6. Exposure Assessment

6.1 Overview

The dispersion model, as described in Section 3, predicts concentrations of toxic pollutants in ambient air spatially distributed across the modeling domain. A risk characterization based on these initial modeled concentrations would assume that an individual would be exposed to these concentrations over the period of the analysis. For cancer risk characterization, the period of exposure is considered to be a lifetime of 70 years.

To get a preliminary risk estimate, the annual average concentration is considered representative of the 70 year period, and is compared to a benchmark concentration for each toxic pollutant. However, the assumption that an average individual would remain in a single location over a 70-year lifetime is unrealistic. An exposure model attempts to correct this by characterizing the activities and movement of individuals within a given area, usually a census area, and from that estimate a range of concentrations to which that population would be subject. For example, in a given census tract there are young children and the elderly who remain indoors most hours of the day, older children who go to school or play outdoors, workers who commute to other areas, and others with a range of activities. People's range of activities expose them at different levels to the outdoor ambient air, or outdoor air as it infiltrates buildings. An exposure model uses information from each census tract to estimate the range in age of the population, their activities and commuting habits, and calculates a range of concentrations to which they are exposed.

The exposure calculations are given in percentiles. For example, half the population of a given census tract will be exposed to concentrations less than the 50th percentile, or median concentration, and half of the population will be exposed to concentrations that are greater. At the 75th percentile concentration, 75% percent of the population will have lower exposures than that level, and only 25% will have greater exposures. The exposure concentrations represent a range of exposures for the mix of people and activities in their census tract. For practical purposes, the risk characterization of the exposure concentrations for each toxic pollutant typically looks at the median and 90th percentile concentrations.

6.2 Elements of HAPEM5, the PATA Exposure Model

The exposure model used for the PATA study is the EPA Hazardous Air Pollution Exposure Model, version 5 (HAPEM5). The model evaluates the average long-term (annual average) inhalation exposures of the population within the domain of the study area. The basic features of the exposure model include the use of demographic data by census tract, a category of microenvironments, activity and commuting pattern data, and the incorporation of modeled air quality concentrations. The components are described more fully below.

6.2.1 Demographic Data

These data are reported by the Census Bureau at the resolution of the census tract. Each census tract may contain between 2,500 and 8,000 residents. For HAPEM5, the default dataset is for the 2000 Census, and includes data on the age, gender, ethnic group, and employment data of the population, by census tract.

6.2.2 Microenvironments

HAPEM5 uses a set of 37 microenvironments within which the population is active. These microenvironments include outdoor areas (including residential areas, school grounds, and parking lots), indoor locations (including offices, residences with a gas stove, and restaurants), and inside vehicles (including buses, cars, and trucks). The concentrations within the microenvironments are controlled by three microenvironment (ME) factors that estimate 1) the proximity of the microenvironment to the emission, 2) the penetration of outdoor air, and 3) the presence of emissions sources within the microenvironment. The only air quality data available to HAPEM5 are the modeled concentrations from the dispersion model, and it is this data that is adjusted within the microenvironments using the ME factors. For example, a school will have a different indoor concentration as a result of different infiltration rates than a residence. Although HAPEM5 has provision for including emissions from within microenvironments, for example off-gassing from carpet or walls in a building, these indoor emissions adjustments were not included in the PATA modeling.

6.2.3 Activity Patterns

Activity patterns in HAPEM5 are based on previous studies of actual individual activities for a range of ages, ethnic groups, education levels, employment status, and other factors. These activity patterns are defined for the 37 microenvironments, and have been compiled in the Consolidated Human Activity Database (CHAD). Activity pattern data is separated into three day types (summer weekdays, other weekdays, and weekends), and into demographic clusters. There are ten demographic clusters that correspond to five age groups (0-4, 5-11, 12-17, 18-64, and > 65) for each gender.

6.2.4 Commuting Patterns

A special 1990 Census study examined the commuting patterns between home census tracts and work census tracts. HAPEM5 adjusts the 1990 data to fit the year 2000 census tract designations and combines these data with the activity pattern to locate individuals in either the home tract or in the work tract for each time step during the day.

