



Estimation and Evaluation of Cancer Risks Attributed to Air Pollution in Southeast Chicago

DRAFT

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REQUEST FOR PUBLIC COMMENTS

The United States Environmental Protection Agency is soliciting public comments on this draft report. Comments submitted by March 31, 1989, will be considered in preparing the final report. Comments should be submitted to:

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This report makes reference to various supporting documents, particularly two reports documenting the emissions inventory used in this risk assessment. These reports may be obtained by writing Mr. Summerhays at the above address or calling him at (312) 886-6067.

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Chicago, Illinois

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A study of this magnitude is not completed by a single individual. This report reflects knowledge possessed by numerous people with expertise on various source types and pollutants. Both in the technical development of emissions and risk estimates and in the documentation of this study, the assistance and advice from many people made this study far better than would otherwise have been possible.

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SUMMARY

Increasing concern has developed that air pollution may cause significant cancer risks in urban areas due to the combined effects of multiple sources and multiple pollutants. Given the density of exposed populations in urban areas, the possibility of high risks would further suggest that the number of incidences of resulting cancer cases may also be relatively high. The Southeast Chicago area has both a substantial concentration of industrial and non-industrial emission sources and a relatively high population density exposed to these emissions. This study was undertaken to evaluate the extent to which this exposure to ambient (outdoor) air contaminants may be a public health problem and to provide an informed basis for determining what emission reductions, if any, might be warranted to reduce the exposure.

The study sought to use as broad a base of information as possible in evaluating air pollution-related cancer risks in the Southeast Chicago area. The study considered every air toxicant for which the United States Environmental Protection Agency (USEPA) can estimate a quantitative relationship between the exposure to the air toxicant and the resulting increase in the probability of contracting cancer. All source types for which emissions of the identified pollutants could be quantitatively estimated were included. Estimates were made of emissions in a relatively broad area, so that impacts both from nearby sources and from more distant sources could be included.

The National Academy of Sciences has defined risk assessment as a process having four steps: hazard identification, exposure assessment, assessment of dose-response relationships, and risk characterization. The hazard identified for assessment in this study is cancer due to ambient air contamination. The exposure assessment principally involves estimation of ambient atmospheric concentrations, which, for most pollutants, were estimated by first deriving an inventory of emissions, and then estimating atmospheric dispersion of these emissions. The assessment of dose-response relationships involves derivation of a unit risk factor, which expresses the probability or risk of contracting cancer that is associated with exposure to a unit concentration of air pollution.

Finally, risk characterization involves deriving various measures of risk. The simplest measure of risk is individual risk, representing the risk attributable to air contaminants at a specific geographic location. An alternative measure of risk is the number of cancer cases attributable to air contaminants estimated to occur among the population in the study area. In addition to estimating these general measures of cancer risk, this study also investigated the origins of these risks and incidences, i.e., which source types and which pollutants are the most significant probable causes of these individual and area-wide risks estimated to result from air pollution in the Southeast Chicago area.

It must be noted that the risk estimates presented in this report should be regarded as only rough approximations of total cancer cases and individual lifetime risks, and are best used in a relative sense. Estimates for individual pollutants are highly uncertain and should be used with particular caution.

This study found atmospheric emissions of 30 pollutants in the study area which USEPA considers to be carcinogens. Some of these pollutants have been shown to be carcinogenic based on human exposure data, and others have been implicated by animal studies.

The cumulative total number of cancer cases that this study estimated to be attributable to air pollution is about 85 cases over 70 years or about 1 per year. The area for which exposure was assessed has a population of about 393,000 residents. Therefore, the average risk across the area due to air pollution as estimated by this study is approximately 2.2×10^{-4} , or about 2 chances in 10,000. It should be noted that, as a national average across the United States, the chance of contracting cancer over a lifetime from a number of factors (including both voluntary and involuntary exposures) which are not fully understood, is about one chance in three. One in seven people die from cancer.

Several types of sources appear to contribute significantly to the cancer cases estimated to result from air pollution in Southeast Chicago. Figure A is a pie chart of the contributions of various source types to cancer cases in the area. The most significant source type is steel mills, particularly the coke ovens found at steel mills. Steel mills appear to contribute almost 34% of the total estimated cancer incidence. Emissions from other industrial facilities, primarily chrome platers, are estimated to cause approximately 16% of the incidence. Consumer-oriented area sources (e.g., home heating and gasoline marketing) contribute about 14%, and roadway vehicles are also estimated to cause about 14% of the total cancer cases. Furthermore, the background pollutant impacts from formaldehyde and carbon tetrachloride contribute almost the entire remaining 22%. Together, these source types account for about 99.8% of the estimated air pollution-related cancer risks in the area.

This study also provides useful information on what source categories in the area make only minor contributions to the total estimated cancer risks. In terms of estimated contributions to overall area cancer incidence, wastewater treatment plants contribute 0.1% of the total, and facilities for the handling and disposal of hazardous and non-hazardous waste (including landfills, two hazardous waste incinerators, and liquid waste storage tanks) also contribute 0.1% of the total. Thus, these facilities are clearly estimated to cause much less risk in the Southeast Chicago area than the more dominant source types discussed previously.

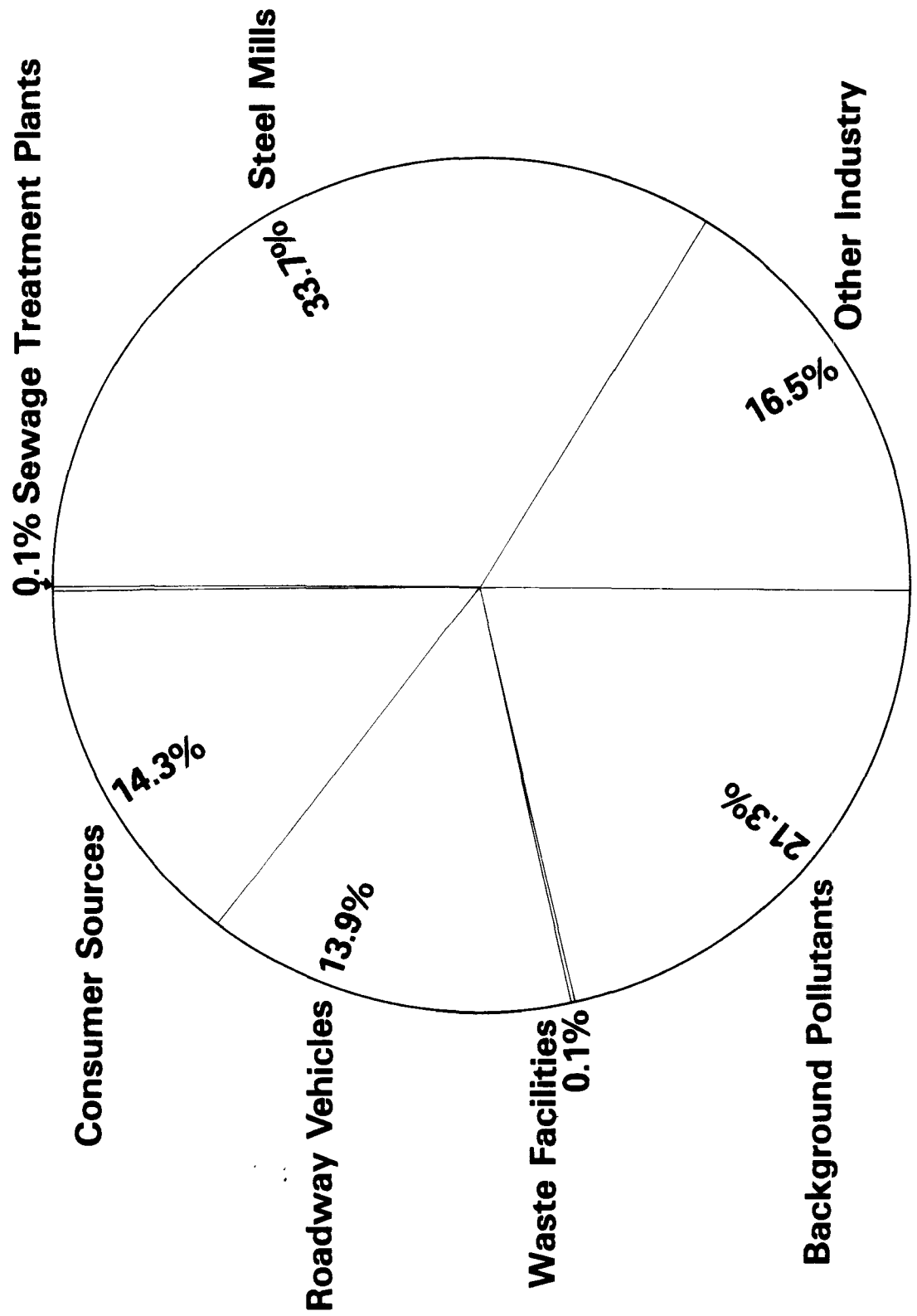
It is useful to apportion the estimated total number of cancer cases according to the weight of evidence that the pollutants are carcinogenic. According to USEPA's review of the weight of evidence of carcinogenicity, the 30 pollutants for which risks were estimated in this study include 6 "known human carcinogens", 22 "probable human carcinogens", and 2 "possible human carcinogens". Of the estimated 85 cancer cases per 70 years, almost 53% are attributable to pollutants that USEPA labels "known human carcinogens," about 47% are attributable to "probable human carcinogens," and about 0.02% are attributable to "possible human carcinogens."

This study also estimated lifetime individual risks in an array of locations. A peak lifetime risk of about 5×10^{-3} (or about 5 chances in 1,000) is estimated

SOUTHEAST CHICAGO STUDY AREA

Figure A.

Contributions to Estimated Annual Cancer Cases by Source Type



in the study area. However, available Census Bureau information does not indicate any residents in this area. The square kilometer with the highest estimated number of cancer cases has an estimated lifetime risk of about 1×10^{-3} (1 in 1,000). In general, risks are greatest in the northeast part of the area and are relatively lower in the southern and western part of the area. The average lifetime risk across the area is about 2.2×10^{-4} (about 2 in 10,000).

Consideration of the results of this study should include consideration of various uncertainties inherent in the study. The estimation of emissions generally relies on extrapolation of studies of emission sources elsewhere to the sources in the Southeast Chicago area. In addition to uncertainties in quantitative emissions estimates, there is also qualitative uncertainty since we may not be aware of some sources and source types for some pollutants. Atmospheric dispersion modeling also introduces uncertainty in the estimation of ambient (outdoor) concentrations. Finally, there are significant uncertainties in the unit risk factors used in this study, due to the necessity for various extrapolations from the exposure conditions in the studies deriving the risk factors to the exposure conditions in the Southeast Chicago area.

It is difficult to judge whether the risks in this study are more likely to be underestimated or overestimated. Comparison of monitoring data to the modeling data used in this study suggests that most pollutants are reasonably well addressed, but some pollutants appear underestimated. Thus, this comparison suggests that actual risks may in fact be higher than indicated in this study. Conversely, the conservatism underlying the unit risk factors used in this study implies that actual risks may be lower. Both types of uncertainty appear to be relatively modest for some pollutants and relatively major for other pollutants. Thus, the risk estimates derived in this study may either overstate or understate actual risks.

This study did not evaluate routes of exposure to environmental contaminants other than ambient air pollution. While most if not all the water consumed in the area is from Lake Michigan, and not groundwater, drinking water is another potential source of risk. Other environmental exposures include indoor air pollution (including radon gas), fish consumption and dermal exposure. Further, there may be other potential carcinogens or source categories which have not yet been identified.

This study identifies various aspects of air toxics exposure in Southeast Chicago that warrant further study. Several such investigations are currently underway.

At the same time, the study suggests that options for reducing risks due to air pollution in Southeast Chicago should be investigated. This study identifies the source categories which contribute most to risk in the area and, therefore, most warrant control. The States and USEPA are working toward regulating several of the important source types that this study indicates are significant. It is hoped that this study will form a basis for further discussions concerning the reduction of cancer risks potentially attributable to air toxic emissions in the Southeast Chicago area.

Introduction

Increasing national attention has focused on the health risks from "toxic" (non-criteria) air pollutants that arise in urban areas where a concentrated level of industrial activity coexists with high population density. Within Region V, an area that combines concentrated industrial activity with high population density is Southeast Chicago. In particular, Southeast Chicago and the surrounding area is one of the nation's foremost locations for integrated steel production and a wide range of other manufacturing activity. This area also has one of the nation's five facilities permitted for polychlorinated biphenyls (PCB) incineration and has a variety of other facilities for treating, storing and disposing of hazardous waste. Therefore, Region V of the United States Environmental Protection Agency (USEPA), with assistance from the Illinois Environmental Protection Agency (IEPA) and the Indiana Department of Environmental Management (IDEM), has completed an extensive study of air toxicants in the Southeast Chicago area.

The goal of this study has been to obtain a broad understanding of the risks of cancer that may be attributable to inhalation of ambient air pollutants found in the Southeast Chicago area. The National Academy of Sciences defines four steps of risk assessments: hazard identification, exposure assessment, evaluation of dose-response relationships for the pollutants in the study, and estimation and characterization of risk. Hazard identification involves identifying an exposure scenario, in this case inhalation of air contaminants, which may be causing adverse health effects. Exposure assessment involves evaluating the ambient concentrations of the pollutants to which the public is exposed. The principal method for assessing exposure in this study is to estimate emissions and then estimate atmospheric dispersion of these emissions. The evaluation of dose-response relationships in this study involves the estimation of cancer risk factors, representing the cancer risk estimated to result from breathing a unit concentration (e.g., one millionth of a gram per cubic meter of air). Finally, estimation and characterization of risk involves compiling and analyzing all this information in a way that provides useful statements about risk.

A more direct means of considering the impact of environmental contaminants on cancer rates is to conduct an epidemiological evaluation of cancer statistics. Unfortunately, due to the difficulties of distinguishing environmental factors from other factors, such studies are often inconclusive. Further, such studies generally do not even attempt to consider the separate influences of the various sources of the various environmental contaminants. The study described in this report thus has different purposes from the purposes of epidemiological studies. Epidemiological studies, if conclusive, can provide a better evaluation of the correlation between air pollution and cancer statistics. However, this study provides a more detailed data base on the potential relative significance of different source types and different pollutants. Further, due to the long periods of exposure that are considered to be involved in cancer induction, current cancer statistics probably reflect exposures over the last several decades. In contrast, this study addresses cancer risks that USEPA methods of risk assessment would associate with current air pollutant concentrations. (This study may be considered to estimate future risks if air pollutant concentrations were to remain constant at current levels for the next several decades.) Furthermore, given the mobility of population in the United States, cancer statistics reflect exposure in multiple areas where members of the studied population have lived. In contrast, this study focuses specifically

on estimated impacts of exposure to pollutant concentrations in the Southeast Chicago area. Thus, this study more serves the purpose of evaluating which source types and which pollutants are best addressed in order to reduce the future cancer risks that current risk assessment methods suggest may result from air pollution in the Southeast Chicago area.

This study may be considered in the context of national concern about urban air toxics issues. A USEPA report entitled The Air Toxics Problem in the United States: An Analysis of Cancer Risks for Selected Pollutants (dated May 1985) estimates that as many as 1800 to 2400 cancer cases per year may be attributed nationally to air pollution (not including indoor radon). This report further finds that while individual industrial operations may lead to high localized risks, a much greater share of the cumulative risk from air toxicants comes from activities that are more population-oriented, such as driving motor vehicles and heating (with fireplaces and wood stoves). In fact, limited monitoring data in some large cities indicates that risks even in residential and commercial areas approach the risks found near the highest risk industrial facilities. Further, various studies suggest that cancer risks from air pollution throughout urban areas are commonly in the range of 1×10^{-3} (i.e., 1 case per thousand people exposed for a lifetime) to 1×10^{-4} (1 case in 10,000). These risks arise from the multiple sources of emissions of multiple pollutants that exist in all urban areas. Since 61% of the United States population lives in urbanized areas, and the exposure to high urban toxics risks extends throughout these urban areas, this urban air toxics exposure appears to contribute the major share of the cases of cancer attributable to air pollution. The purpose of the Southeast Chicago study, then, given the general national picture of urban air toxics risks, is to define, in more detail, the relative contributions of various source types to that risk in this geographic area.

Conducting a study like this requires substantial computerized data handling. Data handling for developing emissions estimates required specifically developed computer programs. Dispersion modeling, risk estimation, and cancer incidence estimation relied heavily on a data handling system known as PIPQUIC (Program Integration Project Queries Using Interactive Commands). PIPQUIC also provided many of the figures shown later in this report.

This report includes eight sections. This introduction has focused on the context in which this study was conducted. The next section describes several of the general features of the design of this study. The third section summarizes the procedures and results of the emissions inventory phase. The fourth section describes the exposure assessment, particularly describing the atmospheric dispersion modeling used as the principal method for estimating pollutant concentrations, and also providing a sampling of the concentration outputs of this study. The fifth section compares the modeled concentration estimates against concentration estimates based on monitoring. The sixth section describes the dose-response relationships (i.e., the health impacts associated with given concentrations) used to estimate risks. The seventh section then presents results of the risk estimations, discussing the estimated magnitude of the cancer risk attributable to air pollutants, the relative contributions of different source types and pollutants, and the spatial distribution of the risks over the studied receptor area. The final section summarizes the conclusions of this study.

Study Design

The first step in this study was to plan a study design. A key decision here was whether to develop a screening study covering multiple pollutants and multiple source types using only readily available information or whether to develop a more focused inventory investigating only a few pollutants and source types. This study was designed for screening purposes, to provide an overview of excess cancer risks that may be attributable to ambient air pollution in the area.

This study has been designed to be comprehensive in several respects. First, it has attempted to include all source types that emit any of the substances being studied. Second, although the focus of this study is on exposure in a moderately sized area (approximately 65 square miles), a much broader area was inventoried to include all sources with potentially significant impacts in the selected receptor area. Third, this study attempted to address a comprehensive list of potential carcinogens.

