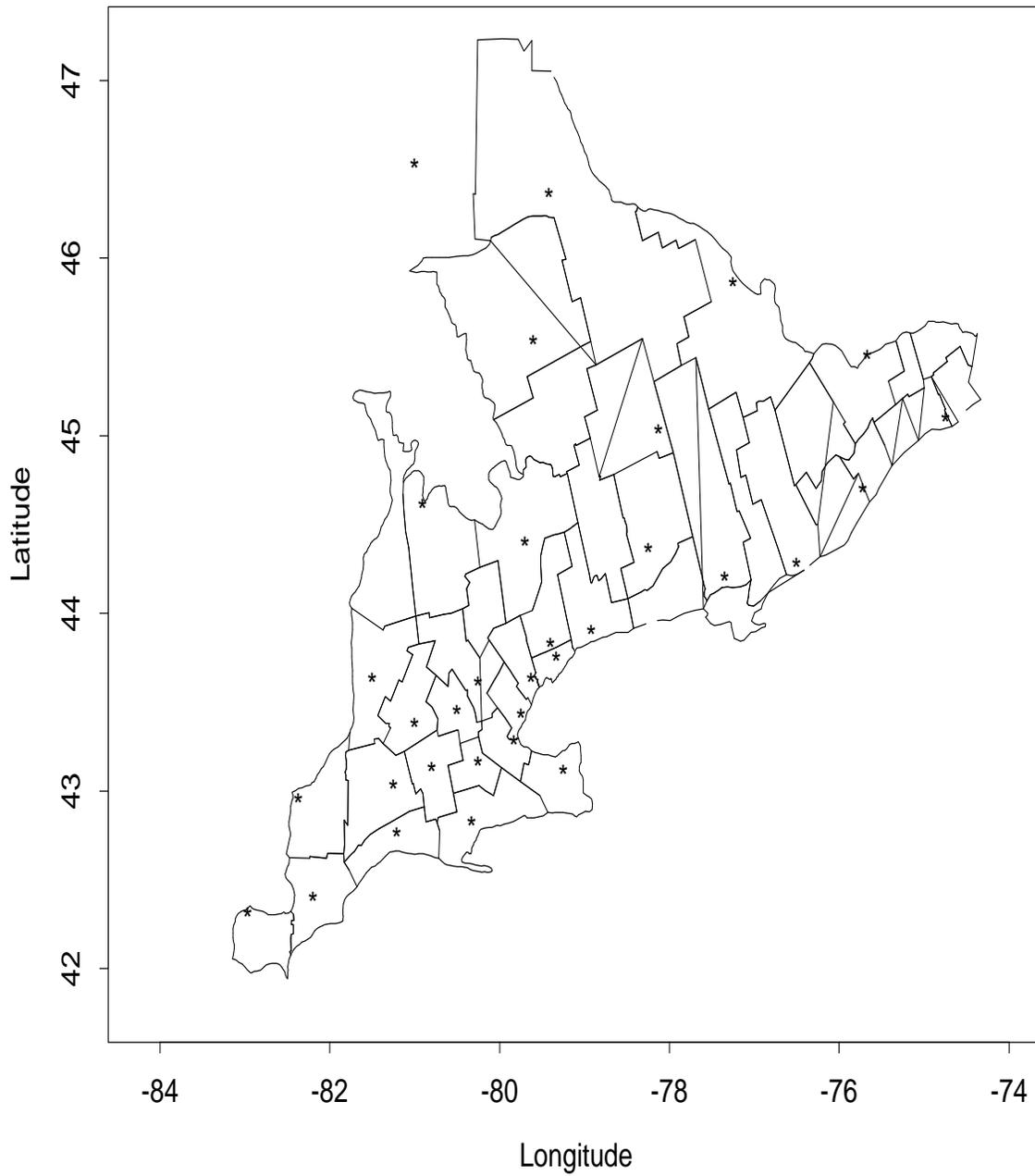


Figure 3.4: Locations of selected sites in Southern Ontario plotted with Census Subdivision's boundaries, where monthly interpolated pollution levels are needed.

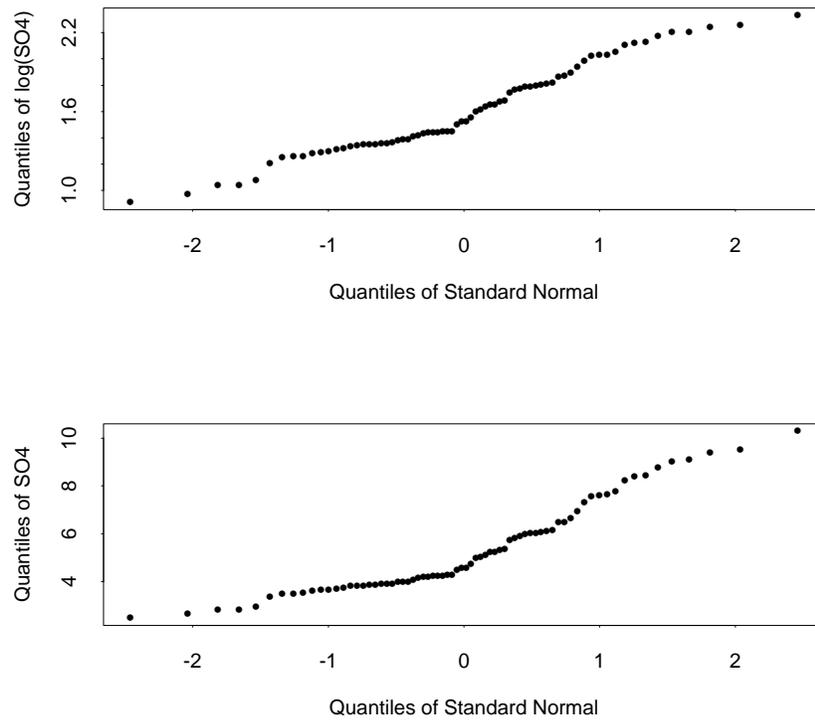
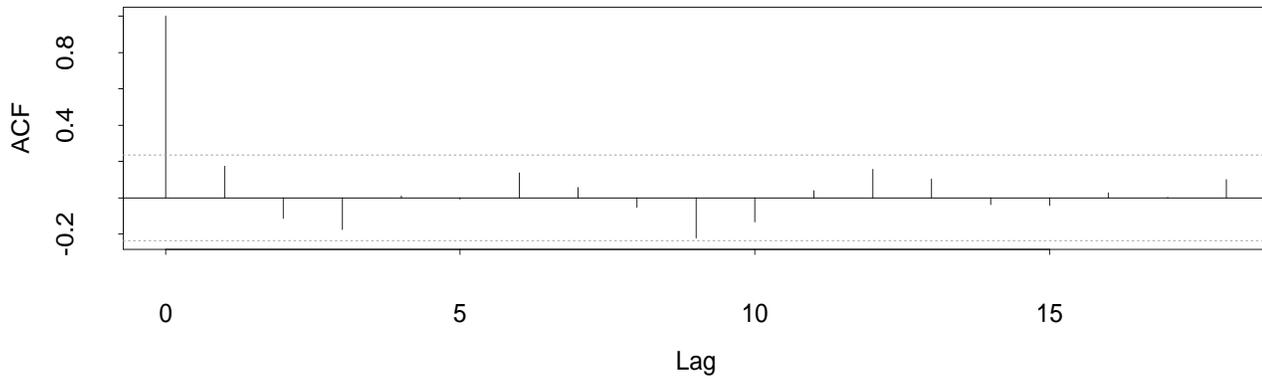


Figure 3.5: Normal quantile-quantile plots for original and log-transformed monthly levels of SO_4 in $\mu g/m^3$ at Gauged Site 4.

Series : SO4



Series : SO4

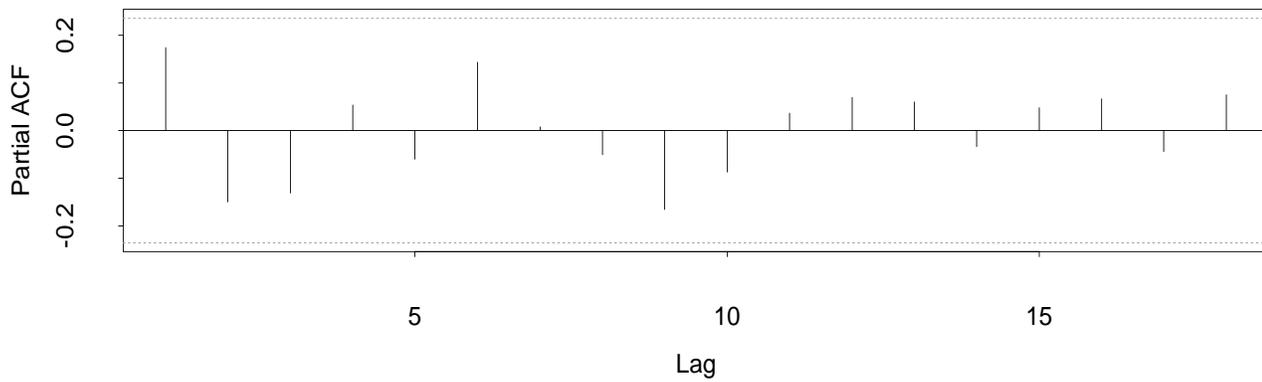
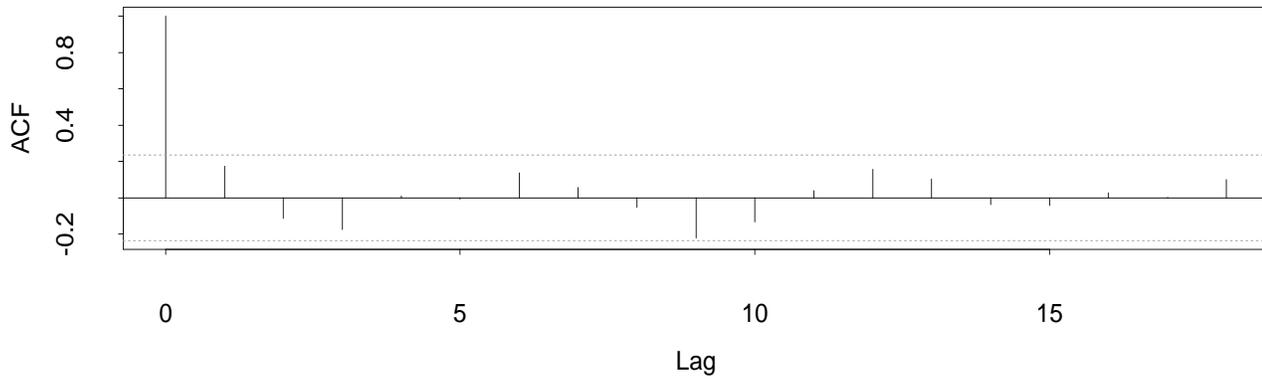


Figure 3.6: Plots for autocorrelation and partial autocorrelation of monthly, log-transformed levels of SO_4 in $\mu g/m^3$ at Gauged Site 4.

Series : SO4



Series : SO4

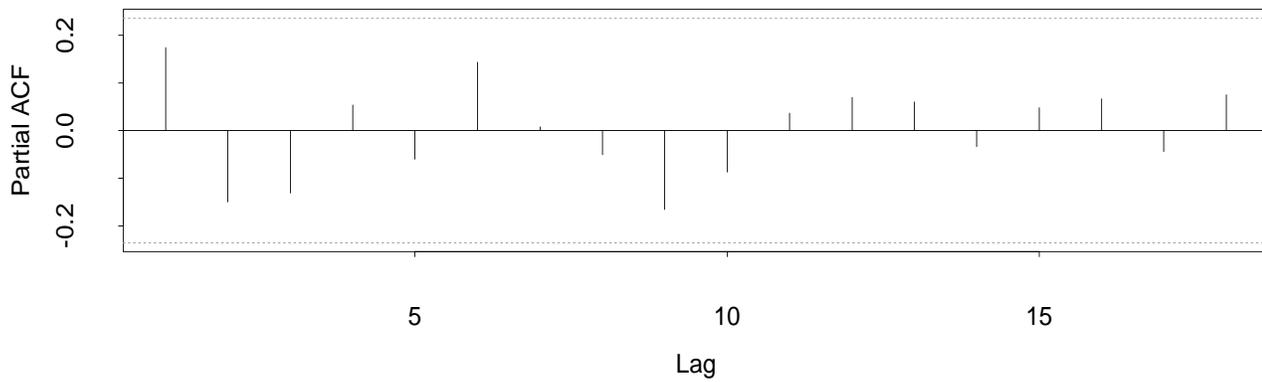


Figure 3.7: Plots for autocorrelation and partial autocorrelation of monthly, log-transformed levels of SO_4 in $\mu g/m^3$ at Gauged Site 4.

The Observed and Fitted Values at Site 5

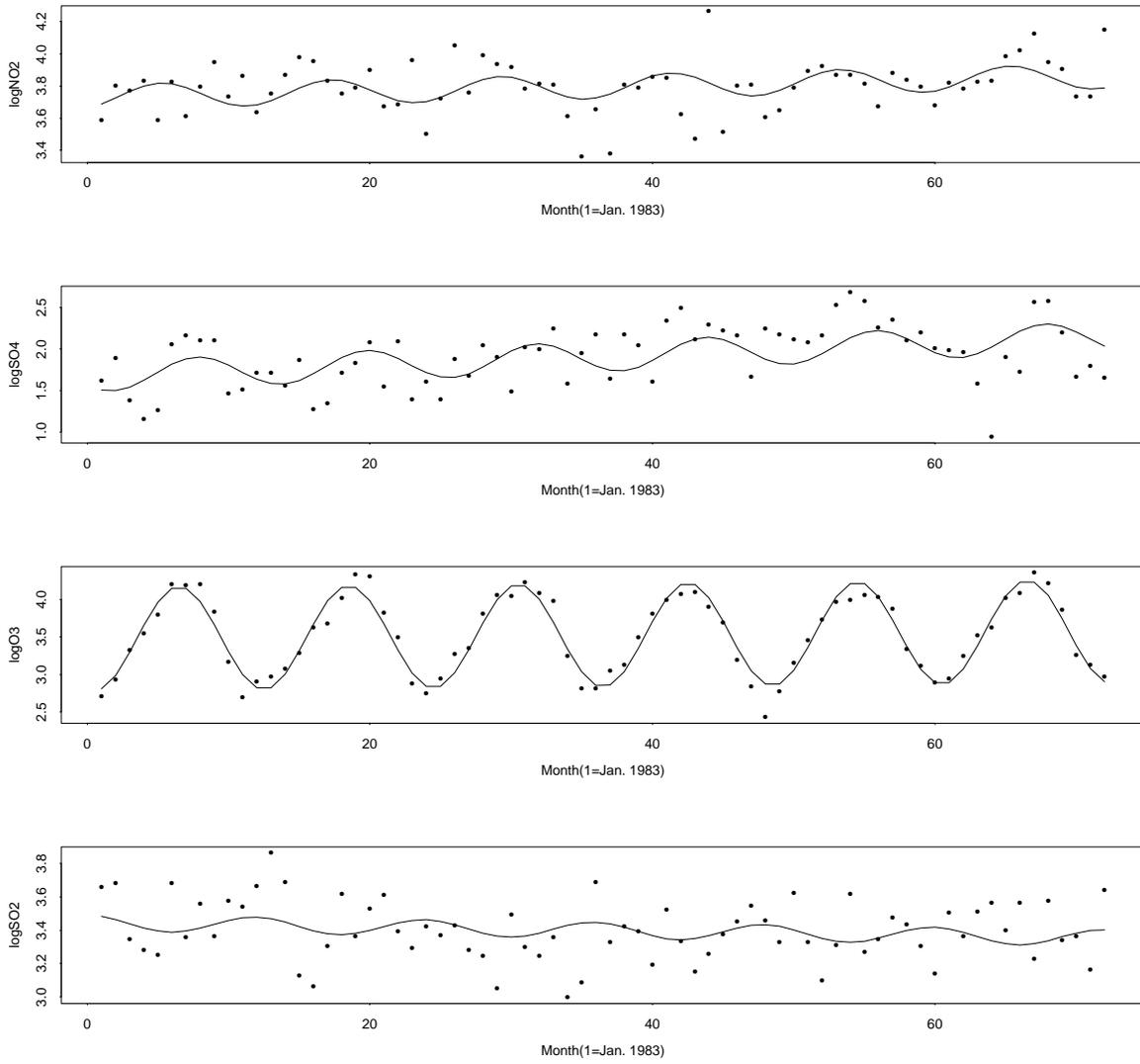
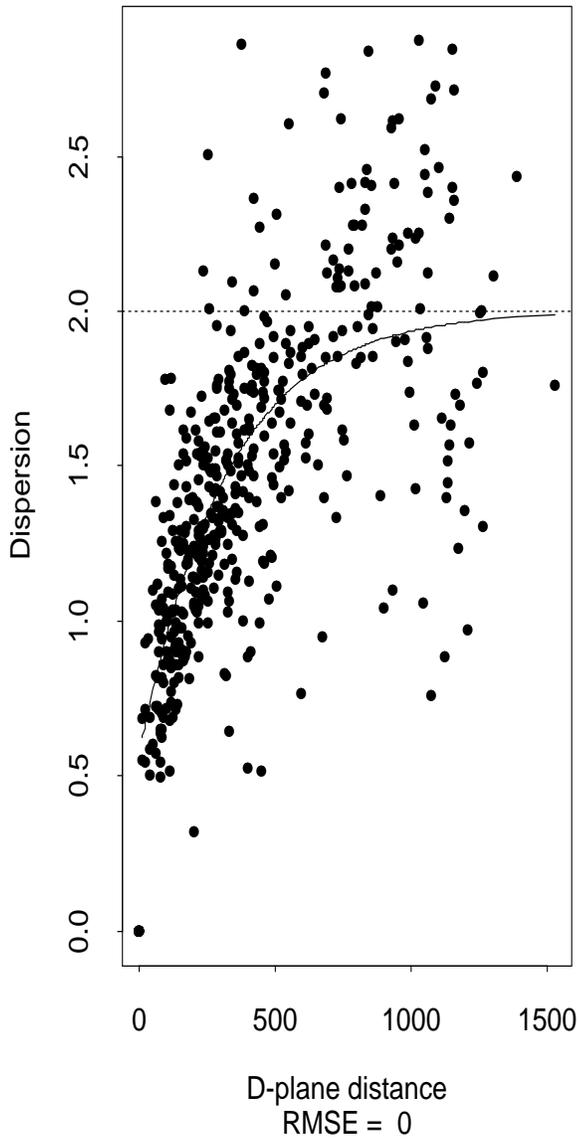


Figure 3.8: Plots for monthly observed and fitted, log-transformed levels of O_3 in ppb , SO_2 , NO_2 and SO_4 in $\mu g/m^3$, at Gauged Site 5.

Fitted Variogram is Exponential



D-plane Coordinates

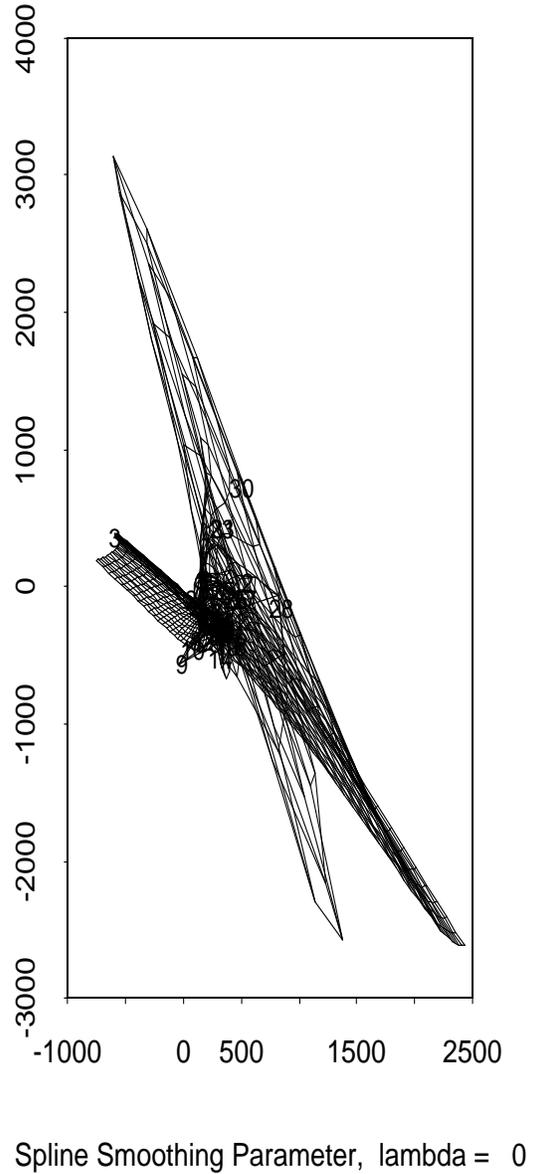
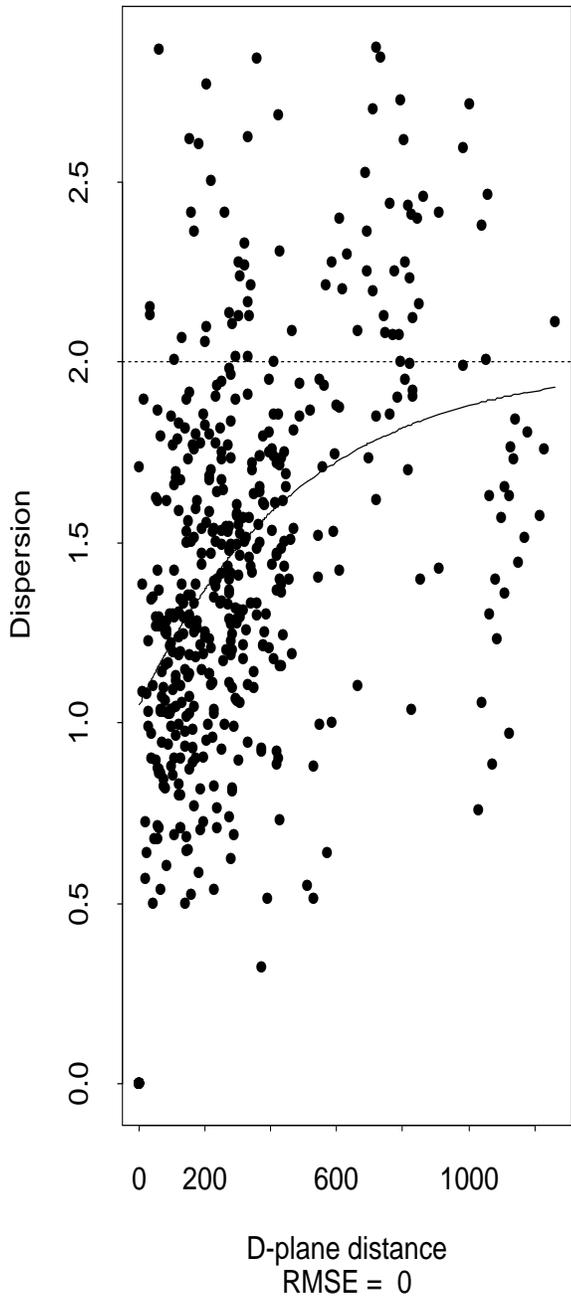
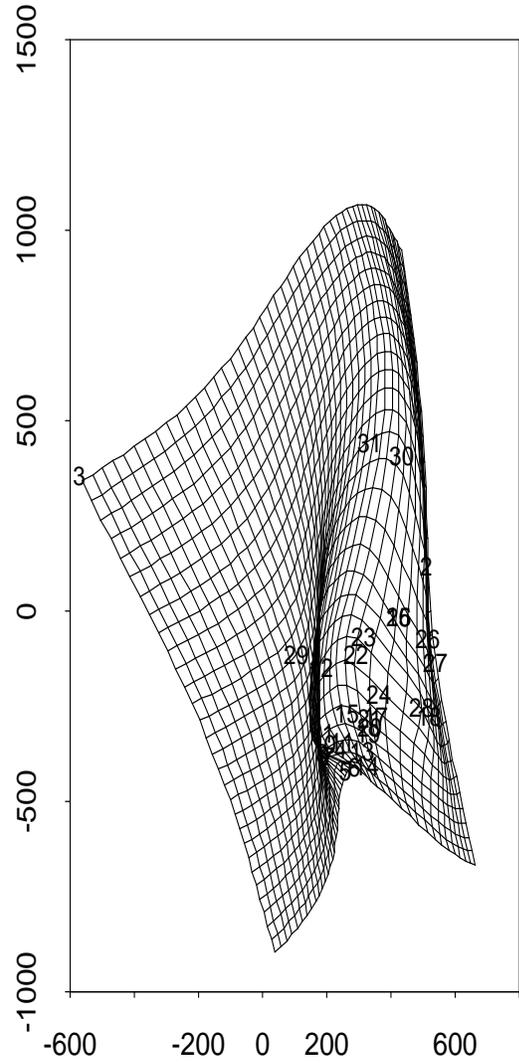


Figure 3.9: A rough checkerboard obtained in the SG step.

