USEPA's National Air Toxics Assessment:

Emissions and Cancer Risk Analysis in Cook County, IL

BY

FRANK PAGONE
BS, Purdue University, 2009

THESIS

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Defense Committee:

Serap Erdal, Chair and Advisor
Seijeoung Kim, Public Health
Motria Caudill, Environmental Protection Agency

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LIST OF ABBREVIATIONS

ADAF	Age-dependent Adjustment Factors
ADAF CSF_i	Age-dependent Adjusted Cancer Slope Factor via Inhalation
AE	Average Exposure
AMD	Air Monitoring Data
ASPEN	Assessment System for Population Exposure Nationwide
BETX	Benzene, Ethyl Benzene, Toluene, Xylene
BW	Body Weight
CAA	Clean Air Act
CMAQ	Community Multiscale Air Quality
CSF	Cancer Slope Factor
DEARS	Detroit Exposure and Aerosol Research Study
EC	Exposure Concentration
ECR	Excess Cancer Risk
EPA	Environmental Protection Agency
GIS	Geographical Information System
HAP	Hazardous Air Pollutants
HAPEM	Hazardous Air Pollutant Exposure Model
HEM	Human Exposure Model
IARC	International Agency for Research on Cancer
IEPA	Illinois Environmental Protection Agency
IR	Inhalation Rate
$L(ADD_i)$	Lifetime Average Daily Dose via Inhalation
NATA	National Air-Toxics Assessment
NEI	National Emissions Inventory

LIST OF ABBREVIATIONS (continued)

PPB-C	Parts per Billion—Carbon
PPB-V	Parts per Billion—Volume
RME	Reasonable Maximum Exposure
UCLM	Upper Confidence Limit of the Mean
URE	Unit Risk Estimate

SUMMARY

An evaluation of the Environmental Protection Agency's (EPA's) National-Scale Air-Toxics Assessment (NATA) was performed in order to determine geographical areas, pollutants, and emissions sources that can be targeted for further reduction, and compare cancer risks for benzene and formaldehyde based on measured data at three fixed-site air monitoring stations in 2005 to those based on modeled EPA's 2005 NATA estimates using both the traditional NATA approach and the EPA Superfund guidance approach.

Illinois county-level emissions results in 2005 showed that Cook County had the highest emissions estimates of any other county in Illinois, contributing to 25% of the total emissions. The source category contributions indicated that point-source emissions dominated the total emissions in rural counties, while roadway emissions dominated urban environments. In Cook County, the chemicals that contributed the most to overall emissions included toluene (22%), methanol (10%), m-xylene (7%), 2,2,4-trimethylpentane (6%), and benzene (6%).

The top contributors to overall cancer risk in Cook County based on the 2005 NATA results were formaldehyde (39%) and benzene (12%). Percentile analysis indicated that the majority of 90th percentile cancer risks from these two chemicals followed the roadways and surrounded the airport.

The benzene results based on all three risk calculation techniques were similar, with the NATA underestimating the risk in the Schiller Park location and overestimating the risk in the Chicago location. The formaldehyde monitoring data risk results in Schiller Park were substantially higher than the NATA modeled risks. The results concluded that although EPA's NATA was very beneficial for performing air quality as well as excess cancer risk (ECR) analysis spatially for certain chemicals, they should only be used to evaluate relative risks across different geographic areas.

I. INTRODUCTION

A. National Air Toxics Assessment

The EPA's 2005 NATA is a comprehensive evaluation of 177 of 187 Clean Air Act (CAA) toxics that includes estimates of air pollution emissions data from different sources, ambient exposure concentrations, human exposures, and inhalation cancer risks (USEPA, 2013).

The first national air-toxics study was the Cumulative Exposure Project (CEP), which was developed based on air-emissions estimates made before the 1990 CAA. The first NATA used a refined inventory of air emissions developed in 1996 called the National Toxics Inventory. This assessment was submitted for peer review in 2001 to a panel of EPA scientists; they provided detailed comments on the overall approach including data, models, and methods. The final results were published in 2002. Since then, there have been three assessments completed based on air toxic emissions: 1999, 2002, and 2005, with the scope progressively expanding with subsequent versions (ICF International, 2011).

The focus of this study, the 2005 NATA assessment, was performed in four steps: compilation of national air-toxics emissions inventory of outdoor stationary and mobile sources from the National Emissions Inventory (NEI); estimation of ambient concentrations of air toxics based on air dispersion and photochemical models; estimation of population exposures based on inhalation exposure models; and characterization of potential cancer and non-cancer public health risks due to inhaling air toxics (ICF International, 2011).

1. National Emissions Inventory

The National Air Toxics Assessment was designed to model the outdoor emissions of all 177 Hazardous Area Pollutants (HAPs) required by the 1990 CAA and diesel particulate matter from all anthropogenic sources that are evaluated as part of the NEI. The EPA compiles the NEI using a variety of data sources, including state and local air-toxics inventories; existing databases related to EPA air-toxics regulatory programs; the EPA Toxic Release Inventory; mobile-source estimates; activity, fuel, and vehicle estimates from local, state, and federal agencies; and emissions estimates from emission factors and activity data. Emissions sources included in the 2005 NATA are categorized into one of six source categories, including major point sources, area point sources, area nonpoint sources, on-road mobile sources, non-road mobile sources, background, and secondary formation (ICF International, 2011). Each of these categories is further summarized in Table I.

TABLE I

EMISSIONS SOURCE TYPES MODELED FOR NATA

Emissions Source Type	Definitions, Examples, and Spatial Resolution
Major Point	Stationary sources that emit either at least 10 tons per year of a HAP or at least 25 tons per year of any combination of HAPs for which the locations are known, such as large was incinerators or factories.
Area Point	Stationary point sources for which the locations are known, but emit at levels below the major point-source emissions threshold.
Area Non-Point	Stationary sources that are not incorporated into the point-source component of NEI, typically because their locations are not known. This includes prescribed burns, dry cleaners, and small manufacturers.
On-Road	Vehicles found on roads and highways, such as cars, trucks, and buses.
Non-Road	Mobile sources not found on roads and highways. This includes airport ground support equipment, trains, lawn mowers, construction vehicles, and farm machinery.
Background	The contributions to outdoor air-toxics concentrations resulting from natural sources in the environment and long-range transport from distant sources. These are not part of the NEI.
Secondary formation and decay	Secondary formation and decay of air toxics from the reaction in the environment of emitted primary air toxics. These are also not part of the NEI.

2. **Concentration estimates**

In order to estimate ambient concentrations, the emissions estimates are entered into air-quality models based on the source type. An air-quality model is a set of equations that uses emissions, meteorological, and other information to simulate behavior and movement of air toxics in the atmosphere. The three models used in NATA for this purpose include the Human Exposure Model-3 (HEM-3) American Meteorological

Society/Environmental Protection Agency version, the Assessment System for Population Exposure Nationwide (ASPEN), and the Community Multiscale Air Quality (CMAQ) model (ICF International, 2011).

TABLE II

MODELS USED TO ESTIMATE AMBIENT CONCENTRATIONS FOR THE 2005 NATA

Emissions Source Type	Model	Spatial Resolution of Modeled Ambient Concentrations
Point[a]	HEM-3	Census Block
Area Non-Point	ASPEN	Census Tract
On-Road Mobile	HEM-3	Census Block
Non-Road Mobile	HEM-3	Census Block
Secondary Formation and Decay	CMAQ	Census Tract
Background	Not Modeled	County

[a] Includes both major and area point sources

Background concentrations utilized in NATA represent contributions from three sources: natural sources, emissions of persistent air toxics that occurred in previous years that are still present, and long-range transport from distant sources. Three different methods were used to estimate background concentrations for the 2002 and 2005 NATAs at the census-tract level; these were the ambient method, the emissions method, and the uniform method. The ambient method uses available monitoring data, the emissions method uses NEI emissions data, and the uniform method assumes a uniform nationwide concentration for the air toxic under study. The background estimates from the 2002 NATA were used for the 2005 NATA. For the 2005 NATA, the

exceptions were for background sources of acetaldehyde and formaldehyde, which were modeled within the CMAQ model as secondary formation in the atmosphere (ICF International, 2011). The method selected for each chemical was varied in accordance with specific criteria employed, as shown in Table III.

TABLE III

BACKGROUND AIR TOXICS AND ESTIMATION METHODS

Ambient Method [a]	Emissions Method [b]	Uniform Method [c]
1,3-Butadiene	1,1,2,2-Tetrachloroethane	Carbon Tetrachloride
1,4-Dichlorobenzene	1,2-Dibromo-3-chloropropane	Methyl bromide
Arsenic	Acrylonitrile	Methyl chloride
Benzene	Benzidine	Methyl chloroform
Chloroform	Beryllium	
Chromium	Cis(2-ethylhexyl)phthalate	
Dichloromethane	Cadmium	
Lead	Chromium (VI)	
Manganese	Ethylene dibromide	
Nickel	Ethylene oxide	
Tetracholorethylene	Ethylene oxide	
Toluene	Hydrazine	
	Naphthalene	
	Propylene dichloride	
	Quinoline	
	Trichloroethylene	

[a] The ambient method was applied to those pollutants that had at least 100 ambient measurement locations throughout the United States for adequate spatial representation and at least 85% of the ambient measurements had to be above the method detection limit (MDL).
[b] The emissions method was used if the pollutant did not meet the criteria of the ambient method.
[c] The uniform method was used for air toxics that had long lifetimes, well-characterized concentrations, and are routinely measured at remote sites.

3. **Exposure estimates**

For the 2005 NATA, the EPA used the exposure ratio approach to estimate inhalation exposure concentrations. This approach relies on exposure ratios calculated from the results of the 1999 Hazardous Air Pollutant Exposure Model (HAPEM). These exposure ratios were calculated by dividing modeled HAPEM5 exposure concentrations by modeled ASPEN ambient concentrations (ICF International, 2011). This is further explained in equation 1.

The exposure estimates for the 2005 NATA were obtained by multiplying modeled census-tract level ambient concentrations by exposure ratios that were calculated in the 1999 HAPEM for each combination of tract, air toxic, and source type (ICF International, 2011).