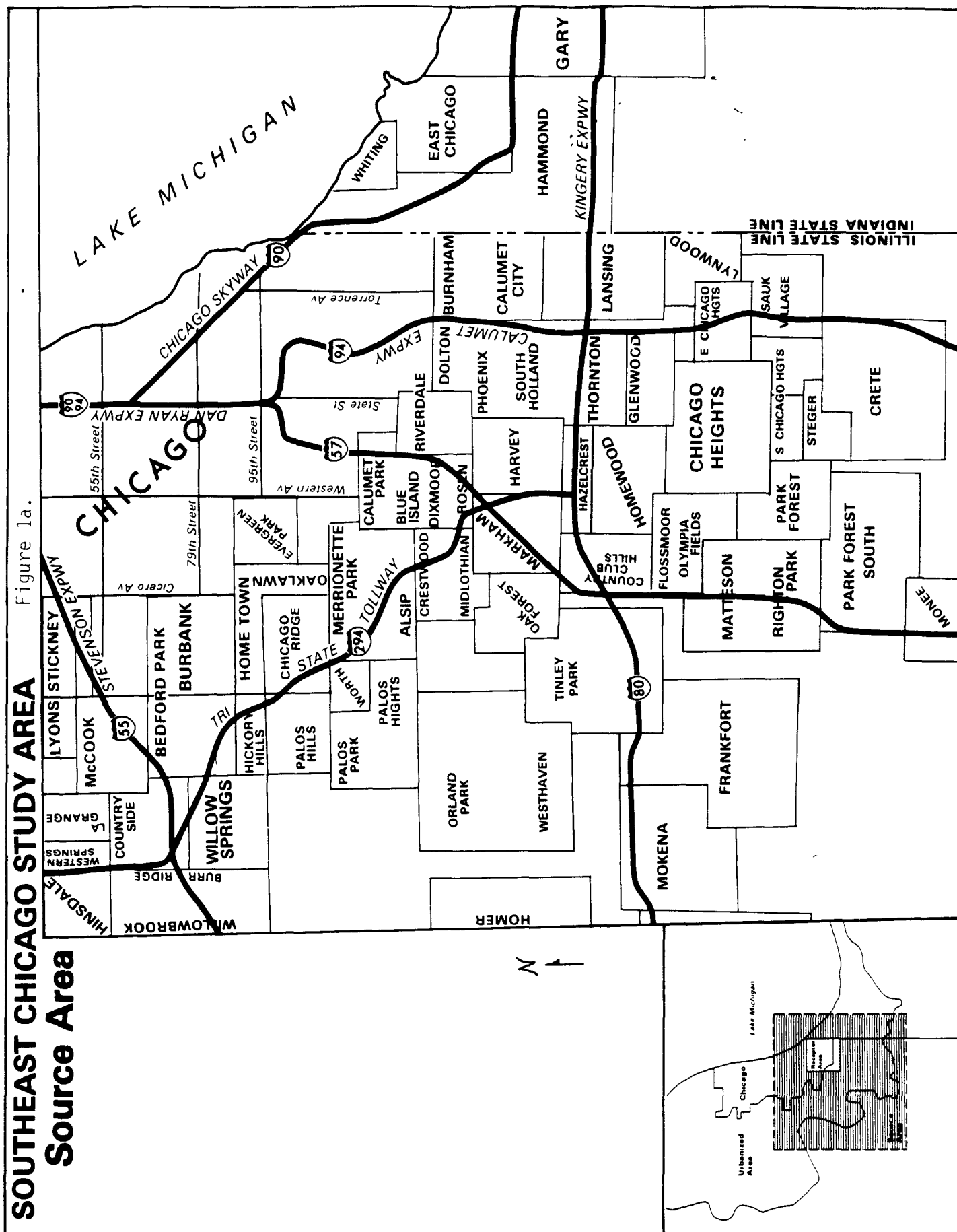
With respect to source types, this study included all source types for which air toxics emissions could be estimated. A special aspect of this study was the inclusion of the volatilization from wastewater treatment plants, emissions from hazardous waste treatment, storage, and disposal facilities (TSDF's), and emissions from landfills for municipal waste. Emissions from these source categories are difficult to estimate and are not included in traditional air pollutant emissions inventories. However, they were included in this study due to national and local interest in their relative contribution to risk. Also included were source types which have more traditionally been inventoried, such as industrial facilities, population-oriented sources (e.g., dry cleaning) and highway vehicles. Although a greater ability has been developed to estimate emissions from these types of sources, the derivation of emissions factors for the substances inventoried in this study nevertheless required substantial literature research and then development of factors suitable for use in this kind of inventory. This study did not involve direct emissions measurements; instead, emissions estimates reflected production rates of sources in the area (e.g. tons of steel produced) in conjunction with results from various studies of the relationship between production and emissions (e.g., pounds of emissions per ton of steel produced).

With respect to spatial coverage, Figure 1a is a map showing the broad "source area" included in the inventory, and Figure 1b is a map showing the smaller target "receptor area" for the exposure analysis. The focus of this study is on air pollutant concentrations in the receptor area and on the cancer impacts that exposure to these air pollutants in this area may cause. However, it is clear that the air quality in this area is affected by emissions that can be transported in from a much broader area. Consequently, emissions were inventoried for a much broader area.

For purposes of this study, the "Southeast Chicago" receptor area was defined as an area that is approximately a 13 kilometer (8 mile) square, having a total area of 169 square kilometers (65 square miles). This area covers much of the southeast corner of the City of Chicago plus portions of adjoining suburbs, ranging specifically from 87th Street to Sibley Boulevard and from Western Avenue to the Indiana State line. This area has a population of about 393,000.

SOUTHEAST CHICAGO STUDY AREA Source Area

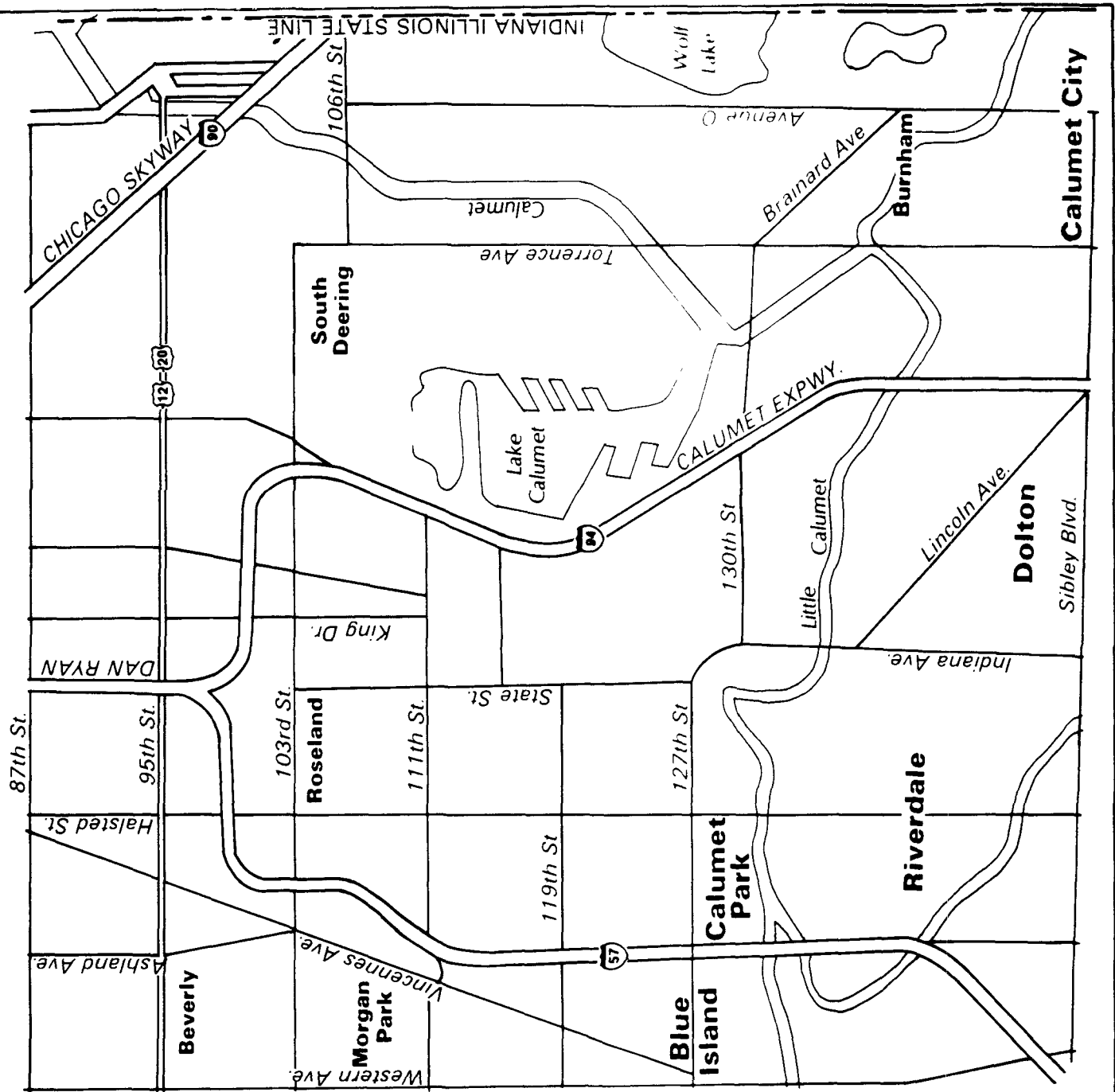
Figure 1a.



SOUTHEAST CHICAGO STUDY AREA

Receptor Area

Figure 1b.



By comparison, the inventoried source area covers a 46 kilometer (about 29 mile) square area, with a total area of 2136 square kilometers (about 817 square miles). Since the prevailing winds in the area are from the southwest quadrant, the source area is skewed toward the south and west of the receptor area. The specific boundaries of the source area are, in terms of UTM (Universal Transverse Mercator) coordinates, from 4584 to 4630 kilometers northing and from 420 to 466 kilometers easting in zone 16. This source area extends 30 kilometers south and west and 16 kilometers north and east of the center of the receptor area. Thus, the emissions study area includes roughly a third of the City of Chicago, most of the city's southern and southwestern suburbs, and a portion of Northwest Indiana. This source area has a population of about 2,361,000. The inventory further includes a few additional point sources outside of this source area which were judged to be potentially significant sources.

With respect to pollutants, this study included all potential carcinogens for which a quantitative relationship between air concentration and risk has been estimated. During the initial design of the study, unit risk factors had been estimated for 47 of the 51 substances on the targeted pollutant list. However, further review led to the conclusion that for many of these 47 substances, the evidence of carcinogenicity is too weak or the cancer risk factor estimates are too unreliable to use in this study. This further review concluded that 32 substances had reasonable evidence of being carcinogenic and risks could reasonably be quantified. Thus, the study list of 51 substances includes 15 substances which may or may not be carcinogenic, but could not be quantitatively analyzed, and 4 substances that were included only on the basis of potential noncarcinogenic impacts. (As will be discussed below, all but 2 of the 32 quantifiably carcinogenic pollutants were found to have atmospheric emissions in the studied source area.)

Analysis of systemic, noncarcinogenic health effects was considered beyond the scope of this study. First, Agency-reviewed dose-response data for systemic effects due to inhalation of air contaminants were not available at the inception of this study. Second, analysis of systemic health effects generally requires consideration of concentration thresholds below which no adverse health effects are observed. Therefore, it is necessary to conduct a substantially different and more complicated exposure assessment to evaluate the extent and frequency with which the threshold may be exceeded. Thus, this study focused on cancer effects of the 32 pollutants with agency-reviewed risk factors.

As indicated above, this study primarily used emissions estimates in conjunction with atmospheric dispersion modeling rather than using monitoring data to estimate ambient concentrations of the pollutants being studied. Both methods have advantages and disadvantages as approaches for estimating ambient concentrations. The advantages of modeling include the ability to address concentrations across an entire geographic area, to address long term average concentrations, and to estimate concentrations below the concentration levels that available monitoring methods can detect. The corresponding disadvantages of monitoring data are that resource constraints generally limit the collectable data to one or a few locations and for relatively short time periods. Additionally, monitoring methods are not available for some pollutants, and for other pollutants, monitoring cannot detect some of the concentrations of interest. A further

advantage of the emissions estimation/dispersion modeling approach is that it readily identifies the separate contributions of sources and source categories to any given concentration, which monitoring data alone cannot do. For these reasons, the emissions estimation/dispersion modeling approach was judged a better means of evaluating concentrations throughout the study area and judged to be a more informative approach, particularly in describing relative contributions of different source types. On the other hand, monitoring data have the advantage that for the time and location being monitored, and if concentrations are detectable, the uncertainties are generally less than the uncertainties inherent in emissions inventorying and dispersion modeling. For this reason, monitoring data can be used to obtain a "reality check", to suggest at least for the locations and pollutants successfully measured whether or not the modeled concentrations are approximately correct.

A further advantage of monitoring is the ability to assess concentrations (at least if concentrations are above detection limits) of atmospheric contamination which is not the direct result of current emissions. Conversely, a disadvantage of the emissions estimation/dispersion modeling approach is that this approach is unable to consider such "background impacts". For most pollutants in this study, "background concentrations" may be presumed to be overwhelmed by urban area emissions, and such background concentrations may reasonably be ignored. However, two pollutants in this study are presumed to have origins other than current emissions: formaldehyde and carbon tetrachloride. Although current emissions of these pollutants contribute to ambient concentrations, most of the ambient concentrations are attributable to other origins. Much of the formaldehyde concentration is presumed to be attributable to atmospheric photochemical reaction of other organics. Since carbon tetrachloride remains unreacted in the atmosphere for a very long time, current concentrations are largely the result of an accumulation of historic emissions over wide geographic areas. Thus, monitoring data were used in this study to indicate the concentrations of these two pollutants from origins not addressed by the emissions estimation/dispersion modeling approach. The term "background pollutants" is used in this report to identify these origins of risk.

Emission Estimation

The emissions inventory is described in separate reports. A detailed description of the inventory is given in a July 1987 report entitled "Air Toxics Emissions Inventory for the Southeast Chicago Area", authored by John Summerhays and Harriet Croke. This report documents emissions estimates for a wide range of source types, including source types that are traditionally inventoried in air pollution studies as well as some source types that are not traditionally inventoried such as volatilization from wastewater at sewage treatment plants. An addendum to this report (dated January 1989) updates this report by describing limited revisions to the previously described inventory and by describing procedures and results of estimating air emissions from the treatment, storage, and disposal of hazardous waste, and from landfills storing municipal waste. Further details on the estimation of air emissions from the handling of hazardous and nonhazardous waste are provided in two reports by the Midwest Research Institute: "Estimation of Hazardous Air Emissions in Southeast Chicago Contributed by TSD's", covering air emissions from the treatment, storage, and disposal of hazardous waste, and "Estimation of Hazardous Air Emissions From

Sanitary Landfills", covering air emissions from landfills for ordinary municipal solid waste. The reader interested in more details of the procedures, data sources, and emissions estimates should consult these separate reports. The discussion that follows will present only an overview of the development and results of the emissions inventory.

This study involved no direct measurement of emissions. Instead, emissions estimates in this study were generally based on local activity levels (e.g., point by point steel production or local traffic levels) in conjunction with the results of measurement studies elsewhere establishing the relationship between activity levels and emissions (e.g., emissions per ton of steel produced or per mile driven). This approach is used partly because emissions measurements even just for the 88 industrial facilities in this study would be prohibitively expensive, and partly because limited emissions measurements do not necessarily provide representative long-term data on emissions.

The sources considered in this study include industrial sources, consumer-oriented sources (e.g. dry cleaning and gasoline marketing), roadway vehicles, facilities for handling hazardous and municipal waste, and wastewater treatment plants. From another perspective, many of the industrial sources as well as the waste handling facilities and the wastewater treatment plants are at clearly identified locations, and are labeled "point sources," whereas other industrial activities, as well as all of the consumer-oriented sources and roadway vehicles, are more broadly distributed, and are labeled "area sources." The distinction between point and area sources leads to the use of different methods for estimating emissions.

For industrial point sources, three emission estimation methods were used. The first method may be labeled the questionnaire method. Questionnaires were sent to 29 companies considered candidates for being significant sources of air toxics emissions. These questionnaires requested the annual emissions for each pollutant in this study, as well as stack data necessary for dispersion modeling. These questionnaires were sent by the Illinois Environmental Protection Agency and the Indiana Department of Environmental Management. Region V then reviewed these company responses to assure that complete and reasonable emissions estimates would be used for these facilities. The second method may be labeled the species fraction method. This method, used for 59 other identified facilities, begins with estimates of emissions of total organic emissions and total suspended particulate emissions, estimates which are based on the best available information on plant operating rates and estimated emissions per unit operation. This method then calls for multiplying these emissions totals times species fractions, expressed as the ratios of the particular species emissions versus the total emissions, thereby estimating species emissions. For example, particulate emissions from blast furnaces (e.g., Standard Classification Code 3-03-008-25) were estimated to be 0.013% arsenic, and so a blast furnace casthouse that emitted 20 tons per year of particulate matter would be estimated to emit 0.0026 tons per year of arsenic. The third method may be labeled the emission factor approach. This method uses a direct emission factor, expressing the quantity of a particular species emitted per unit activity level (e.g. per 1000 gallons of paint solids). The emission factor is multiplied times the actual level of activity to estimate total emissions. This method was only used for one type of source (coke by-product recovery plants), since for all other point source types the direct emission factors were either not available or the source types were not found in the Southeast Chicago area.

For area-type sources, both the species fraction method and the emission factor method were used. As an example of the species fraction method, roadway vehicles were inventoried by multiplying total emissions of organics times measured or derived species fractions. As an example of the emission factor method, wood combustion emissions were estimated by multiplying estimates of wood quantities burned in fireplaces and wood stoves times an emission factor of the quantity of the pollutant, polycyclic organic matter, per pound of wood burned. The companion emissions inventory reports provide more details of the methods used for each category in this study, as well as a discussion of the advantages and disadvantages of the two methods.

A further issue to be addressed in inventorying area and mobile sources is the spatial distribution of these emissions. The impacts of given quantities of emissions at any particular location are a function of how distant and how frequently upwind the emission sources are from the impact location. By definition, area sources are collections of sources too numerous and too dispersed to identify the location of each source. The solution to this problem used in this study was to distribute emissions according to the distribution of "surrogate parameters" such as population, housing, or manufacturing employment. For example, it would not have been feasible to identify locations of the estimated 2650 buildings with air conditioner cooling towers, not to mention identifying the approximately 15% of those towers which use chromium as a corrosion inhibitor. Instead, these emissions were distributed in accordance with the known distribution of nonmanufacturing, nonretail employment. Similarly, roadway vehicle emissions on freeways and other roadways were distributed according to traffic estimates for freeway and other roadway travel.