Fitted Variogram is Exponential



D-plane Coordinates



Spline Smoothing Parameter, lambda = 2500

Figure 3.10: A smoother checkerboard obtained in the SG step.

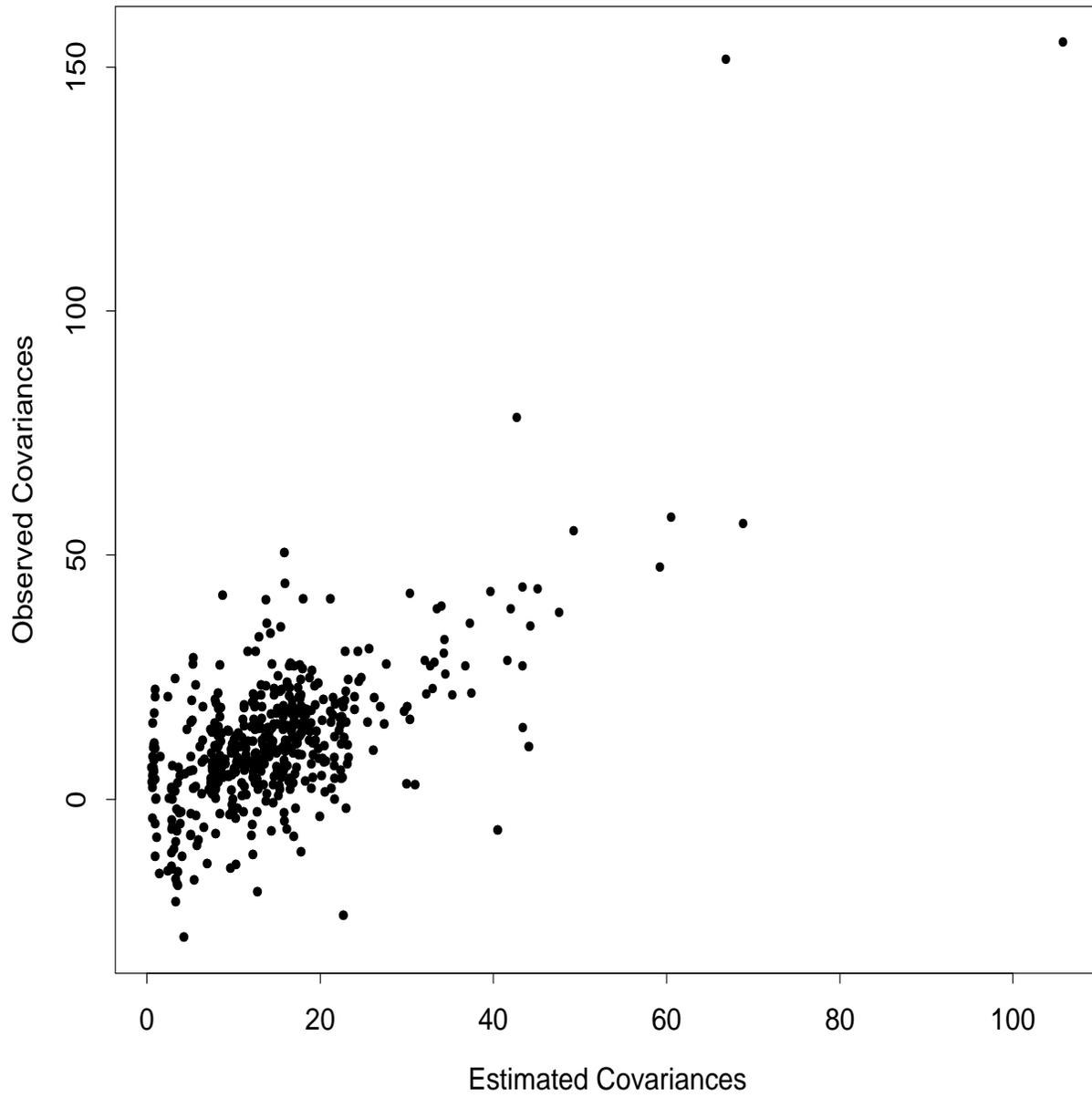


Figure 3.11: Scatter plot of observed covariances vs predicted covariances obtained by the GS approach.

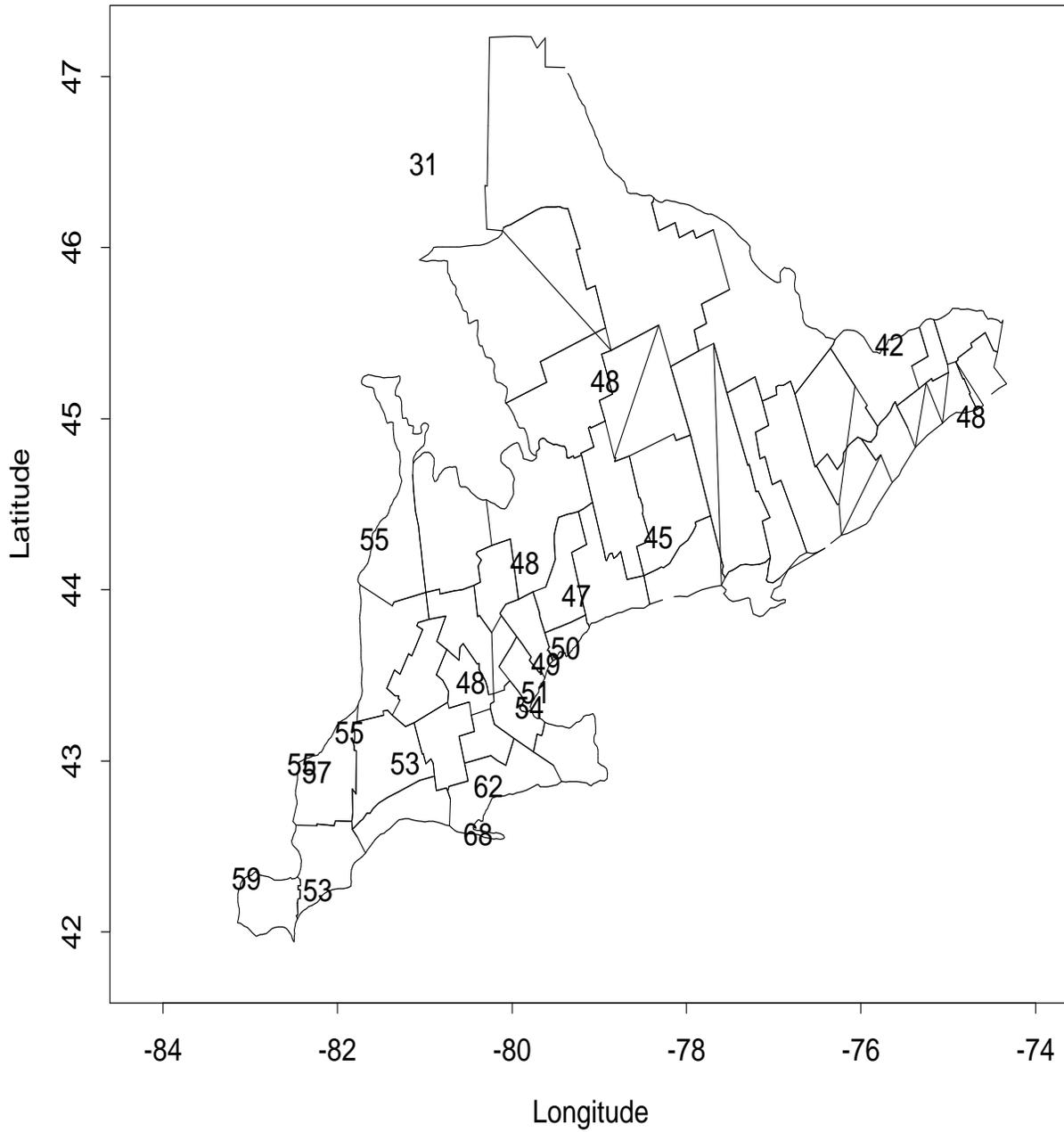


Figure 3.12: Means of monthly levels of O_3 in *ppb*, in summers of 1983 ~ 1988 at gauged sites in Southern Ontario plotted with CSD boundaries.

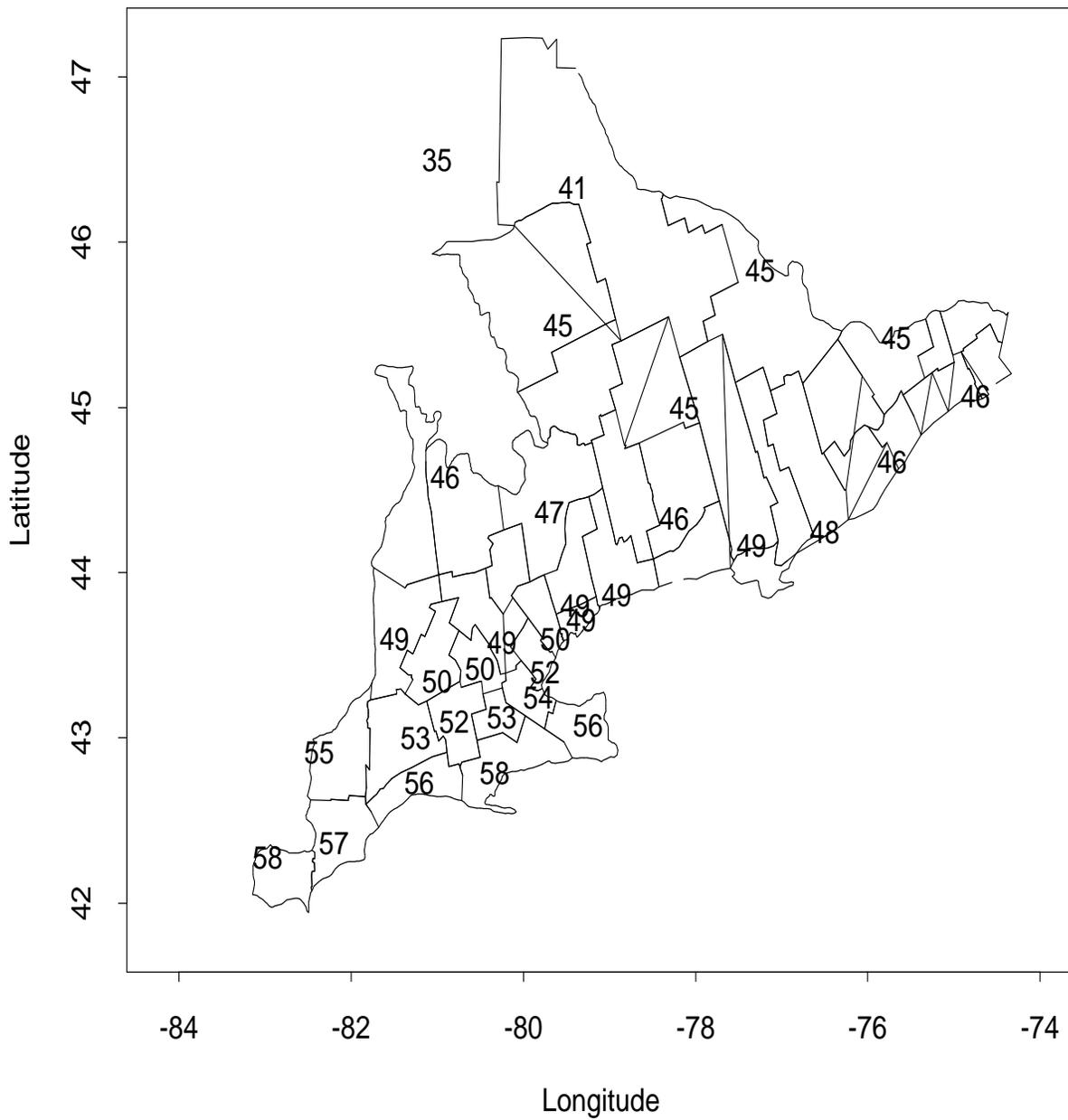


Figure 3.13: Means of monthly levels of O_3 in *ppb*, in summers of 1983 ~ 1988 at selected sites in Southern Ontario plotted with CSD boundaries.

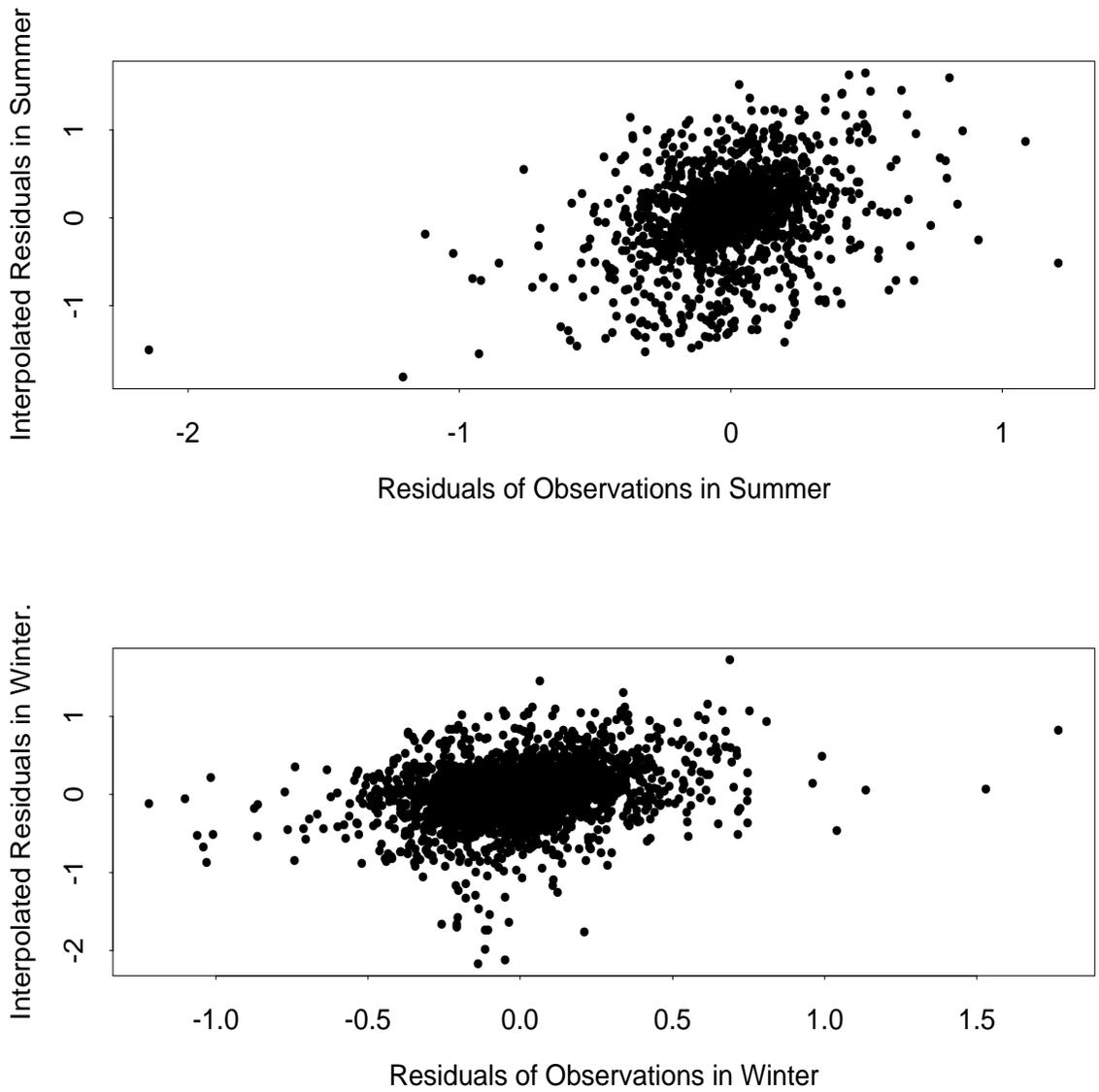


Figure 3.14: Scatter plots for residuals of monthly observed pollutant levels against residuals of interpolated levels at the log-scale in winter and summer respectively, where levels of O_3 are in ppb ; SO_2 , NO_2 and SO_4 in $\mu g/m^3$.

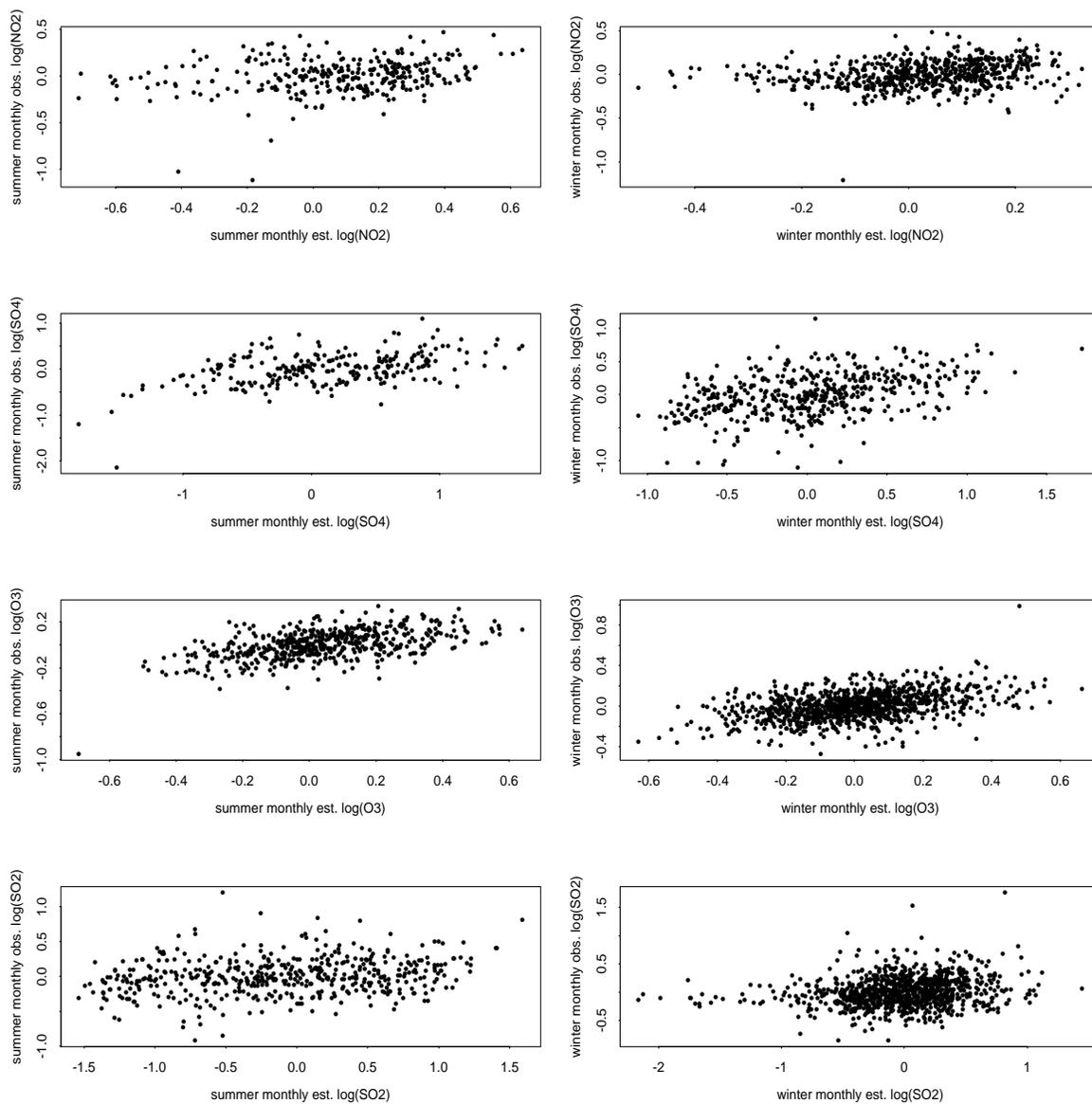


Figure 3.15: Pollutant-wise scatter plots for residuals of monthly observed pollutant levels against residuals of interpolated levels at the log-scale in winter and summer respectively, where levels of O_3 are in ppb ; SO_2 , NO_2 and SO_4 in $\mu g/m^3$.