Exposure Level Concentrations For each Source Category = *2005 NATA Ambient Level Concentrations* x *1999 HAPEM5 Modeling Ratio* (1)

4. **Risk characterization**

The inhalation ECR estimates for the 2005 NATA were calculated by converting the results of the cancer dose-response assessment for a given chemical to a unit risk estimate (URE) and multiplying the URE by the estimated inhalation exposure concentration (EC) for that chemical. This approach is consistent with the EPA's 2005 final guidelines for carcinogenic risk assessment.

$$Risk\ (unitless) = EC\ \left(\frac{\mu g}{m^3}\right)\ x\ URE\ \left(\frac{\mu g}{m^3}\right)^{-1} \quad (2)$$

where risk is the estimated incremental lifetime cancer risk for an individual as a result of lifetime exposure to a specific air toxic, EC is the estimate of long-term inhalation exposure concentration for a specific air toxic, and URE is the inhalation unit risk estimate for that air toxic. The individual lifetime cancer risk resulting from multiple

exposures is estimated by linearly summing the chronic cancer risk for each air toxic (ICF International, 2011).

a. **Variability**

The key components driving variability in risk associated with air toxics in the 2005 NATA results include temporal variation, geographical variation, and variations in where people live, their levels of activity, and degree of susceptibility or sensitivity (ICF International, 2011).

b. **Uncertainty**

The uncertainties in the 2005 NATA arise based on the three steps involved in producing the final risk estimates: ambient concentrations, exposure estimates, and risk estimates. More specifically, the uncertainty can be attributed to emissions characterization (e.g., emissions rates, release characteristics); meteorological characterization; exposure model formulation and methodology; air-monitoring data (AMD) uncertainty related to sampling and laboratory analysis; and uncertainty in background concentrations (ICF International, 2011). In addition, there are uncertainties in the derivation of URE (i.e., cancer dose-response assessment) and estimation of cumulative cancer risk based on linear summation without taking potential synergistic or antagonistic effects among air toxics found in urban air.

B. Purpose of the Study

The general purpose of this study is to determine sources and chemicals that contribute the most to ambient air pollution and cancer risk in Cook County, Illinois by mining the 2005 NATA data for the purpose of steering air pollution control, exposure/risk control, and public health policy development.

The specific goals are (1) to characterize emissions estimates and cancer risks developed by the 2005 NATA in the State of Illinois and Cook County; (2) to determine

geographical areas, pollutants, and emissions sources that can be targeted for further reduction; (3) compare cancer risks for benzene and formaldehyde based on measured data at fixed-site air monitoring stations to those based on modeled EPA's 2005 NATA estimates using both the traditional NATA approach and the EPA Superfund guidance approach; and (4) to guide air pollution control and public health policy in order to reduce the health risk burden on subpopulations in specific geographic locations.

II. BACKGROUND

A. National Air Toxics Assessment—Emissions and Exposures

The NATA-modeled emissions estimates and health-risk results have been utilized for a variety of environmental analysis in the literature since the first NATA was produced in 1996. The EPA states that the NATA results are best used to focus on geographical patterns and ranges of risks. More specifically, it can be used to prioritize pollutants and emissions sources, identify locations of interest for further investigation, provide a starting point for local assessments, focus community efforts, or inform monitoring programs (USEPA, 2013b).

Historically, the 1999 and 2002 NATA and NEI emissions estimates have been used in research studies to allocate on-road emissions to road segments for air-toxic modeling (Kinnee et al., 2004), assess mercury emissions inventories for the Great Lakes states (Murry and Holmes, 2004), determine the intake fraction of nonreactive vehicle emissions in United States urban areas (Marshall, Teoh, and Nazaroff, 2004), assess urban land use and hazardous exposures at the neighborhood scale (Corburn, 2007), evaluate United States on-road vehicle emissions inventories (Parrish, 2006), project hazardous air pollutant emissions to future years (Strum et al., 2006), and assess biologically based modeling of multimedia, multi-pathway, multi-route population exposure to arsenic (Georgopoulos et al., 2008).

A retrospective benzene case study performed in Detroit, Michigan, when comparing the 2002 NATA modeled-predicted estimates for ambient concentrations and human inhalation exposures to monitor measurements from the 2004–2007 Detroit Exposure and Aerosol Research Study (DEARS), found that the average ambient concentration of benzene predicted by NATA were within 5% of the 24-hour integrated average ambient concentrations measured in DEARS (George et al., 2011).

The NATA human exposure estimates, which included only outdoor sources for benzene, were, on average, half the measured breathing zone concentrations from DEARS. Also, in comparing the 2002 NATA to the 2005 NATA, they found that the emissions estimates for the Wayne County, Michigan area showed that the 2005 benzene emissions are about 20% lower than those included in the 2002 NATA analysis (George et al., 2011).

Negatively, a countrywide analysis of brain cancer rates and ambient exposures to criteria air pollutants and hazardous air pollutants, based on the 2002 NATA results, found that the Pearson correlation coefficients with the 30 selected HAPs to be small and results did not support the hypothesis that concentrations of airborne chemical pollutants are an important explanatory factory of the county-by-county variations in brain cancer statistics across the United States (Valberg and Long, 2012).

B. National Air Toxics Assessment—Health Risk Estimates

There are also numerous studies focused on determining if the risk estimates produced by NATA are indeed valid. A study comparing the 2002 NATA predictions and measured air toxic concentrations, risks, and sources in Pittsburgh, Pennsylvania found both similarities and differences between measured and modeled estimates. The assessment's performance on concentration varied widely, ranging from excellent for carbon tetrachloride to differences of more than a factor of 100 for low-concentration chlorinated compounds. Predicted concentrations were generally within a factor of 2 of measured values for air toxics that were estimated as primary cancer risk drivers; therefore the authors concluded that the NATA provided reasonable estimates of the additive cancer risks and risk ranking (Logue, Small, and Robinson, 2011). Likewise, a study comparing three modeling systems, two Minnesota Risk Screening Models and NATA, and ambient outdoor AMD found that high air concentrations and risks were

generally located in the urban core and the lowest in the undeveloped rural area, and emissions from mobile and area (nonpoint) sources accounted for the greater estimated risk than point sources. The modeled-estimated air concentrations were generally highest for NATA. They concluded that there was reasonable agreement between available measurements and model predications, although results varied among pollutants. For formaldehyde, the median inhalation cancer risk estimates calculated using the Minnesota Pollution Control Agency's risk screening tool using the industrial source complex, the Minnesota risk screening tool using the American Meteorological Society/EPA air dispersion model, and the monitored risks were all higher than the NATA estimates. The benzene median inhalation cancer risk results were very similar across all risk calculation methods, with the median NATA risk being the greatest (Pratt, Dymond, and Elickson, 2012).

Weinhold, in a commentary on the EPA's NATA, specified that, in comparison with the notionally acceptable risk of cancer of one in one million, the average risk across the United States is 50 times greater, and for about 5% of the population is more than 100 times greater than this value (Weinhold, 2011). The author emphasizes the need for analysis of these cancer risks, and the importance of more research in certain locations.

III. METHODS

A. National Air Toxics Assessment—Data Organization and Management

The NATA data for the State of Illinois and Cook County was downloaded from the EPA website at the county and census-tract level in order to determine the locations with the highest emissions estimates and inhalation cancer risk (USEPA, 2011a).

B. National Air Toxics Assessment—Air-Quality Data Analysis Tools

The emissions estimates were compiled for each county in Illinois based on the total emissions and each individual source category: major point, area point, area nonpoint, on-road, and non-road. The counties that contributed greater than 2% to the overall emissions in Illinois were displayed graphically and the source-category specific emissions estimates for each county were documented to determine the source categories contributing the most to overall emissions.

Chemical-specific emissions and inhalation cancer risk estimates for Cook County, the highest emitting county in Illinois and the county with the highest population density, were sorted based on location (i.e., census tract) and chemical. The chemicals that contributed greater than 2% to the overall emissions estimates were identified. In addition, the specific census tracts with higher cancer risks were determined.

C. Spatial Data Analysis Tools

Using Arc Geographical Information Systems (GIS) Software, the Cook County census-tract level cumulative excess inhalation cancer risks were displayed geographically in order to determine the areas with elevated risk and those census tracts that have a cancer risk greater than $1x10^{-4}$, the upper bound for acceptable cancer risk in accordance with the EPA (Clay, 1991). Furthermore, the census tracts were

differentiated based on cumulative inhalation cancer risk estimates in the following three different categories in creating GIS maps: census tracts with a cancer risk ≥ $1x10^{-4}$; census tracts with 44% of the maximum cancer risk; and census tracts with 73% of the maximum risk.

A similar GIS analysis was performed for mapping the excess inhalation cancer risks for benzene and formaldehyde, the chemicals that contributed the highest amount to the excess inhalation cancer risk in Cook County (i.e., accounted for 52% of the cumulative cancer risk). Benzene and formaldehyde cancer risks were also displayed geographically at the census-tract level using a number of demarcation points to show the geographic variability in risk and to delineate the sub-geographic areas with higher burden of cancer risk (e.g., below the median, above the median, above the 75th percentile, above the 90th percentile).

D. **Risk Assessment Methodology for Cancer**

The 2005 benzene and formaldehyde monitoring data for Cook County were collected by Illinois EPA and provided by Dr. Motria Caudill at EPA Region 5 Air and Radiation Division. The data were collected at three monitoring stations within Cook County, Illinois: Chicago, Schiller Park, and Northbrook, as shown in Figure 1.

Figure 1. Location of Cook County monitoring stations.

Location of EPA monitoring stations within Cook County and the number of samples of each chemical taken at that location in 2005.

The 2005 measured data collected at these three fixed-site locations were analyzed and compared against the 2005 NATA modeling estimates. The EPA's statistical software, ProUCL Version 4.1 (USEPA, 2011c) was used to analyze the 2005

AMD for benzene and formaldehyde in order to generate the raw statistics, to evaluate the probability distribution, to determine the 95% upper confidence limit for the mean (UCL), and to create a histogram for each chemical measured at each monitoring station. In the original dataset, the majority of the concentrations were in parts per billion—volume (ppb-v). However, all of the benzene measurements at the Chicago location and 99 measurements in the Northbrook location were in parts per billion—Carbon (ppbC). Those values were converted to ppb-v by dividing by six, which is the number of carbon atoms. All benzene and formaldehyde concentrations were converted to mg/m^3 prior to embarking on the inhalation cancer risk estimation.

TABLE IV

EPA MONITORING DATA FOR 2005—BENZENE[a]

	Chicago	Schiller Park	Northbrook
Number of Observations	34	58	164
Minimum	0.248	0.351	0.151
Maximum	2.605	5.327	3.126
Mean	0.882	1.351	0.779
Geometric Mean	0.711	1.171	0.63
Median	0.726	1.085	0.638
Standard Deviation	0.616	0.908	0.533

[a] Data were converted from parts per billion (ppb) to microgram per meters cubed ($\mu g/m^3$) using the conversion factor specified by the EPA of 1 ppm benzene = 3190 $\mu g/m^3$ benzene.

TABLE V

EPA MONITORING DATA FOR 2005—FORMALDEHYDE[a]

	Chicago	Schiller Park[c]	Northbrook[d]
Number of Observations[b]	15	49	84
Minimum	1.476	0.615	0.037
Maximum	5.166	135.3	22.51
Mean	3.116	23.79	2.396
Geometric Mean	2.959	6.317	1.727
Median	2.583	3.395	1.968
Standard Deviation	1.021	38.19	2.689

[a] Data were converted from ppb to µg/m^3 using the conversion factor specified by the EPA of 1 ppm formaldehyde = 1230 µg/m^3 formaldehyde.
[b] The null values in the dataset were removed, which represent the measurements not taken at that sampling time period.
[c] Contained 3 NULL measurements, accounting for 5.8% of the total.
[d] Contained 5 NULL measurements, accounting for 5.6% of the total.