In addition to inventorying the above, which are relatively traditional air pollution source types, this study also included several source types that have not traditionally been included in air pollution inventories. One such source category is hazardous waste treatment, storage, and disposal facilities (TSDFs). The Southeast Chicago study area includes a total of 43 facilities regulated under the Resource Conservation and Recovery Act to handle hazardous waste. Included among these facilities is one of the nation's five incinerators of polychlorinated biphenyls (PCBs), a second incinerator handling non-PCB hazardous waste, a hazardous waste landfill, several facilities storing waste in storage tanks, and a majority of facilities loading wastes into drums or trucks.

Estimating emissions for TSDFs required several steps. The first step was identifying facilities. The second step was obtaining data on the quantity of each type of waste handled by each facility. The third step was reviewing studies of the composition of various waste streams to estimate the quantity of individual pollutants in the waste streams at each facility. Finally, emissions estimation models were used, relying on the derived estimates of waste quantities and often relying on assumptions about operating procedures to estimate emissions of each pollutant at each facility. Most of these emissions estimates were derived by Midwest Research Institute under contract to USEPA Region V, with Region V deriving a few additional emission estimates.

A second type of facility which has not traditionally been included in air pollution studies, but was included in this study, is municipal waste landfills.

Biodegradation in landfills generates methane, and this methane can carry trace amounts of contaminants contained in household and industrial solid waste into the atmosphere.

The first step in estimating these emissions was to review available data on the contaminant concentrations found in gases emanating from landfills. The second step was to estimate landfill gas generation rates based on the estimated volumes of landfill gases for each landfill in the study area. The third step multiplied the results of the first two steps to estimate the emissions of each species of concern from each landfill. These estimates were again developed by Midwest Research Institute under contract to USEPA Region V.

A third source type not traditionally included in air pollution studies but included in this study was wastewater treatment. The focus in this study was on two wastewater treatment plants handling the largest volumes of industrial wastewater in the source area, i.e. the Calumet and the West-Southwest treatment plants. For each of these plants, the Metropolitan Sanitary District of Greater Chicago made measurements of the volatile organic concentrations in the wastewater entering and exiting each of these facilities for seven consecutive days. Daily quantities of volatile organics were computed by multiplying the wastewater concentrations of each compound of interest times the respective day's volume of wastewater, after which the seven days' quantities were averaged. The next step of the analysis was to address the fate of these contaminants. Possible fates for contamination in the influent wastewater include volatilization to the atmosphere, biodegradation in the treatment plant, sludge, and treated wastewater leaving the plant. Contaminants in the wastewater leaving the treatment plant, where significant, were addressed by subtracting outgoing contaminant quantities from incoming contaminant quantities. Partitioning to sludge was in all cases insignificant. Nevertheless, volatilization from sludge is included, insofar as sludge contamination was inventoried as if the contaminants remained in the wastewater available to volatilize. Most wastewater contamination either volatilizes or biodegrades. Based on studies measuring volatilization and biodegradation for nonpolar organic solvents (the most significant contaminants considered here) at other wastewater treatment facilities, it was assumed that volatilization accounts for 40% of incoming contamination (minus any adjustment for contamination in outgoing wastewater) and biodegradation accounts for the remaining 60%.

This study also addressed several other source categories which may be relatively unimportant with respect to the "traditional" (criteria) air pollutants but which have the potential to be significant with respect to toxic air pollutant emissions. While these categories generally emit relatively small quantities of the traditional pollutants, the materials being emitted appear to be highly toxic. Examples of such source categories included in this study are chrome electroplaters (emitting chromium), wood combustion in fireplaces and wood stoves (emitting polycyclic organic matter, a component of "wood smoke", as a product of incomplete combustion), and hospitals (emitting ethylene oxide used in some sterilizing operations).

It should be noted that all emissions estimates were, in general, compiled for a 1985 base year. A minor deviation from use of 1985 data is the deletion of sources which are known to have permanently shut down since that time. In

addition, the estimates compiled in this study are for typical actual emissions. No attempt was made to evaluate emissions for the scenario in which all plants emit maximum allowable amounts, because this scenario is unlikely to persist continuously over a 70 year lifetime.

An important influence on emissions from many source categories is the existence of emission controls. This study sought to develop emissions estimates appropriate to 1985 levels of emission control. A special effort was made to assure that steel mill emissions estimates reflect the current status of controls. For other point sources, it is less clear whether emission controls adopted according to various regulations are, in fact, represented in the emission estimates used in this study, though again, the goal was to use emission estimates that correspond to 1985 levels of control. For roadway vehicles, the emission estimates reflected elaborate, computer-assisted evaluation of what portion of the vehicle fleet had what degree of emission control as of the 1985 inventory date. In particular, the MOBILE 3 emission factor model was used in conjunction with some updates for the consideration of evaporative emissions. It is noted that more recent information suggests that evaporative emissions may be much higher due to "running losses." For other types of sources, for the few source categories where emissions controls are in place, this study attempted to use emissions estimates that reflect these controls.

One special element of the emissions inventory development was the use of data on facility emissions that Section 313 of the Superfund Amendments and Reauthorization Act requires companies to submit. In particular, companies are required under this Section to develop and report emissions estimates for numerous pollutants including most of the pollutants in this study. These data were compared with the emissions estimates that were independently derived in this study. Unfortunately, these reports do not address area sources. Nevertheless, these data were used for additional refinement of the industrial source component of the Southeast Chicago area inventory.

Table 1a summarizes the emissions of known or suspected carcinogens found in this study. In the study area, 30 pollutants were found which USEPA considers carcinogenic. This table distinguishes emissions from steel mills, other industrial operations, consumer-oriented sources, roadway vehicles, hazardous waste treatment storage, and disposal facilities (also including municipal waste landfills), and wastewater treatment plants. This table shows that 30 of the 32 known or suspected carcinogens were found to be emitted in the Southeast Chicago study area. The significance of the emissions shown here is best interpreted in terms of risk assessment results, so this topic will be discussed in the section discussing risk estimates.

As shown in Table 1b, this study found no emissions of allyl chloride or radio-nuclides. This reflects the fact that either this study found no methods for quantifying emissions of these pollutants, or no sources were identified in this area. The emissions inventory phase of this study also attempted to include 19 substances without unit risk factors; as described in the inventory reports, 13 of these 19 substances had quantifiable emissions in the study area.

A variety of uncertainties apply to the emissions inventory used in this study. Emissions measurements were not conducted in the Southeast Chicago area, and so it was necessary to apply emission factors (i.e., emissions per unit operation)

Table 1a. Emissions in Source Area by Source Category and Pollutant (in metric tons/year)

<u>Compound*</u>	<u>Steel Mills</u>	<u>Other Industrial Sources</u>	<u>Consumer Sources</u>	<u>Mobile Sources</u>	<u>Waste Facilities</u>	<u>Sewage Treatment Plants</u>	<u>Total</u>
Acrylamide		.02					.02
Acrylonitrile		1.0			.002		1.0
Arsenic	3.9	1.2					5.1
Asbestos			.02	.04			.06
Benzene	3044.2	55.2	37.1	812.8	12.0	.7	3962.0
Beryllium		.0008					.0008
Butadiene	.2	.5		73.1	.2		74.0
Cadmium	4.3	.2		.02			4.6
Carbon Tet.		.0003			2.7		2.7
Chloroform		.0003	31.1		.2	.7	32.0
Chromium**	.07	2.5	.5				3.2
Coke Oven Em.	388.0						388.0
Dioxin		.0002			.0000007		.0002
Epichlorohydrin		.09			.00002		.09
Eth. Dibromide				.8			.8
Eth. Dichloride		54.6			.2	.7	55.5
Eth. Oxide		61.5	11.2				72.7
Formaldehyde	14.6	12.6	110.0	353.5	.04		491.7
Gas. Vapors		216.2	4737.2	14376.0			19329.2
Hex-chl-benz.		.07			.5	1.3	1.8
Methyl Chl.		.3	10.9		.0003	.07	11.3
Methylene Chl.		287.3	1084.0		61.9	8.6	1441.7
Perchloroeth.		383.7	802.0		.7	6.0	1192.3
PCB's		.0002			.001		.001

Table 1a. (Continued)

<u>Compound*</u>	<u>Steel Mills</u>	<u>Other Industrial Sources</u>	<u>Consumer Sources</u>	<u>Mobile Sources</u>	<u>Waste Facilities</u>	<u>Sewage Treatment Plants</u>	<u>Total</u>
POM		.02	16.9	8.0			24.9
Prop. Oxide		.9					.9
Styrene		11.5			1.5	2.4	15.4
Trichloroeth.		374.7			27.8	1.9	404.4
Vinyl Chl.		2.3			4.0		6.3
Vinylidene Chl.		.4			.8	.01	1.2

*Abbreviations:

Carbon Tet. - Carbon tetrachloride
 Eth. - Ethylene
 Gas. - Gasoline
 Hex-chl-benz. - Hexachlorobenzene

Chl. - Chloride
 PCB's - Polychlorinated biphenyls
 POM - Polycyclic organic matter
 Prop. - Propylene

**Estimates are for hexavalent (+6) form of chromium.

Table 1b. Other Substances in Study

<u>Substances without Unit Risk Factors found in Southeast Chicago Area</u>	<u>Substances without Unit Risk Factors not found</u>	<u>Substances with Unit Risk Factors not found</u>
Acetone	Dimethylnitrosamine	Allyl Chloride
Diethanolamine	Isopropylidene Diphenol	Radionuclides
Dioctylphthalate	Methylene Dianiline	
Ethyl Acrylate	Nitrosomorpholine	
Ethylene	Propylene Dichloride	
Melamine	Terephthalic Acid	
Mercury		
Nickel		
Nitrobenzene		
Pentachlorophenol		
Titanium Dioxide		
Toluene		
Xylene		

measured elsewhere in estimating emissions in the Southeast Chicago area. This extrapolation from sources elsewhere to sources in the Southeast Chicago area is probably the greatest cause of uncertainty in the emissions inventory. On the one hand, this extrapolation is probably fairly good for some source types, especially for area and mobile sources. For example, roadway vehicles in Southeast Chicago are probably similar to the roadway vehicles in other places in the United States. On the other hand, for other source types, source-to-source differences in the raw materials used and differences in source operations may yield significant differences in emissions, not just in the quantity of emissions, but even in whether particular substances are emitted at all. A second major uncertainty is that some sources of some pollutants may be missing in this inventory either due to lack of awareness of the source or source type or due to unavailability of information with which to quantify emissions. This is likely to be a particular problem for relatively unknown pollutants and for pollutants that are difficult to measure.

Lesser uncertainties exist in various aspects of the emissions estimation process. Data used to estimate emissions in this study include source operating rates, emission factors for particulate and organic emissions, data on composition of these emissions, data on the extent of emissions producing activities (e.g., pounds of wood combusted), and data used for area sources to spatially distribute these emissions. For each of these types of data, the best reasonably available data were used, but even the best reasonably available data have uncertainties in their measurement and in their adequacy in representing emissions in the Southeast Chicago area.

Estimation of Concentrations by Atmospheric Dispersion Modeling

The principal method used in this study to estimate concentrations is to model the atmospheric dispersion of the emissions estimates described in the previous section. Atmospheric dispersion is a function of several factors. From the standpoint of selecting atmospheric dispersion models, two important factors are the averaging times of the concentrations and the nature of the emissions sources. With respect to averaging times, some dispersion models are designed to estimate short term average (e.g., 1 hour average) concentrations, and other models are designed to estimate long term average (e.g., annual average) concentrations. The health effect being addressed in this study, cancer, is most appropriately addressed by evaluating lifetime cumulative doses (Cf. the "USEPA Guidelines for Carcinogen Risk Assessment", 51FR33992). Therefore, dispersion models for estimating long term average concentrations were selected. With respect to the emissions sources, some dispersion models are designed to address point sources (i.e., stacks or other similarly localized emission points), and other dispersion models are designed to address area sources. This study includes both types of sources. Therefore this study used one model for point sources and a second model for area sources.

The models used in this study were the Industrial Source Complex Long Term model (ISCLT) for point sources and version 2 of the Climatological Dispersion Model (CDM-2) for area sources. The two models reflect the obvious differences in initial dispersion (e.g., the broad dispersion of area source emissions even at the moment of emission). However, the degree of atmospheric dispersion assumed in the application of these two models was the same. One parameter in both models is the choice of dispersion coefficients. Separate sets of dispersion coefficients are available for urban versus rural areas to represent the

degree of atmospheric mixing under various meteorological conditions. In this study, for both models, Briggs' urban dispersion coefficients were used. A second parameter in both models is the meteorological data used. As a simplification in estimating long-term average concentrations, both models in this study use stability array (STAR) data showing the joint frequency distribution of winds in each of six classes of wind speed and six classes of atmospheric stability for each of 16 wind directions. Both models estimate concentrations for each wind speed/stability/wind direction category. These models then estimate an annual average concentration by averaging the category-specific concentrations, weighted according to the frequency of each meteorological category. For both models, the meteorological frequency distribution was based on 1973 to 1977 data collected at Midway Airport, representing the nearest, most recent, and most representative complete data set available. Further, both models assumed relatively flat terrain. Finally, it should be noted that both of these models are state-of-the-art models which are routinely used for regulatory applications where estimates of atmospheric transport and dispersion are necessary. In fact, both of these models are reference models noted in USEPA's Guideline on Air Quality Models (Revised), July 1986, (EPA-450/2-78-027R). Although this guideline does not address the pollutants in this study, the study uses the models recommended in the guideline for the general type of modeling being conducted here.

The discussion of emissions estimation has noted that point sources in this study include steel mills, most other industrial sources, waste handling facilities, and wastewater treatment plants. That discussion also noted that area sources include a few industrial source types (chrome platers, degreasing, and barge loading), consumer-oriented sources, and roadway vehicles. This same distinction applies to selection of a dispersion model for addressing each source type. An important exception is that a selected set of steel mill operations were simulated with a small but finite initial dispersion, reflecting the modest area from which these emissions arise. These emissions were simulated using the area source algorithm of ISCLT. For example, a typical coke oven was simulated by distributing emissions into three neighboring 40 foot squares. This approach was intended to simulate more realistically the dispersion of these emissions, and was used for coke ovens and for roof monitors at steel-making furnaces. A second exception is chrome platers. In Illinois, it appeared that a sufficient listing of electroplaters was available to treat these emissions as point sources, assigning the area's emissions to the identified plater locations. This treatment has the advantage of providing more realistic treatment of the dispersion characteristics of these sources. Note that in Indiana, where no listing of sources was available, this source category was both inventoried and modeled as area sources. A third exception is municipal waste landfills, which were simulated as area sources using CDM-2 using landfill-specific dimensions.

An unavoidable element of uncertainty is introduced in estimating atmospheric dispersion. In general, the data and equations used to estimate atmospheric dispersion are an approximation of real atmospheric phenomena. Specifically, in Southeast Chicago, the proximity of Lake Michigan may cause alterations in the frequency of some wind directions and wind speeds and may also affect the extent of dispersion in this area as compared to the meteorology at Midway Airport. Generally, atmospheric dispersion models are considered accurate

within a factor of two. Although actual uncertainties for annual average concentration estimates are difficult to quantify, this generalization does give a sense of the uncertainties in the modeling element of this study.

A sample of the concentrations estimated in this study is shown in Figure 2. This figure shows a map of coke oven pollutant concentrations. This map highlights the grid system used in estimating concentrations. The area was divided into 1 kilometer squares, and concentrations were estimated at the center of each square. The geographic coordinate system used in this study was the Universal Transverse Mercator (UTM) system. In UTM coordinates, the square with the highest coke oven pollutant concentrations extends from 4614.5 kilometers to 4615.5 kilometers north and from 452.5 kilometers to 453.5 kilometers east in zone 16. In Chicago streets, this square extends roughly from 117th Street to 112th Street and from almost a kilometer west of Torrence Avenue to a little east of Torrence Avenue. The concentration estimate used for this grid square was estimated at 4615 kilometers north/453 kilometers east, which is near 114th Street and Torrence Avenue.

Although the receptor resolution (i.e., the estimation of concentrations at 1 kilometer intervals) is adequate for the purposes of this screening study, it must be understood that a finer receptor resolution (i.e., estimation of concentrations at more closely spaced intervals) would be expected to yield a higher peak concentration. This is because estimation of concentrations at more locations can be expected to identify some locations with somewhat higher concentrations. That is, the actual peak concentration for coke oven pollutants is probably somewhat higher than the 6.1 ug/m^3 shown in figure 2. However, the design and scope of this study was not to obtain a precise peak concentration estimate but rather to address area-wide impacts from multiple pollutants and multiple sources.

The estimate of area-wide exposure to specific pollutants would also be more precise if a finer receptor resolution were used. However, concentrations generally do not change dramatically more than a few kilometers from a given source, so the use of a finer receptor network would not be expected to alter the area-wide exposure estimates significantly.

Figure 3 shows a map of concentrations of polycyclic organic matter. (This map and Figure 2 were both produced by PIPQUIC.) This figure shows concentrations generally increasing toward the center of Chicago, reflecting the increase in population density and, therefore, density of sources of polycyclic organic matter (particularly mobile sources and homes being heated) as one approaches the center of Chicago.

Similar concentration estimates were made for the other pollutants in this study. However, the most meaningful way of addressing multiple pollutants is to use the common denominator of risk. This discussion will be included later in this report.