6.2.5 Air Quality Data

For the PATA study, the hourly modeled concentrations from the dispersion model (CALPUFF) were aggregated into eight three-hour averages over a 24-hour day for input to HAPEM5. In the center of the domain these modeled concentrations were reported at the centroids of census block groups. In the less populated areas around the periphery of the study area, the concentrations were reported at the centroids of census tracts. HAPEM5 is able to accept multiple points of concentration spatially distributed within each census tract. For example, in the PATA study there were up to seven block groups, with their respective modeled concentrations in a census tract. The grouping of modeled concentrations into three-hour blocks preserves the daily temporal variation of the modeled concentrations, and combined with the temporal variation of the activity data provides exposure concentrations that vary over time.

6.2.6 Random Sampling

The inputs to HAPEM5 include demographic and air quality data, information about microenvironments, and activity and commuting patterns. The desired output is a distribution or range of exposure concentrations that the overall population experiences within each census tract. In HAPEM5 this distribution of concentrations is calculated using a random selection, or stochastic process, that begins with the three day types (summer weekday, weekday, and weekend) and sets of activity patterns for each of the ten demographic groups. The resulting activity patterns are then grouped into two or three like patterns, and using empirical data from previous studies, the probable sequence from one pattern to another pattern is estimated. For example, a 50 year old male on a summer week will have a set of activity patterns. If a given activity pattern is randomly selected to start a sequence, there are patterns that are more likely to follow on the second, third, and subsequent days. As a result, a range of concentrations is calculated for each demographic group in the census tract that represents a mix of activities in a set of indoor and outdoor microenvironments. From these distributions of concentrations, the 50^{th} percentile (median) and 90^{th} percentile are determined for the entire census tract for use in the risk characterization.

6.3 Running the Exposure Model

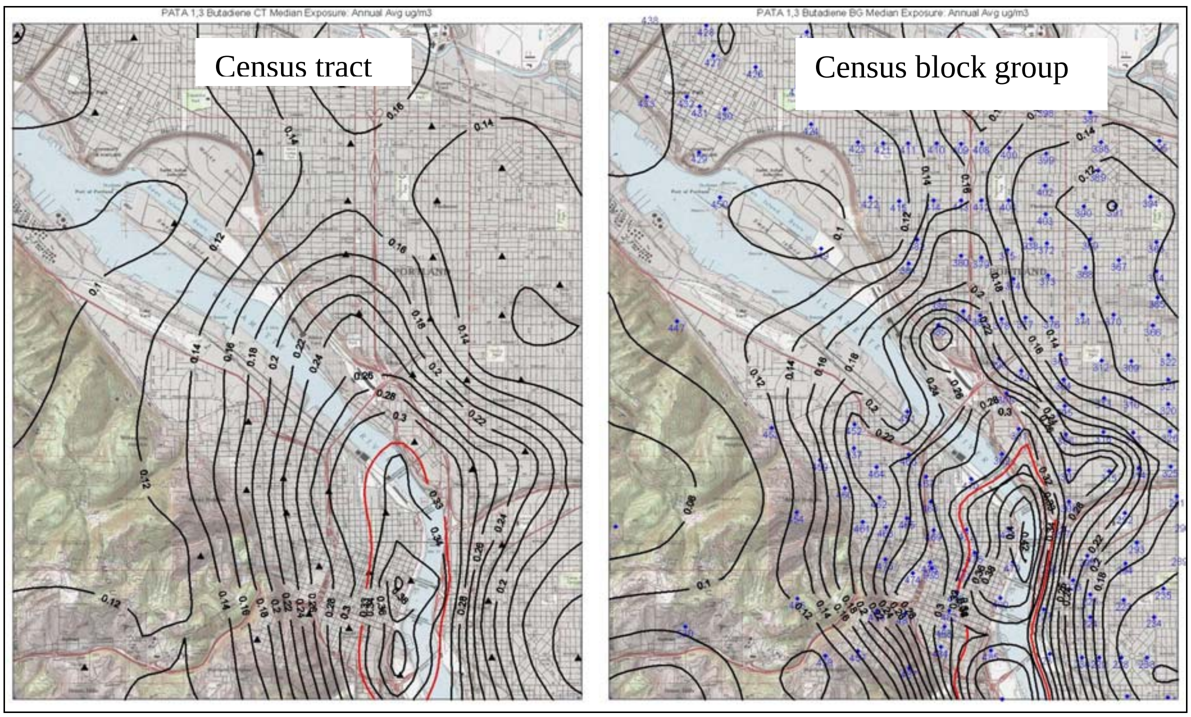
The initial HAPEM5 exposure modeling for the PATA study was performed in the summer of 2004 by the EPA Office of Air Quality Planning and Standards (OAQPS) at Research Triangle Park in North Carolina. Air quality data from the CALPUFF modeling were provided by DEQ to OAQPS as HAPEM5 input files. These input files gave average modeled concentrations in eight three-hour periods for each day for one year for each pollutant. The initial runs by EPA were at the census tract level and used the 2000 Census demographic data coupled with the HAPEM5 default set of microenvironments and activity and commuting patterns. All the default input files, the HAPEM5 exposure model, and post processing software were later provided to DEQ.