1. **Benzene**

a. **Hazard identification**

Benzene is emitted from burning coal and oil, gasoline service stations, and motor vehicle exhaust. Acute (short-term) inhalation exposure to benzene may cause drowsiness, dizziness, headaches, and respiratory tract irritation. Chronic (long-term) inhalation exposure has caused various disorders in the blood. Reproductive effects have been reported for women exposed at high levels, and increased incidence of leukemia has been observed in humans occupationally exposed for long periods of time. The EPA has classified benzene as a known human carcinogen for all routes of exposure (USEPA, 2012a). The International Agency for Research on Cancer (IARC)

classifies benzene as a Group 1 carcinogen, concluding sufficient evidence in humans for carcinogenicity (IARC, 2010).

b. **Dose-response assessment**

The Pliofilm workers of Rinsky et al. (1981, 1987) provide the best published set of data to date for evaluating human cancer risks from exposure to benzene. This cohort has fewer reported co-exposures to other potentially carcinogenic substances in the workplace that might confound the risk analysis. However, not enough is known to determine the shape of the dose-response curve at environmental levels of exposure to provide a sound scientific basis to choose any particular dose-response extrapolation model to estimate human cancer risks at low doses. At present, the true cancer risk from exposure to benzene cannot be ascertained because of the uncertainties in the low-dose exposure scenarios and lack of clear understanding of the mode of action. The range estimates are maximum likelihood values that were derived by Crump et al. (1992,1994) from observable dose responses using a linear extrapolation model to estimate risks associated with low environmental exposures (USEPA, 2012a).

Based on the extensive research of past literature by the EPA, the Rinsky cohort (1981,1987) and the Crump's (1992,1994) analysis of the Crump and Allen (1984, unpublished data) and Paustenback exposure measurements (1992, 1993), a range from $2.2x10^{-6}$ to $7.8x10^{-6}$ was chosen as the increase in lifetime cancer risk of an individual who is exposed for a lifetime to 1 $\mu g/m^3$ benzene in air (USEPA, 2013a). The upper-bound inhalation unit risk estimate (URE) for benzene used for this study is $7.8x10^{-6}$ $(\mu g/m3)^{-1}$. This is the same inhalation URE used in the 2005 NATA by the EPA, which represents the upper-bound range of the Integrated Risk Information System (IRIS) maximum likelihood estimate (MLE) (ICF International, 2011).

2. **Formaldehyde**

a. **Hazard identification**

Formaldehyde is used mainly to produce resins used in particleboard products and as an intermediate in the synthesis of other chemicals. Exposure may occur from breathing indoor air, tobacco smoke, or ambient urban air (USEPA, 2007). An indirect source of formaldehyde is its formation via photochemical oxidation of hydrocarbons, such as methane, and other precursors emitted from combustion processes. It has a short half-life in the environment because it is removed from air by photochemical processes, precipitation, and biodegradation. The IARC concluded that there is sufficient evidence in humans and animals for the carcinogenicity of formaldehyde, making it a Group 1 IARC Carcinogen. It causes leukemia and cancer of the nasopharynx (IARC, 2011).

b. **Dose-response assessment**

The EPA classifies formaldehyde as a B1—"Probable Human Carcinogen" based on limited human evidence and sufficient animal evidence. The principle evidence of carcinogenicity comes from Kerns et al. (1983), who found squamous cell carcinomas in both sexes of two strains of rats and males of one strain of mice. The experimental range is close to expected human exposures. The estimated lifetime ECRs from six epidemiologic studies are close to upper-bound risks based on animal data (USEPA, 2012b). The URE for formaldehyde used for this study is $1.3 \times 10^{-5} (\mu g/m^3)^{-1}$, based on Kerns et al. (1983). This is the same inhalation URE used for the 2005 NATA (ICF International, 2011).

3. **Exposure assessment and risk characterization**

The concentrations used to assess risk, which will be the upper 95th confidence limit concentrations for benzene and formaldehyde at all three sampling sites in 2005 using the EPA's ProUCL Version 4.1 computer program. This statistical support

software serves as a companion software package for calculating UCLs for exposure-point concentrations at hazardous waste sites and guidance for comparing background and chemical concentrations in soil for Comprehensive Environmental Response, Compensation, and Liability Act sites. It is also very helpful in attainment of clean-up standards and often needed in groundwater monitoring applications. The software package provides 15 UCL computation methods for full data sets without any below-detection observations; five are parametric and 10 are nonparametric. It computes the most appropriate 95th UCL based off of the data distribution methods (USEPA, 2011c). The results of this analysis are shown in Table VI for benzene and formaldehyde.

TABLE VI

PROUCL UPPER 95th CONFIDENCE LIMIT FOR THE MEAN
BENZENE AND FORMALDEHYDE

BENZENE

Sample Location	Statistical Basis	95th UCL (mg/m^3)
Chicago	Approximate Gamma UCL	1.1E-3
Schiller Park	Chebyshev (Mean, Sd) UCL	1.9E-3
Northbrook	Approximate Gamma UCL	8.5E-4

FORMALDEHYDE

Sample Location	Statistical Basis	95th UCL (mg/m^3)
Chicago	Approximate Gamma UCL	3.6E-3
Schiller Park	Chebyshev (Mean, Sd) UCL	4.8E-2
Northbrook	95th % H-UCL	2.8E-3

a. **Measurement-based estimates utilizing the National Air Toxics Assessment approach**

In this approach, the excess inhalation cancer risk was calculated in a similar way as the method employed by the EPA for the 2005 NATA, except that the estimated concentration (EC) is replaced by the 95th UCL based on AMD in Cook County. The concentration is modified by the exposure factor that was developed in the NATA for specific census tracts and chemicals, in accordance with the method employed by the EPA in the 2005 NATA.

$$Risk(unitless) = C\ \left(\frac{\mu g}{m^3}\right)\ x\ Exposure\ Factor\ x\ URE\ \left(\frac{\mu g}{m^3}\right)^{-1} \qquad (3)$$

where the URE is the unit risk estimated by the EPA's risk assessment protocol.

b. **Measurement-based estimates utilizing the Environmental Protection Agency's superfund guidance approach**

The second approach used to calculate the excess inhalation cancer risks attributable to the population near the sampling sites utilizes EPA's Superfund Health Risk Assessment guidance approach (USEPA, 1989).

Based on this approach, in the first step, a Lifetime Average Daily Dose via Inhalation L(ADD_i) corresponding to an average exposure (AE) scenario and a plausible reasonable maximum exposure (RME) scenario is estimated using the equation shown below:

$$L(ADDi)\ \left(\frac{mg}{kg-day}\right) = \frac{C\ \left(\frac{mg}{m^3}\right)\ x\ ER\ (unitless)\ x\ IR\ \left(\frac{m^3}{day}\right)\ x\ EF\ \left(\frac{days}{year}\right)\ x\ ED\ (year)}{BW\ (kg)\ x\ AT\ (days)} \qquad (4)$$

where C is the 95th UCL concentration multiplied by the census-tract specific exposure factor ratio used in the NATA calculation, ER is the same exposure ratio used in the other calculation methods based on the census tract, chemical, and source type, IR is inhalation rate, EF is exposure frequency, ED is exposure duration, BW is body weight, and AT is average time. The exposure parameters (e.g., IR, BW) representing AE and RME conditions used in the estimation of the L(ADD_i) were compiled from the EPA Exposure Factors Handbook (USEPA, 2011b) and presented in Table VII for three human receptors of concern, i.e., children (ages 2–6 years); youth (6–16 years); and adults (16 years and older). These age groups were specifically selected to coincide with the age groups identified by the EPA in developing adjustments to the cancer slope factor that takes biological response for different developmental stages into account in its latest guidance (Barton et al., 2005).

TABLE VII

EXPOSURE PARAMETERS UTILIZED IN CANCER RISK ASSESSMENT

Age Group	2–6		6–16		>16	
Exposure Duration[a]	RME	AE	RME	AE	RME	AE
Concentration (mg/m^3)	95th UCL Calculated from each Sampling Location					
Inhalation Rate (m^3/day)[b]	9.5	13.75	19.25	13.6	20.02	14.88
Exposure Frequency (days/year)[c]	350	175	350	175	350	233
Exposure Duration (years)[d]	6	4	6	4	30	9
Body Weight (kg)[e]	16.2	16.2	44.3	44.3	78.2	78.2
Average Time (days)[f]	25550	25550	25550	25550	25550	25550

[a] RME = Reasonable Maximum Exposure; AE = Average Exposure
[b] IRs were calculated using the averages of the Recommended Long-Term Exposure Values for Inhalation (males and females combined) (USEPA, 2011b)
[c,d] Values based on professional judgment and are commonly used in Superfund risk assessments.
[e] Body weights were calculated using the Mean and 95th Percentile Body Weights (kg) derived from NHANES (1999–2006) Males and Females Combined (USEPA, 2011b)
[f] Averaging time represents a 70-year (i.e., 25550 days) lifetime exposure period.

In the second step, $L(ADD_i)$ is multiplied by the inhalation age-dependent adjusted cancer slope factor (ADAF CSF_i) to estimate excess or incremental inhalation cancer risk shown below:

$$Inhalation\ Cancer\ Risk\ (unitless) = L(ADDi)\ \left(\frac{mg}{kg-day}\right)\ x\ ADAF\ CSFi\ \left(\frac{mg}{kg-day}\right)^{-1} \quad (5)$$

The conversion of URE to CSF for each chemical was performed based on the equation shown below:

$$CSF_i \left(\frac{kg-d}{mg}\right) = URE \left(\frac{m^3}{\mu g}\right) x\ BW(kg)\ x\ \frac{1}{IR} \left(\frac{d}{m^3}\right) x \left(\frac{10^{-3}\ \mu g}{mg}\right) \quad (6)$$

where CSF is the inhalation cancer slope factor in milligrams per kilogram per day. Body weight (BW) and inhalation rate (IR) are 70kg and 20 (m^3/day), which are average adult BW and IR values commonly utilized by the EPA in URE and CSF conversions, respectively (USEPA, 2011b).

As noted above, cancer risk for exposures that occur at early stages of life should be calculated by applying default ADAFs to the non-age-specific slope factor (USEPA, 2012c). In accordance with the EPA guidance, the ADAFs for ages 2–6 years and ages 6–16 years will be 3 and ages >16 will be 1.

$$ADAF\ CFS \left(\frac{mg}{kg-day}\right)^{-1} = CSF \left(\frac{mg}{kg-day}\right)^{-1} x\ Adjustment\ Factor \quad (7)$$

The cumulative inhalation cancer risk based on AE and RME conditions for each chemical at each monitoring station was calculated by adding the risk across all age groups. The calculated risk results for each chemical, location, and method were then compared to the NATA modeled results.

IV. RESULTS

A. Air Quality Analysis Based on National Air Toxics Assessment Modeled Estimates

1. Statewide emissions across counties

The comprehensive air-quality analysis of Illinois concluded that nine counties contributed greater than 2% to the overall emissions. However, in these counties, distribution of source categories in terms of their contribution to the total air emissions in 2005 varied, as shown in Figure 2.