Comparison of Modeling and Monitoring Concentration Estimates

This study uses monitoring data in two ways. The first use is to compare with dispersion model estimates, to provide an indication of the reliability of the model estimates. The second use, applicable to formaldehyde and carbon tetrachloride, is for quantifying concentrations of "background pollutants" which are

Figure 2. Map of Estimated Coke Oven Pollutant Concentrations
(in $\mu\text{g}/\text{m}^3$)

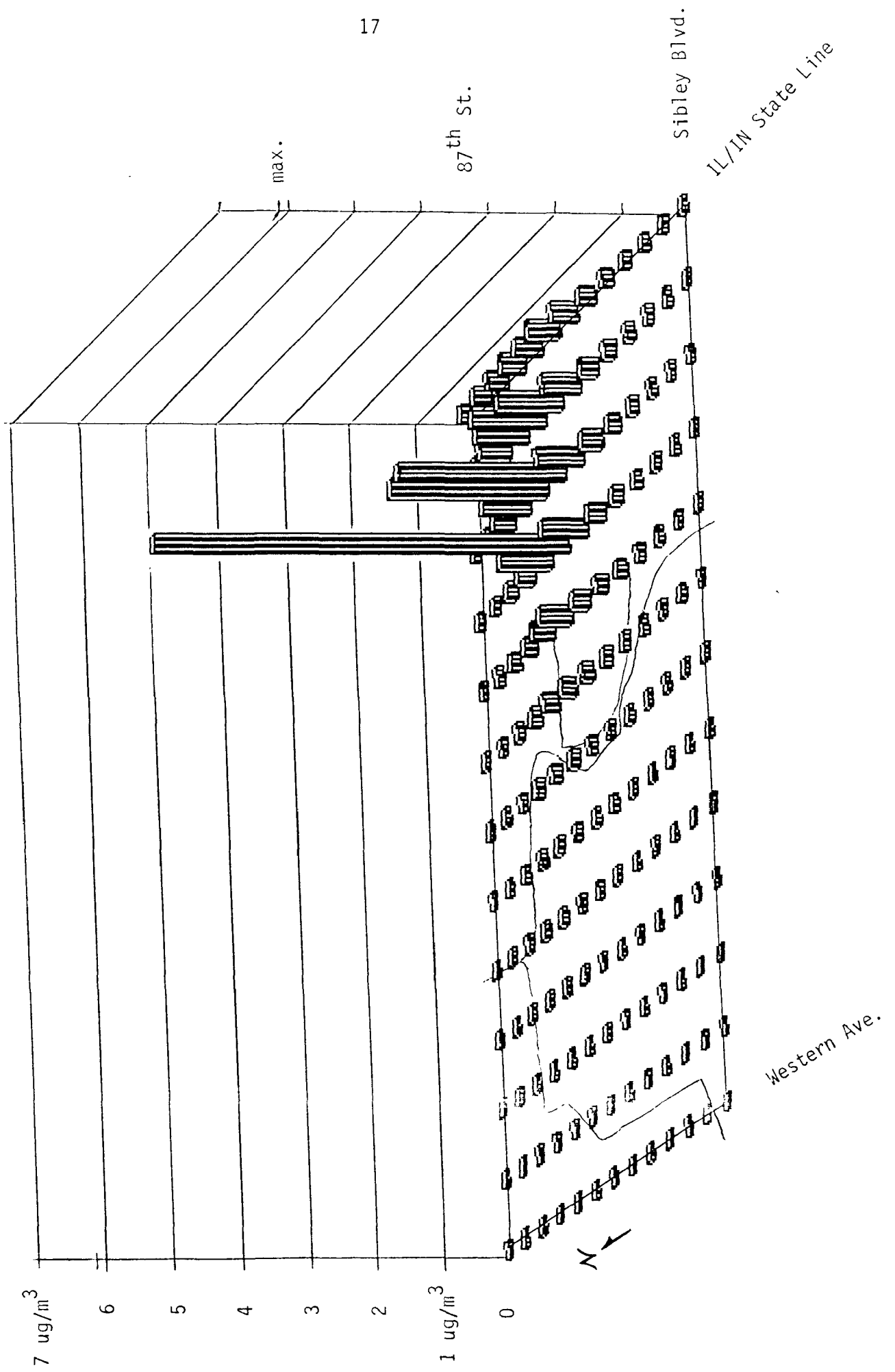
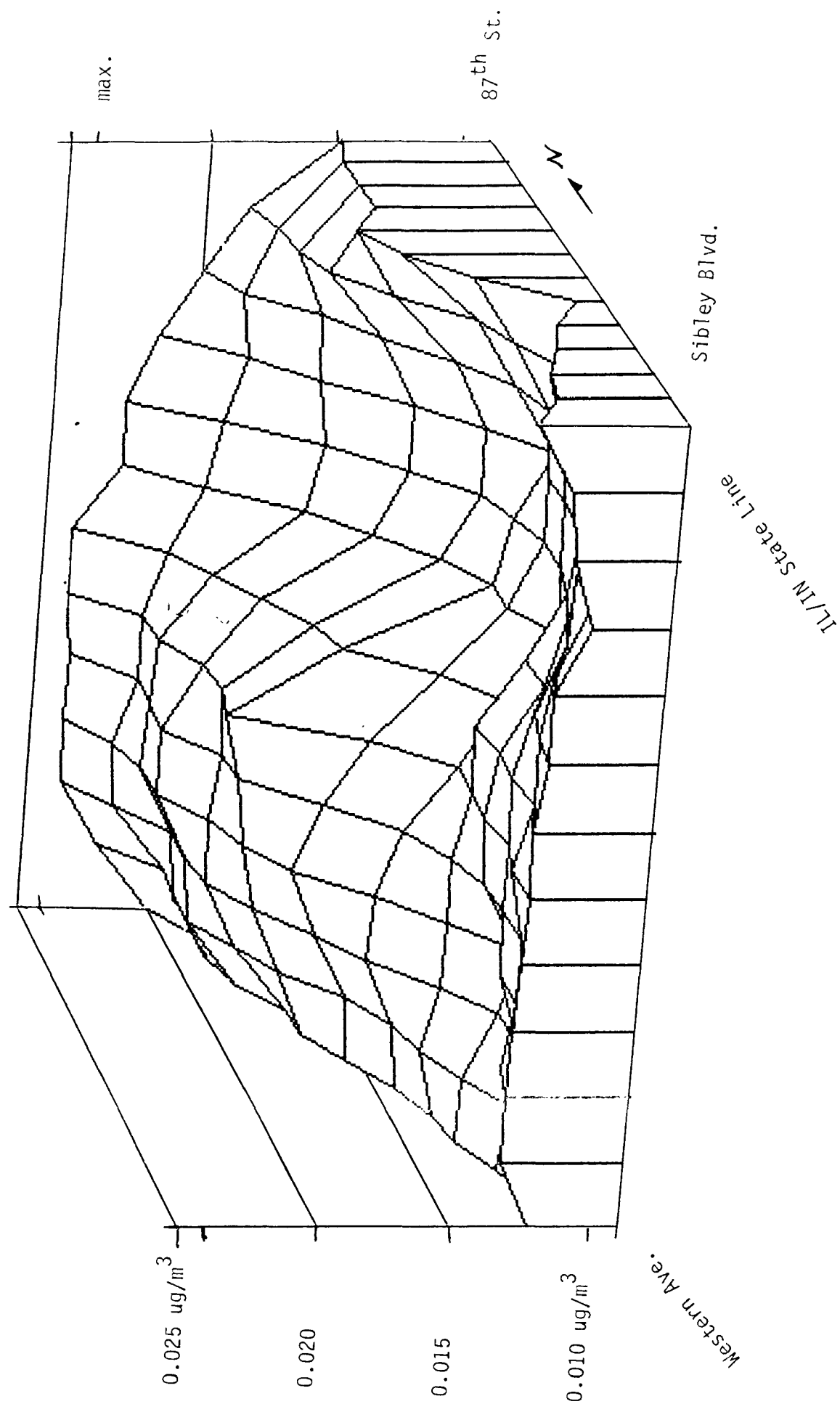


Figure 3. Map of Concentrations of Polycyclic Organic Matter
(in $\mu\text{g}/\text{m}^3$)



not the direct result of current emissions. Various monitoring programs have been conducted in the Southeast Chicago area to measure concentrations of pollutants in this study. Table 2 summarizes the studies from which data were available. This table shows the organization conducting the monitoring, the location(s) of the monitoring site(s), the monitoring method, the sampling period, the number of samples, the sampling duration (frequency and averaging time) and the pollutants monitored.

Table 3 presents a comparison of modeled versus monitored concentration estimates for the organic substances for which monitoring data are available. For each comparison, the monitoring data represent the average over the full time period for which reliable data are available. The modeling data in effect are 5 year averages (since the underlying meteorological data are 5 year averages and the underlying emissions data are intended to be similarly long-term averages). The modeling results are also specifically interpolated to the location of the monitor from the concentrations estimated at the nearest modeling grid points. Although in a few cases such interpolated results may differ significantly from the results that would be obtained by direct modeling for concentrations at the monitor location, particularly near major sources where spatial gradients may be high, in most cases these differences should be small.

The best comparison on Table 3 is for benzene. For this pollutant, the monitored values are within a factor of two to three higher than the modeled concentrations. Given the relative sparsity of monitoring data (in no study were more than about 30 days sampled), the uncertainty of the monitoring methods at concentrations close to the detection limit (generally not more than around three times the detection limit), and the uncertainties in the emissions inventory and modeling analysis, these results should be considered quite comparable. Note that although the modeled estimates could be adjusted to include the benzene component of coke oven emissions, this would only be a few percent increase. Less encouraging are the comparisons for toluene and xylene, where monitored values are between one and two orders of magnitude greater than modeled estimates. The same may be true of chloroform, whereas the comparison for perchloroethylene and trichloroethylene appear to be as close as the comparison for benzene. However, the concentrations that the Illinois Institute of Technology (IIT) and the Hazardous Waste Research Information Center (HWRIC) identify for perchloroethylene, trichloroethylene, chloroform, and carbon tetrachloride are below the monitoring detection limits that Radian identifies for these compounds, so these comparisons may not be reliable.

It has been noted previously that a substantial portion of formaldehyde and carbon tetrachloride concentrations may be attributed to origins other than current emissions. In this study, the emissions estimation/dispersion modeling approach is considered the best means of addressing the impacts of current emissions. For formaldehyde and carbon tetrachloride, monitoring data provide the best indication of the sum of direct impacts from current emissions plus indirect impacts from other causes. Thus, in this study, background concentrations for these two pollutants were evaluated by determining a total concentration from available monitoring data and then subtracting the concentration attributable to current emissions. These background concentrations were assumed to be uniform throughout the Southeast Chicago area. Total concentrations of these two pollutants at each of the receptor locations were then derived by

Table 2. Monitoring Studies Conducted in Southeast Chicago

<u>Organization</u>	<u>Monitoring Location</u>	<u>Monitoring Method</u>	<u>Sampling Period</u>	<u>Number of Samples</u>	<u>Sample Duration</u>	<u>Monitored Pollutants</u>
Illinois EPA/Radian	Carver High School (4611.7N/450.9E)	Canister Cartridge Filter	9/87 to 3/88 " "	16 " "	24 hrs. every 12 days	Organics Formaldehyde metals,B(a)p
USEPA (Toxic Air Monitoring System (TAMS))	S.E. Police Station (4615.5N/450.0E)	Tenax (no data for canister samples)	7/85 to 11/86	30	24 hrs. every 12 days	Organics
Illinois Institute of Technology (IIT)	S.E. Police Station (4615.5N/450.0E)	Canister Tenax	11/86 to 2/87 "	5 to 7 "	4 hrs.	Organics "
National Particulate Network	Carver Elem. School (4611.1N/449.8E) Washington High School (4615.0N/455.0E) Addams School (4616.2N/453.8E) Bright School (4616.5N/453.2E)	Filters	1985 to 1987	30/year	24 hrs. every 12 days	metals, B(a)p
Illinois Dept. of Energy and Natural Resources/Hazardous Waste Research and Information Center (HWRIC)	Bright School (4614.5N/453.2E)	Canister Impactor Dichot.sampler Streaker	10/86 to 6/87 1987 6/86 to 6/87 1987	10-15 4 ? 1	1 min. 24 hrs. 100 hrs. 7 days	Organics metals metals metals
Illinois EPA	Bright School (4616.5N/453.2E) Washington High (4615.0N/455.0E) Grissom School (4612.3N/453.9E)	Polyurethane Foam " "	2/86 to 8/86	6	24 hrs.	PCB

Table 3. Comparison of Modeled-versus Monitored-based Concentration

Estimates for Organic Toxicants

(all concentrations in ug/m³)

COMPOUND	HWRIC*		IIT*		TAMS*		Radian*	
	Monitored	Modeled	Monitored	Modeled	Monitored	Modeled	Monitored	Modeled
Benzene	5.10	3.23	4.75	1.71	4.14	1.71	3.63	1.18
Perchloroethylene	--	--	2.23	0.915	2.37	0.915	<5.4**	--
Trichloroethylene	--	--	0.91	0.366	--	--	<4.8**	--
Chloroform	1.95	.014	2.78	.0254	--	--	<4.4**	--
Formaldehyde	--	--	--	--	--	--	2.93	0.27
Ethylene	--	--	4.61	.018	--	--	--	--
Toluene	6.39	0.57	9.93	1.29	12.97	0.29	11.66	0.19
Carbon Tet.	0.44	.014	2.70	.0033	--	--	<3.8*	--
Methylene Chl.	--	--	--	--	--	--	<1.4*	.05
Xylenes & Styrene	14.35	.221	7.86	.125	9.94	.125	43.03	.09

* These acronyms are defined and details of the monitoring programs are given in Table 2.

** < signifies below the identified detection limit

adding the uniform concentration representing background impacts plus the variable concentrations representing direct emissions impacts.

As seen in Tables 2 and 3, formaldehyde was monitored at one location in the area. Data are available for September 1987 to March 1988. While these are the best data available, it must be noted that the absence of data from the summer, when photochemical formation of formaldehyde is greatest, indicates that available data probably understate the annual average formaldehyde concentration. In any case, the average of available data is a concentration of 2.93 ug/m^3 . At the monitor location, the impact of direct emissions is estimated to be 0.27 ug/m^3 . Therefore, the formaldehyde concentration attributed to photochemical formation is the difference of 2.66 ug/m^3 .

Tables 2 and 3 show that carbon tetrachloride was monitored at three locations in the Southeast Chicago area. However, Table 2 also shows that two of the three studies (by IIT and HWRIC) include only a small number of samples, and Table 3 shows that the third study (by Illinois EPA/Radian) did not report any detectable concentrations. Atmospheric accumulation of carbon tetrachloride over prior decades may be presumed fairly uniformly distributed in the global atmosphere, and so a more reliable indicator of the atmospheric accumulation of carbon tetrachloride is from more thorough studies elsewhere. In areas of the United States that may be presumed not to have significant sources of carbon tetrachloride, available monitoring data suggest concentrations generally between 0.6 and 0.8 ug/m^3 . An average value of 0.76 ug/m^3 is used as the average value in the Southeast Chicago area. Most of this concentration is assumed uniform throughout the area; only the minor portion of the concentration attributable to current emissions is treated as varying from location to location.

Table 4 compares PCB concentrations monitored by IEPA with modeled concentrations. Possible explanations for this relatively poor comparison include missing emission sources, uncertainties in the monitoring method, a short and therefore possibly unrepresentative monitoring period, and the long atmospheric residence of PCBs.

Table 5 compares particulate matter monitoring data with modeled concentrations. For arsenic, cadmium, and chromium, the two sets of concentrations are quite similar, indeed well within the uncertainty ranges for the monitoring and modeling data. (Note that for chromium, both the monitoring and modeling data show total chromium concentrations.) The other pollutant shown in Table 5, benzo(a)pyrene, again seems to show a close comparison between monitored and modeled concentrations. This comparison is complicated by the fact that the monitoring method measures specifically benzo(a)pyrene, a compound which in the inventory is included in the class of compounds labeled polycyclic organic matter (POM) as well as in coke oven emissions. The designated modeled value in Table 5 was estimated as a somewhat arbitrary 1% of the combined mass of POM plus coke oven pollutants. Given the uncertainty in this comparison, no firm conclusions can be drawn from the similarity of these monitored and modeled data.

These comparisons of modeled versus monitored concentration estimates appear to support two generalizations: (1) for most pollutants, the modeled and monitored concentration estimates agree reasonably well, and (2) the differences between

Table 4. Comparison of Modeled- Versus Monitored-based
Concentration Estimates for PCBs
(all concentrations in ug/m³)

	<u>Monitored</u>	<u>Modeled</u>
Bright School	.0019	.000004
Washington School	.0003	.000001
Grissom School	.0005	.000004

Table 5. Comparison of Modeled - Versus Monitored-based Concentration
Estimates for Particulate Toxicants
(all concentrations in ug/m³)

ELEMENT	CARVER		WASHINGTON		ADDAMS		BRIGHT		
	Monitored	Modeled	Monitored	Modeled	Monitored	Modeled	Monitored (NPN)	Modeled	Monitored (HWRIC)
Arsenic	<*	.0012	.0036	.0011	<*	.0024	.00214	.0021	.001
Cadmium	.0044	.0018	.0037	.0015	.003	.0031	.00055	.0028	.002
Chromium	.021	.025	.04	.0216	.029	.024	.0064	.0155	.013
Benzo(a) pyrene	--	--	.0064	.0015	--	--	.0076	.0073	--

* < signifies below detection limit

modeled and monitored concentrations, whether these differences are large or small, in essentially all cases show higher monitored concentrations than modeled concentrations. The first generalization suggests that for most pollutants, this study provides a reasonable assessment of the concentrations of these pollutants. The second generalization suggests that even these reasonably assessed pollutant concentrations are slightly underestimated, and concentrations for a few other pollutants may be substantially underestimating actual ambient concentrations. This in turn suggests the possibility that the emissions inventory of this study underestimates emissions, perhaps by underestimating emissions at identified facilities and perhaps by failing to identify some sources of emissions. Supporting this hypothesis, some of the pollutants which appear most underestimated by modeling (particularly PCBs and chloroform) are also among the more difficult pollutants for which to estimate emissions.

Evaluation of Cancer Risk Factors

Once concentration estimates have been made for the identified pollutants, it is then necessary to estimate the relationship between concentration and the increased probability or risk of contracting cancer that exposure to each pollutant may cause. This relationship is commonly expressed in terms of a unit factor, representing the risk estimated to result from exposure to a unit concentration of a pollutant. For example, if a pollutant has a unit risk factor of 1×10^{-4} per $\mu\text{g}/\text{m}^3$, then lifetime exposure to $1 \mu\text{g}/\text{m}^3$ (1 millionth of a gram of the pollutant per cubic meter of air) would be estimated to increase the probability of contracting cancer by 1×10^{-4} or 1 chance in 10,000. The probability or risk of contracting cancer is generally treated as linear within the range of actual exposure conditions, so that in the example above, exposure to a concentration of $3 \mu\text{g}/\text{m}^3$ would be estimated to increase cancer risks to 3×10^{-4} or 3 chances in 10,000.

There is a lack of data where large numbers of people are exposed to typical environmental concentrations, where the concentrations and the resulting number of cancer cases are well defined for several subpopulations, and where confounding influences from other causes of cancer can be clearly factored out. Therefore, a variety of methods, scientific judgements and assumptions are used to assess the relationship between exposure to a pollutant and the resulting risk of contracting cancer.