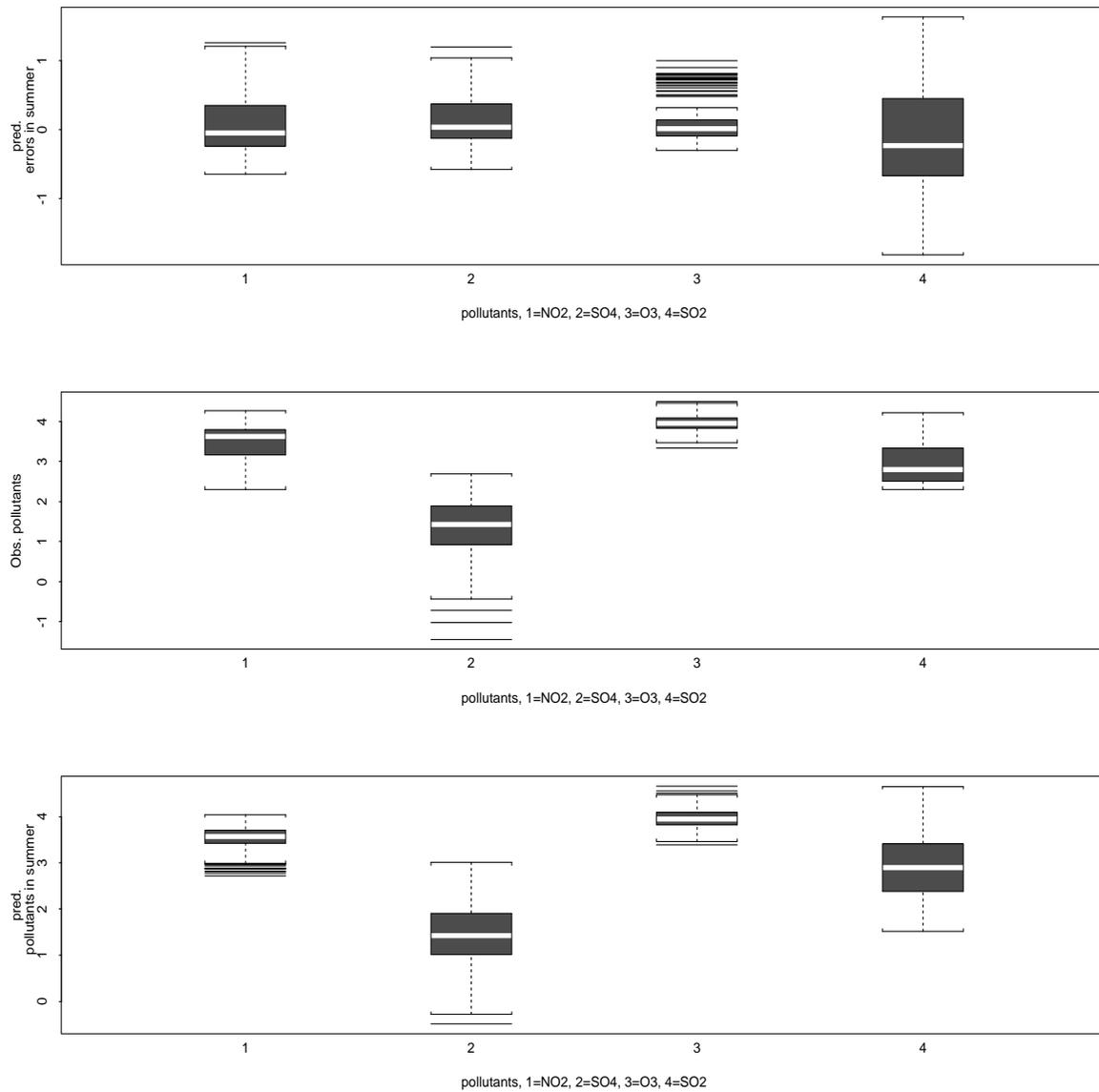


Figure 3.16: Boxplots for predicted, observed and residual levels of log-transformed, monthly concentrations of O_3 in ppb , SO_2 , NO_2 and SO_4 in $\mu g/m^3$, respectively.

Appendix A

Appendix to Chapter 1: Unix to EPA/NCC FTP File Transfers

In this Appendix we give a step-by-step guide to transferring files (“ftping”) from an EPA/NCC machine to one operating in Unix. We will describe here just the procedure for getting files, as this seems to be the most likely process to be needed.

Step 1 Sign on to your Unix account using your account ID taken to be “ID” for expository purposes.

Step 2 The NCC operating system can store a set of files in a single file called a “partitioned data set (PDS).” PDS’s must be handled somewhat differently than ordinary files. So the character of the file you want to ‘get’ from the NCC must be determined in advance. Instructions for dealing with PDS’s begin with Step 18.

Step 3 To get a single file, create and/or move into the directory in which you want to store that file.

****To change directories in unix type ‘cd subdirectory name’ (You can only change to a subdirectory of the directory in which you presently reside. If you need to go back up to your root directory simply type ‘cd’ on its own.)**

Step 4 Type ‘ftp epaibm.rtpnc.epa.gov’ at the Unix prompt and press <return>.

****You will now see on your screen: “Connected to epaibm.rtpnc.epa.gov.”**

```
220-#TCPFTP IBM MVS V2R2.1 at NCCIBM1.RTPNC.EPA.GOV,  
14:57:32 on 08/23/94  
220 Connection will close if idle for more than 15 minutes.  
Name (epaibm.rtpnc.epa.gov:ID):
```

Step 5 Enter your name and press <return> and then you will be prompted to enter your password, consisting of 5 letters followed by a single digit. Enter it and then press <return>.

****You will now see this prompt:**

```
ftp>
```

Step 6 Type 'prompt' and press <return>.

Step 7 You are presently in your EPA/NCC account which may or may not contain files depending on your previous activities on the system. Type 'cdup' to get to the root directory.

****The screen will look like this:**

```
ftp> cdup  
250 " " is working directory name prefix.
```

Step 8 Most of the pNEM files are saved in the NCC directory named 'jlcpeii' . But some are in 'mxkpeii', 'jlcnam', and 'jlcnaoz'. To get files in the jlcpeii directory type 'cd jlcpeii' and press <return>.

****The screen of our monitor will look like this:**

```
ftp> cd jlcpeii  
250 "JLCPEII." is working directory name prefix.
```

Step 9 To display the contents of this directory type 'ls' and press <return>.

**Upon typing ls you will get a list of everything in the directory:

```
ftp> ls
200 Port request OK.
125 List started OK.
```

**This list happens to be very long (several pages) and at the end of the list you will see:

```
250 List completed successfully.
2098 bytes received in 3.4 seconds (0.6 Kbytes/s)
ftp>
```

Step 10 Once you have decided you want to get the file called for this exposition, filename, type 'get filename' and press <return>.

**If for example, you were getting 'cannem.asc.data' your screen will look like this:

```
ftp> get cannem.asc.data
200 Port request OK.
125 Sending data set JLCPEII.CANNEM.ASC.DATA FIXrecfm 700
250 Transfer completed successfully.
local: cannem.asc.data remote: cannem.asc.data
4914 bytes received in 8.3 seconds (0.58 Kbytes/s)
ftp>
```

Step 11 If you want another file from this directory repeat step 10.

Step 12 If you accidentally try to get a PDS set rather than a single file, the system will inform you that your transfer procedure is improper. To get this PDS will entail logging

out of NCC (see the Guide to NCC Services in this Appendix) and in Unix, making a new directory with the appropriate name to house the PDS. [The NCC system does not, like Unix, have a convenient hierarchial file structure. The PDS serves as a crude device for achieving the same objective.] Go to Step 18.

**If you try to get 'cannem.cntl' for example, you will get the following message on your screen:

```
ftp> get cannem.cntl
200 Port request OK.
550 Retrieve of a whole Partitioned data set is not supported. Use MGET
for the
ftp>
```

Step 13 To get a file from a different directory on NCC then you must type 'cdup' until you get to the root directory. To change to any other main directory, for example 'mxkpeii', type 'cd directory name'.

. **After you have typed 'cdup' and then cd 'mxkpeii' you should see this:

```
ftp> cdup
250 " " is working directory name prefix.
ftp> cd mxkpeii
250 "MXKPEIIP" is working directory name prefix.
ftp>
```

Step 14 At this point you can either 'ls' to display this directory or you can 'get' a file. If you would like mxkpeii to appear as part of the local filename, type 'cdup' to get to the root directory. Now when you type 'get filename' you have to include mxkpeii as well. Similarly, you can do this with the jlcepii files to have jlcepii appear in front of all the filenames.

**Assuming that you would like mxkpeii to appear as part of the filename and you type the above mentioned commands at the ftp prompt the following should happen:

```
ftp>cdup
250 “ ” is working directory name prefix.
ftp> get mxkpeii.canada.aq.co.data
200 Port request OK.
150-Waiting for recall of data set MXKPEII.CANADA.AQ.CO.DATA
150 Sending data set MXKPEII.CANADA.AQ.CO.DATA FIXrecfm 127
250 Transfer completed successfully.
local: mxkpeii.canada.aq.co.data remote: mxkpeii.canada.aq.co.data
16080 bytes received in 32 seconds (0.5 Kbytes/s)
ftp>
```

Step 15 To abort any command/request press <Ctrl>. This will take you back to the ftp prompt. (It may take a minute, so don't panic!)

Step 16 To get help type 'help'.

**This screen will display:

```
ftp> help
```

Commands may be abbreviated. Commands are:

!	cr	macdef	proxy	send
\$	delete	mdelete	sendport	status
account	debug	mdir	put	struct
append	dir	mget	pwd	unique
ascii	disconnect	mkdir	quit	tenex
bell	form	mls	quote	trace
binary	get	mode	recv	type
bye	glob	mput	remotehelp	user
case	hash	nmap	rename	verbose
cd	help	ntrans	reset	?
cdup	lcd	open	rmdir	
close	ls	prompt	runique	

**A brief description of the command is given when you type 'help command name' as shown below, 'ls', 'cd', and 'cdup' being the three most used:

```
ftp> help ls
```

```
ls nlist contents of remote directory
```

```
ftp> help help
```

```
help print local help information
```

Step 17 To disconnect from the EPA/NCC system type 'quit'.

**You screen should look like this:

```
ftp> quit 221 Quit command received. Goodbye.
```

Step 18 If you want to get a PDS (starting from Unix), create a directory with the same name as the PDS and move into that new directory.

**To create a new directory type 'mkdir directory name' and to change into that directory type 'cd directory name'.

Step 19 Once in the new directory, type 'ftp epaibm.rtpnc.ep.gov' and follow Steps 4-7.

Step 20 Now that you are in the root directory you must type 'cd name of the partitioned data set'

**If the name you typed is truly a partitioned data set that information will appear on your screen. For example, if you wished to get 'jlcpeii.cannem.cntl', you would see:

```
ftp> cd jlcpeii.cannem.cntl
250 "JLCPEII.CANNEM.CNTL" partitioned data set is working directory.
```

Step 21 To start sending the information type 'mget *' .

**Your screen will look like this:

```
ftp> mget *
200 Port request OK.
125 Sending data set JLCPEII.CANNEM.CNTL(ALLCPOOL) FIXrecfm
80
```

Step 22 When the file transmission is finished the ftp prompt will appear again. Unless you want to put another PDS into the same Unix directory you have to type 'quit' and create another Unix directory and then change into it and ftp back to NCC.

Step 23 If for some reason you want to put another file or PDS into the same Unix directory type 'cdup' until you are in the directory you want.

**In the above case your screen should look like this:

```
ftp> cdup
250 "JLCPEII.CANNEM." is working directory name prefix.
ftp> cdup
250 "JLCPEII." is working directory name prefix.
ftp> cdup
250 "" is working directory name prefix.
ftp>
```

**The command 'cdup' will always take you to your parent directory, not to the root directory. you must keep typing 'cdup' until you reach the root directory. For example, if you are in jlcpeii.cannem.asc.data, you would type 'cdup' four times to get to the root directory.

```
ftp> cd jlcpeii.cannem.asc.data
250 "JLCPEII.CANNEM.ASC.DATA" is working directory name prefix.
ftp> cdup
250 "JLCPEII.CANNEM.ASC." is working directory name prefix.
ftp> cdup
250 "JLCPEII.CANNEM." is working directory name prefix.
ftp> cdup
250 "JLCPEII." is working directory name prefix.
ftp> cdup
250 "" is working directory name prefix.
```

Appendix B

Appendix for Chapter 2 and 3: Data Sets and Outputs

B.1 Data Sets and Their Description

In this section, following files are described in a uniform style:

QST.DATA:	questionnaire data from Cincinnati
CPREP.DATA:	diary data from Cincinnati
SAMPLE.DATA:	diary data from Denver
DENVER.TEMP:	Denver meteorology data
WASH.TEMP:	Washington D.C. meteorology data
DC.DATA:	diary data from Washington D.C.
DC.Q.DATA:	questionnaire data from Washington D.C.
NREC.CCPOOL:	pool index file for Cincinnati's pooled activity data
NREC.CDPOOL:	pool index file for Cincinnati & Denver's pooled activity data
NREC.CWPOOL:	pool index file for Cincinnati, Denver and Washington D.C.'s pooled activity data
CPOOL.DATA:	pooled activity data file
MET.DATA:	meteorology data
AQ.CO.DATA:	raw CO data
HRLY.DATA:	processed and filled-in air quality data for CO
HRAVG.DATA:	model output file of CONEM
MECONC.DATA:	model output file of CONEM

B.1.1 QST: Questionnaire Data for Cincinnati

File length: 4840
Source: survey from Cincinnati
Reading program: CCPOOL
Fortran code and head of the file:

```
51 READ(11,10,END=98)JPID,IWAVE,Q6,Q21,Q23
   &,Q24,Q25,Q29,Q38,Q39,Q43      ,Q51,Q55,Q56
   &,Q62,Q69,QC
10  FORMAT(1X,I7,6X,I3,10X,I2,40X,I2,2X,I3,/14X,I4,F5.1,15X,I3
   &,/54X,I3,I3,11X,I5
   &,/41X,I2,6X,I3,I3,10X,I2
   &,/18X,I3,59X,A2)

222 10023 23 2 5 2 1 3 1 7 5 1 4 3 1 40000 0 2 30 3 0 1 40 1 2 6
222 22435 996 0.0 0.0 0.0 0.0 4 35.0 1.5 1.5 1.5 10.0 10.0
222 33643 6.0 6.0 3.0 3.0 7.0 1.0 8.0 8.0 7 5 2.0 0
222 44466 0 815 1515 5 0 2 0 1 1 5 0 74 9 2 3 2 2 3 3 3 3 2
222 56775 3 2 0 1 25 2 1
```

Variables and format:

PID: individual's id I7
Q24: job code I3
Q51: sex I1
Q55: year of birth I2
Q56: month of birth I2
QC: quality code A2

Remarks:

- A: 968 individuals, 5 lines for each person
- B: at least 69 questions were asked in the questionnaire, but only the questions listed above are used in the CCPOOL program
- C: 171 types of occupations were categorized into two groups, work and no-work status.
- D: QC was used to screen bad data
- E: finally, 968 people were divided in 14 demographics groups by age range, sex and working status.
- F: with new survey data, recoding is necessary since AGE has to be defined according to study year and JOB CODE varies from country to country

B.1.2 CPREP.DATA: Diary Data for Cincinnati

File length: 113710
Source: survey from Cincinnati
Reading program: CCPOOL
Fortran code and head of the file:

```
55 READ(8,15,END=97) JPID,IMO,IDAY,DATA ,DQC,ITEMP
```

```

&,DATA2
15  FORMAT(1X,I7,3X,2I2,1X,A28,T43,A2,27X,I3,5X,A11)

6830196    3 7 1900 41  3 13 19 21 23 25  A/...../ 59 44  201310 2602
6830196    3 7 1920 43  3 13 19 21 23 25  A/...../ 59 44  101310 -12
6830196    3 7 1930 12  3 13 19 21 23 25  A/...../ 59 44  301310 -12
6830196    3 7 2000 12  3 13 19 21 23 25  A/...../ 59 44   11310 -12

```

Variables and format:

PID:	individual's id	I7
MONTH:	month of the event	I2
DAY:	day of the event	I2
TEMP:	maximum temperature	I3
HOUR:	starting hour of the event	I2
MINUTE:	starting minute of the event	I2
DUR:	duration of the event	I2
KME:	mircoenvironment	I2
IDIST:	home or work district	I1
ISMOKE:	smoker present or not	I1
BRCAT	breath category	I1

Remarks:

- A: there are 2445 person-days activities in this file, average 2.5 days' activities for each person
- B: only the above information are saved in the CPOOL.DATA
- C: PID is the link between the two files QST and CPREP.DATA
- D: there are 37 mircoenvironments. They are directly available for the Cincinnati activities data but has to be converted from location and travel mode for Denver & Washington's data.
- E: 4 types of breath categories are directly available from Cincinnati's activities data but has to be simulated for Denver & Washington D.C.'s data.
- F: CCPOOL pools 112 pools each with different numbers of records formed and saved into a direct access file CPOOL.DATA.

B.1.3 SAMPLE.DATA: Diary Data for Denver

File length: 30429
Source: survey from Denver
Reading program: CDPOOL
Fortran code and head of the file:

```

READ(8,10,END=99)PID,IMO,IDAY,IYR,IHR(I),IMIN(I),EVENT(I)
&,IGAS,IJOB,ISEX,IAGE
10  FORMAT(6X,I7,3I2,2X,2I2,4X,A36,T121,I1,T167,I3,2I2)

2110807022283001900    1402 41.03  .....
174816211080702228351193800550902 41.03  .....

```


Remarks:

A: meteorology data for survey period 01/10/82 to 31/03/83

B: only the daily maximum temperature was used

C: with Cincinnati, same information was given together with diary data

B.1.5 DC.DATA: Diary Data for Washington D.C.

File length: 17264

Source: survey from Denver

Reading program: CWPOOL

Fortran code and head of the file:

```
      READ(8,10,END=99)  PID,IHR(I),IMIN(I),IMO,IDAY,IYR,EVENT(I)
10  FORMAT(I7, 18X,I2,I2,3X,3I2,T1,A45)
```

2000636	18602009800	2	1	21900	121782	24	.0500	2	7002001	1566.499947
2000636	18702009800	2	1	21924	121782	36	.0500	2	7002001	1566.499947
2000636	18702009800	2	1	22000	121782	60	.0500	2	7002001	1566.499947
2000636	18702009800	2	1	22100	121782	60	.0500	2	7002001	1566.499947
2000636	18702009800	2	1	22200	121782	37	.0500	2	7002001	1566.499947

Remarks:

A: 418 individuals in the data set and 415 of person-days activities, so this is a one day survey

B: same group of variables are saved in CPOOL.DATA and NREC.CDPOOL, the latter being index file of the updated pool file

C: microenvironment is found from location and travel mode

D: breathing rate categories are not directly available, and have to be simulated

B.1.6 DC.Q.DATA: Questionnaire Data for Washington D.C.

File length: 712

Source: survey from Washington D.C.

Reading program: CWPOOL

Fortran code and head of the file:

```
      READ( 12,FMT=11,END=150) (IPID(IREC,J),J=1,5)
11  FORMAT( I8,I3,I2,I2,i4)
```

2000214	339	1	998
2000636	221	1	391
2000651	233	2	222
2001014	143	2	235
2001022	253	1	265

Variables and format:

PID	individual ID	I8
IGAS	gas stove code	I3
IAGE	age	I2
ISEX	sex	I2
IJOB	occupation code	I4

Remarks:

A: this file contains 712 people's demographical profile, the 418 person in the DC.DATA are included

B: although gas stove code is saved in the CPOOL.DATA, it is not used in CONEM

B.1.7 NREC.CCPOOL(NREC.CDPOOL,NREC.CWPOOL): Index File of the CPOOL.DATA File

File length: 112
Source: created by CCPOOL(CDPOOL,CWPOOL)
Writing program: CCPOOL(CDPOOL,CWPOOL)
Reading program: CONEM
Fortran code and head of the file:

```
WRITE(6,102)IDGRP,SEAS(J),TRANGE(J),DOW(J),NREC(I)
102  FORMAT(I3,1X,A6,1X,A4,1X,A8,I4)

1WINTERWEEKDAY 43LOW
1WINTERWEEKEND 20LOW
1WINTERWEEKDAY 61HIGH
1WINTERWEEKEND 25HIGH
1SUMMERWEEKDAY 32LOW
1SUMMERWEEKEND 5LOW
1SUMMERWEEKDAY 20HIGH
1SUMMERWEEKEND 17HIGH
2WINTERWEEKDAY 27LOW
2WINTERWEEKEND 12LOW
```

Variables and format:

DGRP	demo group	I2
SEASON	season of the pool	A6
DAYTYPE	day type of the pool	A7
TEMP	temperature of the pool	A4
COUNT	record counter of the pool	I3

Remarks:

A: NREC.CDPOOL is the index file after adding Denver survey data, NREC.CWPOOL and Washington D.C.'s data

B: CONEM reads NREC.CWPOOL

C: 3568 person-days, 2445 from Cincinnati, 708 from Denver, 415 from Washington D.C., are distributed into 112 pools which have an average size of 32 a maximum of 209 and a minimum of 1

B.1.8 CPOOL.DATA: Pool Data

File length: direct access file
Source: created by CCPOOL(added by CDPOOL,CWPOOL)
Writing program: CPOOL
Reading program: CONEM
Fortran code:

```
OPEN(UNIT=7,STATUS='NEW',ACCESS='DIRECT'  
&,&,FORM='FORMATTED',RECL=3229)  
  
WRITE(UNIT=7,FMT=100,REC=IREC)IDGRP,SEASON(LM0),JTEMP,DAYTYP  
&,&,Q6,Q21,(DATA1(J),J=1,I)  
100 FORMAT(I2,3I1,'1',2I2,111A29)
```

Remarks:

- A: direct access file, enabling quick record retrieval
- B: it is accessed by record with fixed length 3229(bytes) which is the maximum capacity a record can have
- C: each record consists of variables DGRP, SEASON,TEMPERATURE, DAYTYPE and a series of EVENTS which contains HOUR, MINUTE,DUR, KME, IDIST, ISMOKE and BRCAT.
The number of events within records varies from record to record, but the maximum length was set to 111. DGRP, SEASON,TEMPERATURE and DAYTYPE take 10 bytes and each EVENT takes 29 bytes, so this make up the length of record $3229 = 10 + 111*29$
- D: The maximum number of records within each pool was set to 325 by the POOL program while the actual maximum records within each pool is 209 after accumulating all 3 city's data

B.1.9 MET.DATA: Canadian Meteorology Data

File length 5481
Source: Statistics Canada
Reading program: CONEM(cocal.for)
Fortran code and head of the file:

```
READ(8,40,END=98) JYR,JDAY,JMAX,AVGTMP,JCITY  
40 FORMAT(I3,I4,I4,4X,I4,16X,I3)  
  
88 1 38 23 31 30  
88 2 36 22 29 30  
88 3 38 22 30 30  
88 4 36 26 31 30  
88 5 38 31 35 30  
88 6 39 32 36 30  
88 7 42 31 37 30  
88 8 38 29 34 30  
88 9 46 36 41 30  
88 10 43 35 39 30
```

Variables and format:

YEAR	year of the day	I3
DAY	julian day	I4
MAXT	maximum temperature	I4
MINT	minimum temperature	I4
AVGT	average temperature	I4
CITY	city code	I2

Remarks:

- A: there are 3 cities — Toronto, Vancouver, Montreal and 5 years' 1988-92 meteorology data
- B: minimum temperature is not used in the CONEM program
- C: AVGT is used in aer1.for to determine window status

B.1.10 AQ.CO.DATA: Raw CO Data

File length: 10053

Source: Health Canada

Head of the file:

```
1988010100506040224 0.0 0.0 0.0 0.0 0.0 0.0 /...../0.0 0.0 0.0 0.0 0.0 0.0
1988010200506040224 0.0 0.0 1.0 0.0 0.0 0.0 /...../0.0 0.0 0.0 0.0 0.0 1.0
1988010300506040224 0.3 0.0 1.0 1.0 0.0 0.0 /...../0.0 0.0 0.0 0.0 1.0 1.0
1988010400506040224 0.3 0.0 1.0 1.0 0.0 0.0 /...../0.0 0.0 0.0 0.0 0.0 0.0
1988010500506040222 0.4 0.0 1.0 0.0 0.0 0.0 /...../1.0 0.0 0.0 0.0 0.0 0.0
1988010600506040224 0.3 0.0 1.0 0.0 0.0 0.0 /...../1.0 1.0 1.0 1.0 0.0 0.0
1988010700506040224 0.8 0.0 2.0 0.0 0.0 0.0 /...../1.0 1.0 1.0 1.0 1.0 0.0
1988010800506040224 1.5 0.0 4.0 0.0 0.0 0.0 /...../2.0 2.0 3.0 3.0 3.0 3.0
1988010900506040224 1.0 0.0 3.0 3.0 2.0 1.0 /...../1.0 1.0 1.0 1.0 1.0 1.0
1988011000506040224 0.4 0.0 1.0 1.0 1.0 1.0 /...../0.0 0.0 0.0 0.0 0.0 0.0
```

Remarks:

- A: data set contains Toronto's 6 districts monitor CO reading from 1988 to 1991
- B: missing data present

B.1.11 HRLY.DATA: Processed and Filled-in CO Data

File length: 4380

Source: filled-in data from AQ.CO.DATA

Reading program: CONEM

Fortran code and head of the file:

```
      READ(IUNIT,50) (MON(I,K,J),K=1,24)
50    FORMAT( 15X,12(1X,F4.1),/15X,12(1X,F4.1))

60410    11    1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0
60410    12    1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0
60410    21    1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  2.0  2.0  2.0  1.0  1.0
60410    22    1.0  1.0  1.0  2.0  2.0  2.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0
```

60410	31	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	1.0	1.0	1.0
60410	32	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
60410	41	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
60410	42	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
60410	51	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	1.0
60410	52	2.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0	2.0	2.0

Remarks:

- A: 6 districts' hourly CO reading started from 19:00pm are recorded for 1991
- B: an array MON(1:366,1:24,1:7) was created to save the monitor's CO reading where the 3rd subscript represents the district. District 7 represents the microenvironment in VEHICLE
- C: later, a big array MOA(1:24*366,1:2,1:37) is created to save the simulated CO exposure for given hour, home or work district and microenvironment. MON and hourly INDOOR emission values are the major componets of MOA

B.1.12 HRAVG.DATA: Output File of CONEM

File length: 148920
 Source: created by CONEM
 Reading program: COOUT

Fortran code and head of the file:

```

WRITE(31,150) IDGRP,HD,WD,IGAS,IDAY,NEVENT,(HRAV(I)
&,ELAVG(I),PROAVG(I),COHOUT(I),I=1,24)
150 FORMAT(4I2,2I3,24( F6.1, F5.1, F6.0, F5.2))

1 1 1 1 1 39 0.3 7.6 3. 0.00 /...../ 34. 0.00
1 1 1 1 2 36 0.3 13.2 4. 0.00 /...../ 59. 0.00
1 1 1 1 3 40 0.3 10.2 3. 0.00 /...../ 4. 0.00
1 1 1 1 4 34 1.3 12.9 16. 0.00 /...../ 15. 0.00
1 1 1 1 5 49 2.1 7.3 15. 0.00 /...../ 73. 0.00
1 1 1 1 6 33 1.4 29.7 42. 0.00 /...../ 11. 0.00
1 1 1 1 7 53 0.9 16.9 14. 0.00 /...../ 5. 0.00
1 1 1 1 8 60 3.0 8.1 27. 0.00 /...../ 3. 0.00
1 1 1 1 9 51 1.3 13.4 17. 0.00 /...../ 21. 0.00
1 1 1 1 10 36 1.4 12.2 17. 0.00 /...../ 10. 0.00

```

Variables and format:

IDGRP	demo group	I2
HD	home district	I2
WD	work district	I2
IGAS	gas use or not	I2
IDAY	julian day	I3
NEVENT	number of events	I3
HRAV(I)	hourly average CO	F6.1
ELAVG(I)	hourly average EVR	F5.1
PROAVG(I)	hourly average CO*EVR	F6.0
COHOUT(I)	carboxyhemoglobin level	F5.2

Remarks:

- A. 4 year long hourly time series, HRAV, ELAVG, PROAVG and COHOUT were generated for each cohort
- B. NEVENT is the event happened in that day, this number must greater than 24 (means each event can last at most 1 hour); this number designates the record sampled, different for different runs

B.1.13 MECONC.CO91: Output File of CONEM

File length: 1224

Source: created by CONEM

Reading program: MEDISP

Fortran code and head of the file:

```

WRITE(6,102)IDGRP,SEAS(J),TRANGE(J),DOW(J),NREC(I)
102  FORMAT(I3,1X,A6,1X,A4,1X,A8,I4)

1 1 1 1      4.43    4.70  /...../    0.00    0.00
1 1 1 1    16525.    82.  /...../     0.     0.
1 1 1 1    1066.     3.  /...../     0.     0.
1 1 1 2      4.42    4.70  /...../    0.00    0.00
1 1 1 2    16071.    82.  /...../     0.     0.
1 1 1 2    1070.     3.  /...../     0.     0.
1 2 2 1      4.41    4.42  /...../    0.00    0.00
1 2 2 1    17645.    82.  /...../     0.     0.
1 2 2 1    1089.     3.  /...../     0.     0.
1 2 2 2      4.42    4.70  /...../    0.00    0.00

```

Remarks:

- A. for each cohort, 3 set of statistics (each contain 37 elements corresponding to the 37 microenvironment) were given
- B. first statistic is the average CO concentration, second one is the cohort-hours spent by members of the demographic group in the specified microenvironment, third one number of person-occurences (exposure events) during which a member of the demographic group occupied the specified microenvironment

B.2 Reports Generated by Tabulation Programs

Following reports are from one run of the pNEM at UBC. Our study area is Toronto, our exposure period, 1991. The scenario is 'as is' — existing condition.

B.2.1 First Part of Report Generated by PNEM8HR — pNEM/CO Output Table Listing Average Carbon Monoxide Exposures by Cohort

GROUP	1	HOME	1	WORK	1	GAS	1	POP=	32942	1-hr mean	1.26	Daily Max Mean	2.98
GROUP	1	HOME	1	WORK	1	GAS	2	POP=	2423	1-hr mean	1.39	Daily Max Mean	3.25
GROUP	1	HOME	2	WORK	2	GAS	1	POP=	32216	1-hr mean	1.67	Daily Max Mean	3.73
GROUP	1	HOME	2	WORK	2	GAS	2	POP=	2369	1-hr mean	1.84	Daily Max Mean	4.11
GROUP	1	HOME	3	WORK	3	GAS	1	POP=	5710	1-hr mean	1.14	Daily Max Mean	2.89
GROUP	1	HOME	3	WORK	3	GAS	2	POP=	420	1-hr mean	1.26	Daily Max Mean	3.17
GROUP	1	HOME	4	WORK	4	GAS	1	POP=	8831	1-hr mean	1.25	Daily Max Mean	3.03
GROUP	1	HOME	4	WORK	4	GAS	2	POP=	650	1-hr mean	1.39	Daily Max Mean	3.28
GROUP	1	HOME	5	WORK	5	GAS	1	POP=	8831	1-hr mean	1.16	Daily Max Mean	2.86
GROUP	1	HOME	5	WORK	5	GAS	2	POP=	650	1-hr mean	1.31	Daily Max Mean	3.18
GROUP	1	HOME	6	WORK	6	GAS	1	POP=	33189	1-hr mean	1.28	Daily Max Mean	3.00
GROUP	1	HOME	6	WORK	6	GAS	2	POP=	2441	1-hr mean	1.45	Daily Max Mean	3.37
GROUP	2	HOME	1	WORK	1	GAS	1	POP=	31280	1-hr mean	1.15	Daily Max Mean	2.74
GROUP	2	HOME	1	WORK	1	GAS	2	POP=	2300	1-hr mean	1.29	Daily Max Mean	3.10
GROUP	2	HOME	2	WORK	2	GAS	1	POP=	27149	1-hr mean	1.63	Daily Max Mean	3.80
GROUP	2	HOME	2	WORK	2	GAS	2	POP=	1996	1-hr mean	1.73	Daily Max Mean	3.94
GROUP	2	HOME	3	WORK	3	GAS	1	POP=	4471	1-hr mean	1.04	Daily Max Mean	2.60
GROUP	2	HOME	3	WORK	3	GAS	2	POP=	329	1-hr mean	1.19	Daily Max Mean	2.97
GROUP	2	HOME	4	WORK	4	GAS	1	POP=	7860	1-hr mean	1.17	Daily Max Mean	2.86
GROUP	2	HOME	4	WORK	4	GAS	2	POP=	578	1-hr mean	1.28	Daily Max Mean	3.12
GROUP	2	HOME	5	WORK	5	GAS	1	POP=	7860	1-hr mean	1.09	Daily Max Mean	2.75
GROUP	2	HOME	5	WORK	5	GAS	2	POP=	578	1-hr mean	1.19	Daily Max Mean	3.07
GROUP	2	HOME	6	WORK	6	GAS	1	POP=	31480	1-hr mean	1.21	Daily Max Mean	2.91
GROUP	2	HOME	6	WORK	6	GAS	2	POP=	2315	1-hr mean	1.35	Daily Max Mean	3.28
GROUP	3	HOME	1	WORK	1	GAS	1	POP=	30372	1-hr mean	1.19	Daily Max Mean	3.19
GROUP	3	HOME	1	WORK	1	GAS	2	POP=	2233	1-hr mean	1.31	Daily Max Mean	3.48
GROUP	3	HOME	2	WORK	2	GAS	1	POP=	24927	1-hr mean	1.71	Daily Max Mean	4.18
GROUP	3	HOME	2	WORK	2	GAS	2	POP=	1833	1-hr mean	1.81	Daily Max Mean	4.44
GROUP	3	HOME	3	WORK	3	GAS	1	POP=	4220	1-hr mean	1.09	Daily Max Mean	2.98
GROUP	3	HOME	3	WORK	3	GAS	2	POP=	310	1-hr mean	1.19	Daily Max Mean	3.43
GROUP	3	HOME	4	WORK	4	GAS	1	POP=	7268	1-hr mean	1.18	Daily Max Mean	3.20
GROUP	3	HOME	4	WORK	4	GAS	2	POP=	535	1-hr mean	1.26	Daily Max Mean	3.39
GROUP	3	HOME	5	WORK	5	GAS	1	POP=	7268	1-hr mean	1.09	Daily Max Mean	3.04
GROUP	3	HOME	5	WORK	5	GAS	2	POP=	535	1-hr mean	1.19	Daily Max Mean	3.17
GROUP	3	HOME	6	WORK	6	GAS	1	POP=	30772	1-hr mean	1.23	Daily Max Mean	3.20
GROUP	3	HOME	6	WORK	6	GAS	2	POP=	2263	1-hr mean	1.34	Daily Max Mean	3.46
GROUP	4	HOME	1	WORK	1	GAS	1	POP=	33520	1-hr mean	1.36	Daily Max Mean	3.31
GROUP	4	HOME	1	WORK	1	GAS	2	POP=	2465	1-hr mean	1.43	Daily Max Mean	3.51

GROUP	4	HOME	2	WORK	2	GAS	1	POP=	28718	1-hr mean	1.79	Daily Max Mean	4.09
GROUP	4	HOME	2	WORK	2	GAS	2	POP=	2112	1-hr mean	1.87	Daily Max Mean	4.30
GROUP	4	HOME	3	WORK	3	GAS	1	POP=	4387	1-hr mean	1.20	Daily Max Mean	3.13
GROUP	4	HOME	3	WORK	3	GAS	2	POP=	323	1-hr mean	1.36	Daily Max Mean	3.45
GROUP	4	HOME	4	WORK	4	GAS	1	POP=	8058	1-hr mean	1.31	Daily Max Mean	3.29
GROUP	4	HOME	4	WORK	4	GAS	2	POP=	593	1-hr mean	1.47	Daily Max Mean	3.51
GROUP	4	HOME	5	WORK	5	GAS	1	POP=	8058	1-hr mean	1.25	Daily Max Mean	3.24
GROUP	4	HOME	5	WORK	5	GAS	2	POP=	593	1-hr mean	1.38	Daily Max Mean	3.48
GROUP	4	HOME	6	WORK	6	GAS	1	POP=	30898	1-hr mean	1.36	Daily Max Mean	3.37
GROUP	4	HOME	6	WORK	6	GAS	2	POP=	2272	1-hr mean	1.49	Daily Max Mean	3.58
GROUP	5	HOME	1	WORK	1	GAS	1	POP=	29960	1-hr mean	1.44	Daily Max Mean	3.71
GROUP	5	HOME	1	WORK	1	GAS	2	POP=	2203	1-hr mean	1.54	Daily Max Mean	3.90
GROUP	5	HOME	1	WORK	2	GAS	1	POP=	19692	1-hr mean	1.54	Daily Max Mean	3.92
GROUP	5	HOME	1	WORK	2	GAS	2	POP=	1448	1-hr mean	1.63	Daily Max Mean	4.06
GROUP	5	HOME	1	WORK	3	GAS	1	POP=	1349	1-hr mean	1.45	Daily Max Mean	3.78
GROUP	5	HOME	1	WORK	3	GAS	2	POP=	99	1-hr mean	1.49	Daily Max Mean	3.72
GROUP	5	HOME	1	WORK	4	GAS	1	POP=	562	1-hr mean	1.48	Daily Max Mean	3.75
GROUP	5	HOME	1	WORK	4	GAS	2	POP=	41	1-hr mean	1.63	Daily Max Mean	4.06
GROUP	5	HOME	1	WORK	5	GAS	1	POP=	562	1-hr mean	1.48	Daily Max Mean	3.70
GROUP	5	HOME	1	WORK	5	GAS	2	POP=	41	1-hr mean	1.53	Daily Max Mean	3.92
GROUP	5	HOME	1	WORK	6	GAS	1	POP=	1481	1-hr mean	1.52	Daily Max Mean	3.86
GROUP	5	HOME	1	WORK	6	GAS	2	POP=	109	1-hr mean	1.59	Daily Max Mean	3.98
GROUP	5	HOME	2	WORK	1	GAS	1	POP=	3373	1-hr mean	1.77	Daily Max Mean	4.23
GROUP	5	HOME	2	WORK	1	GAS	2	POP=	248	1-hr mean	1.93	Daily Max Mean	4.44
GROUP	5	HOME	2	WORK	2	GAS	1	POP=	74886	1-hr mean	1.95	Daily Max Mean	4.59
GROUP	5	HOME	2	WORK	2	GAS	2	POP=	5507	1-hr mean	1.94	Daily Max Mean	4.47
GROUP	5	HOME	2	WORK	3	GAS	1	POP=	1066	1-hr mean	1.80	Daily Max Mean	4.29
GROUP	5	HOME	2	WORK	3	GAS	2	POP=	78	1-hr mean	1.87	Daily Max Mean	4.44
GROUP	5	HOME	2	WORK	4	GAS	1	POP=	1780	1-hr mean	1.78	Daily Max Mean	4.21
GROUP	5	HOME	2	WORK	4	GAS	2	POP=	131	1-hr mean	1.87	Daily Max Mean	4.39
GROUP	5	HOME	2	WORK	5	GAS	1	POP=	1780	1-hr mean	1.78	Daily Max Mean	4.24
GROUP	5	HOME	2	WORK	5	GAS	2	POP=	131	1-hr mean	1.91	Daily Max Mean	4.44
GROUP	5	HOME	2	WORK	6	GAS	1	POP=	3694	1-hr mean	1.87	Daily Max Mean	4.37
GROUP	5	HOME	2	WORK	6	GAS	2	POP=	272	1-hr mean	2.00	Daily Max Mean	4.57
GROUP	5	HOME	3	WORK	1	GAS	1	POP=	1182	1-hr mean	1.40	Daily Max Mean	3.73
GROUP	5	HOME	3	WORK	1	GAS	2	POP=	87	1-hr mean	1.53	Daily Max Mean	3.87
GROUP	5	HOME	3	WORK	2	GAS	1	POP=	7841	1-hr mean	1.44	Daily Max Mean	4.00
GROUP	5	HOME	3	WORK	2	GAS	2	POP=	576	1-hr mean	1.61	Daily Max Mean	4.00
GROUP	5	HOME	3	WORK	3	GAS	1	POP=	1582	1-hr mean	1.36	Daily Max Mean	3.66
GROUP	5	HOME	3	WORK	3	GAS	2	POP=	116	1-hr mean	1.48	Daily Max Mean	3.81
GROUP	5	HOME	3	WORK	4	GAS	1	POP=	126	1-hr mean	1.41	Daily Max Mean	3.83
GROUP	5	HOME	3	WORK	4	GAS	2	POP=	9	1-hr mean	1.54	Daily Max Mean	4.02
GROUP	5	HOME	3	WORK	5	GAS	1	POP=	126	1-hr mean	1.35	Daily Max Mean	3.64
GROUP	5	HOME	3	WORK	5	GAS	2	POP=	9	1-hr mean	1.42	Daily Max Mean	3.68
GROUP	5	HOME	3	WORK	6	GAS	1	POP=	308	1-hr mean	1.39	Daily Max Mean	3.72
GROUP	5	HOME	3	WORK	6	GAS	2	POP=	23	1-hr mean	1.51	Daily Max Mean	3.94
GROUP	5	HOME	4	WORK	1	GAS	1	POP=	289	1-hr mean	1.41	Daily Max Mean	3.78
GROUP	5	HOME	4	WORK	1	GAS	2	POP=	21	1-hr mean	1.58	Daily Max Mean	3.85
GROUP	5	HOME	4	WORK	2	GAS	1	POP=	5752	1-hr mean	1.57	Daily Max Mean	4.04

GROUP	5	HOME	4	WORK	2	GAS	2	POP=	423	1-hr mean	1.66	Daily Max Mean	4.05
GROUP	5	HOME	4	WORK	3	GAS	1	POP=	59	1-hr mean	1.41	Daily Max Mean	3.83
GROUP	5	HOME	4	WORK	3	GAS	2	POP=	4	1-hr mean	1.56	Daily Max Mean	3.94
GROUP	5	HOME	4	WORK	4	GAS	1	POP=	3624	1-hr mean	1.44	Daily Max Mean	3.76
GROUP	5	HOME	4	WORK	4	GAS	2	POP=	267	1-hr mean	1.59	Daily Max Mean	4.04
GROUP	5	HOME	4	WORK	5	GAS	1	POP=	3624	1-hr mean	1.42	Daily Max Mean	3.81
GROUP	5	HOME	4	WORK	5	GAS	2	POP=	267	1-hr mean	1.57	Daily Max Mean	3.98
GROUP	5	HOME	4	WORK	6	GAS	1	POP=	2650	1-hr mean	1.47	Daily Max Mean	3.80
GROUP	5	HOME	4	WORK	6	GAS	2	POP=	195	1-hr mean	1.53	Daily Max Mean	3.96
GROUP	5	HOME	5	WORK	1	GAS	1	POP=	289	1-hr mean	1.41	Daily Max Mean	3.68
GROUP	5	HOME	5	WORK	1	GAS	2	POP=	21	1-hr mean	1.58	Daily Max Mean	3.92
GROUP	5	HOME	5	WORK	2	GAS	1	POP=	5752	1-hr mean	1.51	Daily Max Mean	3.90
GROUP	5	HOME	5	WORK	2	GAS	2	POP=	423	1-hr mean	1.57	Daily Max Mean	3.91
GROUP	5	HOME	5	WORK	3	GAS	1	POP=	59	1-hr mean	1.39	Daily Max Mean	3.69
GROUP	5	HOME	5	WORK	3	GAS	2	POP=	4	1-hr mean	1.47	Daily Max Mean	3.74
GROUP	5	HOME	5	WORK	4	GAS	1	POP=	3624	1-hr mean	1.41	Daily Max Mean	3.70
GROUP	5	HOME	5	WORK	4	GAS	2	POP=	267	1-hr mean	1.52	Daily Max Mean	3.89
GROUP	5	HOME	5	WORK	5	GAS	1	POP=	3624	1-hr mean	1.38	Daily Max Mean	3.61
GROUP	5	HOME	5	WORK	5	GAS	2	POP=	267	1-hr mean	1.53	Daily Max Mean	3.83
GROUP	5	HOME	5	WORK	6	GAS	1	POP=	2650	1-hr mean	1.41	Daily Max Mean	3.76
GROUP	5	HOME	5	WORK	6	GAS	2	POP=	195	1-hr mean	1.50	Daily Max Mean	3.97
GROUP	5	HOME	6	WORK	1	GAS	1	POP=	625	1-hr mean	1.52	Daily Max Mean	3.90
GROUP	5	HOME	6	WORK	1	GAS	2	POP=	46	1-hr mean	1.57	Daily Max Mean	3.92
GROUP	5	HOME	6	WORK	2	GAS	1	POP=	14793	1-hr mean	1.54	Daily Max Mean	3.84
GROUP	5	HOME	6	WORK	2	GAS	2	POP=	1088	1-hr mean	1.68	Daily Max Mean	4.18
GROUP	5	HOME	6	WORK	3	GAS	1	POP=	123	1-hr mean	1.49	Daily Max Mean	3.82
GROUP	5	HOME	6	WORK	3	GAS	2	POP=	9	1-hr mean	1.55	Daily Max Mean	3.92
GROUP	5	HOME	6	WORK	4	GAS	1	POP=	4319	1-hr mean	1.45	Daily Max Mean	3.74
GROUP	5	HOME	6	WORK	4	GAS	2	POP=	318	1-hr mean	1.56	Daily Max Mean	3.78
GROUP	5	HOME	6	WORK	5	GAS	1	POP=	4319	1-hr mean	1.51	Daily Max Mean	3.86
GROUP	5	HOME	6	WORK	5	GAS	2	POP=	318	1-hr mean	1.54	Daily Max Mean	3.90
GROUP	5	HOME	6	WORK	6	GAS	1	POP=	40940	1-hr mean	1.54	Daily Max Mean	3.80
GROUP	5	HOME	6	WORK	6	GAS	2	POP=	3011	1-hr mean	1.63	Daily Max Mean	3.96
GROUP	6	HOME	1	WORK	1	GAS	1	POP=	28005	1-hr mean	1.24	Daily Max Mean	3.57
GROUP	6	HOME	1	WORK	1	GAS	2	POP=	2059	1-hr mean	1.39	Daily Max Mean	3.64
GROUP	6	HOME	2	WORK	2	GAS	1	POP=	44455	1-hr mean	1.67	Daily Max Mean	4.35
GROUP	6	HOME	2	WORK	2	GAS	2	POP=	3269	1-hr mean	1.82	Daily Max Mean	4.47
GROUP	6	HOME	3	WORK	3	GAS	1	POP=	6237	1-hr mean	1.14	Daily Max Mean	3.44
GROUP	6	HOME	3	WORK	3	GAS	2	POP=	459	1-hr mean	1.27	Daily Max Mean	3.63
GROUP	6	HOME	4	WORK	4	GAS	1	POP=	8678	1-hr mean	1.25	Daily Max Mean	3.42
GROUP	6	HOME	4	WORK	4	GAS	2	POP=	638	1-hr mean	1.34	Daily Max Mean	3.58
GROUP	6	HOME	5	WORK	5	GAS	1	POP=	8678	1-hr mean	1.17	Daily Max Mean	3.47
GROUP	6	HOME	5	WORK	5	GAS	2	POP=	638	1-hr mean	1.28	Daily Max Mean	3.56
GROUP	6	HOME	6	WORK	6	GAS	1	POP=	18686	1-hr mean	1.27	Daily Max Mean	3.48
GROUP	6	HOME	6	WORK	6	GAS	2	POP=	1374	1-hr mean	1.38	Daily Max Mean	3.67
GROUP	7	HOME	1	WORK	1	GAS	1	POP=	14643	1-hr mean	1.54	Daily Max Mean	3.80
GROUP	7	HOME	1	WORK	1	GAS	2	POP=	1077	1-hr mean	1.63	Daily Max Mean	3.93
GROUP	7	HOME	1	WORK	2	GAS	1	POP=	9624	1-hr mean	1.66	Daily Max Mean	3.98
GROUP	7	HOME	1	WORK	2	GAS	2	POP=	708	1-hr mean	1.75	Daily Max Mean	4.13