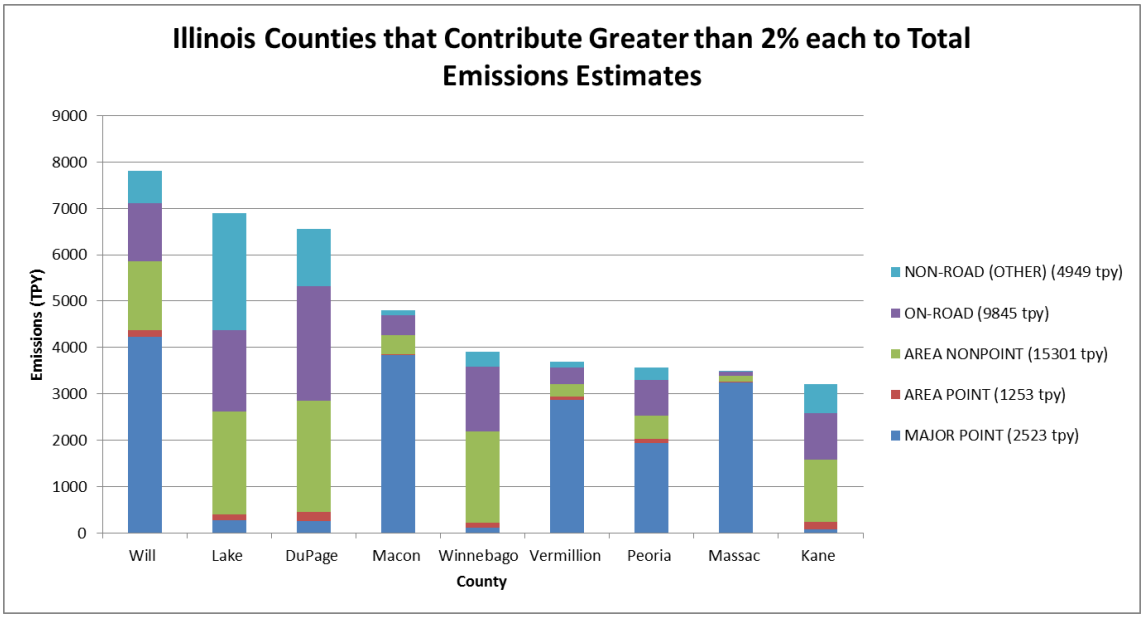

Figure 2. Illinois county emissions results.

County-specific air emission source categories that contributed greater than 2% each to the total 2005 NATA emissions estimates in Illinois. Cook County is excluded from this figure because the total emissions are substantially higher.

Cook County had the highest emissions estimates of any other county in Illinois in 2005, contributing to 25% of the total emissions estimates in Illinois. The next highest contributors were Will County (6%), Lake County (5%) and DuPage County (5%). The source-category contributions highlights the major contributor source signature in ambient air and guides the scientific and regulatory communities about specific emissions sources to control for air-quality management. For example, while major point sources are the primary driver for air emissions in Will, Macon, Vermillion, and Massac Counties, area-nonpoint, on-road, non-road-other source categories constitute three major contributors to total emissions in Lake, DuPage, and Kane Counties. Thus, air-quality control policies and management options for these different regions should be tailored to specific source signatures in these air sheds for implementation of successful outcomes.

2. **Emissions in Cook County**

The emissions results in Cook County showed that the majority of the emissions in the 2005 NATA and NEI are from area-nonpoint sources, as shown in Figure 3.

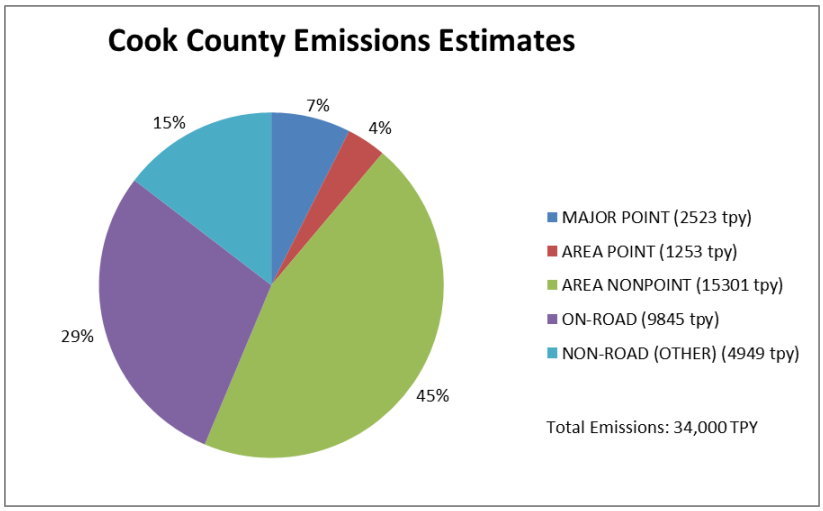

Figure 3. Cook County emissions results.

Cook County air emissions estimates and source categories modeled in the 2005 NATA.

Area non-point sources are stationary sources that are not incorporated into the point-source component of NEI, typically because their locations are not known. This can make it very difficult to accurately determine where the highest emissions contributions are located; however, knowing that on-road sources are contributing approximately 30% to the emissions estimates could be a viable starting point for public health policy makers.

3. **Chemical specific emissions estimates in Cook County**

The chemical-specific analysis of the emissions inventory in the 2005 NATA for Cook County, Illinois, as presented in Figure 4, revealed that toluene (22%), methanol (10%), m-xylene (7%), 2,2,4-Trimethylpentane (6%), and benzene (6%) were the top contributors to the total air emissions. Each chemical and their use are described in detail in Table VIII.

TABLE VIII

TOP EMITTING CHEMICALS IN THE 2005 NATA AND THEIR INDUSTRY USES

Chemical	Use
Toluene	Toluene is used as an additive in gasoline to improve octane ratings. It is also used to produce benzene, as a solvent in paints, coatings fragrances, adhesives, inks, and cleaning agents (ATSDR, 2000).
Methanol	Methanol is used for applications including transportation fuel, wastewater denitrification, fuel-cell hydrogen carrier, and electricity generation. It is also the key component in many different types of materials such as plastics, paints, resins, adhesives, solvents, insulation, and pigments and dyes (Methanol Institute, 2011).
m-xylene	The xylene isomers are used primarily for industrial operations as solvents and intermediates in synthetic reactions; m-xylene is a chemical intermediate in the production of isophthalic acid and isophthalonitrile. Isophthalic acid is used to manufacture polyesters (ATSDR, 2007).
2,2,4-Trimethylpentane	2,2,4-Trimethylpentane is released to the environment through the manufacture, use, and disposal of products associated with petroleum and gasoline. More specifically, it is used in the alkylation step of the reaction of isobutene and butylene in deriving high-octane fuels (USEPA, 2007b).
Benzene	Discussed in Section III.1.a.

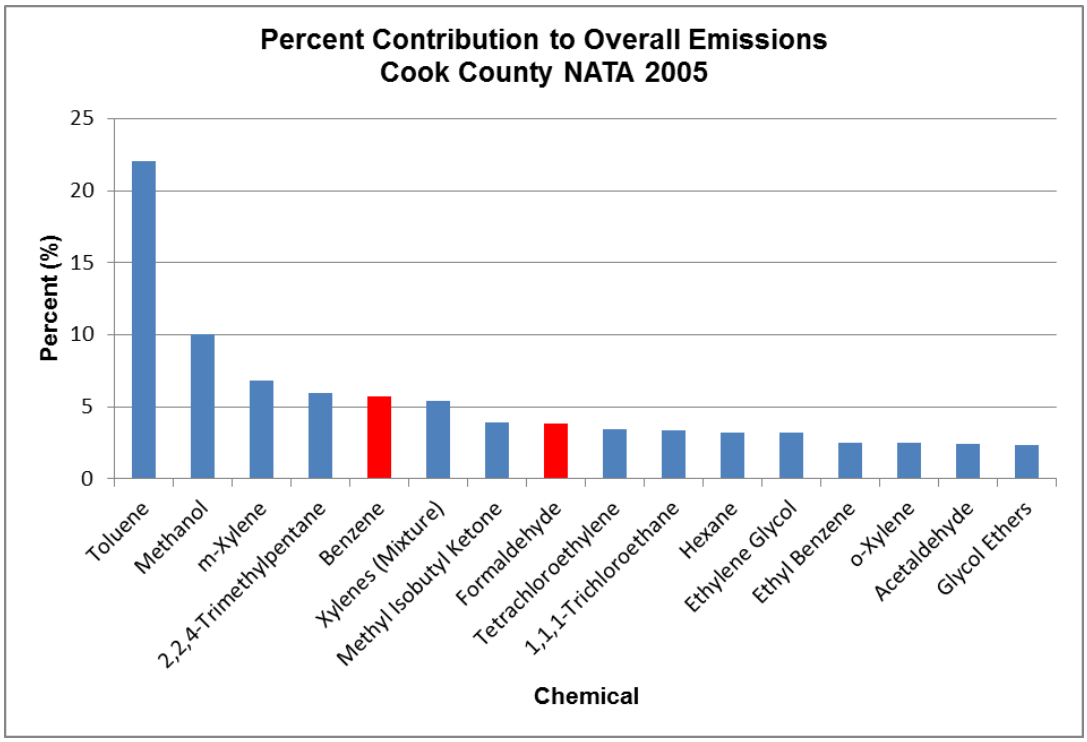

Figure 4. Cook County chemical specific emissions results.

The chemicals that contributed greater than 2% to the total emissions estimates in Cook County. The carcinogens benzene and formaldehyde are highlighted in red.

Figure 4 shows that sixteen organic chemicals contributed greater than 2% each to the total air emissions in Cook County in 2005. Among these chemicals, benzene and formaldehyde are the two cancer causing chemicals per EPA and IARC classifications. This finding, along with the findings of the NATA cancer risk analysis presented in the next section, formed the basis of the subsequent cancer risk analysis that focuses on these two chemicals.

B. Excess Cancer Risk Analysis for Cook County

1. Excess cancer risk analysis based on modeled National Air Toxics Assessment estimates

Analysis of cancer risk estimates performed by the 2005 NATA using modeled air concentrations identified ten carcinogens shown in Figure 5 contributing greater than 3% each to the cumulative cancer risk across all carcinogens found in 177 Hazardous Air Pollutants defined by the 2005 NATA (ICF International, 2011).

As shown in Figure 5, formaldehyde and benzene are the two greatest contributors to the cumulative cancer risk, contributing 39% and 12% respectively. This finding was also the rationale behind our cancer risk analysis focusing only on these two cancer-causing chemicals.