For some pollutants, sufficient data do exist for specifiable human exposure circumstances to estimate the exposure levels and to evaluate the cancer risks that apparently result. The interpretation of these statistical data is generally designed to derive a maximum likelihood estimate of the unit risk factor (i.e., deriving a unit risk factor which the data suggest will have the greatest likelihood of accurately representing the ratio between exposure and cancer risk for the conditions of the study). In general, the exposures that can be studied are higher than typical ambient concentrations, and so extrapolation of the exposure-cancer risk relationship must be performed. This extrapolation of the dose-response relationship down to lower exposure levels uses conservative methods, so as to decrease the likelihood of underestimating risks.

For a majority of pollutants, however, no human exposure situation can be sufficiently characterized to support the derivation of a unit risk factor. The only data for deriving unit risk factors for these pollutants, then, will

generally be from studies involving animals. These studies provide statistical data which by various interpretations can yield alternative unit risk factor estimates. The usual interpretation method is to select a 95% upper confidence level value. This signifies that the selected unit risk factor is the value which has a 95% likelihood of not understating the true risk factor indicated by the data. It should be noted that this discussion refers only to the conservatism inherent in the statistical interpretation of cancer data, which is not the only element of conservatism in the unit risk factor. As with the maximum likelihood estimate, a downward extrapolation from studied exposures to ambient exposures is necessary, and this extrapolation is done in a way that adds conservatism. (For animal studies, practical considerations generally require studied exposures to be higher than ambient exposures. For example, a study involving 100 animals cannot provide a meaningful result if the risk is 1 in 1,000,000.) The extrapolation of the unit risk factor applicable to typical ambient concentrations involves best scientific judgement of a plausible yet conservative extrapolation. With animal studies, an additional adjustment is made from animal carcinogenicity to human carcinogenicity based on differences in body weight and breathing rate, again involving best scientific judgement of a plausible yet conservative extrapolation. Thus, the methods of extrapolating unit risk factors add some conservatism to the conservatism inherent in the use of a 95% upper confidence limit.

The relationship between pollutant concentration and cancer risk is a function of both the quantity of pollutant inhaled and the body's reaction to the inhaled quantity. Unit risk factors are designed to estimate the cancer risk resulting from inhaling a unit concentration for 24 hours a day for a 70 year lifetime. Similarly, cancer risks in this study are estimated by assuming that Southeast Chicago area residents are exposed to the estimated concentrations for 24 hours per day for a 70 year lifetime. Clearly, these residents spend some time outside the study area and spend some time indoors, but the absence of knowledge of pollutant concentrations in these other environments makes it impossible to make upward or downward adjustments according to these other exposures.

In addition to variability in carcinogenic strength, there is also variability in how much evidence exists to indicate more fundamentally whether individual pollutants are in fact carcinogenic. Therefore, USEPA has established a classification system describing the weight of experimental evidence that a pollutant is carcinogenic. The classifications used by the U.S. EPA are: A - human carcinogen; B - probable human carcinogen; C - possible human carcinogen; D - not classifiable as to human carcinogenicity; and E - evidence of noncarcinogenicity in humans. These ratings reflect the following types of evidence: A - "sufficient" human data show carcinogenicity; B - is subdivided into B1 and B2, in which either "limited" human data or "sufficient" animal data show carcinogenicity; C - human data are inadequate or nonexistent but limited animal data show carcinogenicity; D - data to assess carcinogenicity are inadequate or nonexistent; and E - well designed studies suggest that the pollutant is noncarcinogenic. More detailed definitions of these classifications can be found in USEPA's Risk Assessment Guidelines of 1986. For clarity, references to group A pollutants in this report will use the term "known human carcinogen."

The classifications in the weight of evidence approach are intended to indicate the strength of the evidence of carcinogenicity independently of any evaluation of carcinogenic strength. As yet, no equivalent system has been developed to

address the accuracy of the unit risk factors. For some pollutants, a greater weight of evidence of carcinogenicity also signifies a better data base from which to estimate unit risk factors, but this is not the case for all pollutants.

This study found and quantified emissions for 30 presumed carcinogens. USEPA's evaluation of the weight of evidence is that these 30 pollutants include 6 known human carcinogens, 22 probable human carcinogens, and 2 possible human carcinogens. Table 6 provides the names of these pollutants, the weight of evidence classification, the unit risk factor used in this study, and whether this risk factor is calculated as a 95% upper confidence level (UCL), a maximum likelihood estimate value (MLE), or a best estimate (BE). This table also shows which USEPA office developed the unit risk factor. In this table, IRIS (Integrated Risk Information System) signifies risk factors that have received agency-wide review. Other values have not received agency-wide review but have been developed by the Office of Health and Environmental Assessment in the Office of Research and Development (designated OHEA), by the Office of Air Quality Planning and Standards (designated OAQPS), or by the Office of Toxic Substances (designated UTS).

Several of the pollutants in Table 6 represent mixtures of compounds. One such mixture is designated in Table 6 as "Benzo(a)pyrene (POM)." Benzo(a)pyrene is the most studied member of the class of compounds known as polycyclic organic matter (POM). This study inventoried emissions and estimated concentrations of the full class of POM compounds, and then estimated risk by multiplying the POM concentrations times the benzo(a)pyrene unit risk factor. While some POM compounds are probably more carcinogenic and other POM compounds are less carcinogenic, this approach in effect assumes that the average cancer potency of the full range of POM compounds equals the cancer potency of benzo(a)pyrene.

Another mixture shown in Table 6 is coke oven emissions. For this mixture, a unit risk factor for the full mixture has been developed (based on epidemiological analysis of occupational exposure data). This mixture includes substantial quantities of other pollutants in this study, including polycyclic organic matter and benzene. However, no effort was made to assess emissions or risk from these coke oven gas constituents individually. Instead, the emissions estimates, the unit risk factor, and the risk estimates for coke oven emissions are designed to address the emissions, toxicity, and risk of the full mixture emitted from coke batteries.

A third mixture shown in Table 6 is dioxin. In this study "dioxin" represents a class of 75 chlorinated dibenzo-dioxins and 135 chlorinated dibenzo-furans. The unit risk factor shown in Table 6 is for 2,3,7,8 - tetrachloro-dibenzo-dioxin (2,3,7,8 - TCDD), the best studied dioxin. Other dioxins were inventoried on the basis of toxic equivalents, i.e., what mass of 2,3,7,8 - TCDD would have equivalent toxicity to the given mass of identified dioxin. For example, 10 grams of 2,3,7,8 - tetrachloro-dibenzo-furan, having an estimated toxicity equivalence factor of 0.1, would be inventoried as if it were 1 gram of 2,3,7,8 - TCDD. Quantitative details are given in the inventoried documentation.

Two other mixtures shown in Table 6 are gasoline vapors and polychlorinated biphenyls (PCBs). The unit risk factor for gasoline vapors was derived from a

Table 6. Carcinogenicity of Inventoried Pollutants

<u>Pollutant</u>	<u>Weight of Evidence Rating*</u>	<u>Unit Risk Factor (in (ug/m³)⁻¹)</u>	<u>Type of Risk Factor**</u>	<u>Source of Data***</u>
Acrylamide	B2	1.2×10^{-3}	UCL	IRIS
Acrylonitrile	B1	6.8×10^{-5}	UCL	IRIS
Arsenic	A	4.3×10^{-3}	MLE	IRIS
Asbestos	A	8.1×10^{-3}	BE	IRIS
Benzene	A	8.3×10^{-6}	MLE	IRIS
Benzo(a)pyrene (POM)	B2	1.7×10^{-3}	UCL	OAQPS
Beryllium	B2	2.4×10^{-3}	UCL	IRIS
Butadiene	B1	1.1×10^{-4}	UCL	IRIS
Cadmium	B1	1.8×10^{-3}	MLE	IRIS
Carbon Tetrachloride	B2	1.5×10^{-5}	UCL	IRIS
Chloroform	B2	2.3×10^{-5}	UCL	IRIS
Chromium	A	1.2×10^{-2}	MLE	IRIS
Coke Oven Emissions	A	6.2×10^{-4}	UCL	OHEA
Dioxin	B2	3.3×10^{-1}	UCL	OHEA
Epichlorohydrin	B2	1.2×10^{-6}	UCL	IRIS
Ethylene Dibromide	B2	2.2×10^{-4}	UCL	IRIS
Ethylene Dichloride	B2	2.6×10^{-5}	UCL	IRIS
Ethylene Oxide	B1-B2	1.0×10^{-4}	UCL	OHEA
Formaldehyde	B1	1.3×10^{-5}	UCL	OTS
Gasoline Vapors	B2	6.6×10^{-7}	UCL	OAQPS
Hexachlorobenzene	B2	4.9×10^{-4}	UCL	OHEA
Methyl Chloride	C	3.6×10^{-6}	UCL	OHEA

Table 6. (Continued)

<u>Pollutant</u>	<u>Weight of Evidence Rating*</u>	<u>Unit Risk Factor (in (ug/m³)-1)</u>	<u>Type of Risk Factor**</u>	<u>Source of Data***</u>
Methylene Chloride	B2	4.7×10^{-7}	UCL	OHEA
Perchloroethylene	B2	5.8×10^{-7}	UCL	OHEA
PCB's	B2	2.2×10^{-3}	UCL	OHEA
Propylene Oxide	B2	3.8×10^{-6}	UCL	OHEA
Styrene	B2	5.7×10^{-7}	UCL	OHEA
Trichloroethylene	B2	1.7×10^{-6}	UCL	OHEA
Vinyl Chloride	A	4.1×10^{-6}	UCL	OAQPS
Vinylidene Chloride	C	5.0×10^{-5}	UCL	IRIS

* - As discussed in text, these ratings signify:

- A - Known human carcinogen
- B - Probable human carcinogen
- B1 - Based on "limited" human data
- B2 - Based on "sufficient" animal studies
- C - Possible human carcinogen

** - The three types of risk factors used in this study are:

- UCL - 95% upper confidence limit
- MLE - maximum likelihood estimate
- BE - best estimate

*** IRIS - Integrated Risk Information System

OAQPS - Office of Air Quality Planning and Standards

OHEA - Office of Health and Environmental Assessment

OTS - Office of Toxic Substances

Note: As described in the text, each unit risk factor estimates risk from lifetime exposure to a unit pollutant concentration.

study of the full mixture, though it does not include the impact of gasoline's benzene component. The unit risk factor for PCBs was derived for a representative compound of this set of compounds.

Chromium and ethylene oxide also warrant special comment. For chromium, both the emissions estimates and the unit risk factor are only for the hexavalent (+6) form of chromium. For ethylene oxide, the classification B1-B2 refers to the fact there is both "limited" human evidence and "sufficient" animal evidence of the carcinogenicity of this compound.

The above discussion addresses the calculation of risks from individual pollutants. This study also seeks to estimate the combined impact of all the pollutants included in this study. The methodology recommended in the "Chemical Mixtures Risk Assessment Guidelines" (part of USEPA's Risk Assessment Guidelines of 1986) is to estimate total risks as a linear sum of the individual pollutant risks, in the absence of information suggesting otherwise. It is possible that exposure to some combinations of pollutants may cause a greater risk (synergism) or a lesser risk (antagonism) than the sum of the risks resulting from exposure to the substances individually. However, there are no clear means of quantifying any synergistic or antagonistic effects from exposure to the complex and variable mixtures in the Southeast Chicago area atmosphere, if in fact such effects are occurring. Therefore, the method for combining risks used in this study was to sum the risks estimated for individual pollutants.

The unit risk factors used in this study reflect the best judgements of USEPA scientists in evaluating available evidence both as to the interpretation of specific studies and as to the procedures that most reliably extrapolate unit risk factors from these studies. Nevertheless, the uncertainties in the unit risk factors are probably the greatest uncertainties in this study. These uncertainties arise from the significant extrapolations such as from high concentrations to lower concentrations and from rats or mice to humans that are necessary to estimate the risk factors.

The Risk Assessment Guidelines of 1986 discuss the significant assumptions and therefore the significant uncertainties that are necessary in developing unit risk factors. In summary, these assumptions and uncertainties are as follows: (1) Exposure to any amount of the substance, no matter how small, is assumed to represent an increased probability of cancer. There is uncertainty that cancer impacts may occur only above some pollutant-specific threshold concentration; (2) For risk factors based on animal studies, the development of cancer in humans is analogous to the development of cancer in the animals. There is uncertainty that the biological process of cancer formation is the same process in humans as in animals. For this and other reasons, there is also uncertainty in the quantitative extrapolation of the relationship between cancer risks and exposure for humans from the relationship for animals; (3) Information on the carcinogenicity of substances at "high" concentrations can be used to predict the effects at "low" concentrations; and (4) The increased probability of cancer incidence is proportional to the concentration of the substance at low concentrations.

Incidence and Risk Estimates

As indicated previously, risks at a given location were estimated by multiplying, for each pollutant, the modeled concentration estimate (in $\mu\text{g}/\text{m}^3$) times the risk per $\mu\text{g}/\text{m}^3$ of that pollutant, and then summing for all pollutants. These risks are commonly expressed in exponential form, where, for example,

2×10^{-3} equals 2 chances in 1,000. Thus, a person residing for a lifetime at such a location will have 2 chances in 1000 of contracting cancer from this exposure.

Incidence is a more population-oriented measure of pollutant impacts. By multiplying the risk in a given grid times the number of people in that grid, one can estimate a probable number of cancer cases contracted as a result of the exposure. For example, if a grid square with an estimated lifetime risk of 2×10^{-3} has a population of 2000, one would estimate that a lifetime of exposure would lead to 4 cancer cases. This figure is sometimes translated to an annual probability: a probability estimate of 4 cases divided by a 70 year lifetime suggests a probability estimate of $4/70$ or 0.057 cases per year or one case per 17.5 years. This calculation is done for each grid square; the total across all grids is then the estimated number of cancer cases in the entire study area attributable to air pollution.

It should be noted that the risk estimates presented in this report should be regarded as only rough approximations of total cancer cases and individual lifetime risks, and are best used in a relative sense. Estimates for individual pollutants are highly uncertain and should be used with particular caution.

The total cancer incidence estimated in this study is approximately 85 cases over 70 years, or about 1 case per year. Figure 4 is a pie chart illustrating the contributions of the various source types to this estimated incidence. (This figure is titled as contributions to annual cancer cases, but percentage contributions to the lifetime (70 year) number of cases are the same.) Table 7 presents a more detailed table breaking down the contributions by pollutant and by source type. Figure 5 shows the spatial distribution of cancer incidence estimates. (Areas with zero incidence estimates, such as in the Lake Calumet area, represent areas with no residents.)

Figure 4 and Table 7 show that the greatest contribution to cancer incidence in the Southeast Chicago area appears to result from emissions at steelmaking facilities. In total, the various integrated steel mills in the southern Lake Michigan area were estimated to cause about 29 cancer cases over 70 years, representing almost 34% of the total. Coke ovens in particular appear to contribute more than any other individual operation to air pollution-related cancer incidence. Specifically, the emissions from coke ovens, including the emissions from charging coal into the ovens and from leaks around the oven doors, lids, and oftakes were estimated to contribute 24 cases over 70 years, or about 85% of the steel mill contribution to area incidence. Coke oven by-product recovery plants, which refine the gases baked out of coal by the coke ovens, are estimated to contribute an additional 2 cases over 70 years. Since this operation may be considered an adjunct to coke production, the total risk estimated for coke production is 26 cases over 70 years, or about 92% of the steel mill contribution. The remaining 8% of the steel mill contribution to incidence arises principally from arsenic, cadmium, and chromium emissions from basic oxygen furnaces, electric arc furnaces, blast furnaces, and sintering operations.

Figure 4 and Table 7 indicate other significant contributors to estimated air pollution related cancer cases in the Southeast Chicago area. Also useful here is Figure 6, showing a more detailed breakdown than Figure 4 of specific source types to area cancer case estimates. After steel production,

SOUTHEAST CHICAGO STUDY AREA

Figure 4.