DEQ ran HAPEM5 to compare results with the modeled exposure data from OAQPS. This exercise provided quality assurance and quality control to the OAQPS model run. DEQ was then able to run the model, and provide results that were further refined to the census block level as opposed to the census tract level provided by OAQPS. Subsequently, adjustments were made to some of the air quality data, the location of five receptors was corrected, and the air quality data was re-ordered as entered in the input files. The input files were re-generated and HAPEM5 re-run for the full set of toxics.

The HAPEM5 model runs by OAQPS and the initial runs by DEQ were at the census tract level. Since the demographic data used by the model is collected at the census tract, this is the level at which HAPEM5 was designed to run. To accommodate the use of air quality data that might be available at a higher resolution than the census tract, multiple air quality concentrations can be entered for each census tract, as noted above.

Because the CALPUFF dispersion modeling was performed mostly at the census block group level, DEQ sought to preserve this higher level resolution in the exposure modeling. In order to circumvent the limitation in HAPEM5, the CALPUFF modeled concentrations were grouped into unique sets of input data so that only one block group concentration for each census tract would be present in any input file. The result was up to seven separate input files for each of 12 pollutants. HAPEM5 was re-run with these input files to generate exposure concentrations at the block group level. These exposure concentrations reflect the higher resolution of the air quality data only, as the demographic data is only resolved at the census tract level. A comparison of the plotted exposure concentrations at the census tract (352 receptors) and the block group (938 receptors) levels shows that at the scale of the domain, the plots are very similar. At a neighborhood scale, the block group exposures reveal a higher level of spatial resolution, as might be expected. For example, the results for 1,3 Butadiene at the census tract and block group levels are shown below in Figure 6.1.

Figure 6.1 Comparison of 1,3 Butadiene Exposure Concentrations at the Census Tract and Block Group Levels



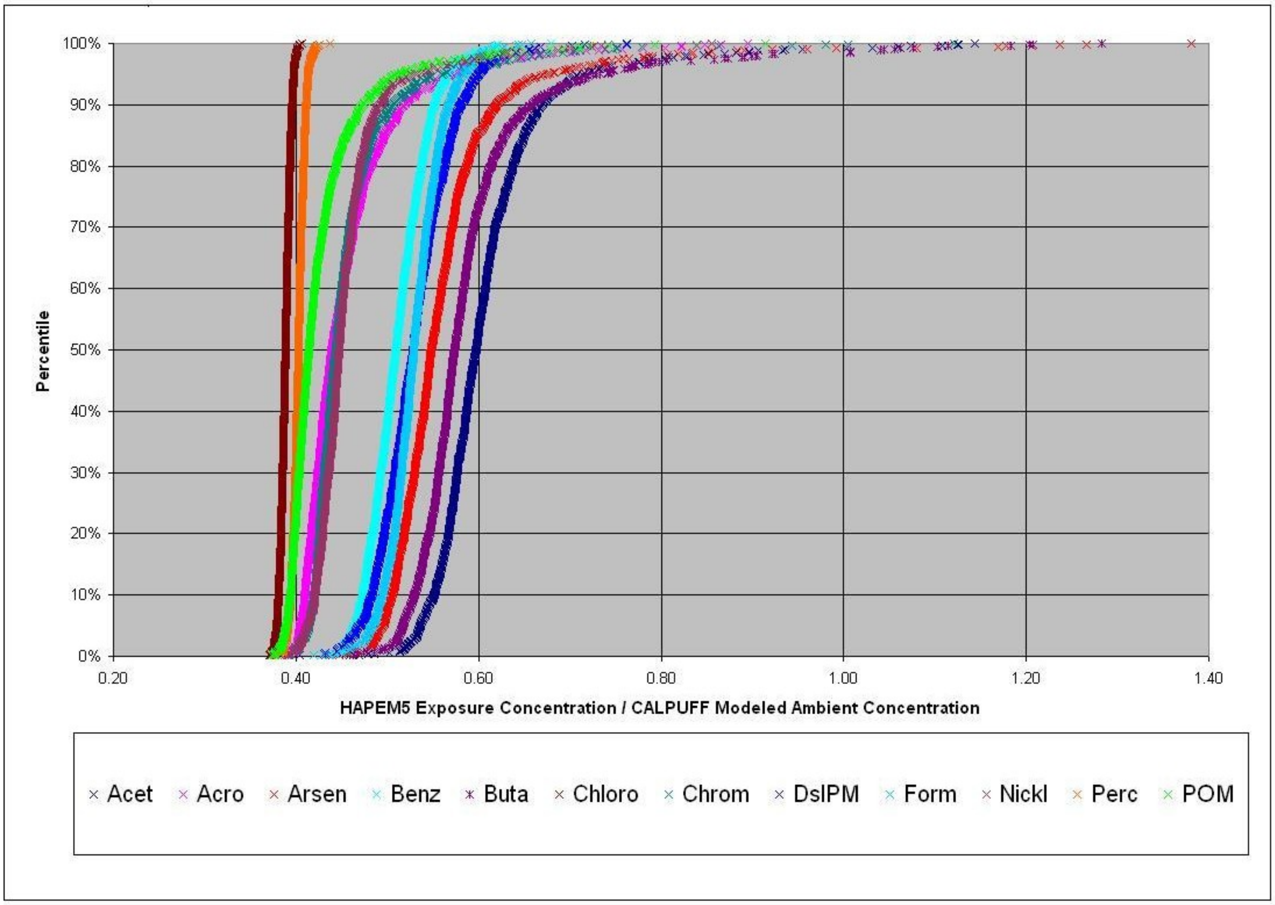
6.4 Comparison of Modeled Concentrations to Exposure Concentrations