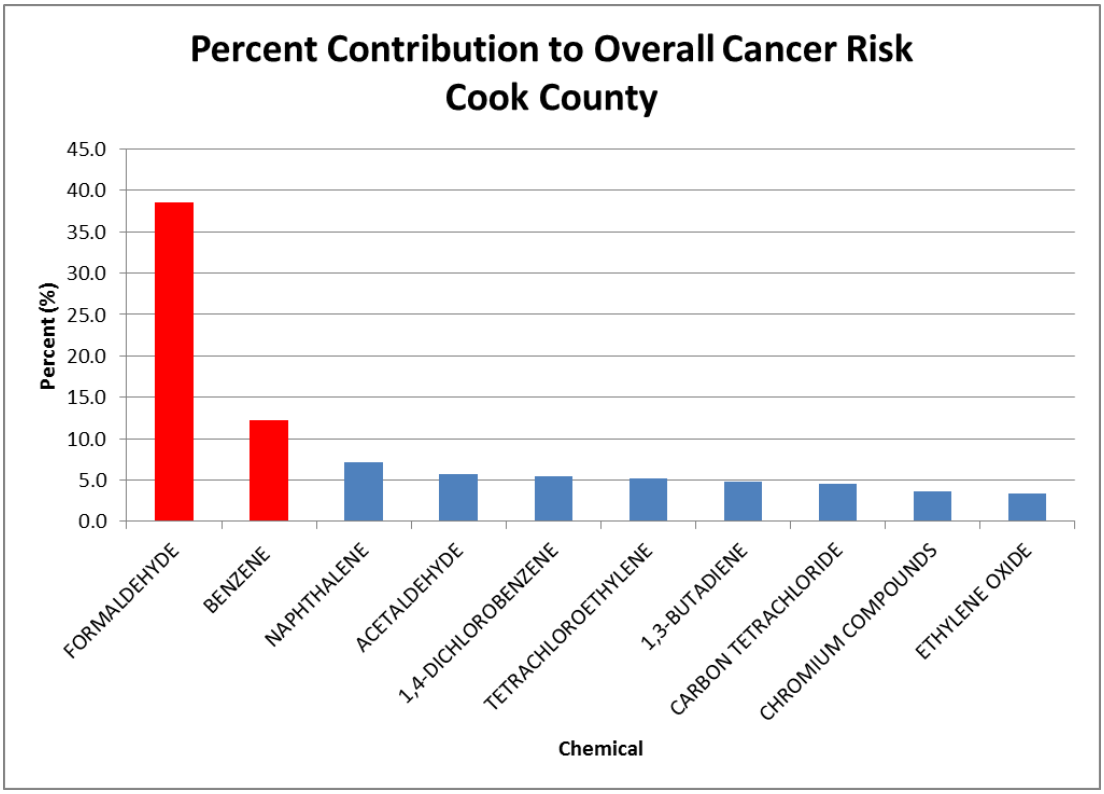

Figure 5. Cook County 2005 NATA percent contribution of chemicals to total county risk.

Chemicals that contribute greater than 3% to the overall county level cancer risk.

A GIS analysis was also performed to show spatial variation in cumulative inhalation cancer risk estimates performed by the 2005 NATA for each census-tract (see Figure 6) and in benzene and formaldehyde inhalation cancer risk (see Figure 7) in order to identify specific environmental justice areas and to develop public health policy development based on air quality controls and management strategies for these areas.

In the GIS map, the areas with cancer risk equal to or greater than $1x10^{-4}$ (i.e., threshold of acceptability for cancer risk per the EPA [Clay, 1991]) were highlighted in red. Two other demarcation points, 44% and 73% of the maximum risk, were assigned by the GIS software.

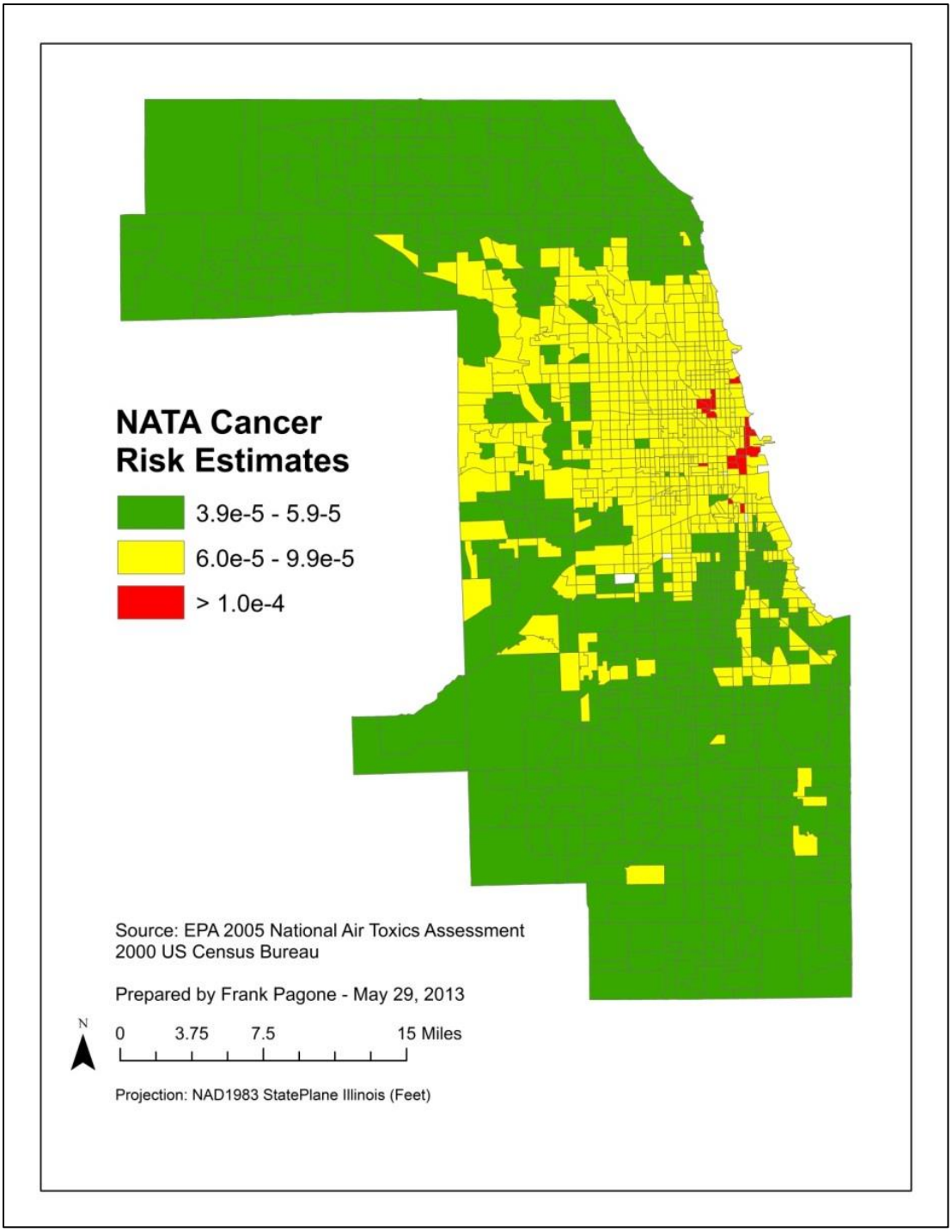

Figure 6. Cook County 2005 NATA risk estimates census-tract level map for all chemicals.

NATA census-tract level inhalation cancer risk. Red census tracts are those with a cancer risk greater than or equal to $1x10^{-4}$.

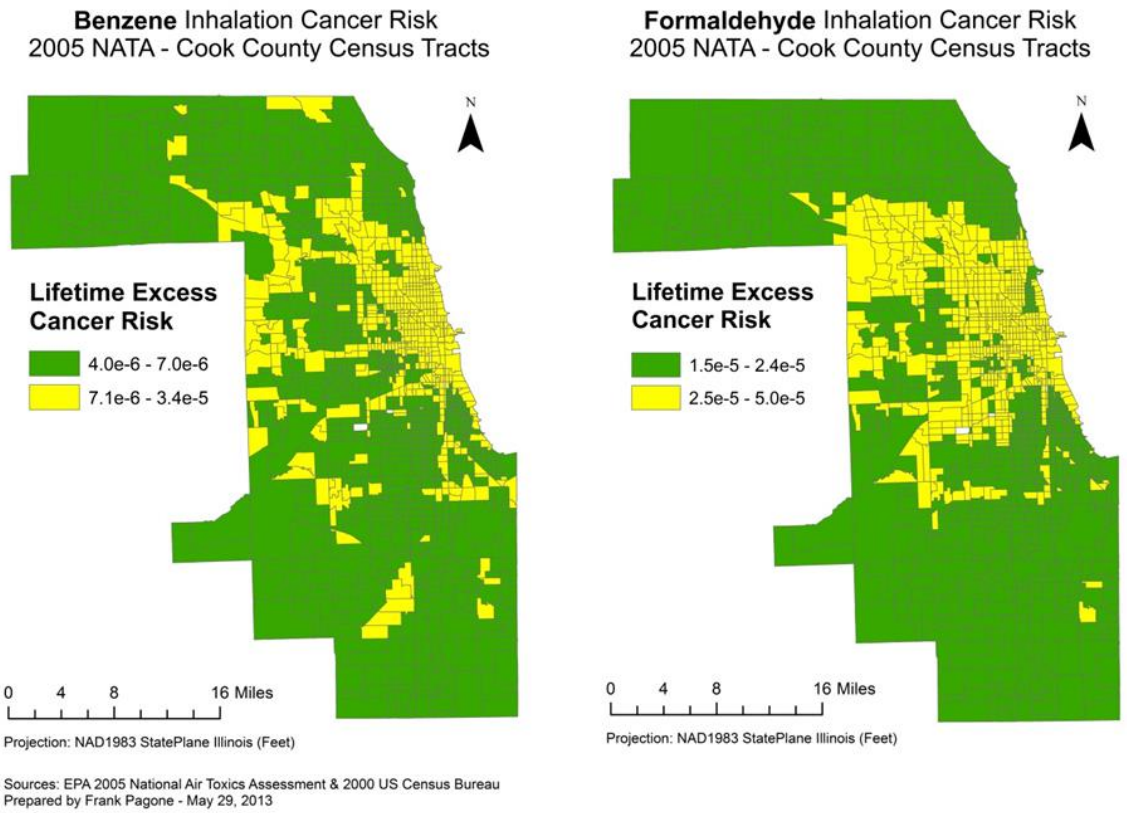

Figure 7. Cook County 2005 NATA risk estimates census-tract level map for benzene and formaldehyde.