GROUP	7	HOME	1	WORK	3	GAS	1	POP=	659	1-hr mean	1.49	Daily Max Mean	3.71
GROUP	7	HOME	1	WORK	3	GAS	2	POP=	48	1-hr mean	1.61	Daily Max Mean	3.88
GROUP	7	HOME	1	WORK	4	GAS	1	POP=	274	1-hr mean	1.52	Daily Max Mean	3.77
GROUP	7	HOME	1	WORK	4	GAS	2	POP=	20	1-hr mean	1.68	Daily Max Mean	4.00
GROUP	7	HOME	1	WORK	5	GAS	1	POP=	274	1-hr mean	1.55	Daily Max Mean	3.81
GROUP	7	HOME	1	WORK	5	GAS	2	POP=	20	1-hr mean	1.63	Daily Max Mean	3.92
GROUP	7	HOME	1	WORK	6	GAS	1	POP=	724	1-hr mean	1.49	Daily Max Mean	3.74
GROUP	7	HOME	1	WORK	6	GAS	2	POP=	53	1-hr mean	1.59	Daily Max Mean	3.84
GROUP	7	HOME	2	WORK	1	GAS	1	POP=	1273	1-hr mean	1.83	Daily Max Mean	4.18
GROUP	7	HOME	2	WORK	1	GAS	2	POP=	94	1-hr mean	1.90	Daily Max Mean	4.37
GROUP	7	HOME	2	WORK	2	GAS	1	POP=	28250	1-hr mean	1.88	Daily Max Mean	4.26
GROUP	7	HOME	2	WORK	2	GAS	2	POP=	2078	1-hr mean	2.09	Daily Max Mean	4.56
GROUP	7	HOME	2	WORK	3	GAS	1	POP=	402	1-hr mean	1.77	Daily Max Mean	4.13
GROUP	7	HOME	2	WORK	3	GAS	2	POP=	30	1-hr mean	1.91	Daily Max Mean	4.44
GROUP	7	HOME	2	WORK	4	GAS	1	POP=	671	1-hr mean	1.91	Daily Max Mean	4.30
GROUP	7	HOME	2	WORK	4	GAS	2	POP=	49	1-hr mean	1.95	Daily Max Mean	4.33
GROUP	7	HOME	2	WORK	5	GAS	1	POP=	671	1-hr mean	1.79	Daily Max Mean	4.19
GROUP	7	HOME	2	WORK	5	GAS	2	POP=	49	1-hr mean	1.94	Daily Max Mean	4.37
GROUP	7	HOME	2	WORK	6	GAS	1	POP=	1394	1-hr mean	1.85	Daily Max Mean	4.25
GROUP	7	HOME	2	WORK	6	GAS	2	POP=	102	1-hr mean	1.99	Daily Max Mean	4.46
GROUP	7	HOME	3	WORK	1	GAS	1	POP=	538	1-hr mean	1.47	Daily Max Mean	3.71
GROUP	7	HOME	3	WORK	1	GAS	2	POP=	40	1-hr mean	1.56	Daily Max Mean	3.84
GROUP	7	HOME	3	WORK	2	GAS	1	POP=	3568	1-hr mean	1.49	Daily Max Mean	3.81
GROUP	7	HOME	3	WORK	2	GAS	2	POP=	263	1-hr mean	1.62	Daily Max Mean	3.92
GROUP	7	HOME	3	WORK	3	GAS	1	POP=	720	1-hr mean	1.44	Daily Max Mean	3.75
GROUP	7	HOME	3	WORK	3	GAS	2	POP=	53	1-hr mean	1.52	Daily Max Mean	3.87
GROUP	7	HOME	3	WORK	4	GAS	1	POP=	57	1-hr mean	1.47	Daily Max Mean	3.71
GROUP	7	HOME	3	WORK	4	GAS	2	POP=	4	1-hr mean	1.55	Daily Max Mean	3.88
GROUP	7	HOME	3	WORK	5	GAS	1	POP=	57	1-hr mean	1.44	Daily Max Mean	3.69
GROUP	7	HOME	3	WORK	5	GAS	2	POP=	4	1-hr mean	1.56	Daily Max Mean	3.84
GROUP	7	HOME	3	WORK	6	GAS	1	POP=	140	1-hr mean	1.40	Daily Max Mean	3.64
GROUP	7	HOME	3	WORK	6	GAS	2	POP=	10	1-hr mean	1.55	Daily Max Mean	3.80
GROUP	7	HOME	4	WORK	1	GAS	1	POP=	155	1-hr mean	1.52	Daily Max Mean	3.72
GROUP	7	HOME	4	WORK	1	GAS	2	POP=	11	1-hr mean	1.61	Daily Max Mean	3.90
GROUP	7	HOME	4	WORK	2	GAS	1	POP=	3076	1-hr mean	1.57	Daily Max Mean	3.88
GROUP	7	HOME	4	WORK	2	GAS	2	POP=	226	1-hr mean	1.63	Daily Max Mean	4.00
GROUP	7	HOME	4	WORK	3	GAS	1	POP=	32	1-hr mean	1.48	Daily Max Mean	3.74
GROUP	7	HOME	4	WORK	3	GAS	2	POP=	2	1-hr mean	1.54	Daily Max Mean	3.81
GROUP	7	HOME	4	WORK	4	GAS	1	POP=	1938	1-hr mean	1.49	Daily Max Mean	3.75
GROUP	7	HOME	4	WORK	4	GAS	2	POP=	143	1-hr mean	1.64	Daily Max Mean	3.88
GROUP	7	HOME	4	WORK	5	GAS	1	POP=	1938	1-hr mean	1.50	Daily Max Mean	3.71
GROUP	7	HOME	4	WORK	5	GAS	2	POP=	143	1-hr mean	1.61	Daily Max Mean	3.92
GROUP	7	HOME	4	WORK	6	GAS	1	POP=	1417	1-hr mean	1.51	Daily Max Mean	3.81
GROUP	7	HOME	4	WORK	6	GAS	2	POP=	104	1-hr mean	1.62	Daily Max Mean	3.94
GROUP	7	HOME	5	WORK	1	GAS	1	POP=	155	1-hr mean	1.50	Daily Max Mean	3.78
GROUP	7	HOME	5	WORK	1	GAS	2	POP=	11	1-hr mean	1.58	Daily Max Mean	3.77
GROUP	7	HOME	5	WORK	2	GAS	1	POP=	3076	1-hr mean	1.57	Daily Max Mean	3.88
GROUP	7	HOME	5	WORK	2	GAS	2	POP=	226	1-hr mean	1.65	Daily Max Mean	3.96
GROUP	7	HOME	5	WORK	3	GAS	1	POP=	32	1-hr mean	1.48	Daily Max Mean	3.65

GROUP 7 HOME 5 WORK 3 GAS 2 POP=	2	1-hr mean	1.52	Daily Max Mean	3.83
GROUP 7 HOME 5 WORK 4 GAS 1 POP=	1938	1-hr mean	1.51	Daily Max Mean	3.74
GROUP 7 HOME 5 WORK 4 GAS 2 POP=	143	1-hr mean	1.59	Daily Max Mean	3.87
GROUP 7 HOME 5 WORK 5 GAS 1 POP=	1938	1-hr mean	1.46	Daily Max Mean	3.73
GROUP 7 HOME 5 WORK 5 GAS 2 POP=	143	1-hr mean	1.56	Daily Max Mean	3.89
GROUP 7 HOME 5 WORK 6 GAS 1 POP=	1417	1-hr mean	1.48	Daily Max Mean	3.71
GROUP 7 HOME 5 WORK 6 GAS 2 POP=	104	1-hr mean	1.67	Daily Max Mean	4.00
GROUP 7 HOME 6 WORK 1 GAS 1 POP=	271	1-hr mean	1.53	Daily Max Mean	3.73
GROUP 7 HOME 6 WORK 1 GAS 2 POP=	20	1-hr mean	1.65	Daily Max Mean	4.03
GROUP 7 HOME 6 WORK 2 GAS 1 POP=	6419	1-hr mean	1.67	Daily Max Mean	3.95
GROUP 7 HOME 6 WORK 2 GAS 2 POP=	472	1-hr mean	1.74	Daily Max Mean	4.00
GROUP 7 HOME 6 WORK 3 GAS 1 POP=	54	1-hr mean	1.51	Daily Max Mean	3.73
GROUP 7 HOME 6 WORK 3 GAS 2 POP=	4	1-hr mean	1.62	Daily Max Mean	3.96
GROUP 7 HOME 6 WORK 4 GAS 1 POP=	1874	1-hr mean	1.58	Daily Max Mean	3.76
GROUP 7 HOME 6 WORK 4 GAS 2 POP=	138	1-hr mean	1.66	Daily Max Mean	3.94
GROUP 7 HOME 6 WORK 5 GAS 1 POP=	1874	1-hr mean	1.48	Daily Max Mean	3.75
GROUP 7 HOME 6 WORK 5 GAS 2 POP=	138	1-hr mean	1.63	Daily Max Mean	3.84
GROUP 7 HOME 6 WORK 6 GAS 1 POP=	17765	1-hr mean	1.57	Daily Max Mean	3.69
GROUP 7 HOME 6 WORK 6 GAS 2 POP=	1306	1-hr mean	1.64	Daily Max Mean	3.91
GROUP 8 HOME 1 WORK 1 GAS 1 POP=	13687	1-hr mean	1.07	Daily Max Mean	3.08
GROUP 8 HOME 1 WORK 1 GAS 2 POP=	1007	1-hr mean	1.28	Daily Max Mean	3.38
GROUP 8 HOME 2 WORK 2 GAS 1 POP=	16770	1-hr mean	1.49	Daily Max Mean	3.79
GROUP 8 HOME 2 WORK 2 GAS 2 POP=	1233	1-hr mean	1.72	Daily Max Mean	4.03
GROUP 8 HOME 3 WORK 3 GAS 1 POP=	2838	1-hr mean	1.01	Daily Max Mean	2.98
GROUP 8 HOME 3 WORK 3 GAS 2 POP=	209	1-hr mean	1.18	Daily Max Mean	3.23
GROUP 8 HOME 4 WORK 4 GAS 1 POP=	4641	1-hr mean	1.13	Daily Max Mean	3.29
GROUP 8 HOME 4 WORK 4 GAS 2 POP=	342	1-hr mean	1.27	Daily Max Mean	3.50
GROUP 8 HOME 5 WORK 5 GAS 1 POP=	4641	1-hr mean	1.05	Daily Max Mean	3.14
GROUP 8 HOME 5 WORK 5 GAS 2 POP=	342	1-hr mean	1.19	Daily Max Mean	3.29
GROUP 8 HOME 6 WORK 6 GAS 1 POP=	8109	1-hr mean	1.16	Daily Max Mean	3.22
GROUP 8 HOME 6 WORK 6 GAS 2 POP=	596	1-hr mean	1.26	Daily Max Mean	3.40
GROUP 9 HOME 1 WORK 1 GAS 1 POP=	20642	1-hr mean	1.37	Daily Max Mean	3.31
GROUP 9 HOME 1 WORK 1 GAS 2 POP=	1518	1-hr mean	1.53	Daily Max Mean	3.65
GROUP 9 HOME 2 WORK 2 GAS 1 POP=	27787	1-hr mean	1.76	Daily Max Mean	4.08
GROUP 9 HOME 2 WORK 2 GAS 2 POP=	2043	1-hr mean	1.88	Daily Max Mean	4.32
GROUP 9 HOME 3 WORK 3 GAS 1 POP=	5882	1-hr mean	1.26	Daily Max Mean	3.33
GROUP 9 HOME 3 WORK 3 GAS 2 POP=	433	1-hr mean	1.38	Daily Max Mean	3.43
GROUP 9 HOME 4 WORK 4 GAS 1 POP=	8915	1-hr mean	1.38	Daily Max Mean	3.47
GROUP 9 HOME 4 WORK 4 GAS 2 POP=	656	1-hr mean	1.55	Daily Max Mean	3.93
GROUP 9 HOME 5 WORK 5 GAS 1 POP=	8915	1-hr mean	1.29	Daily Max Mean	3.39
GROUP 9 HOME 5 WORK 5 GAS 2 POP=	656	1-hr mean	1.43	Daily Max Mean	3.44
GROUP 9 HOME 6 WORK 6 GAS 1 POP=	12100	1-hr mean	1.37	Daily Max Mean	3.43
GROUP 9 HOME 6 WORK 6 GAS 2 POP=	890	1-hr mean	1.59	Daily Max Mean	3.84
GROUP 10 HOME 1 WORK 1 GAS 1 POP=	25557	1-hr mean	1.35	Daily Max Mean	3.58
GROUP 10 HOME 1 WORK 1 GAS 2 POP=	1879	1-hr mean	1.47	Daily Max Mean	3.78
GROUP 10 HOME 1 WORK 2 GAS 1 POP=	16797	1-hr mean	1.40	Daily Max Mean	3.64
GROUP 10 HOME 1 WORK 2 GAS 2 POP=	1235	1-hr mean	1.48	Daily Max Mean	3.70
GROUP 10 HOME 1 WORK 3 GAS 1 POP=	1151	1-hr mean	1.24	Daily Max Mean	3.43
GROUP 10 HOME 1 WORK 3 GAS 2 POP=	85	1-hr mean	1.44	Daily Max Mean	3.74

GROUP 10	HOME	1	WORK	4	GAS	1	POP=	479	1-hr mean	1.31	Daily Max Mean	3.54
GROUP 10	HOME	1	WORK	4	GAS	2	POP=	35	1-hr mean	1.47	Daily Max Mean	3.79
GROUP 10	HOME	1	WORK	5	GAS	1	POP=	479	1-hr mean	1.34	Daily Max Mean	3.59
GROUP 10	HOME	1	WORK	5	GAS	2	POP=	35	1-hr mean	1.45	Daily Max Mean	3.70
GROUP 10	HOME	1	WORK	6	GAS	1	POP=	1263	1-hr mean	1.39	Daily Max Mean	3.70
GROUP 10	HOME	1	WORK	6	GAS	2	POP=	93	1-hr mean	1.41	Daily Max Mean	3.56
GROUP 10	HOME	2	WORK	1	GAS	1	POP=	2885	1-hr mean	1.72	Daily Max Mean	4.11
GROUP 10	HOME	2	WORK	1	GAS	2	POP=	212	1-hr mean	1.76	Daily Max Mean	4.26
GROUP 10	HOME	2	WORK	2	GAS	1	POP=	64053	1-hr mean	1.72	Daily Max Mean	4.22
GROUP 10	HOME	2	WORK	2	GAS	2	POP=	4711	1-hr mean	1.89	Daily Max Mean	4.34
GROUP 10	HOME	2	WORK	3	GAS	1	POP=	912	1-hr mean	1.66	Daily Max Mean	4.10
GROUP 10	HOME	2	WORK	3	GAS	2	POP=	67	1-hr mean	1.83	Daily Max Mean	4.33
GROUP 10	HOME	2	WORK	4	GAS	1	POP=	1522	1-hr mean	1.70	Daily Max Mean	4.11
GROUP 10	HOME	2	WORK	4	GAS	2	POP=	112	1-hr mean	1.84	Daily Max Mean	4.51
GROUP 10	HOME	2	WORK	5	GAS	1	POP=	1522	1-hr mean	1.67	Daily Max Mean	4.07
GROUP 10	HOME	2	WORK	5	GAS	2	POP=	112	1-hr mean	1.78	Daily Max Mean	4.34
GROUP 10	HOME	2	WORK	6	GAS	1	POP=	3160	1-hr mean	1.65	Daily Max Mean	4.06
GROUP 10	HOME	2	WORK	6	GAS	2	POP=	232	1-hr mean	1.82	Daily Max Mean	4.22
GROUP 10	HOME	3	WORK	1	GAS	1	POP=	1043	1-hr mean	1.25	Daily Max Mean	3.43
GROUP 10	HOME	3	WORK	1	GAS	2	POP=	77	1-hr mean	1.37	Daily Max Mean	3.63
GROUP 10	HOME	3	WORK	2	GAS	1	POP=	6915	1-hr mean	1.35	Daily Max Mean	3.66
GROUP 10	HOME	3	WORK	2	GAS	2	POP=	509	1-hr mean	1.46	Daily Max Mean	3.69
GROUP 10	HOME	3	WORK	3	GAS	1	POP=	1395	1-hr mean	1.21	Daily Max Mean	3.54
GROUP 10	HOME	3	WORK	3	GAS	2	POP=	103	1-hr mean	1.36	Daily Max Mean	3.55
GROUP 10	HOME	3	WORK	4	GAS	1	POP=	111	1-hr mean	1.25	Daily Max Mean	3.41
GROUP 10	HOME	3	WORK	4	GAS	2	POP=	8	1-hr mean	1.39	Daily Max Mean	3.60
GROUP 10	HOME	3	WORK	5	GAS	1	POP=	111	1-hr mean	1.22	Daily Max Mean	3.40
GROUP 10	HOME	3	WORK	5	GAS	2	POP=	8	1-hr mean	1.32	Daily Max Mean	3.61
GROUP 10	HOME	3	WORK	6	GAS	1	POP=	271	1-hr mean	1.29	Daily Max Mean	3.57
GROUP 10	HOME	3	WORK	6	GAS	2	POP=	20	1-hr mean	1.39	Daily Max Mean	3.73
GROUP 10	HOME	4	WORK	1	GAS	1	POP=	233	1-hr mean	1.37	Daily Max Mean	3.77
GROUP 10	HOME	4	WORK	1	GAS	2	POP=	17	1-hr mean	1.48	Daily Max Mean	3.78
GROUP 10	HOME	4	WORK	2	GAS	1	POP=	4628	1-hr mean	1.43	Daily Max Mean	3.66
GROUP 10	HOME	4	WORK	2	GAS	2	POP=	340	1-hr mean	1.53	Daily Max Mean	3.82
GROUP 10	HOME	4	WORK	3	GAS	1	POP=	48	1-hr mean	1.35	Daily Max Mean	3.62
GROUP 10	HOME	4	WORK	3	GAS	2	POP=	4	1-hr mean	1.40	Daily Max Mean	3.64
GROUP 10	HOME	4	WORK	4	GAS	1	POP=	2916	1-hr mean	1.30	Daily Max Mean	3.52
GROUP 10	HOME	4	WORK	4	GAS	2	POP=	214	1-hr mean	1.44	Daily Max Mean	3.70
GROUP 10	HOME	4	WORK	5	GAS	1	POP=	2916	1-hr mean	1.36	Daily Max Mean	3.54
GROUP 10	HOME	4	WORK	5	GAS	2	POP=	214	1-hr mean	1.45	Daily Max Mean	3.74
GROUP 10	HOME	4	WORK	6	GAS	1	POP=	2133	1-hr mean	1.38	Daily Max Mean	3.52
GROUP 10	HOME	4	WORK	6	GAS	2	POP=	157	1-hr mean	1.47	Daily Max Mean	3.77
GROUP 10	HOME	5	WORK	1	GAS	1	POP=	233	1-hr mean	1.32	Daily Max Mean	3.53
GROUP 10	HOME	5	WORK	1	GAS	2	POP=	17	1-hr mean	1.44	Daily Max Mean	3.74
GROUP 10	HOME	5	WORK	2	GAS	1	POP=	4628	1-hr mean	1.35	Daily Max Mean	3.62
GROUP 10	HOME	5	WORK	2	GAS	2	POP=	340	1-hr mean	1.48	Daily Max Mean	3.71
GROUP 10	HOME	5	WORK	3	GAS	1	POP=	48	1-hr mean	1.30	Daily Max Mean	3.43
GROUP 10	HOME	5	WORK	3	GAS	2	POP=	4	1-hr mean	1.40	Daily Max Mean	3.70
GROUP 10	HOME	5	WORK	4	GAS	1	POP=	2916	1-hr mean	1.29	Daily Max Mean	3.41