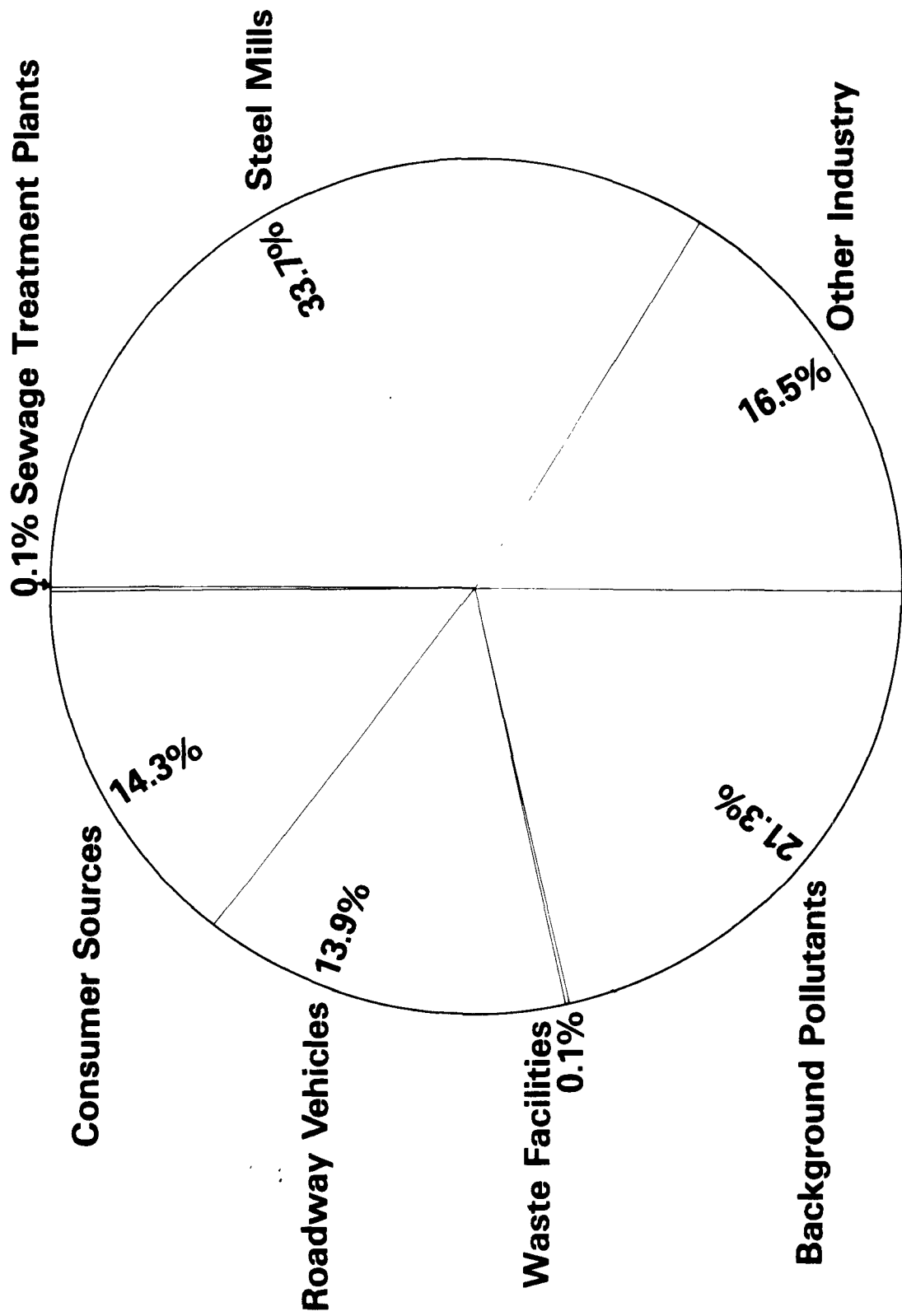
Contributions to Estimated Annual Cancer Cases by Source Type

Table 7. Contributions to Estimated Area Cancer Cases by Source Type and Pollutant Across the Study Area (in cases per 70 years)

Compound*	Steel Mills	Other Industrial Sources	Consumer Sources	Mobile Sources	Waste Handling	Sewage Treatment Plants	Background Pollutants	Total
Acrylamide		m**						m
Acrylonitrile		m			m			m
Arsenic	1.4	.1						1.5
Asbestos			.04	.1				.1
Benzene	2.2	.06	.1	1.9	m	m		4
Beryllium		m						m
Butadiene	m	m		2.2	m			2
Cadmium	.8	.01		.01				.8
Carbon Tet.		m			.01		4.5	5
Chloroform		m	.2		m	m		.2
Chromium	.06	13.0	1.7					14
Coke Oven Em.	24.2							24
Dioxin		.2			.01			.2
Epichlorohydrin		m			m			m
Eth. Dibromide				.05				.05
Eth. Dichloride		.05			m	m		.05
Eth. Oxide		.2	.3					.5
Formaldehyde	m	m	.4	1.3	m		13.6	15
Gas. Vapors		m	.9	2.6				3
Hex-chl-benz.		m			.06	.1		.2
Methyl Chl.		m	.01			m		.01
Methylene Chl.		.04	.1		m	m		.2
Perchloroeth.		.04	.1		m	m		.2
PCB's		m			m			m
POM		m	8	3.7				12
Prop. Oxide		m						m
Styrene		m			m	m		m
Trichloroeth.		.2			.01	m		.2
Vinyl Chl.		m			m			m
Vinylidene Chl.		m			m	m		m
TOTAL***	29	14	12	12	.1	.1	18	85

*Abbreviations:

Carbon Tet. - Carbon tetrachloride
 Eth. - Ethylene
 Gas. - Gasoline
 Hex-chl-benz. - Hexachlorobenzene

Chl. - Chloride
 PCB's - Polychlorinated biphenyls
 POM - Polycyclic organic matter
 Prop. - Propylene

**m - minor (<.005 cases per 70 years)

*** Most figures have been rounded to nearest whole number.

BECAUSE OF UNCERTAINTY IN PROCEDURES, METHODS, ASSUMPTIONS AND DATA, THESE RISK NUMBERS SHOULD BE REGARDED AS ONLY ROUGH APPROXIMATIONS AND ARE BEST USED IN A RELATIVE SENSE. ESTIMATES FOR INDIVIDUAL POLLUTANTS ARE HIGHLY UNCERTAIN AND SHOULD BE USED WITH PARTICULAR CAUTION.

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Figure 5.

Relative Distribution of Estimated Lifetime Cancer Cases

(TOTAL CASES APPROXIMATELY 85 OVER 70 YEARS)

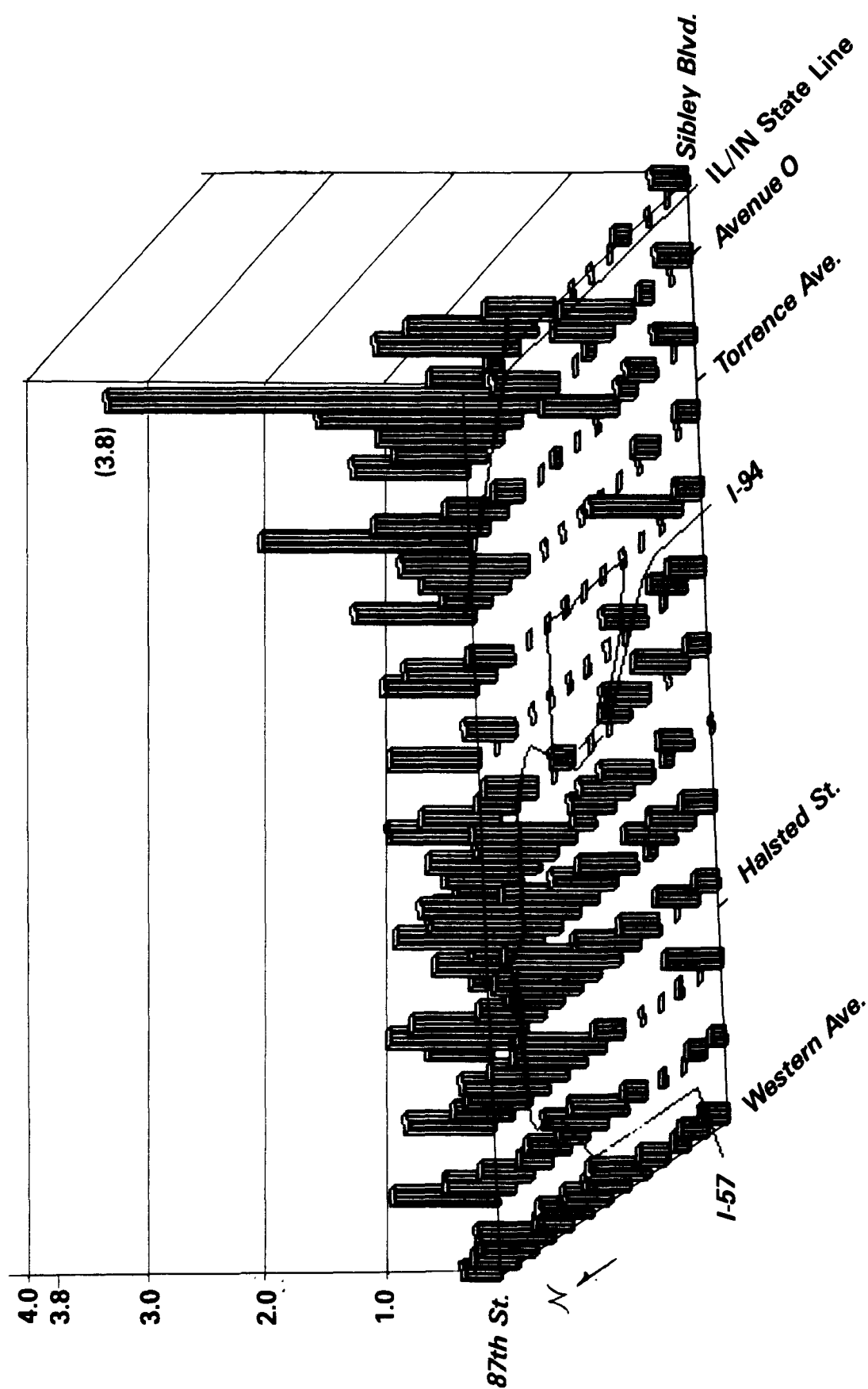
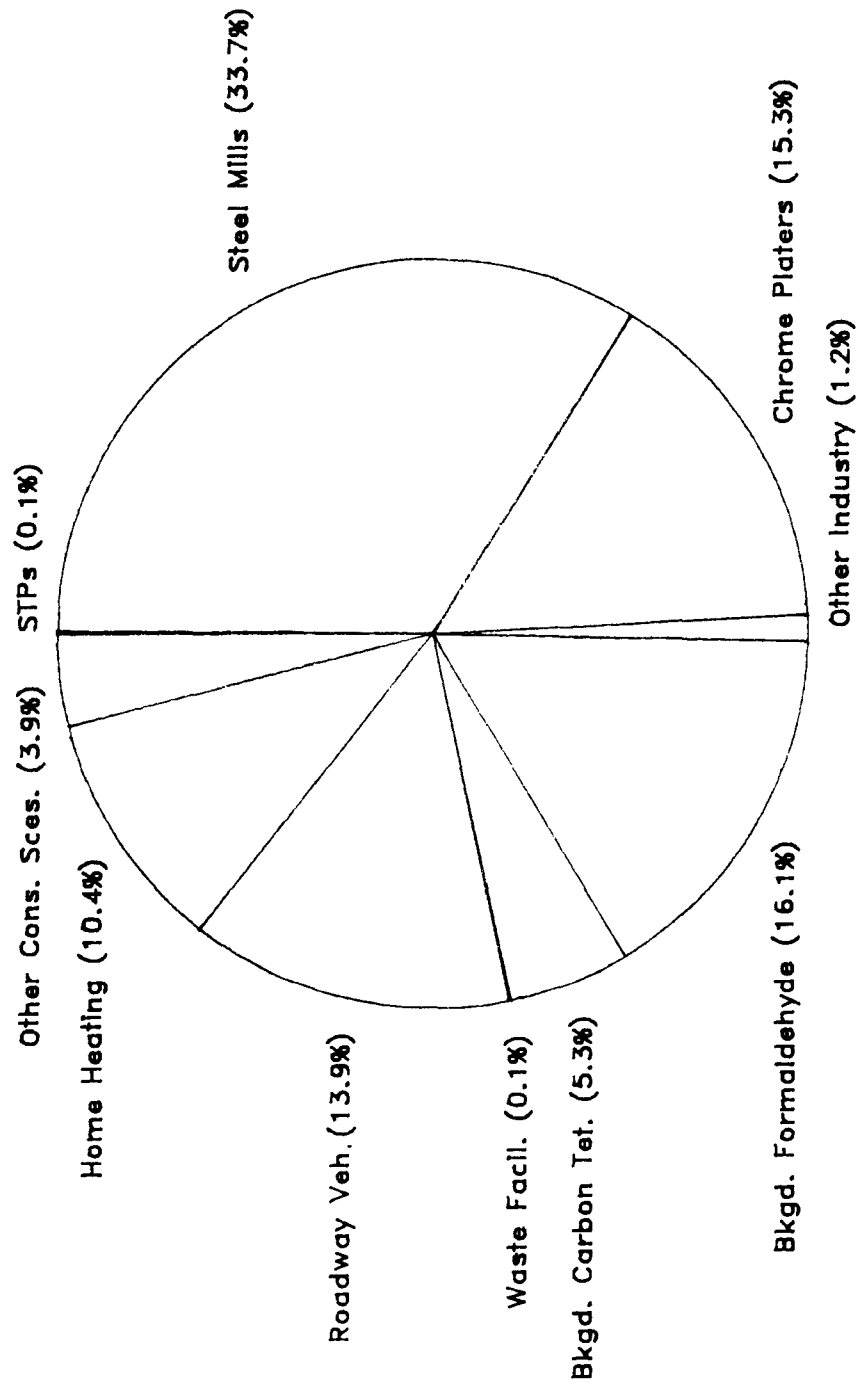


Figure 6. Breakdown by Source Category
of Contributions to Estimated Cases



the most significant contribution to risk is labeled "background pollutants," which contribute 18 cases over 70 years or about 21% of the total. This category includes air pollution which is not caused by current emissions, but rather represent "background concentrations" from other causes. Specifically, this category includes formaldehyde, which results from atmospheric photochemical reactions of other currently emitted organics, and carbon tetrachloride, which results largely from atmospheric accumulation of previous carbon tetrachloride emissions. As seen in Figure 6, photochemically formed formaldehyde appears to be one of the most significant air pollution-related causes of area cancer cases. Atmospheric accumulation of carbon tetrachloride also appears significant, although less significant than other contributions in Figure 6.

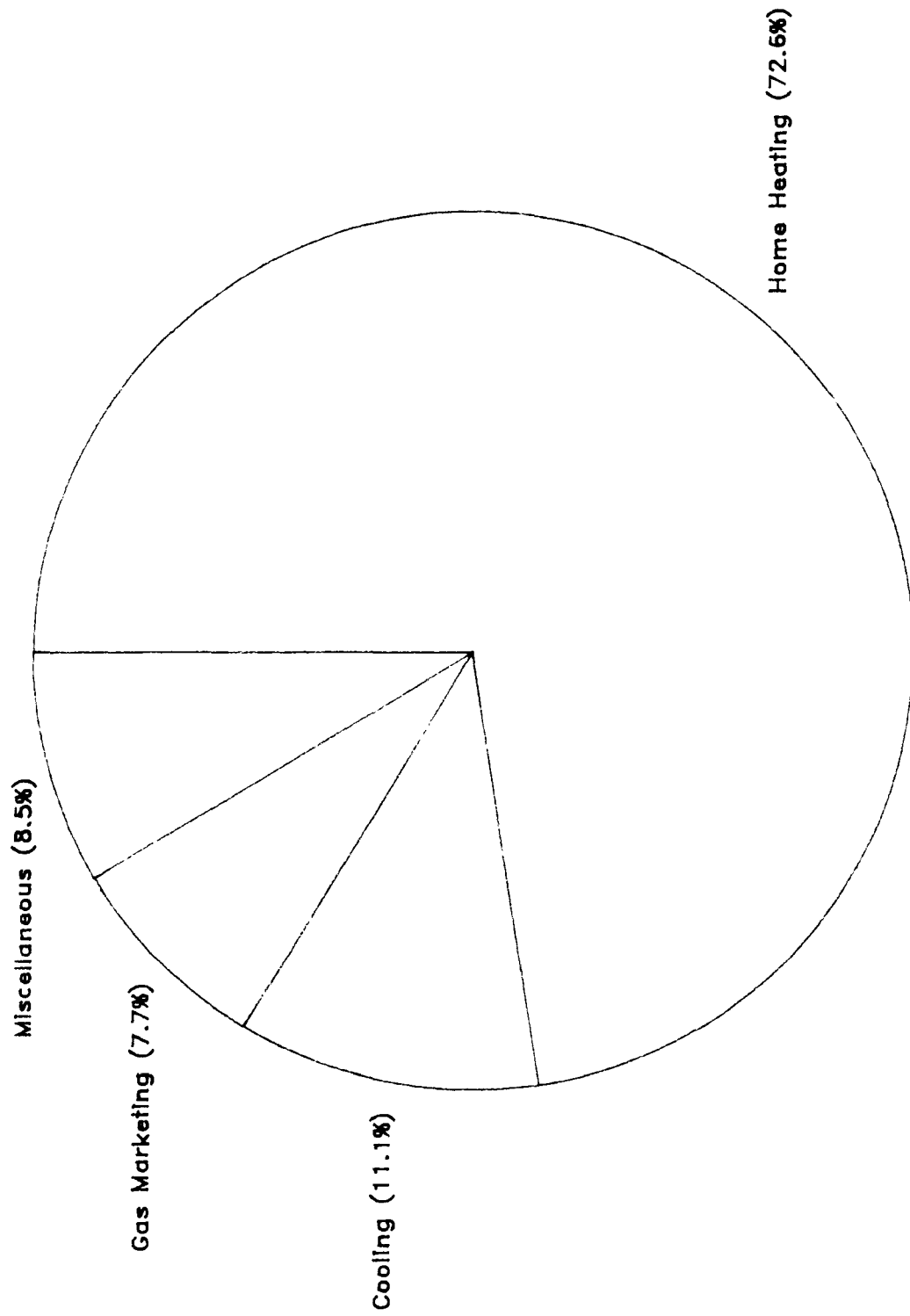
A third significant contribution to risk as shown in Figure 4 is industrial operations other than steelmaking, which cause about 14 cases over 70 years or about 16% of the total. As seen in Figure 6, this risk is predominantly due to chrome plating operations. Degreasing and miscellaneous other manufacturing operations add a fairly modest contribution to estimated cancer cases relative to other causes of air pollution-related risks. A fourth significant contributor to risk is identified on Figure 4 as consumer sources, which cause about 12 cases over 70 years, or about 14% of the total. This category includes several activities engaged in by the general public which result in emissions of presumed carcinogens. A fifth significant contributor to risk is from roadway vehicles such as cars and trucks traveling on streets and highways, also causing about 12 cases over 70 years, or about 14% of the total.

Figure 7 provides more detailed information on the contribution of consumer-oriented sources of air emissions to the estimated number of area cancer cases across the study area. Home heating appears to be the most significant such source type. Although some of this estimated risk is from combustion by-products (polycyclic organic matter and formaldehyde) from gas furnaces, the bulk of this contribution to risk is from wood combustion in fireplaces and wood stoves. Although the actual quantity of wood burned in the study's source area is small, a significant fraction of this wood is transformed during combustion into polycyclic organic matter. This pollutant is sufficiently toxic, so that wood combustion emerges as a relatively significant source category.

Figure 7 also shows contributions from other types of consumer-oriented source categories. The activities aggregated as "miscellaneous activities" each are estimated to contribute less than 0.3 cases over 70 years (about 4 cases in 1,000 years), and include, in order of estimated significance: sterilizing operations at hospitals using ethylene oxide, chloroform from chlorinated drinking water, formaldehyde in miscellaneous consumer products, dry cleaning, methylene chloride in aerosol cans and paint stripping, various minor constituents of house paint, and asbestos from demolition and renovation of asbestos-containing structures. The total contribution of these "miscellaneous activities" is estimated to be about 1 case over 70 years.

Collectively, the impacts of steel mills, other industrial operations, background pollutants, consumer sources, and roadway vehicles contribute all but 0.2% of the total estimated number of cancer cases attributable to air pollution. Using more narrowly drawn source categories, the collective impact of steel mills,

Figure 7. Contributions to Estimated Cases from Consumer-oriented Sources



chrome plating, background formaldehyde, background carbon tetrachloride, home heating, and roadway vehicles contribute almost 95% of the total estimated air pollution related cancer cases. (Other industrial sources and other consumer sources contribute the remainder of the 99.8% referenced above ("all but 0.2%").)