One of the goals in running HAPEM5 was to compare the resulting exposure concentrations to the unmodified CALPUFF modeled concentrations. This comparison provides a basis for evaluating the usefulness of an exposure model, such as HAPEM5, to estimate exposure concentrations, rather than using the air dispersion concentrations directly.

An initial examination of the HAPEM5 to CALPUFF ratios showed high ratios at the CALPUFF receptors (located at census tract and block group centroids) adjacent to the perimeter of the modeling domain. These ratios are frequently greater than one, that is, the exposure concentrations are greater than the CALPUFF concentrations. Most of the tracts and block groups around the edge of the modeling domain cross the border of the modeling domain, with portions lying in and outside the domain. When the receptor locations were established for CALPUFF, any area lying outside the domain was removed from a tract or block group, and the centroid recalculated for that portion of the area remaining within the domain. An examination of a plot of centroids adjacent to the perimeter of the domain also showed apparent duplications and mislocations (for example, centroids located on block group boundaries). For the final comparison of exposure to CALPUFF concentrations, these problem centroids were removed from the exposure results (a total of 33 receptors removed out of a total of 938). Since the primary interest lies in the center of the domain where the population is highest and the density of census block group is greatest, removal of these few low-population block group centroids at the edges of the domain does not significantly alter the utility of the exposure modeling

The calculated ratios of the HAPEM5 exposure to CALPUFF concentrations shows that with some relative differences between pollutants, the exposure concentrations are generally about half of the modeled concentrations, and are relatively uniform across the modeling domain. Figure 6.2 shows a percentile plot of these ratios for the 12 air toxics modeled in PATA.

Figure 6.2 Frequency Plot of HAPEM exposure to CALPUFF modeled concentrations



As shown in the plot, the ratios of perchloroethylene and chloroform are very constant at about 0.4 over the entire distribution. The patterns for the ratios of the other ten toxics are similar to one another, but show a somewhat greater range. As an example, the ratio for benzene ranges from a low of 0.43, to 0.55 at the 90th percentile.

Further evaluation of these results may suggest that an exposure-to-modeled concentration factor, for each toxic, could be developed for the Portland area. If modeling resource constraints were an issue, this factor could be employed to estimate exposure concentrations for risk characterization in future applications, rather than re-run the HAPEM5 model. Given the relatively large range of uncertainties in the benchmark levels for each toxic in the risk assessment, the use of a simple exposure factor may provide acceptable results when modeling resources are not available.

Figure 6.3 is a plot of the Exposure to CALPUFF ratios for acetaldehyde that shows relatively high ratios around the perimeter of the domain. This pattern is typical for most of the toxics in the study. In this example, the areas where the ratios are greater than 1.0 are shown by red hatching.