NATA Census tract level excess lifetime inhalation cancer risk due to benzene and formaldehyde respectively. The yellow census tracts indicate those census tracts with a risk greater than the median risk for the distribution of all risks for that chemical throughout

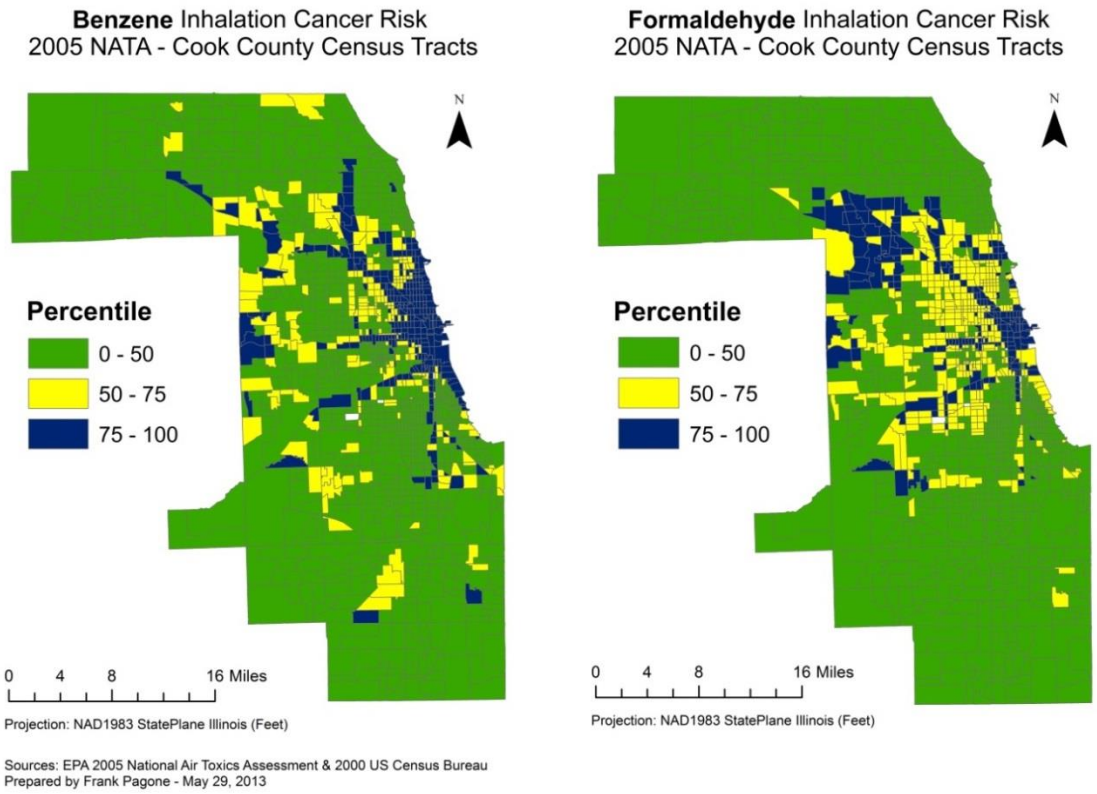

Figure 8. Cook County 2005 NATA risk estimates percentiles: Upper 75th percent for benzene and formaldehyde.

NATA census-tract level excess lifetime inhalation cancer risk percentiles for benzene and formaldehyde. The census tracts are separated by the location of the cancer risk within a certain percentile of the population of risks. The blue census tracts indicate the upper 75th percentile risks located for each chemical in Cook County.

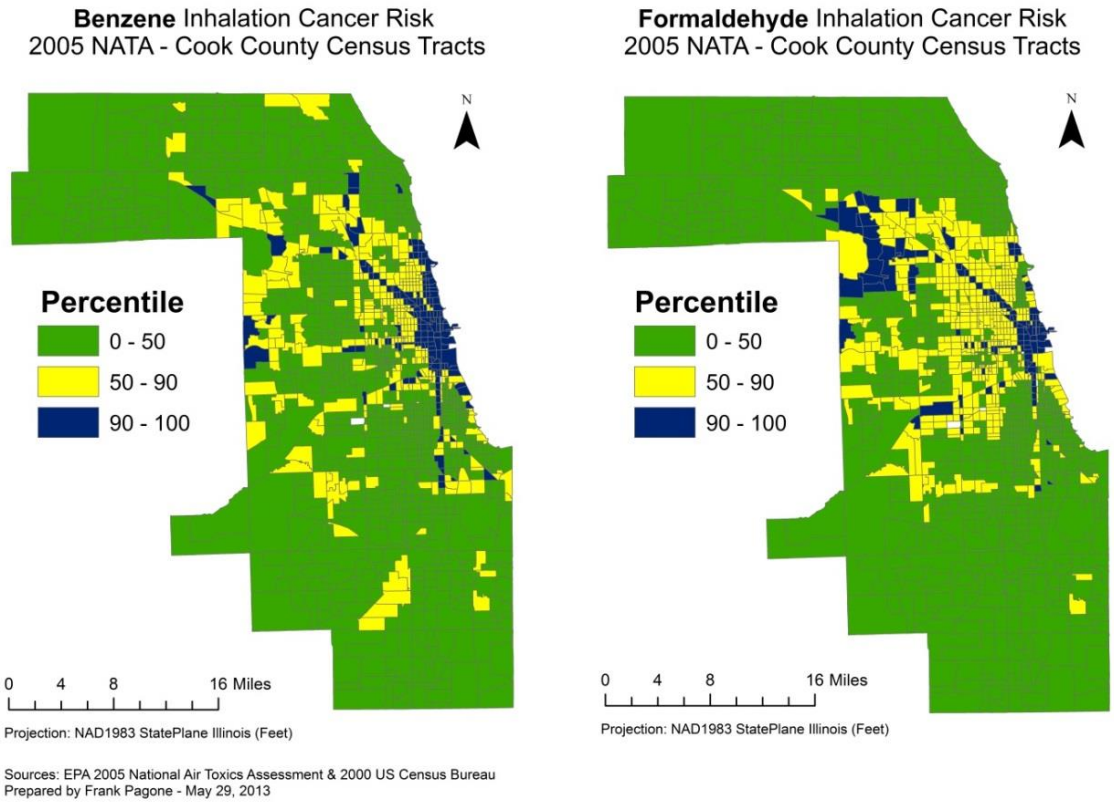

Figure 9. Cook County 2005 NATA risk estimates percentiles: Upper 90th percent for benzene and formaldehyde.

NATA census-tract level excess lifetime inhalation cancer risk percentiles for benzene and formaldehyde. The census tracts are separated by the location of the cancer risk within a certain percentile of the population of risks. The blue census tracts indicate the upper 90th percentile risks located for each chemical in Cook County.

Figures 7, 8, and 9 indicate that a substantial amount of elevated risks are located along major roadways and surround the airports. This points to both on-road and non-road-other source categories dominating the benzene and formaldehyde cancer risk signature in these areas. It is important to note that these cancer risk estimates are only for benzene and formaldehyde, and the addition of other carcinogenic HAPs among the 177 1990 CAA HAPs will result in higher risk.

2. **Excess inhalation cancer risk analysis based on Environmental Protection Agency's air quality monitoring data for benzene and formaldehyde**

a. **National Air Toxics Assessment approach**

Using the same calculation method as the 2005 NATA, inhalation lifetime ECRs were calculated using the air-monitoring data collected for benzene (see Table IV) and formaldehyde (see Table V) at the three fixed-site locations in Cook County in 2005. In these calculations, the 95th upper confidence limits for the mean (UCLM) data presented in Table VII were utilized as the exposure point concentrations. The results of the inhalation ECR estimates for benzene and formaldehyde using the method employed by the 2005 NATA are presented in Table IX and Table X, respectively. In these tables, the bolded locations and census tracts (081400, 811600, and 801500) indicate the primary physical locations of the EPA fixed-site air-monitoring stations in Cook County based on GIS coding. Unbolded census tracts are adjacent to those census tracts with air monitoring stations.

TABLE IX

INHALATION EXCESS CANCER RISK ESTIMATES USING EPA AIR MONITORING DATA AND NATA APPROACH—BENZENE

Location	Census Tract	95th UCLM Concentration ($\mu g/m^3$)	Exposure Ratio	URE $(\mu g/m)^{-1}$	Calculated ECR
Chicago	**081400[a]**	**1.1**	**0.92**	**7.8E-6**	**7.9E-6**
Schiller Park	760900	1.9	0.82	7.8E-6	1.2E-5
Schiller Park	770800	1.9	0.92	7.8E-6	1.4E-5
Schiller Park	**811600[a]**	**1.9**	**0.92**	**7.8E-6**	**1.4E-5**
Northbrook	**801500[a]**	**0.85**	**0.94**	**7.8E-6**	**6.6E-6**
Northbrook	801800	0.85	0.94	7.8E-6	6.6E-6

[a]Primary location of sampling stations based on GIS Geocoding. Other census tracts border the primary location.

TABLE X

INHALATION EXCESS CANCER RISK ESTIMATES USING EPA AIR MONITORING DATA AND NATA APPROACH—FORMALDEHYDE

Location	Census Tract	95th UCLM Concentration ($\mu g/m^3$)	Exposure Ratio	URE $(\mu g/m)^{-1}$	Calculated ECR
Chicago	**081400[a]**	**3.6**	**0.83**	**1.3E-5**	3.9E-5
Schiller Park	760900	48	0.74	1.3E-5	4.6E-4
Schiller Park	770800	48	0.81	1.3E-5	5.1E-4
Schiller Park	**811600[a]**	**48**	**0.82**	**1.3E-5**	**5.1E-4**
Northbrook	**801500[a]**	**2.8**	**0.83**	**1.3E-5**	**3.0E-5**
Northbrook	801800	2.8	0.82	1.3E-5	3.0E-5

[a]Primary location of sampling stations based on GIS Geocoding. Other census tracts border the primary location.

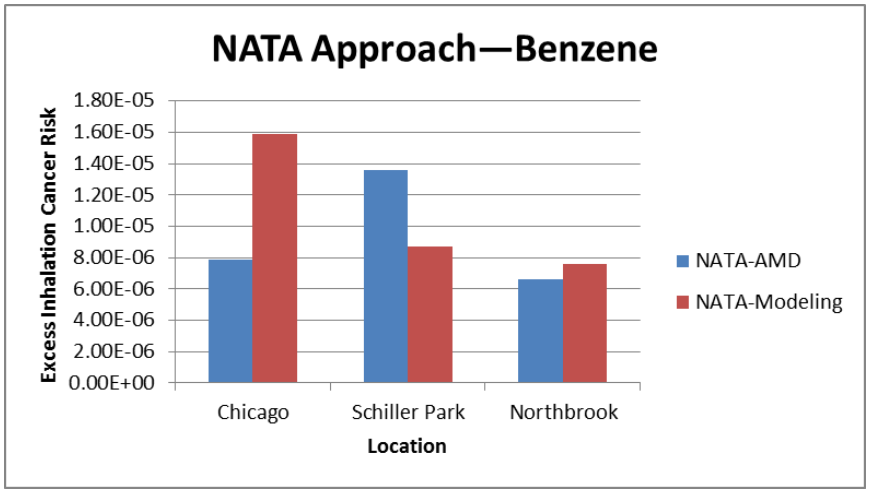

Figure 10. Inhalation benzene cancer risk based on NATA approach: Risk based on EPA monitoring data versus risk based on NATA modeling data.