GROUP 10	HOME	5	WORK	4	GAS	2	POP=	214	1-hr mean	1.41	Daily Max Mean	3.71
GROUP 10	HOME	5	WORK	5	GAS	1	POP=	2916	1-hr mean	1.28	Daily Max Mean	3.51
GROUP 10	HOME	5	WORK	5	GAS	2	POP=	214	1-hr mean	1.37	Daily Max Mean	3.62
GROUP 10	HOME	5	WORK	6	GAS	1	POP=	2133	1-hr mean	1.30	Daily Max Mean	3.55
GROUP 10	HOME	5	WORK	6	GAS	2	POP=	157	1-hr mean	1.38	Daily Max Mean	3.64
GROUP 10	HOME	6	WORK	1	GAS	1	POP=	531	1-hr mean	1.36	Daily Max Mean	3.57
GROUP 10	HOME	6	WORK	1	GAS	2	POP=	39	1-hr mean	1.48	Daily Max Mean	3.78
GROUP 10	HOME	6	WORK	2	GAS	1	POP=	12569	1-hr mean	1.47	Daily Max Mean	3.72
GROUP 10	HOME	6	WORK	2	GAS	2	POP=	924	1-hr mean	1.52	Daily Max Mean	3.68
GROUP 10	HOME	6	WORK	3	GAS	1	POP=	105	1-hr mean	1.26	Daily Max Mean	3.47
GROUP 10	HOME	6	WORK	3	GAS	2	POP=	8	1-hr mean	1.44	Daily Max Mean	3.59
GROUP 10	HOME	6	WORK	4	GAS	1	POP=	3670	1-hr mean	1.39	Daily Max Mean	3.66
GROUP 10	HOME	6	WORK	4	GAS	2	POP=	270	1-hr mean	1.49	Daily Max Mean	3.86
GROUP 10	HOME	6	WORK	5	GAS	1	POP=	3670	1-hr mean	1.32	Daily Max Mean	3.44
GROUP 10	HOME	6	WORK	5	GAS	2	POP=	270	1-hr mean	1.47	Daily Max Mean	3.78
GROUP 10	HOME	6	WORK	6	GAS	1	POP=	34784	1-hr mean	1.33	Daily Max Mean	3.53
GROUP 10	HOME	6	WORK	6	GAS	2	POP=	2558	1-hr mean	1.45	Daily Max Mean	3.67
GROUP 11	HOME	1	WORK	1	GAS	1	POP=	43821	1-hr mean	1.17	Daily Max Mean	3.01
GROUP 11	HOME	1	WORK	1	GAS	2	POP=	3222	1-hr mean	1.33	Daily Max Mean	3.32
GROUP 11	HOME	2	WORK	2	GAS	1	POP=	58571	1-hr mean	1.64	Daily Max Mean	3.77
GROUP 11	HOME	2	WORK	2	GAS	2	POP=	4307	1-hr mean	1.79	Daily Max Mean	4.16
GROUP 11	HOME	3	WORK	3	GAS	1	POP=	9222	1-hr mean	1.09	Daily Max Mean	2.99
GROUP 11	HOME	3	WORK	3	GAS	2	POP=	678	1-hr mean	1.28	Daily Max Mean	3.25
GROUP 11	HOME	4	WORK	4	GAS	1	POP=	12824	1-hr mean	1.23	Daily Max Mean	3.16
GROUP 11	HOME	4	WORK	4	GAS	2	POP=	943	1-hr mean	1.35	Daily Max Mean	3.31
GROUP 11	HOME	5	WORK	5	GAS	1	POP=	12824	1-hr mean	1.14	Daily Max Mean	3.03
GROUP 11	HOME	5	WORK	5	GAS	2	POP=	943	1-hr mean	1.32	Daily Max Mean	3.30
GROUP 11	HOME	6	WORK	6	GAS	1	POP=	33469	1-hr mean	1.23	Daily Max Mean	3.08
GROUP 11	HOME	6	WORK	6	GAS	2	POP=	2461	1-hr mean	1.32	Daily Max Mean	3.28
GROUP 12	HOME	1	WORK	1	GAS	1	POP=	12886	1-hr mean	1.38	Daily Max Mean	3.37
GROUP 12	HOME	1	WORK	1	GAS	2	POP=	948	1-hr mean	1.54	Daily Max Mean	3.54
GROUP 12	HOME	1	WORK	2	GAS	1	POP=	8469	1-hr mean	1.53	Daily Max Mean	3.67
GROUP 12	HOME	1	WORK	2	GAS	2	POP=	623	1-hr mean	1.63	Daily Max Mean	3.68
GROUP 12	HOME	1	WORK	3	GAS	1	POP=	580	1-hr mean	1.40	Daily Max Mean	3.41
GROUP 12	HOME	1	WORK	3	GAS	2	POP=	43	1-hr mean	1.49	Daily Max Mean	3.54
GROUP 12	HOME	1	WORK	4	GAS	1	POP=	242	1-hr mean	1.41	Daily Max Mean	3.41
GROUP 12	HOME	1	WORK	4	GAS	2	POP=	18	1-hr mean	1.52	Daily Max Mean	3.56
GROUP 12	HOME	1	WORK	5	GAS	1	POP=	242	1-hr mean	1.42	Daily Max Mean	3.45
GROUP 12	HOME	1	WORK	5	GAS	2	POP=	18	1-hr mean	1.51	Daily Max Mean	3.55
GROUP 12	HOME	1	WORK	6	GAS	1	POP=	637	1-hr mean	1.40	Daily Max Mean	3.36
GROUP 12	HOME	1	WORK	6	GAS	2	POP=	47	1-hr mean	1.55	Daily Max Mean	3.71
GROUP 12	HOME	2	WORK	1	GAS	1	POP=	1118	1-hr mean	1.79	Daily Max Mean	4.01
GROUP 12	HOME	2	WORK	1	GAS	2	POP=	82	1-hr mean	1.85	Daily Max Mean	4.12
GROUP 12	HOME	2	WORK	2	GAS	1	POP=	24817	1-hr mean	1.87	Daily Max Mean	4.05
GROUP 12	HOME	2	WORK	2	GAS	2	POP=	1825	1-hr mean	1.99	Daily Max Mean	4.23
GROUP 12	HOME	2	WORK	3	GAS	1	POP=	353	1-hr mean	1.74	Daily Max Mean	3.93
GROUP 12	HOME	2	WORK	3	GAS	2	POP=	26	1-hr mean	1.89	Daily Max Mean	4.18
GROUP 12	HOME	2	WORK	4	GAS	1	POP=	590	1-hr mean	1.75	Daily Max Mean	4.02
GROUP 12	HOME	2	WORK	4	GAS	2	POP=	43	1-hr mean	1.90	Daily Max Mean	4.15

GROUP 12	HOME	2	WORK	5	GAS	1	POP=	590	1-hr mean	1.77	Daily Max Mean	3.96
GROUP 12	HOME	2	WORK	5	GAS	2	POP=	43	1-hr mean	1.87	Daily Max Mean	4.27
GROUP 12	HOME	2	WORK	6	GAS	1	POP=	1224	1-hr mean	1.77	Daily Max Mean	3.92
GROUP 12	HOME	2	WORK	6	GAS	2	POP=	90	1-hr mean	1.88	Daily Max Mean	4.20
GROUP 12	HOME	3	WORK	1	GAS	1	POP=	508	1-hr mean	1.36	Daily Max Mean	3.28
GROUP 12	HOME	3	WORK	1	GAS	2	POP=	37	1-hr mean	1.46	Daily Max Mean	3.54
GROUP 12	HOME	3	WORK	2	GAS	1	POP=	3370	1-hr mean	1.39	Daily Max Mean	3.60
GROUP 12	HOME	3	WORK	2	GAS	2	POP=	248	1-hr mean	1.53	Daily Max Mean	3.69
GROUP 12	HOME	3	WORK	3	GAS	1	POP=	680	1-hr mean	1.28	Daily Max Mean	3.23
GROUP 12	HOME	3	WORK	3	GAS	2	POP=	50	1-hr mean	1.44	Daily Max Mean	3.52
GROUP 12	HOME	3	WORK	4	GAS	1	POP=	54	1-hr mean	1.34	Daily Max Mean	3.38
GROUP 12	HOME	3	WORK	4	GAS	2	POP=	4	1-hr mean	1.48	Daily Max Mean	3.63
GROUP 12	HOME	3	WORK	5	GAS	1	POP=	54	1-hr mean	1.34	Daily Max Mean	3.34
GROUP 12	HOME	3	WORK	5	GAS	2	POP=	4	1-hr mean	1.46	Daily Max Mean	3.56
GROUP 12	HOME	3	WORK	6	GAS	1	POP=	132	1-hr mean	1.36	Daily Max Mean	3.31
GROUP 12	HOME	3	WORK	6	GAS	2	POP=	10	1-hr mean	1.52	Daily Max Mean	3.65
GROUP 12	HOME	4	WORK	1	GAS	1	POP=	136	1-hr mean	1.38	Daily Max Mean	3.34
GROUP 12	HOME	4	WORK	1	GAS	2	POP=	10	1-hr mean	1.53	Daily Max Mean	3.71
GROUP 12	HOME	4	WORK	2	GAS	1	POP=	2700	1-hr mean	1.53	Daily Max Mean	3.81
GROUP 12	HOME	4	WORK	2	GAS	2	POP=	199	1-hr mean	1.68	Daily Max Mean	3.94
GROUP 12	HOME	4	WORK	3	GAS	1	POP=	28	1-hr mean	1.36	Daily Max Mean	3.38
GROUP 12	HOME	4	WORK	3	GAS	2	POP=	2	1-hr mean	1.52	Daily Max Mean	3.64
GROUP 12	HOME	4	WORK	4	GAS	1	POP=	1701	1-hr mean	1.45	Daily Max Mean	3.52
GROUP 12	HOME	4	WORK	4	GAS	2	POP=	125	1-hr mean	1.55	Daily Max Mean	3.59
GROUP 12	HOME	4	WORK	5	GAS	1	POP=	1701	1-hr mean	1.36	Daily Max Mean	3.39
GROUP 12	HOME	4	WORK	5	GAS	2	POP=	125	1-hr mean	1.52	Daily Max Mean	3.57
GROUP 12	HOME	4	WORK	6	GAS	1	POP=	1244	1-hr mean	1.43	Daily Max Mean	3.39
GROUP 12	HOME	4	WORK	6	GAS	2	POP=	92	1-hr mean	1.49	Daily Max Mean	3.60
GROUP 12	HOME	5	WORK	1	GAS	1	POP=	136	1-hr mean	1.37	Daily Max Mean	3.32
GROUP 12	HOME	5	WORK	1	GAS	2	POP=	10	1-hr mean	1.50	Daily Max Mean	3.54
GROUP 12	HOME	5	WORK	2	GAS	1	POP=	2700	1-hr mean	1.43	Daily Max Mean	3.61
GROUP 12	HOME	5	WORK	2	GAS	2	POP=	199	1-hr mean	1.53	Daily Max Mean	3.66
GROUP 12	HOME	5	WORK	3	GAS	1	POP=	28	1-hr mean	1.34	Daily Max Mean	3.28
GROUP 12	HOME	5	WORK	3	GAS	2	POP=	2	1-hr mean	1.46	Daily Max Mean	3.47
GROUP 12	HOME	5	WORK	4	GAS	1	POP=	1701	1-hr mean	1.37	Daily Max Mean	3.39
GROUP 12	HOME	5	WORK	4	GAS	2	POP=	125	1-hr mean	1.44	Daily Max Mean	3.62
GROUP 12	HOME	5	WORK	5	GAS	1	POP=	1701	1-hr mean	1.38	Daily Max Mean	3.28
GROUP 12	HOME	5	WORK	5	GAS	2	POP=	125	1-hr mean	1.44	Daily Max Mean	3.56
GROUP 12	HOME	5	WORK	6	GAS	1	POP=	1244	1-hr mean	1.32	Daily Max Mean	3.34
GROUP 12	HOME	5	WORK	6	GAS	2	POP=	92	1-hr mean	1.53	Daily Max Mean	3.68
GROUP 12	HOME	6	WORK	1	GAS	1	POP=	213	1-hr mean	1.43	Daily Max Mean	3.42
GROUP 12	HOME	6	WORK	1	GAS	2	POP=	16	1-hr mean	1.55	Daily Max Mean	3.56
GROUP 12	HOME	6	WORK	2	GAS	1	POP=	5038	1-hr mean	1.47	Daily Max Mean	3.43
GROUP 12	HOME	6	WORK	2	GAS	2	POP=	371	1-hr mean	1.61	Daily Max Mean	3.71
GROUP 12	HOME	6	WORK	3	GAS	1	POP=	42	1-hr mean	1.40	Daily Max Mean	3.48
GROUP 12	HOME	6	WORK	3	GAS	2	POP=	3	1-hr mean	1.60	Daily Max Mean	3.54
GROUP 12	HOME	6	WORK	4	GAS	1	POP=	1471	1-hr mean	1.45	Daily Max Mean	3.57
GROUP 12	HOME	6	WORK	4	GAS	2	POP=	108	1-hr mean	1.55	Daily Max Mean	3.75
GROUP 12	HOME	6	WORK	5	GAS	1	POP=	1471	1-hr mean	1.46	Daily Max Mean	3.42

GROUP 12	HOME 6	WORK 5	GAS 2	POP= 108	1-hr mean	1.54	Daily Max Mean	3.53
GROUP 12	HOME 6	WORK 6	GAS 1	POP= 13942	1-hr mean	1.43	Daily Max Mean	3.42
GROUP 12	HOME 6	WORK 6	GAS 2	POP= 1026	1-hr mean	1.56	Daily Max Mean	3.62
GROUP 13	HOME 1	WORK 1	GAS 1	POP= 22095	1-hr mean	1.23	Daily Max Mean	3.15
GROUP 13	HOME 1	WORK 1	GAS 2	POP= 1625	1-hr mean	1.34	Daily Max Mean	3.37
GROUP 13	HOME 2	WORK 2	GAS 1	POP= 22693	1-hr mean	1.64	Daily Max Mean	3.97
GROUP 13	HOME 2	WORK 2	GAS 2	POP= 1669	1-hr mean	1.75	Daily Max Mean	4.12
GROUP 13	HOME 3	WORK 3	GAS 1	POP= 4494	1-hr mean	1.13	Daily Max Mean	3.04
GROUP 13	HOME 3	WORK 3	GAS 2	POP= 331	1-hr mean	1.27	Daily Max Mean	3.41
GROUP 13	HOME 4	WORK 4	GAS 1	POP= 7481	1-hr mean	1.18	Daily Max Mean	3.09
GROUP 13	HOME 4	WORK 4	GAS 2	POP= 550	1-hr mean	1.31	Daily Max Mean	3.23
GROUP 13	HOME 5	WORK 5	GAS 1	POP= 7481	1-hr mean	1.09	Daily Max Mean	2.96
GROUP 13	HOME 5	WORK 5	GAS 2	POP= 550	1-hr mean	1.24	Daily Max Mean	3.15
GROUP 13	HOME 6	WORK 6	GAS 1	POP= 13415	1-hr mean	1.20	Daily Max Mean	3.08
GROUP 13	HOME 6	WORK 6	GAS 2	POP= 987	1-hr mean	1.33	Daily Max Mean	3.23
GROUP 14	HOME 1	WORK 1	GAS 1	POP= 30162	1-hr mean	1.21	Daily Max Mean	2.98
GROUP 14	HOME 1	WORK 1	GAS 2	POP= 2218	1-hr mean	1.37	Daily Max Mean	3.27
GROUP 14	HOME 2	WORK 2	GAS 1	POP= 43264	1-hr mean	1.64	Daily Max Mean	3.85
GROUP 14	HOME 2	WORK 2	GAS 2	POP= 3181	1-hr mean	1.72	Daily Max Mean	3.86
GROUP 14	HOME 3	WORK 3	GAS 1	POP= 10051	1-hr mean	1.04	Daily Max Mean	2.75
GROUP 14	HOME 3	WORK 3	GAS 2	POP= 739	1-hr mean	1.21	Daily Max Mean	3.01
GROUP 14	HOME 4	WORK 4	GAS 1	POP= 12256	1-hr mean	1.13	Daily Max Mean	2.97
GROUP 14	HOME 4	WORK 4	GAS 2	POP= 902	1-hr mean	1.31	Daily Max Mean	3.19
GROUP 14	HOME 5	WORK 5	GAS 1	POP= 12256	1-hr mean	1.13	Daily Max Mean	2.86
GROUP 14	HOME 5	WORK 5	GAS 2	POP= 902	1-hr mean	1.21	Daily Max Mean	3.10
GROUP 14	HOME 6	WORK 6	GAS 1	POP= 17140	1-hr mean	1.21	Daily Max Mean	3.01
GROUP 14	HOME 6	WORK 6	GAS 2	POP= 1260	1-hr mean	1.31	Daily Max Mean	3.17

B.2.2 Second Part of Report Generated by PNEM8HR — Tables of Cumulative Numbers of People at Certain Level of Exposures

Study Area = TORONTO

Scenario = AS IS

No. exposure districts = 6

Demographic categories = All

Table 1.
Cumulative Numbers of People at 1hr Daily Max. Exposure
During Season by Equivalent Ventilation Rate

CO Level Equalled or Exceeded, ppm	Equivalent Ventilation Rate, l/min-m**2						ANY
	<5	5-9.9	10-14.9	15-19.9	20-24.9	25+	
60.0+	0	0	0	0	0	0	0
50.0	0	0	0	0	0	0	0
45.0	0	0	0	0	0	0	0
40.0	0	0	0	0	0	0	0
35.0	0	0	0	0	0	0	0
30.0	0	230	0	0	0	0	230
25.0	43	463	0	0	0	0	506
20.0	43	88594	19098	0	0	0	105902
13.0	83710	477858	98497	31172	1833	2441	544500
10.0	256304	897617	476964	46080	1945	4810	1004038
0.000	1863336	1863336	1863336	1604560	934091	864260	1863336

Table 2.
 Occurrences of People at 1hr Daily Max. Exposure
 During Season by Equivalent Ventilation Rate

CO Interval, ppm	Equivalent Ventilation Rate, l/min-min**2						ANY
	<5	5-9.9	10-14.9	15-19.9	20-24.9	25+	
60.0+	0	0	0	0	0	0	0
50.0-59.9	0	0	0	0	0	0	0
45.0-49.9	0	0	0	0	0	0	0
40.0-44.9	0	0	0	0	0	0	0
35.0-39.9	0	0	0	0	0	0	0
30.0-34.9	0	230	0	0	0	0	230
25.0-29.9	43	233	0	0	0	0	276
20.0-24.9	0	90174	19098	0	0	0	109272
13.0-19.9	158553	506048	81893	31172	1833	2441	781940
10.0-12.9	271457	2353268	515908	41668	112	2369	3184782
0.000	29944600	493125280	126951211	20650501	3962070	1407478	676041140

Table 3.
 Number of People at Their Highest 1hr Daily Max. Exposure
 During Season Within Ventilation Rate Categories

CO Interval, ppm	Equivalent Ventilation Rate, l/min-m**2						ANY
	<5	5-9.9	10-14.9	15-19.9	20-24.9	25+	
60.0+	0	0	0	0	0	0	0
50.0-59.9	0	0	0	0	0	0	0
45.0-49.9	0	0	0	0	0	0	0
40.0-44.9	0	0	0	0	0	0	0
35.0-39.9	0	0	0	0	0	0	0
30.0-34.9	0	230	0	0	0	0	230
25.0-29.9	43	233	0	0	0	0	276
20.0-24.9	0	88131	19098	0	0	0	105396
13.0-19.9	83667	389264	79399	31172	1833	2441	438598
10.0-12.9	172594	419759	378467	14908	112	2369	459538
0.000	1607032	965719	1386372	1558480	932146	859450	859298

Table 4.
Cumulative Numbers of People at Seasonal Mean Exposure

=====	
CO Level	
Equalled or	
Exceeded, ppm	

5.0 +	0
4.0	0
3.0	0
2.0	2350
1.0	1863336
0.000	1863336
=====	

Table 5.
Occurrences of People at Seasonal Mean Exposure

=====	
CO Interval,	
ppm	

5.0 +	0
4.0 -4.9	0
3.0 -3.9	0
2.0 -2.9	2350
1.0 -1.9	1860986
0.000	0
=====	

Table 6.
 Cumulative Numbers of People at 8hr Daily Max. Exposure
 During Season by Equivalent Ventilation Rate

CO Level Equalled or Exceeded, ppm	Equivalent Ventilation Rate, l/min-m**2						ANY
	<5	5-9.9	10-14.9	15-19.9	20-24.9	25+	
25.0+	0	0	0	0	0	0	0
20.0	0	0	0	0	0	0	0
17.4	0	0	0	0	0	0	0
13.0	0	3490	24927	0	0	0	28417
11.0	0	121583	24927	0	0	0	146510
5.0	322	1220150	279363	4800	25444	0	1252763
0.000	380042	1863336	1659761	747193	39572	3624	1863336

Table 7.
 Occurrences of People at 8hr Daily Max. Exposure
 During Season by Equivalent Ventilation Rate

CO Interval, ppm	Ventilation Rate, E L P M						ANY
	<5	5-9.9	10-14.9	15-19.9	20-24.9	25+	
25.0+	0	0	0	0	0	0	0
20.0-24.9	0	0	0	0	0	0	0
17.4-19.9	0	0	0	0	0	0	0
13.0-17.3	0	5323	24927	0	0	0	30250
11.0-12.9	0	195128	24927	0	0	0	220055
5.0-10.9	322	12499647	762685	4800	25444	0	13292898
0.000	488014	536962703	126992829	2093447	33820	3624	666574437

Table 8.
 Number of People at Their Highest 8hr Daily Max. Exposure
 During Season Within Ventilation Rate Categories

CO Interval, ppm	Equivalent Ventilation Rate, l/min-m**2						
	<5	5-9.9	10-14.9	15-19.9	20-24.9	25+	ANY
25.0+	0	0	0	0	0	0	0
20.0-24.9	0	0	0	0	0	0	0
17.4-19.9	0	0	0	0	0	0	0
13.0-17.3	0	3490	24927	0	0	0	28417
11.0-12.9	0	118093	0	0	0	0	118093
5.0-10.9	322	1098567	254436	4800	25444	0	1106253
0.000	379720	643186	1380398	742393	14128	3624	610573

B.2.3 Reports Generated by COHBHR2 and COHBTB2 — Tables of Cumulative Numbers of Adults at Certain Level of COHbs

Study Area = TORONTO

Scenario = AS IS

No. exposure districts = 6

Table 9.
Cumulative Numbers of Adults at 1hr Daily Max COHB Levels
during CO Season by Equivalent Ventilation Rate

COHB Level Equalled or Exceeded, %	Equivalent Ventilation Rate, l/min-m**2						ANY
	<5	5-9.9	10-14.9	15-19.9	20-24.9	25+	
6.0 +	0	0	0	0	0	0	0
5.0	0	0	0	0	0	0	0
4.0	0	0	0	0	0	0	0
3.0	0	249	0	0	0	0	249
2.9	0	249	0	0	0	0	249
2.8	0	249	0	0	0	0	249
2.7	0	374	0	0	0	0	374
2.6	0	374	0	0	0	0	374
2.5	195	374	0	0	0	0	569
2.4	195	1030	0	0	0	0	1225
2.3	195	1361	0	0	0	0	1556
2.2	195	1813	0	0	0	0	2008
2.1	195	3574	0	0	0	0	3769
2.0	8664	21079	112	0	0	0	29743
1.5	45730	449882	130874	1654	0	0	508627
1.0	656629	1109822	654281	96726	4794	798	1129410
.50	1379935	1379935	1379935	799874	205012	170029	1379935
0.000	1379935	1379935	1379935	948166	258104	202334	1379935

Table 10.
 Occurrences of Adults at 1hr COHB Levels
 during CO Season by Equivalent Ventilation Rate