Figure 6.3 Exposure Concentration/Modeled Concentration Ratio for Acetaldehyde Plotted on Modeling Domain

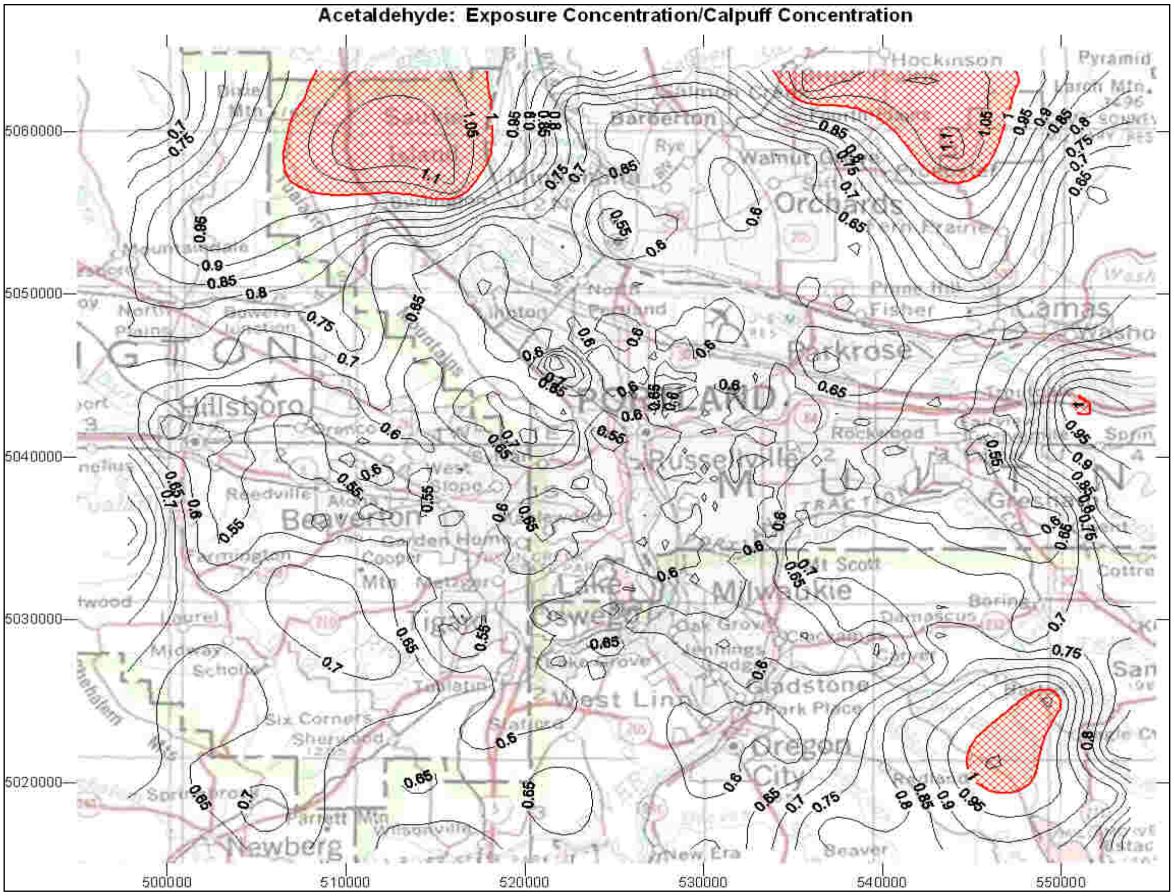
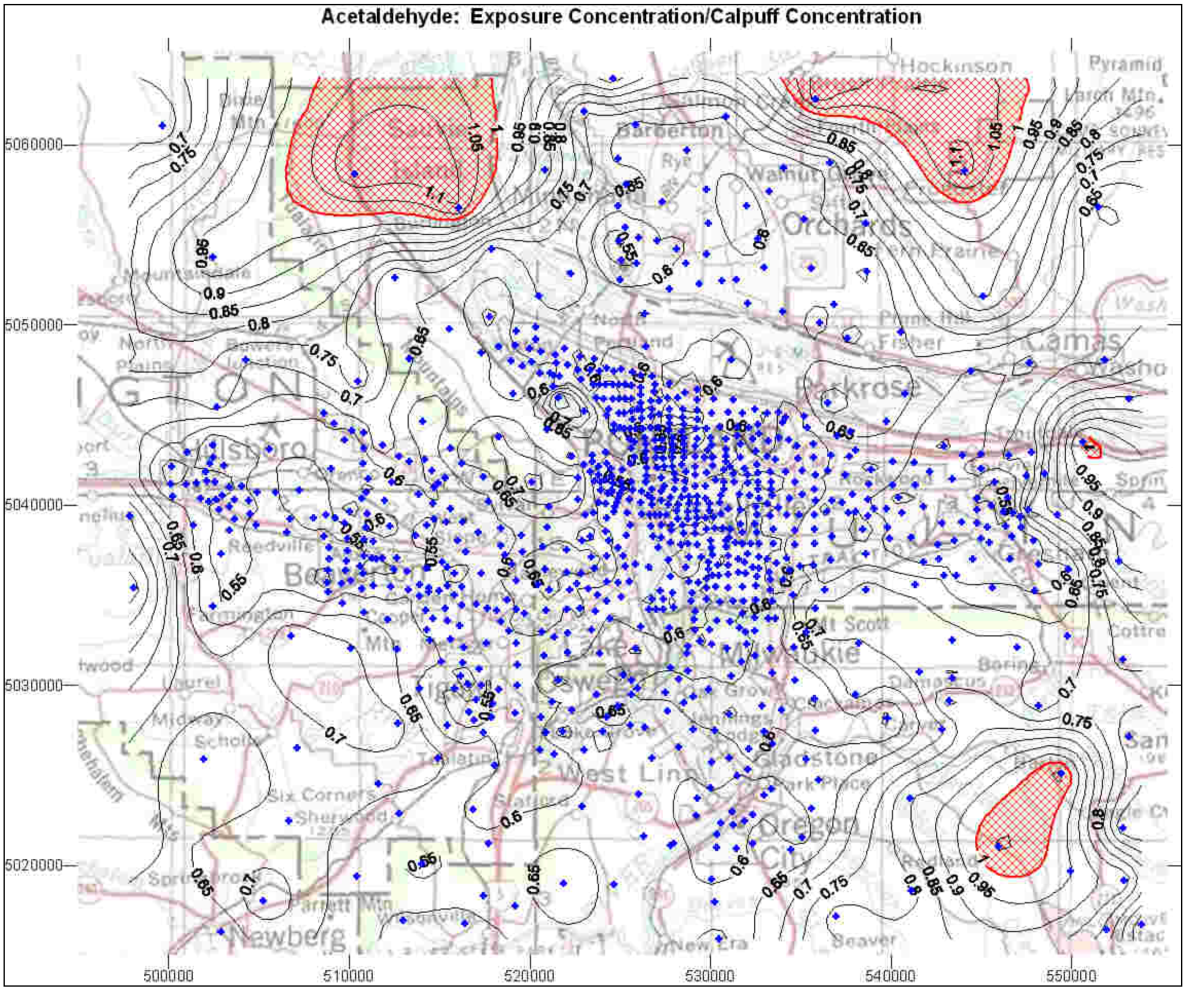