Figures 4 and 6 and Table 7 also suggest what source categories make relatively minor contributions to estimated risks. In particular, both wastewater treatment plants and waste handling facilities (including both hazardous waste and municipal solid waste) each contribute only about 0.1% of the total air pollution-related number of cancer cases in the area.

Figures 4 and 6 and Table 7 suggest a variety of additional statements on the contribution of various air pollution source types to cancer incidence in the Southeast Chicago area. One proposition supported by these data is that while steelmaking is the most significant contributor to estimated lifetime risk, several other specific source categories also make significant contributions. These source categories include chrome platers, background pollutants, roadway vehicles, and home heating, each estimated to contribute between 10 to 20% of the total incidence. The remaining 5% of risks are divided among a wide range of additional source types.

Another finding is that while the most significant pollutant is coke oven emissions, several other pollutants also make significant contributions to air pollution-related cancer risks. This point is illustrated in Figure 8, showing a pie chart of the contributions of various pollutants to total estimated number of cases across the study area. (As with Figure 4, the percentage contributions to the lifetime (70 year) number of cases are the same as the contributions to annual cases.) This figure illustrates the fact that the combined contribution of the five most significant pollutants yields only 83% of the total estimated number of cancer cases. The contributions from the 10 most significant pollutants must be included to explain 98% of the cases.

A second means of examining cancer impacts of air pollution in Southeast Chicago is to evaluate individual risks. Figure 9 presents a map of the individual risks estimated in the Southeast Chicago area. This same information is presented in a different format in Figure 10. These figures include background pollutants, which are assumed to be uniform throughout the area, representing a risk of 5×10^{-5} in each grid square.

The highest estimated lifetime risk in the study area is about 5×10^{-3} (5 chances in 1,000), at the square centered near 114th Street and Torrence Avenue. However, this grid is indicated by Census Bureau data to have no residents. (If this grid in fact has any residents, these residents would be included in exposure estimates for a neighboring grid. Note that this study does not address exposure in nonresidential locations such as workplaces in this or other grids.) The grid with the greatest estimated number of cancer cases attributed to air pollution is a grid where individual risks are somewhat lower but where substantial population lives. Specifically, the grid square with the highest estimated number of cancer cases is centered on the UTM coordinates at 4616 N/455 E (ranging from about 107th Street to 112th Street and from about Burley Avenue to Avenue J). Risk in this grid square is estimated to be slightly less than 1×10^{-3} (1 in 1,000). The incidence at this site is estimated to be almost 4 cases (about 3.8) over 70 years. The estimated average risk across the entire study area is about 2.2×10^{-4} (about 2 chances in 10,000).

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Figure 8.

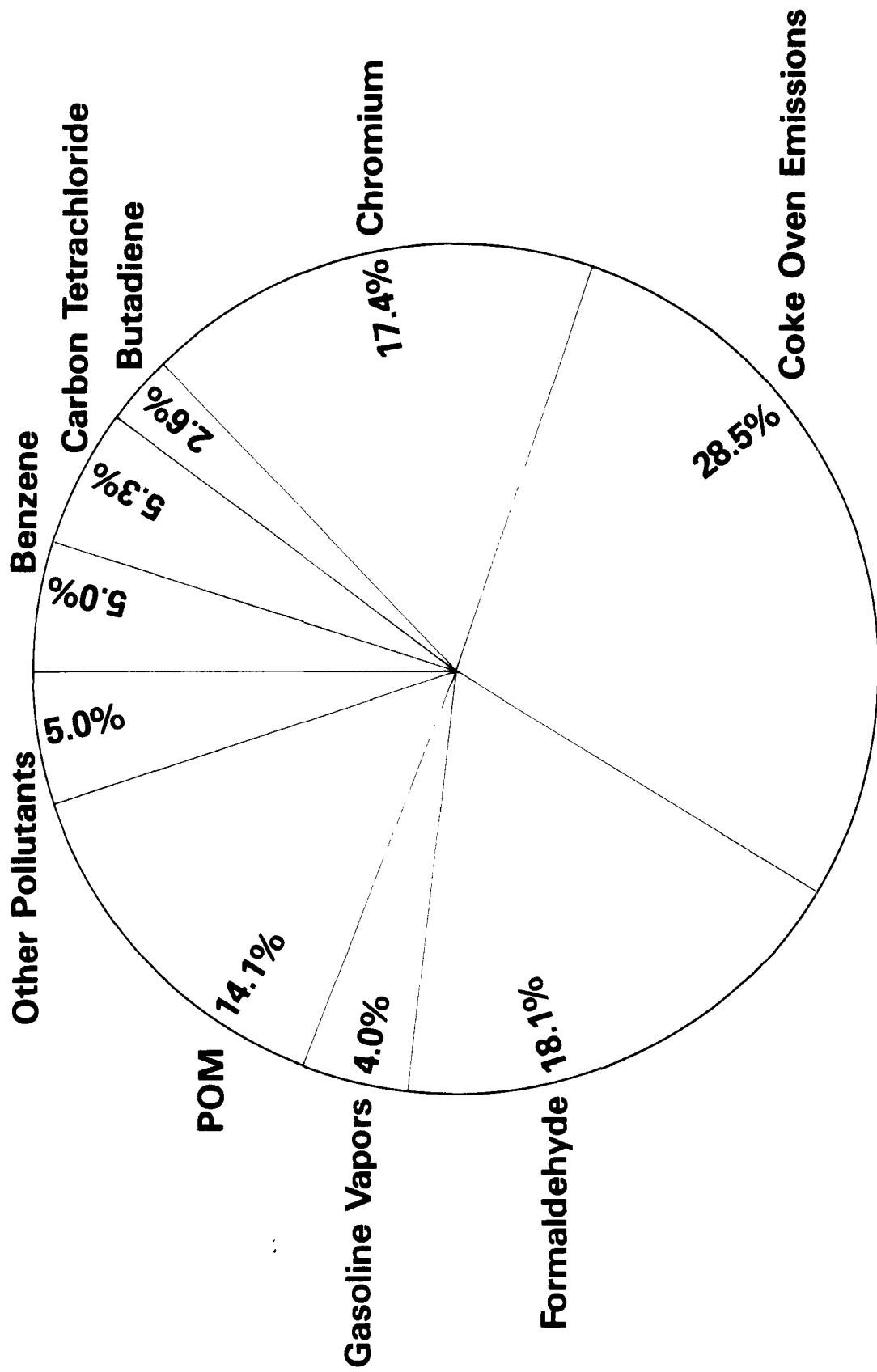
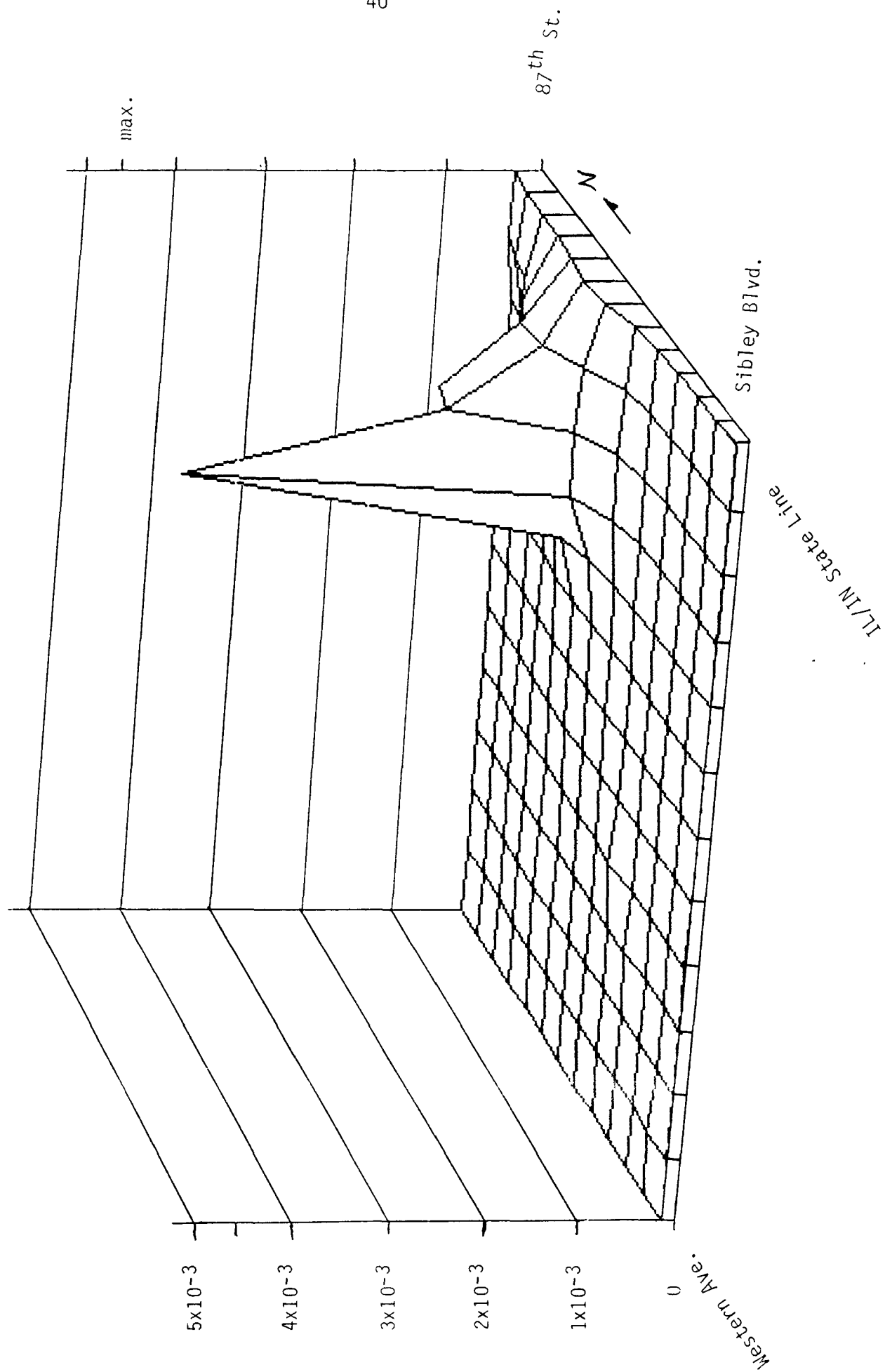
Contributions to Estimated Annual Cancer Cases by Pollutant

Figure 9. Map of Estimated Lifetime Cancer Risks from Air Pollutants
in Southeast Chicago Area (in probability units)



SOUTHEAST CHICAGO STUDY AREA

Estimated Lifetime Cancer Risks from Air Pollutants

Figure 10.

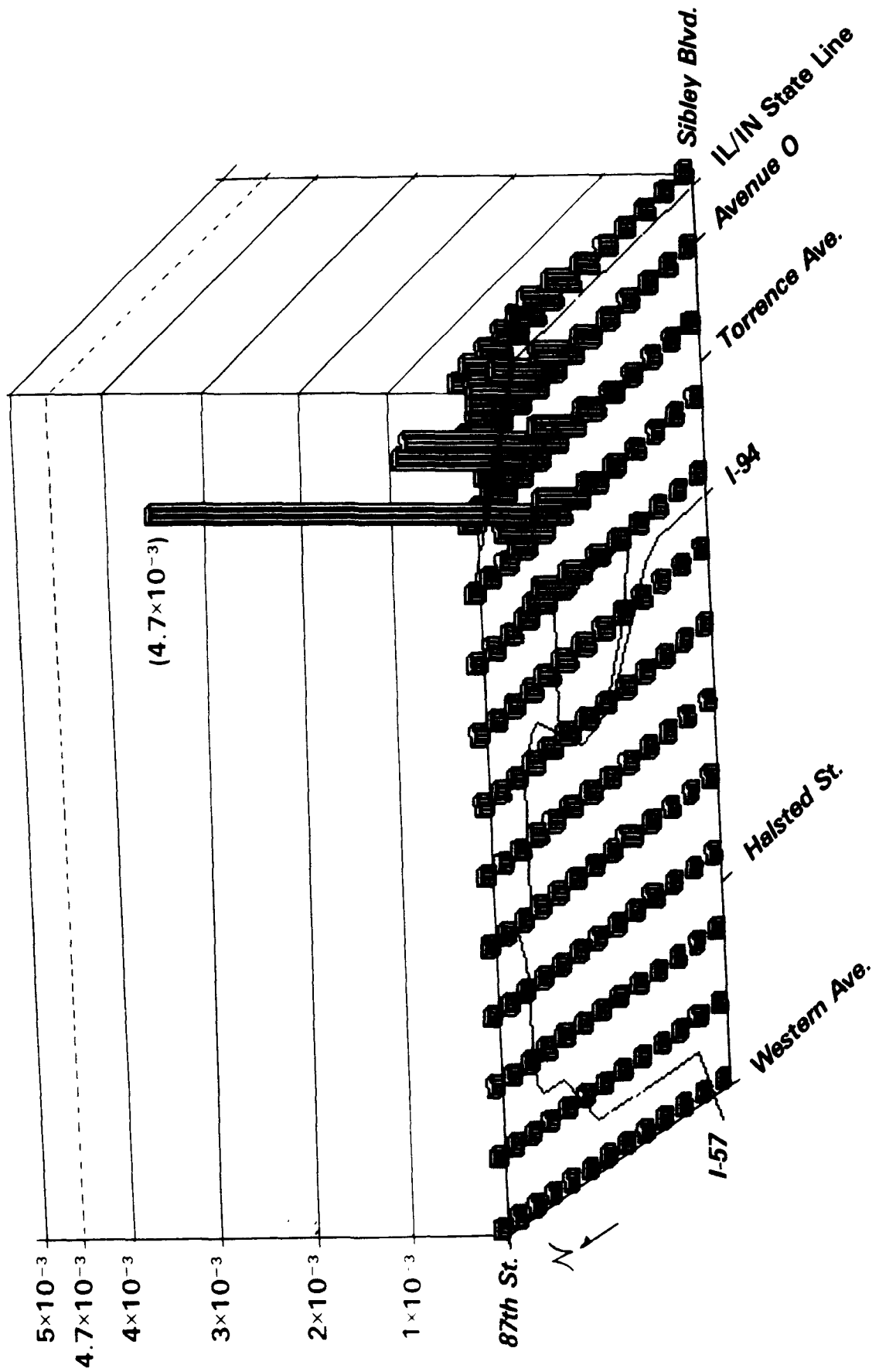


Table 8 summarizes the various contributions to risk at the grid with the highest incidence location, showing the components of the risks in terms of source type and pollutant. Clearly steel sources, particularly coke ovens, are the dominant source of estimated risk at this location. Figure 11 shows contribution to risk at the peak incidence locations in another format.

Figures 9 and 10 also suggest findings about the spatial distribution of risk in the Southeast Chicago area. Although the spatial resolution in this study is insufficient for a detailed examination of spatial variations, these figures do suggest that the highest risks are generally in the predominant downwind direction (northeast) of the steel mills near Lake Calumet, and that risks in the southern and western parts of the area are more uniform and relatively lower.

Figures 9 and 10 may also be compared with Figure 5. Figure 5 shows estimated cancer cases, which reflect population exposed as well as individual risks. Figure 5 shows the most cases in the northern and northeastern parts of the study area.

The risk estimates presented in this report should be regarded as only rough approximations, and should be considered in the context of the substantial uncertainties that are inherent in state-of-the-art of risk assessment techniques. The discussions of emissions estimates, dispersion analysis, and estimation of unit risk factors have each identified various uncertainties. A useful illustration of these unavoidable uncertainties is the improvements that have become available even during the last six months. In estimating emissions, recent information suggested that chrome plating facilities emit 25% more than previously thought, and information was recently discovered that permitted the estimation of asbestos emissions from two types of sources. In unit risk factors, recent revisions indicated a roughly 2-fold increase in the PCB unit risk factor, a 9-fold reduction in the methylene chloride unit risk factor, and deletion of melamine from consideration as a carcinogen. It is reasonable to presume that even the best estimates that can be developed today are prone to have errors of these general magnitudes.

A further indication of the degree of uncertainty in this study can be obtained by reviewing the comparison of modeled versus monitored concentrations. This comparison suggests that some pollutants (particularly the metals) seem to be reasonably accurately characterized, some pollutants are suggested to be underestimated two- to four-fold, and a few pollutants appear to be understated by as much as two or three orders of magnitude.

It should be noted that an assessment of the actual health effects attributable to air pollution in the study area could only be answered by an epidemiological study. Unfortunately, epidemiological studies often produce inconclusive results, due to the difficulties of obtaining the necessary detailed cancer statistics, of distinguishing effects of exposure to outdoor air versus the effects of other exposures (e.g., indoor air, occupational exposure, and air inhaled outside the study receptor area), and of distinguishing the effects of exposure to air pollutants from potentially much larger effects such as cigarette smoking. In any case, an epidemiological analysis was outside the scope of this study. Thus, it is only possible to make qualitative statements about the uncertainties inherent in the risk factors. In particular, risk factors based on human data will generally have less uncertainty than risk factors based on animal data.