NATA-AMD: NATA approach to calculating ECR based on AMD
NATA-Modeling: NATA approach to calculating ECR based on air quality and human

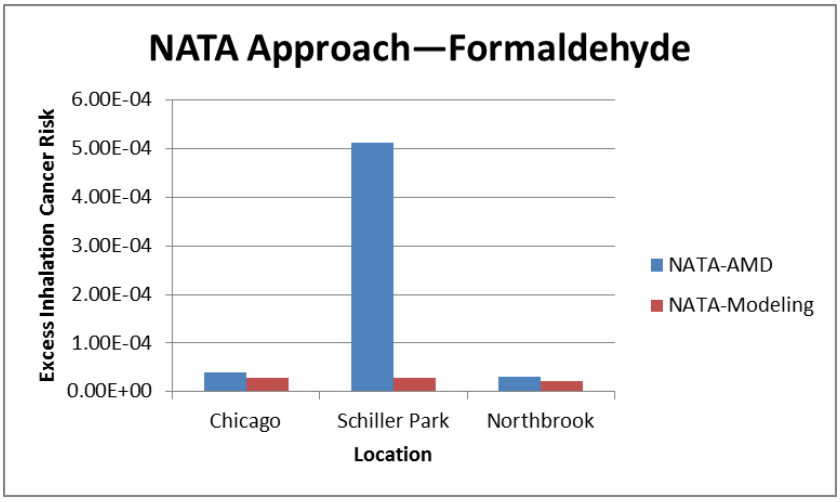

Figure 11. Inhalation benzene cancer risk based on NATA approach: Risk based on EPA monitoring data versus risk based on NATA modeling data.

NATA-AMD: NATA approach to calculating ECR based on AMD
NATA-Modeling: NATA approach to calculating ECR based on air quality and human

The inhalation ECR calculations for benzene using the NATA approach showed that the risk estimates utilizing EPA air-monitoring data were higher than the NATA risk estimates at the Schiller Park location and lower at the Chicago and Northbrook monitoring stations, as shown in Figure 10. In figure 11, the ECR results for formaldehyde using the NATA approach utilizing the EPA AMD were higher than the modeled risks at each location. The Schiller Park location is unique because it is located near a large international airport (i.e., O'Hare). The Chicago location is unique in that Lake Michigan may have an effect on the discrepancy between the monitored and modeled results because NATA did not account for dilution from the weather patterns.

b. **Environmental Protection Agency's superfund guidance approach**

Using the EPA Superfund guidance approach employing EPA air-monitoring data collected at the three air-monitoring stations, first, the lifetime inhalation average daily dose ($L(ADD_i)$) was calculated for each receptor of concern (ages: 2–6

years; 6–16 years; 16 years and over), for each chemical (benzene and formaldehyde) and for each exposure scenario (RME and AE), as shown in Table XI and XII, respectively. These L(ADDi) estimates were then multiplied by the age-adjusted inhalation CSF specific to the chemical under study in order to calculate RME and AE inhalation ECR for benzene and formaldehyde for the three receptors of concern potentially located near the air-monitoring stations studied, as described in equation 6. Table XIII and XIV presents the results of the inhalation ECR estimates based on the EPA Superfund approach for benzene and formaldehyde, respectively.

TABLE XI

LIFETIME AVERAGE INHALATION DAILY DOSE L(ADD_i) RESULTS (mg/kg-day)—BENZENE

				Age 2–6		Age 6–16		Age > 16	
Location	Census Tract	95th UCL Concentration (mg/m^3)	Exposure Factor	RME	AE	RME	AE	RME	AE
Chicago	**081400***	**0.0064**	**0.92**	**4.7E-5**	**2.3E-5**	**3.5E-5**	**8.3E-6**	**1.0E-4**	**1.5E-5**
Schiller Park	760900	0.0019	0.82	7.4E-5	3.6E-5	5.5E-5	1.3E-5	1.6E-4	2.4E-5
Schiller Park	770800	0.0019	0.92	8.3E-5	4.0E-5	6.2E-5	1.5E-5	1.8E-4	2.7E-5
Schiller Park	**811600***	**0.0019**	**0.92**	**8.3E-5**	**4.0E-5**	**6.2E-5**	**1.5E-5**	**1.8E-4**	**2.7E-5**
Northbrook	**801500***	**0.0037**	**0.94**	**3.9E-5**	**1.9E-5**	**2.9E-5**	**6.7E-6**	**8.4E-5**	**1.2E-5**
Northbrook	801800	0.0037	0.94	3.8E-5	1.9E-5	2.8E-5	6.7E-6	8.4E-5	1.2E-5

TABLE XII

LIFETIME AVERAGE INHALATION DAILY DOSE L(ADD_i) RESULTS (mg/kg-day)—FORMALDEHYDE

Location	Census Tract	95th UCL Concentration (mg/m^3)	Exposure Factor	Age 2–6		Age 6–16		Age > 16	
				RME	AE	RME	AE	RME	AE
Chicago	**081400***	**0.0036**	**0.83**	**1.4E-4**	**6.9E-5**	**1.1E-4**	**2.5E-5**	**3.1E-4**	**4.7E-5**
Schiller Park	760900	0.048	0.74	1.7E-3	8.2E-4	1.3E-3	3.0E-4	3.7E-3	5.5E-4
Schiller Park	770800	0.048	0.81	1.9E-3	9.0E-4	1.4E-3	3.2E-4	4.1E-3	6.0E-4
Schiller Park	**811600***	**0.048**	**0.82**	**1.9E-3**	**9.1E-4**	**1.4E-3**	**3.3E-4**	**4.1E-3**	**6.1E-4**
Northbrook	**801500***	**0.0028**	**0.83**	**1.1E-4**	**5.4E-5**	**8.2E-5**	**1.9E-5**	**2.4E-4**	**3.6E-5**
Northbrook	801800	0.0028	0.82	1.1E-4	5.3E-5	8.1E-5	1.9E-5	2.4E-4	3.5E-5

TABLE XIII

LIFETIME EXCESS INHALATION CANCER RISK ESTIMATES BASED ON EPA SUPERFUND APPROACH—BENZENE

		Age 2–6		Age 6–16		Age > 16	
Location	Census Tract	RME	AE	RME	AE	RME	AE
Chicago	**081400***	**3.9E-6**	**1.9E-6**	**2.9E-6**	**6.8E-7**	**2.8E-6**	**4.2E-7**
Schiller Park	760900	6.1E-6	2.9E-6	4.5E-6	1.1E-6	4.4E-6	6.6E-7
Schiller Park	770800	6.8E-6	3.3E-6	5.1E-6	1.2E-6	5.0E-6	7.4E-7
Schiller Park	**811600***	**6.8E-6**	**3.3E-6**	**5.0E-6**	**1.2E-6**	**4.9E-6**	**7.3E-7**
Northbrook	**801500***	**3.2E-6**	**1.5E-6**	**2.3E-6**	**5.5E-7**	**2.3E-6**	**3.4E-7**
Northbrook	801800	3.1E-6	1.5E-6	2.3E-6	5.5E-7	2.3E-6	3.4E-7

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TABLE XIV

LIFETIME EXCESS INHALATION CANCER RISK ESTIMATES BASED ON EPA SUPERFUND APPROACH—FORMALDEHYDE

		Age 2–6		Age 6–16		Age > 16	
Location	Census Tract	RME	AE	RME	AE	RME	AE
Chicago	**081400***	**2.0E-5**	**9.5E-6**	**1.5E-5**	**3.4E-6**	**1.4E-5**	**2.1E-6**
Schiller Park	760900	2.3E-4	1.1E-4	1.7E-4	4.1E-5	1.7E-4	2.5E-5
Schiller Park	770800	2.5E-4	1.2E-4	1.9E-4	4.4E-5	1.8E-4	2.7E-5
Schiller Park	**811600***	**2.6E-4**	**1.2E-4**	**1.9E-4**	**4.5E-5**	**1.9E-4**	**2.8E-5**
Northbrook	**801500***	**1.5E-5**	**7.3E-6**	**1.1E-5**	**2.6E-6**	**1.1E-5**	**1.6E-6**
Northbrook	801800	1.5E-5	7.2E-6	1.1E-5	2.6E-6	1.1E-5	1.6E-6

C. Comparison of Modeled and Measurement-based Inhalation Excess Cancer Risk Estimates for Benzene and Formaldehyde

All of the inhalation ECRs based on modeling or air quality monitoring were compared to evaluate the compatibility of the results and to "groundtruth" the NATA modeling estimates using the actual measurements in specific airsheds. Due to the small scale of this assessment, the observations should be considered with caution.

Table XV and Table XVI present the inhalation ECR estimates across the three approaches evaluated for benzene and formaldehyde, respectively: NATA approach utilizing AMD (NATA-AMD); EPA Superfund approach utilizing AMD (SUPERFUND-AMD); and EPA's 2005 NATA utilizing air-quality and HEM approach (NATA-Modeling). In these tables, the age group-specific ECR results corresponding to RME and AE exposure scenarios for the Superfund are also documented. The ECR estimates are within $1x10^{-7}$ to $1x10^{-5}$ for benzene based on evaluation of the ECR results across the different approaches employed. For formaldehyde, they are higher—within a $1x10^{-8}$ to $1x10^{-4}$ range. While all of the benzene ECR results are within the EPA-adopted acceptability range for cancer (i.e., $<1x10^{-4}$) across all approaches employed, the ECR results for all census tracts in Schiller Park are higher than this acceptability threshold for formaldehyde, as highlighted in red in Table XVI. However, this threshold exceedance is only emerged when ECR estimates were based on air-quality monitoring data, independent of the approach employed (i.e., NATA or EPA Superfund). On the other hand, the ECR estimates based on EPA's 2005 NATA modeling techniques did not result in any exceedances of this threshold for formaldehyde. This is counterintuitive and it points to the importance of validating modeling-based data against measurement-based data prior to making regulatory decisions and developing air-pollution control policy for public health protection. It also points to not relying on NATA data for exposure control and public health protection policy and development for carcinogenic effects.