COHB Interval, %	Equivalent Ventilation Rate, l/min-min**2						ANY
	<5	5-9.9	10-14.9	15-19.9	20-24.9	25+	
6.0 +	0	0	0	0	0	0	0
5.0 -5.99	0	0	0	0	0	0	0
4.0 -4.99	0	0	0	0	0	0	0
3.0 -3.99	0	249	0	0	0	0	249
2.9 -2.99	0	0	0	0	0	0	0
2.8 -2.89	0	214	0	0	0	0	214
2.7 -2.79	0	374	0	0	0	0	374
2.6 -2.69	0	0	0	0	0	0	0
2.5 -2.59	195	0	0	0	0	0	195
2.4 -2.49	0	656	0	0	0	0	656
2.3 -2.39	0	1678	0	0	0	0	1678
2.2 -2.29	0	2203	0	0	0	0	2203
2.1 -2.19	0	3257	0	0	0	0	3257
2.0 -2.09	8577	18780	16882	0	0	0	44239
1.5 -1.99	228821	2563216	508862	8819	0	0	3309718
1.0 -1.49	4103966	25782151	4131165	373177	8246	10062	34408767
.50 -.99	278964403	1548199229	135940077	7764103	1529717	810689	1973208218
0.000	1543138224	7742699486	735825212	40471564	7497569	7618777	10077250832

Table 11.
Number of Adults at 1hr Daily Max COHB Levels during
CO Season within Ventilation Rate Categories

COHB Interval, %	Equivalent Ventilation Rate, l/min-m**2						ANY
	<5	5-9.9	10-14.9	15-19.9	20-24.9	25+	
6.0 +	0	0	0	0	0	0	0
5.0 -5.99	0	0	0	0	0	0	0
4.0 -4.99	0	0	0	0	0	0	0
3.0 -3.99	0	249	0	0	0	0	249
2.9 -2.99	0	0	0	0	0	0	0
2.8 -2.89	0	0	0	0	0	0	0
2.7 -2.79	0	125	0	0	0	0	125
2.6 -2.69	0	0	0	0	0	0	0
2.5 -2.59	195	0	0	0	0	0	195
2.4 -2.49	0	656	0	0	0	0	656
2.3 -2.39	0	331	0	0	0	0	331
2.2 -2.29	0	452	0	0	0	0	452
2.1 -2.19	0	1761	0	0	0	0	1761
2.0 -2.09	8469	17505	112	0	0	0	25974
1.5 -1.99	37066	428803	130762	1654	0	0	478884
1.0 -1.49	610899	659940	523407	95072	4794	798	620783
.50 -.99	723306	270113	725654	703148	200218	169231	250525
0.000	0	0	0	148292	53092	32305	0

Table 12.
 Number of Adults that Exceed Specified 1 Hour
 COHB Levels 1 or More Times per Year

COHB Level Equalled or Exceeded, ppm	Hours / Year					
	1	2	3	4	5	>5
6.0 +	0	0	0	0	0	0
5.0	0	0	0	0	0	0
4.0	0	0	0	0	0	0
3.0	249	0	0	0	0	0
2.9	249	0	0	0	0	0
2.8	35	214	0	0	0	0
2.7	125	35	214	0	0	0
2.6	125	35	214	0	0	0
2.5	320	35	214	0	0	0
2.4	976	35	214	0	0	0
2.3	651	0	905	0	0	0
2.2	553	219	366	870	0	0
2.1	1907	407	585	0	870	0
2.0	10999	16987	462	425	214	656
1.5	82573	52202	114856	32775	51746	174475
1.0	19155	13250	53884	40399	27871	974851
.50	0	0	0	0	0	1379935
0.000	0	0	0	0	0	1379935

Table 13.
 Number of Adults that Exceed Specified Daily
 Max COHB Levels 1 or More Times per Year

COHB Level Equalled or Exceeded, ppm	Days / Year					
	1	2	3	4	5	>5
6.0 +	0	0	0	0	0	0
5.0	0	0	0	0	0	0
4.0	0	0	0	0	0	0
3.0	249	0	0	0	0	0
2.9	249	0	0	0	0	0
2.8	249	0	0	0	0	0
2.7	374	0	0	0	0	0
2.6	374	0	0	0	0	0
2.5	569	0	0	0	0	0
2.4	1225	0	0	0	0	0
2.3	1556	0	0	0	0	0
2.2	2008	0	0	0	0	0
2.1	3769	0	0	0	0	0
2.0	29631	112	0	0	0	0
1.5	175074	162349	30033	51006	14900	75265
1.0	126588	142343	22961	35515	67494	734509
.50	0	0	0	0	0	1379935
0.000	0	0	0	0	0	1379935

B.2.4 pNEM/CO Output Table Listing Average Carbon Monoxide Exposures by Demographic Group and Microenvironment

No. exposure districts = 6

TOTAL POPULATION = 1863336.
 BY DGRP = 130672 118196 112536 121997 266737 123176 117346 54415
 90437 226197 183285 100640 83371 134331

ME	DEMOGRAPHIC GROUP													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 A	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.6	4.6
H	0.34E+08	0.24E+08	0.27E+08	0.44E+08	0.14E+09	0.72E+08	0.68E+08	0.20E+08	0.47E+08	0.11E+09	0.70E+08	0.47E+08	0.29E+08	0.47E+08
O	0.14E+09	0.11E+09	0.11E+09	0.16E+09	0.48E+09	0.23E+09	0.22E+09	0.72E+08	0.15E+09	0.43E+09	0.27E+09	0.17E+09	0.11E+09	0.14E+09
2 A	4.6	4.6	4.7	4.5	4.5	4.6	4.5	4.1	4.8	4.6	4.6	4.3	4.3	4.5
H	0.28E+06	0.75E+07	0.51E+07	0.52E+07	0.21E+07	0.12E+07	0.40E+07	0.25E+07	0.85E+06	0.36E+07	0.22E+07	0.20E+07	0.50E+06	0.54E+06
O	0.60E+06	0.24E+08	0.19E+08	0.16E+08	0.76E+07	0.38E+07	0.81E+07	0.35E+07	0.23E+07	0.10E+08	0.44E+07	0.72E+07	0.19E+07	0.29E+07
3 A	3.7	3.7		3.9	3.9	3.9	3.9			4.0	3.8		3.6	
H	0.65E+06	0.42E+06		0.43E+07	0.25E+08	0.42E+07	0.89E+07			0.42E+07	0.69E+07		0.15E+07	
O	0.24E+07	0.19E+07	0	0.99E+07	0.71E+08	0.16E+08	0.22E+08	0	0	0.15E+08	0.24E+08	0	0.43E+07	0
4 A	4.6	4.3	4.7	4.7	4.7		4.6	4.5	4.6	4.5	4.5	4.7	4.7	4.7
H	0.66E+07	0.41E+05	0.16E+07	0.14E+07	0.71E+07		0.28E+07	0.19E+06	0.17E+05	0.22E+07	0.14E+06	0.98E+06	0.58E+06	0.33E+06
O	0.95E+07	0.33E+06	0.43E+07	0.38E+07	0.14E+08	0	0.60E+07	0.64E+06	0.25E+06	0.77E+07	0.90E+06	0.18E+07	0.15E+07	0.12E+07
5 A			8.9	8.7	9.3		9.3	9.1	8.7	9.1	9.0	9.2	8.9	9.5
H			0.63E+05	0.31E+05	0.13E+08		0.14E+07	0.81E+04	0.65E+05	0.17E+07	0.24E+06	0.19E+06	0.25E+06	0.33E+06
O	0	0	0.12E+07	0.84E+05	0.26E+08	0	0.95E+07	0.24E+06	0.55E+06	0.84E+07	0.26E+07	0.20E+07	0.11E+07	0.18E+07
6 A	2.7	2.7	2.7	2.6	2.8	2.8	2.8	2.7	2.9	2.8	2.8	2.7	2.8	2.7
H	0.31E+07	0.42E+07	0.24E+07	0.49E+07	0.16E+08	0.53E+07	0.47E+07	0.64E+07	0.50E+07	0.70E+07	0.48E+07	0.41E+07	0.23E+07	0.24E+07
O	0.48E+08	0.48E+08	0.40E+08	0.56E+08	0.12E+09	0.72E+08	0.55E+08	0.36E+08	0.35E+08	0.12E+09	0.78E+08	0.39E+08	0.32E+08	0.33E+08
7 A	2.3	2.3	2.4	2.3	2.6	2.7	2.4	2.5	2.5	2.4	2.4	2.3	2.3	2.4
H	0.34E+08	0.57E+08	0.45E+08	0.31E+08	0.65E+08	0.45E+08	0.26E+08	0.80E+07	0.17E+08	0.36E+08	0.32E+08	0.16E+08	0.13E+08	0.20E+08
O	0.19E+09	0.24E+09	0.20E+09	0.18E+09	0.33E+09	0.24E+09	0.17E+09	0.46E+08	0.87E+08	0.31E+09	0.21E+09	0.98E+08	0.63E+08	0.98E+08
8 A		7.9	8.2	8.0	8.8					8.0				
H		0.89E+05	0.95E+06	0.21E+06	0.45E+06					0.30E+07				
O	0	0.10E+07	0.19E+07	0.95E+06	0.47E+06	0	0	0	0	0.40E+07	0	0	0	0
9 A		5.5	6.1	5.6	6.1	5.9	6.2			6.2	5.6	5.6	6.4	5.8
H		0.77E+04	0.21E+04	0.26E+06	0.13E+08	0.85E+05	0.23E+07			0.24E+06	0.82E+05	0.37E+05	0.20E+05	0.65E+05
O	0	0.12E+06	0.64E+05	0.99E+06	0.22E+08	0.11E+07	0.82E+07	0	0.87E+06	0.75E+06	0.36E+06	0.28E+06	0.64E+06	0.26E+06
10 A	7.1	7.1	7.1	7.1	7.1	7.1	7.1			7.1	7.1	7.1	7.1	7.1
H	0.37E+04	0.13E+06	0.45E+05	0.16E+06	0.45E+06	0.11E+06	0.18E+06			0.42E+06	0.48E+05	0.79E+06	0.11E+06	0.79E+04
O	0.12E+05	0.11E+07	0.54E+06	0.49E+06	0.51E+07	0.13E+07	0.13E+07	0	0	0.29E+07	0.41E+06	0.14E+07	0.35E+06	0.47E+05
11 A	1.5	1.4	0.9		1.1		0.7	0.9	0.9	1.6	1.0	0.9	0.7	0.4
H	0.42E+06	0.38E+06	0.18E+06		0.43E+07		0.19E+06	0.12E+07	0.44E+05	0.72E+05	0.67E+06	0.23E+05	0.37E+04	0.12E+06
O	0.24E+07	0.13E+07	0.26E+06	0	0.12E+08	0	0.26E+07	0.33E+07	0.21E+07	0.17E+07	0.10E+08	0.59E+06	0.22E+06	0.49E+06
12 A					2.0					2.3	1.4	3.7		
H					0.62E+07					0.69E+04	0.94E+04	0.16E+06		
O	0	0	0	0	0.10E+08	0	0	0	0	0.42E+06	0.47E+05	0.34E+06	0	0

ME	DEMOGRAPHIC GROUP													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
13 A	0.5	0.5	0.5	0.5	0.5	0.6	0.5	0.5	0.6	0.6	0.6	0.5	0.5	0.5
H	0.29E+09	0.24E+09	0.26E+09	0.14E+09	0.59E+09	0.33E+09	0.17E+09	0.18E+09	0.19E+09	0.50E+09	0.48E+09	0.16E+09	0.19E+09	0.24E+09
O	0.48E+09	0.36E+09	0.41E+09	0.21E+09	0.89E+09	0.50E+09	0.25E+09	0.25E+09	0.30E+09	0.80E+09	0.83E+09	0.25E+09	0.30E+09	0.36E+09
14 A	0.6	0.5	0.5	0.5	0.6	0.6	0.5	0.6	0.5	0.6	0.6	0.5	0.5	0.6
H	0.14E+09	0.20E+09	0.11E+09	0.13E+09	0.25E+09	0.14E+09	0.88E+08	0.87E+08	0.90E+08	0.23E+09	0.20E+09	0.67E+08	0.16E+09	0.25E+09
O	0.21E+09	0.30E+09	0.18E+09	0.20E+09	0.37E+09	0.22E+09	0.14E+09	0.13E+09	0.13E+09	0.37E+09	0.32E+09	0.10E+09	0.27E+09	0.38E+09
15 A	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.5	1.4	1.4	1.4	1.4	1.4	1.5
H	0.40E+09	0.27E+09	0.14E+09	0.33E+09	0.52E+09	0.21E+09	0.30E+09	0.88E+08	0.23E+09	0.44E+09	0.53E+09	0.25E+09	0.20E+09	0.35E+09
O	0.63E+09	0.40E+09	0.20E+09	0.49E+09	0.78E+09	0.29E+09	0.45E+09	0.12E+09	0.34E+09	0.70E+09	0.88E+09	0.40E+09	0.32E+09	0.52E+09
16 A	1.6	1.5	1.6	1.5	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.6	1.6
H	0.12E+09	0.67E+08	0.15E+09	0.13E+09	0.12E+09	0.73E+08	0.73E+08	0.35E+08	0.12E+09	0.16E+09	0.13E+09	0.12E+09	0.68E+08	0.18E+09
O	0.20E+09	0.10E+09	0.22E+09	0.20E+09	0.19E+09	0.12E+09	0.11E+09	0.48E+08	0.18E+09	0.25E+09	0.22E+09	0.18E+09	0.11E+09	0.30E+09
17 A	0.4	0.4	0.5	0.5	0.6	0.5	0.6	0.4	0.5	0.6	0.5	0.6	0.5	0.5
H	0.17E+07	0.22E+06	0.13E+07	0.17E+08	0.23E+09	0.47E+08	0.14E+09	0.15E+07	0.22E+08	0.23E+09	0.61E+07	0.92E+08	0.22E+07	0.76E+07
O	0.24E+07	0.27E+06	0.17E+07	0.24E+08	0.36E+09	0.70E+08	0.20E+09	0.29E+07	0.31E+08	0.32E+09	0.89E+07	0.13E+09	0.42E+07	0.12E+08
18 A	2.9	2.9	2.9	2.9	2.9	2.9	3.0	2.9	2.9	3.0	2.9	2.9	2.9	2.9
H	0.16E+08	0.73E+07	0.83E+07	0.23E+08	0.57E+08	0.54E+07	0.28E+08	0.78E+07	0.76E+07	0.59E+08	0.33E+08	0.22E+08	0.13E+08	0.19E+08
O	0.34E+08	0.19E+08	0.20E+08	0.49E+08	0.11E+09	0.24E+08	0.56E+08	0.20E+08	0.21E+08	0.13E+09	0.80E+08	0.42E+08	0.32E+08	0.42E+08
19 A	0.8	0.8	0.9	1.0	1.1	1.0	1.0	0.9	1.0	1.0	1.1	1.2	1.0	0.8
H	0.68E+07	0.26E+07	0.58E+07	0.21E+08	0.39E+08	0.10E+08	0.16E+08	0.23E+07	0.93E+07	0.39E+08	0.13E+08	0.16E+08	0.64E+07	0.99E+07
O	0.16E+08	0.68E+07	0.12E+08	0.34E+08	0.76E+08	0.25E+08	0.34E+08	0.68E+07	0.18E+08	0.69E+08	0.25E+08	0.28E+08	0.13E+08	0.21E+08
20 A				0.5	0.8	0.7	0.8		0.6	0.6		0.7	0.7	
H				0.69E+07	0.53E+08	0.63E+07	0.22E+08		0.49E+07	0.11E+08		0.13E+08	0.11E+06	
O	0	0	0	0.94E+07	0.83E+08	0.70E+07	0.32E+08	0	0.66E+07	0.15E+08	0	0.23E+08	0.23E+06	0
21 A	0.6	0.6	0.6	0.6	0.7	0.6	0.7	0.7	0.5	0.7	0.7	0.7	0.6	0.8
H	0.45E+08	0.10E+09	0.16E+09	0.12E+09	0.22E+08	0.46E+08	0.78E+07	0.26E+07	0.38E+07	0.38E+08	0.17E+08	0.14E+08	0.16E+07	0.21E+06
O	0.69E+08	0.16E+09	0.26E+09	0.19E+09	0.36E+08	0.68E+08	0.11E+08	0.37E+07	0.54E+07	0.64E+08	0.30E+08	0.23E+08	0.39E+07	0.33E+06
22 A	0.3	0.3	0.3	0.3	0.4	0.4	0.3	0.4	0.3	0.3	0.4	0.3	0.3	0.3
H	0.48E+07	0.81E+07	0.47E+07	0.40E+07	0.12E+08	0.39E+07	0.68E+07	0.16E+07	0.54E+07	0.11E+08	0.67E+07	0.69E+07	0.50E+07	0.15E+08
O	0.85E+07	0.12E+08	0.86E+07	0.74E+07	0.21E+08	0.50E+07	0.11E+08	0.40E+07	0.88E+07	0.19E+08	0.11E+08	0.11E+08	0.82E+07	0.23E+08
23 A	2.5	2.2	2.3	1.6	2.7	4.8	2.5	2.2	2.4	3.1	2.0	2.3	3.0	4.4
H	0.58E+06	0.80E+06	0.23E+07	0.53E+06	0.16E+07	0.55E+06	0.10E+07	0.12E+07	0.24E+07	0.32E+07	0.27E+07	0.11E+07	0.14E+07	0.25E+07
O	0.80E+06	0.19E+07	0.31E+07	0.94E+06	0.28E+07	0.63E+06	0.20E+07	0.21E+07	0.41E+07	0.62E+07	0.45E+07	0.19E+07	0.26E+07	0.41E+07
24 A	0.1	0.2	0.1	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.1	0.5	0.1	0.2
H	0.14E+07	0.71E+06	0.28E+07	0.43E+07	0.51E+07	0.64E+07	0.21E+07	0.16E+07	0.56E+07	0.43E+07	0.83E+07	0.40E+06	0.74E+06	0.15E+07
O	0.20E+07	0.14E+07	0.36E+07	0.58E+07	0.75E+07	0.14E+08	0.33E+07	0.21E+07	0.11E+08	0.73E+07	0.11E+08	0.57E+06	0.18E+07	0.23E+07

		DEMOGRAPHIC GROUP													
25	A	0.4	0.4	0.4	0.3	0.5	0.5	0.4	0.5	0.4	0.5	0.4	0.4	0.4	0.4
	H	0.34E+07	0.51E+07	0.70E+07	0.66E+07	0.17E+08	0.41E+07	0.64E+07	0.51E+07	0.29E+07	0.29E+08	0.47E+07	0.17E+08	0.53E+07	0.86E+07
	O	0.77E+07	0.85E+07	0.15E+08	0.11E+08	0.30E+08	0.92E+07	0.12E+08	0.10E+08	0.92E+07	0.48E+08	0.87E+07	0.28E+08	0.95E+07	0.18E+08
26	A	0.5	0.5	0.4	0.5	0.6	0.6	0.5	0.4	0.4	0.5	0.5	0.4	0.7	0.6
	H	0.28E+06	0.96E+06	0.32E+07	0.20E+07	0.15E+08	0.85E+07	0.72E+07	0.66E+06	0.18E+07	0.58E+07	0.32E+07	0.11E+07	0.12E+07	0.28E+07
	O	0.21E+07	0.30E+07	0.58E+07	0.42E+07	0.25E+08	0.10E+08	0.14E+08	0.21E+07	0.43E+07	0.16E+08	0.76E+07	0.27E+07	0.31E+07	0.65E+07
27	A	1.1	1.1	1.2	1.1	1.3	1.3	1.2	0.8	1.3	1.4	1.0	1.1	1.0	0.9
	H	0.27E+07	0.23E+07	0.17E+07	0.14E+08	0.43E+08	0.17E+08	0.24E+08	0.91E+07	0.39E+07	0.25E+08	0.15E+08	0.17E+08	0.58E+07	0.65E+07
	O	0.48E+07	0.38E+07	0.30E+07	0.23E+08	0.70E+08	0.30E+08	0.39E+08	0.15E+08	0.94E+07	0.46E+08	0.28E+08	0.32E+08	0.11E+08	0.11E+08
28	A				1.0	1.1	0.8	1.1	1.0	1.0	1.1	1.1	0.8	1.1	1.0
	H				0.29E+07	0.19E+08	0.35E+07	0.43E+07	0.87E+06	0.11E+07	0.77E+07	0.35E+07	0.46E+07	0.24E+07	0.86E+07
	O	0	0	0	0.59E+07	0.31E+08	0.79E+07	0.11E+08	0.35E+07	0.39E+07	0.22E+08	0.86E+07	0.97E+07	0.63E+07	0.29E+08
29	A				0.5	1.4		1.0							
	H				0.20E+06	0.74E+07		0.64E+06							
	O	0	0	0	0.27E+06	0.13E+08		0.15E+07	0	0	0	0	0	0	0
30	A	0.7	0.7	0.6	0.8	0.8	0.9	0.7	0.7	0.6	0.9	1.0	0.6	0.7	0.8
	H	0.23E+08	0.23E+08	0.23E+08	0.86E+07	0.14E+08	0.88E+07	0.82E+07	0.95E+07	0.16E+08	0.99E+07	0.14E+08	0.42E+07	0.75E+07	0.64E+07
	O	0.60E+08	0.53E+08	0.45E+08	0.27E+08	0.48E+08	0.29E+08	0.31E+08	0.22E+08	0.37E+08	0.40E+08	0.37E+08	0.12E+08	0.23E+08	0.23E+08
31	A	1.1	1.2	1.2	1.3	1.5			1.4	1.1	1.3	2.0	1.2		
	H	0.17E+07	0.91E+07	0.99E+07	0.77E+07	0.73E+06			0.47E+06	0.10E+07	0.60E+06	0.32E+06	0.52E+05		
	O	0.50E+07	0.28E+08	0.26E+08	0.22E+08	0.50E+07	0	0	0.63E+06	0.29E+07	0.11E+07	0.11E+07	0.11E+06	0	
32	A	0.5	0.3	0.4	0.3	0.4	0.5		0.5		0.4	0.4	0.4	0.3	0.3
	H	0.85E+06	0.99E+06	0.19E+07	0.33E+07	0.65E+07	0.39E+07		0.95E+06		0.45E+07	0.30E+07	0.83E+06	0.11E+07	0.14E+07
	O	0.20E+07	0.17E+07	0.30E+07	0.65E+07	0.94E+07	0.59E+07	0	0.10E+07	0	0.65E+07	0.46E+07	0.11E+07	0.16E+07	0.23E+07
33	A	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.3	0.4	0.3	0.4
	H	0.74E+07	0.62E+07	0.68E+07	0.72E+07	0.62E+07	0.52E+07	0.47E+07	0.15E+07	0.56E+07	0.38E+07	0.54E+07	0.17E+06	0.33E+07	0.13E+07
	O	0.13E+08	0.12E+08	0.13E+08	0.10E+08	0.11E+08	0.85E+07	0.67E+07	0.27E+07	0.80E+07	0.69E+07	0.10E+08	0.59E+06	0.46E+07	0.18E+07
34	A	0.7	0.6	0.9	1.2	1.0	0.8	0.8	0.7	0.9	1.2	0.8	1.1	1.1	0.9
	H	0.19E+07	0.65E+07	0.63E+07	0.88E+07	0.29E+08	0.9E+07	0.51E+07	0.33E+07	0.47E+06	0.16E+07	0.0E+00	0.0E+00	0.0E+00	0.0E+06
	O	0.35E+07	0.11E+08	0.10E+08	0.10E+08	0.10E+08	0.11E+08	0.11E+08	0.33E+08	0.1E+08	0.1E+08	0.1E+08	0.2E+08	0.2E+08	0.1E+07
35	A				1.0	1.1		0.9		2.1	1.1	1.2		0.5	
	H				0.84E+05	0.39E+06		0.36E+03		0.14E+06	0.54E+05	0.41E+04		0.61E+05	
	O	0	0	0	0.65E+06	0.95E+06	0	0.21E+05	0	0.30E+06	0.81E+06	0.24E+06	0	0.11E+06	0
36	A				4.6	4.8	4.8	4.8		4.6	5.3	4.8			
	H				0.18E+07	0.82E+06	0.13E+06	0.13E+06		0.67E+06	0.32E+06	0.13E+06			
	O	0	0	0	0.42E+07	0.14E+07	0.86E+06	0.86E+06	0	0.17E+07	0.14E+07	0.51E+06	0	0	0
37	A														
	H														
	O	0	0	0	0	0	0	0	0	0	0	0	0	0	0