Table 8. Estimated Contributions to Lifetime Cancer Risk at the Grid with the Highest Estimated Number of Cancer Cases

Compound*	Steel Mills	Other Industrial Sources	Consumer Sources	Mobile Sources	Waste Handling	Sewage Treatment Plants	Background Pollutants	Total
Acrylamide		m**						m
Acrylonitrile		m			m			m
Arsenic	2E-5	6E-7						2E-5
Asbestos			9E-8	2E-7				3E-7
Benzene	6E-5	3E-7	2E-7	4E-6	m	m		6E-5
Beryllium		m						m
Butadiene	m	m		4E-6	m			4E-6
Cadmium	1E-5	4E-8		2E-8				1E-5
Carbon Tet.		m			2E-7		1E-5	1E-5
Chloroform		m	4E-7		m	m		4E-7
Chromium	4E-7	4E-5	3E-6					5E-5
Coke Oven Em.	7E-4							7E-4
Dioxin		5E-7			3E-8			6E-7
Epichlorohydrin		m			m			m
Eth. Dibromide				9E-8				9E-8
Eth. Dichloride		1E-7			1E-8	m		2E-7
Eth. Oxide		5E-7	2E-7					7E-7
Formaldehyde	m	m	8E-7	2E-6			3E-5	4E-5
Gas. Vapors		m	2E-6	5E-6				7E-6
Hex-chl-benz.		m			9E-7	2E-7		1E-6
Methyl Chl.		m	3E-8			m		3E-8
Methylene Chl.		2E-7	3E-7		3E-8	m		5E-7
Perchloroeth.		2E-7	2E-7		m	m		4E-7
PCB's		m			m			m
POM		m	2E-5	7E-6				3E-5
Prop. Oxide		m						m
Styrene		m			m	m		m
Trichloroeth.		8E-7			1E-7	m		9E-7
Vinyl Chl.		m			6E-8			6E-8
Vinylidene Chl.					6E-8	m		6E-8
TOTAL	8E-4	5E-5	3E-5	2E-5	1E-6	2E-7	5E-5	9E-4 or 9x10 ⁻⁴

*Abbreviations:

Carbon Tet. - Carbon tetrachloride

Eth. - Ethylene

Gas. - Gasoline

Hex-chl-benz. - Hexachlorobenzene

Chl. - Chloride

PCB's - Polychlorinated biphenyls

POM - Polycyclic organic matter

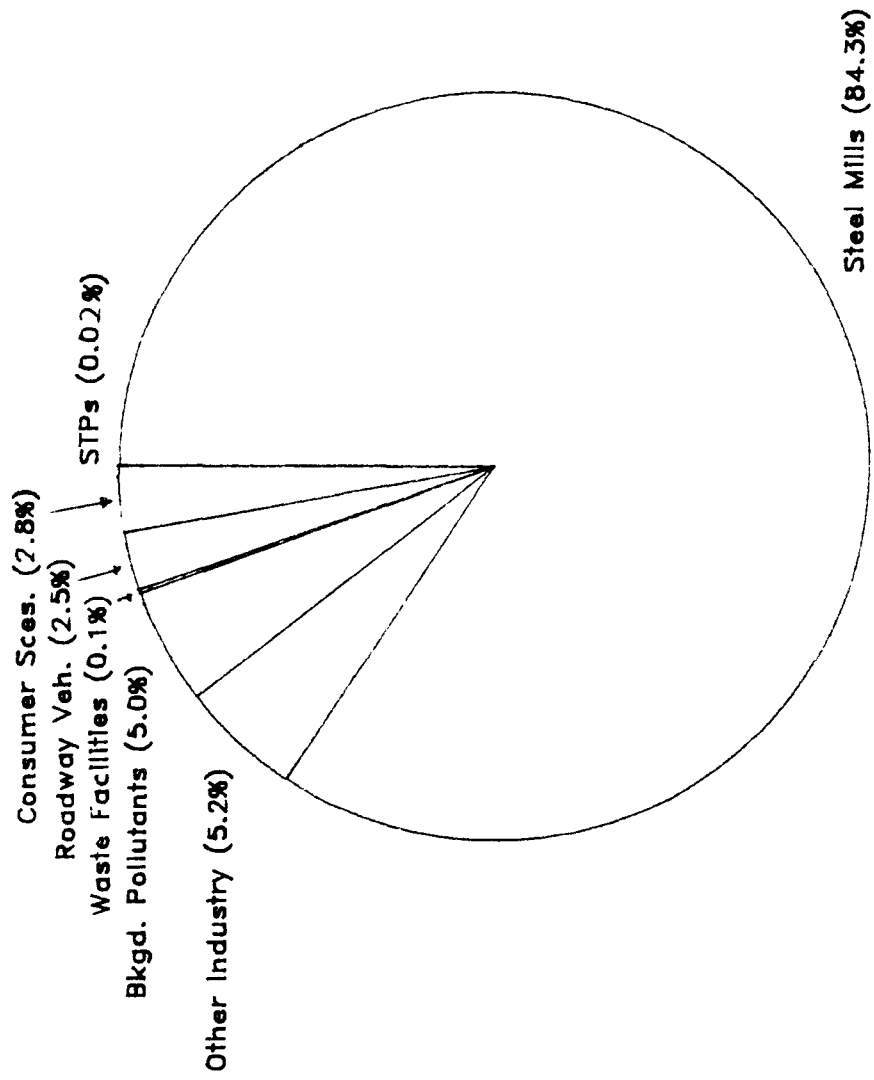
Prop. - Propylene

**To emphasize the higher contributions to risk, three formats are used:

m - minor - designates risks below 1×10^{-8} (0.00000001)exponential format used for risks above 1×10^{-8} : for example, $6E-5 = 6 \times 10^{-5} = .00006$

BECAUSE OF UNCERTAINTY IN PROCEDURES, METHODS, ASSUMPTIONS AND DATA, THESE RISK NUMBERS SHOULD BE REGARDED AS ONLY ROUGH APPROXIMATIONS AND ARE BEST USED IN A RELATIVE SENSE. ESTIMATES FOR INDIVIDUAL POLLUTANTS ARE HIGHLY UNCERTAIN AND SHOULD BE USED WITH PARTICULAR CAUTION.

Figure 11. Contributions to Estimated Risk at the Peak Incidence Location



A related issue is whether this study is likely to understate or overstate actual risks. The comparison of modeling and monitoring data suggests that this study may understate exposure for many pollutants. On the other hand, the risk factors are designed to be more likely too high than too low, particularly those risk factors designed as 95% upper confidence limits. Indeed, for some pollutants the risk may even be zero, since some of the 30 pollutants in this study may not actually be carcinogenic to humans at ambient air concentrations. However, the net effect of these causes of understatement and overstatement of risk is not clear.

An additional perspective on uncertainty is to review the relative significance of those groups of pollutants which are more or less uncertain. A measure of uncertainty of the health data, at least a measure of the uncertainty that specific pollutants are indeed carcinogenic, are the classifications of weight of evidence of carcinogenicity. Thus, one means of addressing the uncertainty with respect to health data is to sum the estimated number of cancer cases estimated for each group of pollutants (i.e. known human carcinogens, probable human carcinogens, and possible human carcinogens). A means of addressing the uncertainty in exposure estimates can be derived from the comparison of modeling versus monitoring concentration estimates. Using the results in Table 7, the 6 known human carcinogens contribute almost 53% of the estimated cases, the 22 probable human carcinogens contribute 47% of the estimated cases, and the 2 possible human carcinogens contribute less than 0.02% of the estimated cases. Thus, the pollutants with the least uncertainty (at least with respect to the fact of being carcinogenic) are the most significant, and the pollutants with the most uncertainty (at least with respect to being carcinogenic) appear to be relatively insignificant pollutants.

The modeling-monitoring comparison suggests that the pollutants which appear to be most underestimated also appear relatively insignificant. For example, even if concentrations of PCBs and chloroform were arbitrarily assumed to be 100 times higher, PCBs would still only contribute 0.04% of total air toxics-related cancer cases and chloroform would be increased to about 20% of these cases, producing only a modest increase in the total estimate of air toxics related cases per year. Combining this review with the review of carcinogenicity, it appears that while some pollutants and some source types may be significantly mischaracterized, the most significant pollutants and source types in this study also appear to have relatively more reliable risk estimates than the less significant pollutants and source types in this study.

Conclusions

The risk estimates presented in this report should be regarded as only rough approximations of total cancer cases and individual lifetime risks, and are best used in a relative sense. Estimates for individual pollutants are highly uncertain and should be used with particular caution. More detailed discussions of the uncertainties are included in the respective individual sections on Emission Estimation, Estimation of Concentrations by Atmospheric Dispersion Modeling, Evaluation of Cancer Risk Factors and Incidence and Risk Estimates.

This project found atmospheric emissions of 30 pollutants in the study area which USEPA considers carcinogenic. Some of these pollutants have been shown to be carcinogenic based on human exposure data, and others have been implicated by animal studies.

This study suggests that about 85 cases of cancer over 70 years or about 1 cancer case per year in this study area may be attributable to air pollution. Further, a peak lifetime risk of about 5×10^{-3} (or about 5 chances in 1,000) is estimated in the study area. However, Census Bureau information does not indicate any residents in this area. The square kilometer with the highest estimated number of cancer cases has an estimated lifetime risk of slightly less than 1×10^{-3} (1 in 1,000). There is some geographic variability in the risks across the study area. In general, risks are greatest in the northeast part of the area and are relatively lower in the southern and western part of the area. An average lifetime risk across the area is about 2.2×10^{-4} (about 2 in 10,000).

In evaluating the sources of airborne risk in this area, steel mills contribute to about 29 cancer cases over a 70 year lifetime (almost 34% of the total). Emissions from other industrial facilities, primarily chrome platers, are estimated to cause approximately 14 cancer cases over a 70 year lifetime (approximately 16% of the total), and consumer-oriented area sources (e.g., home heating and gasoline marketing) contribute approximately 12 cancer cases over 70 years (about 14% of the total). Roadway vehicles are also estimated to cause about 12 cases over 70 years (about 14% of the total). Furthermore, the background pollutant impacts from formaldehyde and carbon tetrachloride, which contribute an estimated 18 cases of cancer over 70 years (almost the entire remaining 22% of the total incidence) may also be attributed principally to industrial facilities, consumer-oriented sources, and roadway vehicle emissions. In total, these source categories contribute about 99.8% of the risk.

Correspondingly, there are some source categories which appear to contribute relatively little to airborne risk in this area. This study suggests that the sum of air toxic based risks attributable to the handling of both hazardous and municipal wastes equals about 0.1% of the total air pollution related cancer risk in the area, or about 0.07 cases over 70 years (1 case in 1,000 years). Thus, these sources are estimated to pose considerably less air toxic risks than other source types evaluated in this study.

Another relatively minor source type is air emissions from wastewater treatment plants, which were estimated to lead to about 0.14 cancer cases over 70 years (about 2 cases in 1,000 years), or about 0.1% of the total area's air pollution-related incidence. These risks are somewhat greater than those from handling hazardous and municipal wastes, but are still much smaller than several other source types evaluated in this study.

It is useful to apportion the estimated total number of cancer cases according to the weight of evidence that the pollutants are carcinogenic. According to USEPA's review of the weight of evidence of carcinogenicity, the 30 pollutants for which risks were estimated in this study include 6 "known human carcinogens", 22 "probable human carcinogens, and 2 "possible human carcinogens". Of the estimated 85 cancer cases per 70 years, almost 53% are attributable to "known human carcinogens," about 47% are attributable to "probable human carcinogens," and about 0.02% are attributable to "possible human carcinogens."

To put the air toxics risk in perspective, it would be desirable to discuss cancer risks due to other forms of environmental pollution. However, this

study focused on air pollution risks and did not evaluate risks from other forms of exposure to environmental contamination. Other exposure routes include exposure through drinking water, skin contact, eating fish or swimming in lakes (e.g., Wolf Lake) which may contain contaminants, and exposure to indoor air contaminants including radon. Also complicating any review of the relative significance of air pollution is the potential for other air pollutants which cannot currently be quantitatively evaluated but nevertheless cause significant risks. Air pollution appears to be an important cause of environmental pollution-related cancer cases in this area, but a comparison of airborne risks to risks from other environmental exposures is outside the scope of this study.

Although specific estimates of individual risks and area-wide cancer cases have been given in this report, the uncertainties underlying these estimates dictate that these estimates be used cautiously. The specific types of uncertainty inherent in these estimates have been described in various sections of the report, and include various uncertainties in estimating emissions, uncertainty in quantifying atmospheric dispersion, and various uncertainties in developing unit risk factors from available human or animal data. Also, evidence in this study suggests that concentrations may generally be understated, whereas unit risk factors are designed to be more likely to overstate than to understate risks. Thus, this study may either overstate or understate risks, and in either case may provide estimates which differ substantially from true risks. This study was designed as a screening study of a broad range of source types and air pollutants, rather than as a more intensive study of any single source type or pollutant. As such, more reliable results could be obtained by further investigation of several elements of the study. Given the evolving nature of knowledge for the pollutants in this study, a new review of the literature would likely suggest several modifications in the emissions estimates used in the study.

The evolutionary nature of these types of study is illustrated by the numerous improvements that became available during the course of this study. In particular, the emissions inventory update documents several source categories for which improvements became available between mid-1987 and the end of 1988. Similar improvements were developed during the same period for several unit risk factors. It is likely that similar improvements for various source categories and pollutants will be discovered in the future.

Several additional studies are underway which should also help improve the reliability of the study. Two studies are underway to evaluate the significance of home wood combustion in the Southeast Chicago area. One study is analyzing atmospheric monitoring data for characteristic pollutants emitted by wood combustion to discern the relative contribution of home wood combustion. A second study is a telephone survey polling Southeast Chicago area residents on their actual wood usage. Another study is underway to evaluate emissions from abandoned hazardous waste sites. A fourth study, being conducted in Cincinnati, Ohio, is evaluating the extent to which volatilization of contaminants in wastewater occurs in sewers, i.e., prior to arrival at wastewater treatment plants.

Another relevant study is being performed by the Illinois Cancer Council as mandated by the Illinois General Assembly. This study is an epidemiological investigation of leukemias and lymphomas.

Other studies could also be conducted to improve the reliability of the risk estimates in this study. Further studies of unit risk factors, while expensive, could substantially improve risk estimates. Forthcoming summertime monitoring data for formaldehyde could be incorporated. Monitoring focusing on carbon tetrachloride could be conducted. Further investigation to resolve discrepancies between monitored and modeled concentrations could be conducted.

In addressing the risks identified in this study, the USEPA is subject to some important limitations in the legal authority provided in the Clean Air Act and other legislation for air toxics regulations. The development of regulations under these statutes requires intensive investigations. Also, USEPA's policy is to address source categories which are significant from a national perspective, not to address individual sources which are significant in a given local area. Thus, State and local air pollution agencies in the area have an important role in identifying and adopting regulations to address the risks estimated in this study. At the same time, the State and local air pollution agencies are also subject to limitations in statutory authority for addressing these issues.

Despite its limitations on authority, USEPA is developing regulations at a national level for numerous categories. For coke ovens, USEPA has proposed regulations to require more control of leaks from doors, lids, oftakes, and from charging. For coke oven by-product recovery plants, USEPA has proposed regulations to require numerous measures to reduce benzene emissions. For chrome platers, the Agency is nearing completion of a background information document which is necessary to provide technical support for regulating these sources. For gasoline vapor emissions from automobile refueling, the Agency has proposed two alternatives (controlling these vapors either with equipment built into automobiles or with equipment installed at gasoline stations) and is working to resolve technical concerns about these alternatives. For facilities that treat, store, and dispose of hazardous waste, an assortment of regulations are being developed for proposal. For chromium emissions from comfort cooling towers, the Agency has proposed banning the use of chromium in these units and, thereby, eliminating these emissions.

An important relevant type of State activity is the adoption of regulations designed to reduce emissions of volatile organic pollutants and particulate matter and thus reduce air toxics emissions. One example of such a regulation is the regulation for the coke by-product recovery plants adopted by Indiana, which was designed to reduce volatile organic compound emissions for ozone control, but which will significantly reduce benzene emissions. A second example is motor vehicle inspection and maintenance programs adopted by both Illinois and Indiana, which again was designed to reduce volatile organic compound emissions in general, but which will also simultaneously reduce emissions of several individual organic species. Reductions in organic emissions also have the effect of reducing the risks from formaldehyde which is photochemically created in the atmosphere. Note that for both of these examples, the required emission reductions have not been reflected in the emissions and risks estimated in this study because these programs had not been effectively started up in the year selected for this study. A third example is enforcement of existing regulations controlling volatile organic compound and particulate matter emissions. Illustrative of this activity are enforcement negotiations

which are leading to improved control of one of the coke batteries in the area. Further reductions in emissions of volatile organic compounds and particulate matter are mandated both for Southeast Chicago and for Northwest Indiana, which can be expected to further reduce emissions and risks from the pollutants in this study.

Other State programs more directly address air toxics issues. Illinois currently considers air toxics in reviewing companies' air pollution permit applications, and both Illinois and Indiana are in the process of developing more formalized air toxics programs. USEPA believes this report documents sufficient risk to warrant investigation of possible means for its reduction. It is hoped that this study will lead to informed discussions on how to design USEPA's and the States' control programs to achieve effective reductions to cancer risks in the Southeast Chicago area.

References

Emissions Estimation

Many references were used in developing emissions estimates. The inventory is described in the following two reports, which provide detailed data on references:

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Guideline on Air Quality Models (Revised), EPA-450/2-78-027R, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, 1986.

Industrial Source Complex (ISC) Dispersion Model User's Guide - Second Edition (Revised), EPA-450/4-88-002, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, December 1987.

J. Irwin, T. Chico, J. Catalano, CDM 2.0 - Climatological Dispersion Model User's Guide, EPA-600/8-85-029, Atmospheric Sciences Research Laboratory, U.S. Environmental Protection Agency, 1985.

Monitoring

Urban Air Toxics Program (UATP), First Quarterly Report, Fourth Quarter 1987, Radian Corp., April 1988.

Urban Air Toxics Program (UATP) Second Quarterly Report, First Quarter 1988, Radian Corp., July 1988.

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P. Aronian, P. Scheff, R. Wadden, "Winter Time Source-Reconciliation of Ambient Organics," Illinois Institute of Technology/University of Illinois at Chicago, Paper presented at Annual Meeting of Air Pollution Control Association, June 1988.

C. Sweet, D. Gatz, Atmosphere Research and Monitoring Study of Hazardous Substances: Third Annual Report, Hazardous Waste Research and Information Center, Illinois Department of Energy and Natural Resources, November 1987.

An Interim Report on the Results of PCB Sampling in the Lake Calumet Area of Southeast Chicago, Division of Air Pollution Control, Illinois Environmental Protection Agency, May 1987.

Unit Risk Factor Data

Each pollutant in this study has a body of literature that was considered in the development of the unit risk factor. However, Region V, in conducting this study, did not itself develop any unit risk factor and did not conduct any associated literature review. Readers interested in the literature relevant to unit risk factors for particular pollutants are advised to consult the office identified in Table 6 as the source of the factor.

General References

E. Haemisegger, A. Jones, B. Steigerwald, V. Thomson, The Air Toxics Problem in the United States: An Analysis of Cancer Risks for Selected Pollutants, Office of Air and Radiation/Office of Policy, Planning and Evaluation, U.S. Environmental Protection Agency, May 1985.

The Risk Assessments Guidelines of 1986, U.S. Environmental Protection Agency, originally published in 51 Federal Register 33992-34052, September 24, 1986, and reprinted as EPA Report #600/8-87-045 in August 1987.