Figure 6.4 shows the same plot for the acetaldehyde exposure/ modeled concentration ratio, but with the addition of the census tract and block group centroids. The highest HAPEM5 to CALPUFF ratios lie in areas with the fewest census tracts and block groups, in areas of lowest population. It is not clear why these ratios are high, but they may be found in areas with growing populations in which census tracts with possibly high populations have not yet been subdivided into block groups. The center of the domain, in which the density of census block groups is high, is the area of greatest population and interest.

Figure 6.4 Exposure Concentration/Modeled Concentration Ratio for Acetaldehyde Plotted on Modeling Domain with Census Tract and Block Group Centroids



6.5 Summary

The HAPEM5 exposure model adjusts the dispersion model concentrations based on assumed activities of the population in each census area to produce exposure concentrations. The exposure concentrations indicate that the residents in the Portland area are actually exposed to about half of the initial modeled concentrations. A comparison of exposure to dispersion model concentrations shows that the ratios of the concentrations are relatively constant (from about 0.4 to about 0.7, for most of the tracts and block groups in the domain). This suggests that for future analyses an exposure to dispersion factor could be used if time and exposure modeling resources were constrained. The exposure concentrations form the basis of the risk characterization, which is discussed in the next section. The plots showing risk for each modeled pollutant are also derived from the HAPEM5 exposure concentration.