B.3 Output from pNEM/O3 for VANCOUVER 1988

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					ANY
	<15	15-24	25-29	30-34	35+	
.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	1098	0	0	0	1098
.201	4446	1098	0	0	0	5544
.181	4972	2135	0	0	0	7107
.161	43216	2434	1466	0	0	44452
.141	78385	2526	1466	11	21	78617
.121	234852	36357	17539	18	45	266038
.101	546968	74704	41042	18	1107	551262
.081	771082	185834	107692	1844	3442	785368
.061	1041902	332975	179290	24640	19057	1042068
.041	1138699	702293	295578	124817	157494	1138699
.021	1152693	1040636	609615	348466	301466	1152693
.001	1152693	1152693	986874	604703	694311	1152693
0.000	1152693	1152693	1009937	641941	740532	1152693

Study Area = VANCOUVER Entire Population
 No. exposure districts = 9
 First day of O3 season = 122
 Last day of O3 season = 274
 No. days in O3 season = 153

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.	1098.	0.	0.	0.	1098.
.201-.220	4446.	0.	0.	0.	0.	4446.
.181-.200	526.	1037.	0.	0.	0.	1563.
.161-.180	41212.	498.	1466.	0.	0.	43176.
.141-.160	73624.	131.	0.	11.	21.	73787.
.121-.140	265325.	33860.	16073.	7.	24.	315289.
.101-.120	840049.	40024.	23588.	0.	1117.	904778.
.081-.100	2499620.	176579.	72739.	1826.	2541.	2753305.
.061-.080	9404383.	954943.	145031.	22876.	23491.	10550724.
.041-.060	45006722.	4187065.	429069.	110985.	291889.	50025730.
.021-.040	261574779.	17533898.	1056288.	463920.	430130.	281059015.
.001-.020	3172497186.	110689617.	5548842.	1784701.	1204055.	3291724401.
0.000	575763375.	17905496.	1058617.	350436.	153460.	595231384.

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Study Area = VANCOUVER

Entire Population

No. exposure districts = 9

First day of O3 season = 122

Last day of O3 season = 274

No. days in O3 season = 153

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					ANY
	<15	15-24	25-29	30-34	35+	
.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	1098	0	0	0	1098
.201	4446	1098	0	0	0	5544
.181	4972	2135	0	0	0	7107
.161	42228	2399	1466	0	0	44452
.141	77287	2474	1466	0	21	78617
.121	233502	18303	17462	0	21	266038
.101	545629	44615	20421	0	761	551262
.081	770752	104273	86153	216	1313	785368
.061	1033651	178249	148209	9467	11871	1042068
.041	1138699	514380	214714	45128	99046	1138699
.021	1152693	831695	451595	181726	160772	1152693
.001	1152693	1022507	522448	237513	206940	1152693
0.000	1152693	1022507	522448	237513	206940	1152693

Study Area = VANCOUVER Entire Population
 No. exposure districts = 9
 First day of O3 season = 122
 Last day of O3 season = 274
 No. days in O3 season = 153

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.	1098.	0.	0.	0.	1098.
.201-.220	4446.	0.	0.	0.	0.	4446.
.181-.200	526.	1037.	0.	0.	0.	1563.
.161-.180	37311.	264.	1466.	0.	0.	39041.
.141-.160	36385.	75.	0.	0.	21.	36481.
.121-.140	180742.	15843.	15996.	0.	0.	212581.
.101-.120	461833.	26387.	2959.	0.	740.	491919.
.081-.100	1050859.	61521.	65732.	216.	552.	1178880.
.061-.080	3583521.	235435.	62056.	9251.	11217.	3901480.
.041-.060	15536681.	1768214.	173659.	38412.	206162.	17723128.
.021-.040	51136368.	4089594.	421881.	154116.	185263.	55987222.
.001-.020	92009205.	4278079.	244654.	82423.	69803.	96684164.
0.000	100026.	0.	0.	0.	0.	100026.

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Study Area = VANCOUVER Entire Population
 No. exposure districts = 9
 First day of O3 season = 122
 Last day of O3 season = 274
 No. days in O3 season = 153

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					ANY
	<15	15-24	25-29	30-34	35+	
.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	1098	0	0	0	1098
.201	0	1098	0	0	0	1098
.181	104	2135	0	0	0	2239
.161	15446	2413	1466	0	0	17922
.141	42128	2487	1466	11	21	44710
.121	113618	19732	17539	11	45	148499
.101	342433	57710	41042	11	1107	377622
.081	678583	170238	107510	682	3442	691270
.061	958533	297865	177044	23189	18909	993805
.041	1129501	678139	289855	119222	157484	1138677
.021	1152693	1009590	546387	329880	260944	1152693
.001	1152693	1152311	740783	515434	518810	1152693
0.000	1152693	1152311	740842	515434	518810	1152693

Study Area = VANCOUVER Entire Population
 No. exposure districts = 9
 First day of O3 season = 122
 Last day of O3 season = 274
 No. days in O3 season = 153

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					ANY
	<15	15-24	25-29	30-34	35+	
.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.	1098.	0.	0.	0.	1098.
.201-.220	0.	0.	0.	0.	0.	0.
.181-.200	104.	1037.	0.	0.	0.	1141.
.161-.180	15397.	477.	1466.	0.	0.	17340.
.141-.160	27284.	113.	0.	11.	21.	27429.
.121-.140	85395.	17245.	16073.	0.	24.	118737.
.101-.120	283457.	38053.	23588.	0.	1062.	346160.
.081-.100	736031.	156392.	66468.	671.	2441.	962003.
.061-.080	2285623.	603637.	126409.	22520.	23300.	3061489.
.041-.060	10587181.	2728723.	376890.	102989.	284416.	14080199.
.021-.040	42334893.	8476187.	808400.	370269.	338255.	52328004.
.001-.020	88086143.	14741374.	1381899.	605161.	471385.	105285962.
0.000	100007.	32002.	365.	0.	93.	132467.

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Study Area = VANCOUVER Entire Population
 No. exposure districts = 9
 First day of O3 season = 122
 Last day of O3 season = 274
 No. days in O3 season = 153

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					ANY
	<15	15-24	25-29	30-34	35+	
.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	1098	0	0	0	1098
.201-.220	4446	0	0	0	0	4446
.181-.200	526	1037	0	0	0	1563
.161-.180	37256	264	1466	0	0	37345
.141-.160	35059	75	0	0	21	34165
.121-.140	156215	15829	15996	0	0	187421
.101-.120	312127	26312	2959	0	740	285224
.081-.100	225123	59658	65732	216	552	234106
.061-.080	262899	73976	62056	9251	10558	256700
.041-.060	105048	336131	66505	35661	87175	96631
.021-.040	13994	317315	236881	136598	61726	13994
.001-.020	0	190812	70853	55787	46168	0
0.000	0	0	0	0	0	0

Study Area = VANCOUVER Entire Population
 No. exposure districts = 9
 First day of O3 season = 122
 Last day of O3 season = 274
 No. days in O3 season = 153

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					ANY
	<15	15-24	25-29	30-34	35+	
.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	950	0	0	0	0	950
.101	15763	0	0	0	0	15763
.091	24224	0	0	0	0	24224
.081	159034	681	0	0	0	159715
.071	321162	871	0	0	0	321306
.061	549835	4822	0	0	0	552645
.041	1024319	67633	42	0	0	1024472
.021	1152297	279457	6250	0	0	1152413
.001	1152693	427517	6434	0	0	1152693
0.000	1152693	427517	6434	0	0	1152693

Study Area = VANCOUVER Entire Population

No. exposure districts = 9

First day of O3 season = 122

Last day of O3 season = 274

No. days in O3 season = 153

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					ANY
	<15	15-24	25-29	30-34	35+	
.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	950.	0.	0.	0.	0.	950.
.101-.110	14813.	0.	0.	0.	0.	14813.
.091-.100	8461.	0.	0.	0.	0.	8461.
.081-.090	135419.	681.	0.	0.	0.	136100.
.071-.080	210129.	190.	0.	0.	0.	210319.
.061-.070	573300.	3951.	0.	0.	0.	577251.
.041-.060	4668515.	63819.	42.	0.	0.	4732376.
.021-.040	31816423.	371002.	6208.	0.	0.	32193633.
.001-.020	137420648.	894063.	351.	0.	0.	138315062.
0.000	173064.	0.	0.	0.	0.	173064.

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Study Area = VANCOUVER Entire Population
 No. exposure districts = 9
 First day of O3 season = 122
 Last day of O3 season = 274
 No. days in O3 season = 153

Table 4A.
 Cumulative Numbers of People at 8-Hr Daily Max. Dose
 During 03 Season by 8-Hr 03 and 8-Hr EVR.

O3 Level						
Equalled or Exceeded, ppm	8hr Equivalent Ventilation Rate, l/min-m**2					ANY
	<15	15-24	25-29	30-34	35+	
.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	913	0	0	0	0	913
.101	9182	0	0	0	0	9182
.091	24211	0	0	0	0	24211
.081	157934	1772	0	0	0	159706
.071	319755	1926	7	0	0	321002
.061	550746	5915	7	0	0	553558
.041	1019235	67685	596	0	0	1019603
.021	1152297	320215	9746	0	0	1152413
.001	1152693	477280	14733	0	0	1152693
0.000	1152693	477280	14733	0	0	1152693

Study Area = VANCOUVER Entire Population
 No. exposure districts = 9
 First day of 03 season = 122
 Last day of 03 season = 274
 No. days in 03 season = 153

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					ANY
	<15	15-24	25-29	30-34	35+	
.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	913.	0.	0.	0.	0.	913.
.101-.110	8269.	0.	0.	0.	0.	8269.
.091-.100	15029.	0.	0.	0.	0.	15029.
.081-.090	134181.	1772.	0.	0.	0.	135953.
.071-.080	209306.	821.	7.	0.	0.	210134.
.061-.070	570891.	3991.	0.	0.	0.	574882.
.041-.060	4569504.	63067.	589.	0.	0.	4633160.
.021-.040	30897887.	484194.	9150.	0.	0.	31391231.
.001-.020	137831576.	1385304.	5154.	0.	0.	139222034.
0.000	170424.	0.	0.	0.	0.	170424.

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Study Area = VANCOUVER Entire Population
 No. exposure districts = 9
 First day of O3 season = 122
 Last day of O3 season = 274
 No. days in O3 season = 153

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					ANY
	<15	15-24	25-29	30-34	35+	
.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	950	0	0	0	0	950
.101-.110	14813	0	0	0	0	14813
.091-.100	8461	0	0	0	0	8461
.081-.090	134810	681	0	0	0	135491
.071-.080	162128	190	0	0	0	161591
.061-.070	228673	3951	0	0	0	231339
.041-.060	474484	62811	42	0	0	471827
.021-.040	127978	211824	6208	0	0	127941
.001-.020	396	148060	184	0	0	280
0.000	0	0	0	0	0	0

Study Area = VANCOUVER Entire Population

No. exposure districts = 9

First day of O3 season = 122

Last day of O3 season = 274

No. days in O3 season = 153

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	0
.026	0
.021	0
.011	1011054
.001	1152693
0.000	1152693

=====	
Study Area = VANCOUVER	Entire Population
No. exposure districts =	9
First day of O3 season =	122
Last day of O3 season =	274
No. days in O3 season =	153

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	0
.026-.030	0
.021-.025	0
.011-.020	1011054
.001-.010	141639
0.000	0

Study Area = VANCOUVER	Entire Population
No. exposure districts =	9
First day of O3 season =	122
Last day of O3 season =	274
No. days in O3 season =	153

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	1098	0	0	0	0	0
.201	1098	0	0	0	0	0
.181	2239	0	0	0	0	0
.161	16265	1657	0	0	0	0
.141	42412	2298	0	0	0	0
.121	131292	17168	39	0	0	0
.101	259839	101322	16422	39	0	0
.081	292473	165317	138137	40406	54856	81
.061	156217	117927	128917	158666	71710	360368
.041	13150	35962	21795	31183	41380	995207
.021	0	0	0	0	0	1152693
.001	0	0	0	0	0	1152693
0.000	0	0	0	0	0	1152693

Study Area = VANCOUVER Entire Population
 No. exposure districts = 9
 First day of O3 season = 122
 Last day of O3 season = 274
 No. days in O3 season = 153

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	913	0	0	0	0	0
.101	9182	0	0	0	0	0
.091	24211	0	0	0	0	0
.081	159248	458	0	0	0	0
.071	272373	47962	667	0	0	0
.061	283055	150090	119707	706	0	0
.041	146868	118816	114240	54589	159271	425819
.021	6922	21574	8117	5186	18246	1092368
.001	0	0	0	0	0	1152693
0.000	0	0	0	0	0	1152693

Study Area = VANCOUVER Entire Population
 No. exposure districts = 9
 First day of O3 season = 122
 Last day of O3 season = 274
 No. days in O3 season = 153

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	32	0	0	0	0	0
.121	56	0	0	0	0	0
.101	1118	0	0	0	0	0
.081	3214	508	0	0	0	0
.061	30037	9996	7	0	0	0
.041	173372	13745	54460	17459	185	391
.021	233956	81724	60879	61816	14731	33518
.001	152964	160199	118063	129472	42718	86494
0.000	152964	160199	118063	129472	42718	86494

Study Area = VANCOUVER Entire Population
 No. exposure districts = 9
 First day of O3 season = 122
 Last day of O3 season = 274
 No. days in O3 season = 153

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	1772	0	0	0	0	0
.071	1266	667	0	0	0	0
.061	5253	669	0	0	0	0
.041	66776	1044	461	0	0	0
.021	179072	81376	33953	17540	3556	5328
.001	71178	147866	24563	58099	51141	124481
0.000	71178	147866	24563	58099	51141	124481

Study Area = VANCOUVER Entire Population

No. exposure districts = 9

First day of O3 season = 122

Last day of O3 season = 274

No. days in O3 season = 153

Table 13.
 Cumulative Numbers of People at 6-Hr Daily Max. Exposure
 During O3 Season by 6-Hr Equivalent Ventilation Rate

O3 Level						
Equalled or Exceeded, ppm	6hr Equivalent Ventilation Rate, l/min-m**2					ANY
	<15	15-24	25-29	30-34	35+	
.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	7313	39	0	0	0	7352
.111	22816	39	0	0	0	22855
.101	44649	1139	0	0	0	45788
.091	192725	1980	0	0	0	194515
.081	317554	2078	0	0	0	319418
.071	507531	59011	0	0	0	511267
.061	766231	102207	0	1	0	766532
.041	1077186	203233	1757	2	0	1077499
.021	1152690	382764	27965	75	0	1152690
.001	1152693	543233	35235	2043	0	1152693
0.000	1152693	543233	35235	2043	0	1152693

Study Area = VANCOUVER Entire Population
 No. exposure districts = 9
 First day of O3 season = 122
 Last day of O3 season = 274
 No. days in O3 season = 153

Table 14.
 Occurrences of People at 6-Hr Daily Max. Exposure
 During O3 Season by 6-Hr Equivalent Ventilation Rate

O3 Interval, ppm	6hr Equivalent Ventilation Rate, l/min-m**2					ANY
	<15	15-24	25-29	30-34	35+	
.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	7313.	39.	0.	0.	0.	7352.
.111-.120	15503.	0.	0.	0.	0.	15503.
.101-.110	22490.	1100.	0.	0.	0.	23590.
.091-.100	161609.	841.	0.	0.	0.	162450.
.081-.090	151812.	806.	0.	0.	0.	152618.
.071-.080	475289.	56933.	0.	0.	0.	532222.
.061-.070	703175.	43281.	0.	1.	0.	746457.
.041-.060	5778446.	116350.	1757.	1.	0.	5896554.
.021-.040	34049415.	717292.	30468.	73.	0.	34797248.
.001-.020	132384094.	1357782.	10370.	1968.	0.	133754214.
0.000	273821.	0.	0.	0.	0.	273821.

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Study Area = VANCOUVER Entire Population
 No. exposure districts = 9
 First day of O3 season = 122
 Last day of O3 season = 274
 No. days in O3 season = 153

Table 13A.
 Cumulative Numbers of People at 6-Hr Daily Max. Dose
 During O3 Season by 6-Hr O3 and 6-Hr EVR.

O3 Level						
Equalled or Exceeded, ppm	6hr Equivalent Ventilation Rate, l/min-m**2					ANY
	<15	15-24	25-29	30-34	35+	
.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	6325	39	0	0	0	6364
.111	22824	39	0	0	0	22863
.101	44609	1137	0	0	0	45746
.091	172055	1997	14	7	0	174034
.081	319976	2142	14	7	0	322071
.071	501926	60474	14	7	0	506559
.061	717469	111350	99	8	0	725729
.041	1077266	243923	2099	596	0	1077807
.021	1152690	417539	30347	3376	5	1152690
.001	1152693	577855	39634	9305	5	1152693
0.000	1152693	577855	39634	9305	5	1152693

Study Area = VANCOUVER Entire Population
 No. exposure districts = 9
 First day of O3 season = 122
 Last day of O3 season = 274
 No. days in O3 season = 153

Table 14A.
 Occurrences of People at 6-Hr Daily Max. Dose
 During O3 Season by 6-Hr O3 and 6-Hr EVR

O3 Interval, ppm	6hr Equivalent Ventilation Rate, l/min-m**2					ANY
	<15	15-24	25-29	30-34	35+	
.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	6325.	39.	0.	0.	0.	6364.
.111-.120	16499.	0.	0.	0.	0.	16499.
.101-.110	22434.	1098.	0.	0.	0.	23532.
.091-.100	140987.	860.	14.	7.	0.	141868.
.081-.090	174727.	963.	0.	0.	0.	175690.
.071-.080	437299.	58373.	0.	0.	0.	495672.
.061-.070	616347.	50876.	85.	1.	0.	667309.
.041-.060	5540704.	230917.	2000.	588.	0.	5774209.
.021-.040	32926277.	1086093.	34238.	2780.	5.	34049393.
.001-.020	132480508.	2212128.	14746.	6263.	0.	134713645.
0.000	297848.	0.	0.	0.	0.	297848.

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Study Area = VANCOUVER Entire Population
 No. exposure districts = 9
 First day of O3 season = 122
 Last day of O3 season = 274
 No. days in O3 season = 153

Table 15.
 Number of People at Their Highest 6-Hr Daily Max. Exposure
 During O3 Season by 6-Hr Ventilation Rate Categories

O3 Interval, ppm	6hr Equivalent Ventilation Rate, l/min-m**2					ANY
	<15	15-24	25-29	30-34	35+	
.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	7313	39	0	0	0	7352
.111-.120	15503	0	0	0	0	15503
.101-.110	21833	1100	0	0	0	22933
.091-.100	148076	841	0	0	0	148727
.081-.090	124829	98	0	0	0	124903
.071-.080	189977	56933	0	0	0	191849
.061-.070	258700	43196	0	1	0	255265
.041-.060	310955	101026	1757	1	0	310967
.021-.040	75504	179531	26208	73	0	75191
.001-.020	3	160469	7270	1968	0	3
0.000	0	0	0	0	0	0

Study Area = VANCOUVER Entire Population

No. exposure districts = 9

First day of O3 season = 122

Last day of O3 season = 274

No. days in O3 season = 153

Table 16.
 Cumulative Numbers of People at 6-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	0
.026	0
.021	42356
.011	1056485
.001	1152693
0.000	1152693

Study Area = VANCOUVER		Entire Population
No. exposure districts =	9	
First day of O3 season =	122	
Last day of O3 season =	274	
No. days in O3 season =	153	

Table 17.
 Occurrences of People at 6-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	0
.026-.030	0
.021-.025	42356
.011-.020	1014129
.001-.010	96208
0.000	0

Study Area = VANCOUVER	Entire Population
No. exposure districts =	9
First day of O3 season =	122
Last day of O3 season =	274
No. days in O3 season =	153

Table 18.
 Number of People at Daily Max 6-HR Dose that Exceed
 Specified 6-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	6364	0	0	0	0	0
.111	22863	0	0	0	0	0
.101	45097	649	0	0	0	0
.091	159805	14229	0	0	0	0
.081	280189	41882	0	0	0	0
.071	265352	151809	66937	22461	0	0
.061	284304	235759	135923	8350	38415	22978
.041	82578	105891	125542	82499	75600	605697
.021	327	6488	958	7789	15241	1121887
.001	0	0	0	0	0	1152693
0.000	0	0	0	0	0	1152693

Study Area = VANCOUVER Entire Population
 No. exposure districts = 9
 First day of O3 season = 122
 Last day of O3 season = 274
 No. days in O3 season = 153

Table 19.
 Number of People that Exceed Specified 6 HR O3 Levels
 at Daily Max 6-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	39	0	0	0	0	0
.111	39	0	0	0	0	0
.101	1137	0	0	0	0	0
.091	2018	0	0	0	0	0
.081	1345	818	0	0	0	0
.071	59636	859	0	0	0	0
.061	110428	944	0	0	0	0
.041	185746	21980	38381	243	0	0
.021	126512	27448	62248	68273	56283	79220
.001	134111	29931	26484	28187	12428	347281
0.000	134111	29931	26484	28187	12428	347281

Study Area = VANCOUVER Entire Population
 No. exposure districts = 9
 First day of O3 season = 122
 Last day of O3 season = 274
 No. days in O3 season = 153