TABLE XV

LIFETIME EXCESS INHALATION CANCER RISK ESTIMATES, COMPARISON OF METHODS—BENZENE

		EPA Superfund-AMD							
		Age 2–6		Age 6–16		Age>16			
Location	Census Tract	RME	AE	RME	AE	RME	AE	NATA AMD	NATA Modeling
Chicago	**081400***	**3.9E-6**	**1.9E-6**	**2.9E-6**	**6.8E-7**	**2.8E-6**	**4.2E-7**	**7.9E-6**	**1.6E-5**
Schiller Park	760900	6.1E-6	2.9E-6	4.5E-6	1.1E-6	4.4E-6	6.6E-7	1.2E-5	5.7E-6
Schiller Park	770800	6.8E-6	3.3E-6	5.1E-6	1.2E-6	5.0E-6	7.4E-7	1.4E-5	8.1E-6
Schiller Park	**811600***	**6.8E-6**	**3.3E-6**	**5.0E-6**	**1.2E-6**	**4.9E-6**	**7.3E-7**	**1.4E-5**	**8.7E-6**
Northbrook	**801500***	**3.2E-6**	**1.5E-6**	**2.3E-6**	**5.5E-7**	**2.3E-6**	**3.4E-7**	**6.6E-6**	**7.6E-6**
Northbrook	801800	3.1E-6	1.5E-6	2.3E-6	5.5E-7	2.3E-6	3.4E-7	6.6E-6	6.7E-6

TABLE XVI

LIFETIME EXCESS INHALATION CANCER RISK ESTIMATES, COMPARISON OF METHODS—FORMALDEHYDE

		EPA Superfund-AMD							
		Age 2–6		Age 6–16		Age > 16			
Location	Census Tract	RME	AE	RME	AE	RME	AE	NATA AMD	NATA Modeling
Chicago	**081400***	**2.0E-5**	**9.6E-6**	**1.5E-5**	**3.4E-6**	**1.4E-5**	**2.1E-6**	**3.9E-5**	**2.9E-5**
Schiller Park	760900	2.3E-4	1.1E-4	1.7E-4	4.1E-5	1.7E-4	2.5E-5	4.6E-4	2.5E-5
Schiller Park	770800	2.5E-4	1.2E-4	1.9E-4	4.4E-5	1.8E-4	2.7E-5	5.1E-4	2.9E-5
Schiller Park	**811600***	**2.6E-4**	**1.2E-4**	**1.9E-4**	**4.5E-5**	**1.9E-4**	**2.8E-5**	**5.1E-4**	**2.9E-5**
Northbrook	**801500***	**1.5E-5**	**7.3E-6**	**1.1E-5**	**2.6E-6**	**1.1E-5**	**1.6E-6**	**3.0E-5**	**2.3E-5**
Northbrook	801800	1.5E-5	7.2E-6	1.1E-5	2.6E-6	1.1E-5	1.6E-6	3.0E-5	2.1E-5

The age range-specific ECR estimates using the EPA's Superfund approach utilizing AMD was added together to estimate a lifetime ECR corresponding to RME and AE conditions. Tables XVII and XVIII present these estimates along with ECR estimates based on the other two approaches (i.e., NATA approach utilizing the AMD and EPA's 2005 NATA based on modeling techniques-NATA-modeling). The same results are also depicted in Figures 12 and 13 for benzene and formaldehyde, respectively. These results show that the ECR estimates based on the monitoring results are consistently higher for benzene and formaldehyde at the Schiller Park location. This alludes to spatial variability in benzene and formaldehyde results with certain census tracts being burdened with higher inhalation cancer risks than the others. The source of this variability could partially be explained by the emissions inventory data presented in Sections (IV.A.1) and (IV.A.2), pointing to prominence of on-road and non-road air-pollution sources. Both benzene and formaldehyde are emitted by these emission sources. Benzene ECR based on the EPA monitoring data was the highest in Schiller Park, followed by one location within the urban core (i.e., Chicago) and a suburban location north of the urban core (i.e., Northbrook). Consequently, Chicago had the highest cancer risk based on the NATA modeled results. For formaldehyde, a stronger pattern emerged, with Schiller Park having substantially higher inhalation cancer estimates across all three census tracts for which analysis could be performed. These results should be interpreted with caution since all of the ECR estimates for benzene (i.e., 10^{-6}-10^{-5}) and formaldehyde (i.e., 10^{-5}-10^{-4}) are within an order of magnitude across the census tracts studied and the observed spatial differences may be an artifact of small sample size. It could also be due to errors in emission inventories and/or sampling and laboratory protocols. However, these results show that future research should be conducted in this area and EPA's NATA cancer risk results should only be used to evaluate relative risk across different geographic areas. Furthermore, EPA should not

develop any air-pollution control and management policy based on NATA ECR results. Our results provide a rationale for not developing public health protection policy or cancer risk reduction policy based on NATA results. We advocate personal sampling studies or saturation community-based monitoring in urban, suburban, industrial, rural, and background airsheds, along with epidemiological case-control or cohort studies for carcinogenic air-toxic exposure and cancer risk reduction measures and policy development.

TABLE XVII

LIFETIME EXCESS INHALATION CANCER RISK ESTIMATES, COMPARISON OF TOTAL RISK ACROSS DIFFERENT APPROACHES—BENZENE

		Superfund-AMD [c]			
Location	Census Tract	Total Risk (RME) [a]	Total Risk (AE) [b]	NATA-AMD [d]	NATA Modeling [e]
Chicago	**081400***	**9.6E-6**	**3.0E-6**	**7.9E-6**	**1.6E-5**
Schiller Park	760900	1.5E-5	4.7E-6	1.2E-5	5.7E-6
Schiller Park	770800	1.7E-5	5.2E-6	1.4E-5	8.1E-6
Schiller Park	**811600***	**1.7E-5**	**5.2E-6**	**1.4E-5**	**8.7E-6**
Northbrook	**801500***	**7.8E-6**	**2.4E-6**	**6.6E-6**	**7.6E-6**
Northbrook	801800	7.7E-6	2.4E-6	6.6E-6	6.7E-6

[a] The RME Total Risk was calculated by adding the RME risk estimates for each age group, 2–6, 6–16, and >16, at each census tract location.
[b] The AE Total Risk was calculated by adding the AE risk estimates for each age group, 2–6, 6–16, and >16, at each census-tract location.
[c] Superfund-AMD: EPA Superfund approach to calculating ECR based on AMD.
[d] NATA-AMD: NATA approach to calculating ECR based on AMD.
[e] NATA-Modeling: NATA approach to calculating ECR based on air quality and HEM techniques.

TABLE XVIII

LIFETIME EXCESS INHALATION CANCER RISK ESTIMATES, COMPARISON OF TOTAL RISK—FORMALDEHYDE

		Superfund-AMD [c]			
Location	Census Tract	Total Risk (RME) [a]	Total Risk (AE) [b]	NATA-AMD [d]	NATA Modeling [e]
Chicago	**081400***	**4.8E-5**	**1.5E-5**	**3.9E-5**	**2.9E-5**
Schiller Park	760900	5.7E-4	1.8E-4	4.6E-4	2.5E-5
Schiller Park	770800	6.3E-4	1.9E-4	5.1E-4	2.9E-5
Schiller Park	**811600***	**6.4E-4**	**2.0E-4**	**5.1E-4**	**2.9E-5**
Northbrook	**801500***	**3.7E-5**	**1.2E-5**	**3.0E-5**	**2.3E-5**
Northbrook	801800	3.7E-5	1.1E-5	3.0E-5	2.1E-5

[a] The RME Total Risk was calculated by adding the RME risk estimates for each age group, 2–6, 6–16, and >16, at each census tract location.
[b] The AE Total Risk was calculated by adding the AE risk estimates for each age group, 2–6, 6–16, and >16, at each census tract location.
[c] Superfund-AMD: EPA Superfund approach to calculating ECR based on AMD.
[d] NATA-AMD: NATA approach to calculating ECR based on AMD.
[e] NATA-Modeling: NATA approach to calculating ECR based on air quality and HEM techniques.

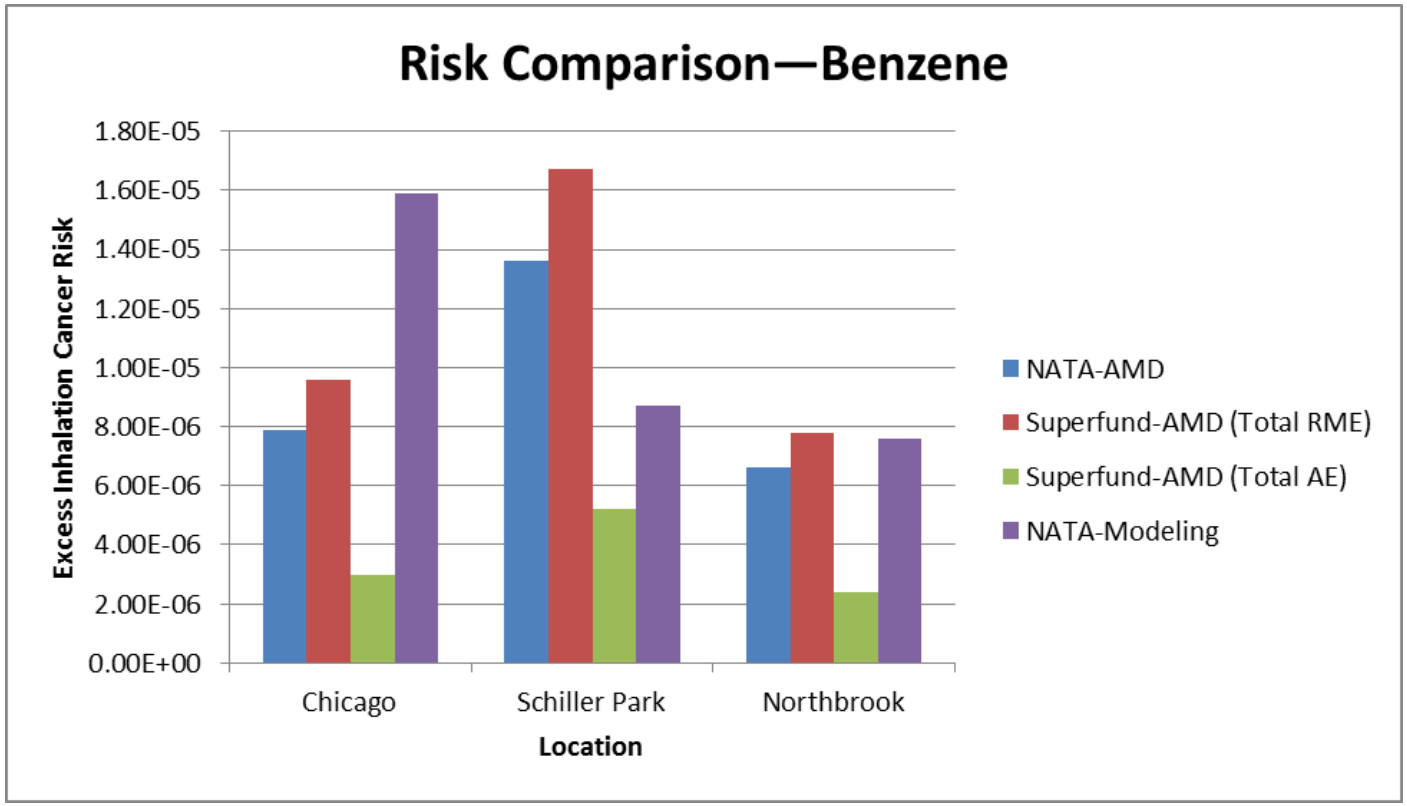

Figure 12. Comparison of inhalation ECR estimates across all approaches employed—benzene.

NATA-AMD: NATA approach to calculating ECR based on AMD.
Superfund-AMD: EPA Superfund approach to calculating ECR based on AMD.
NATA-Modeling: NATA approach to calculating ECR based on air quality and HEM techniques.

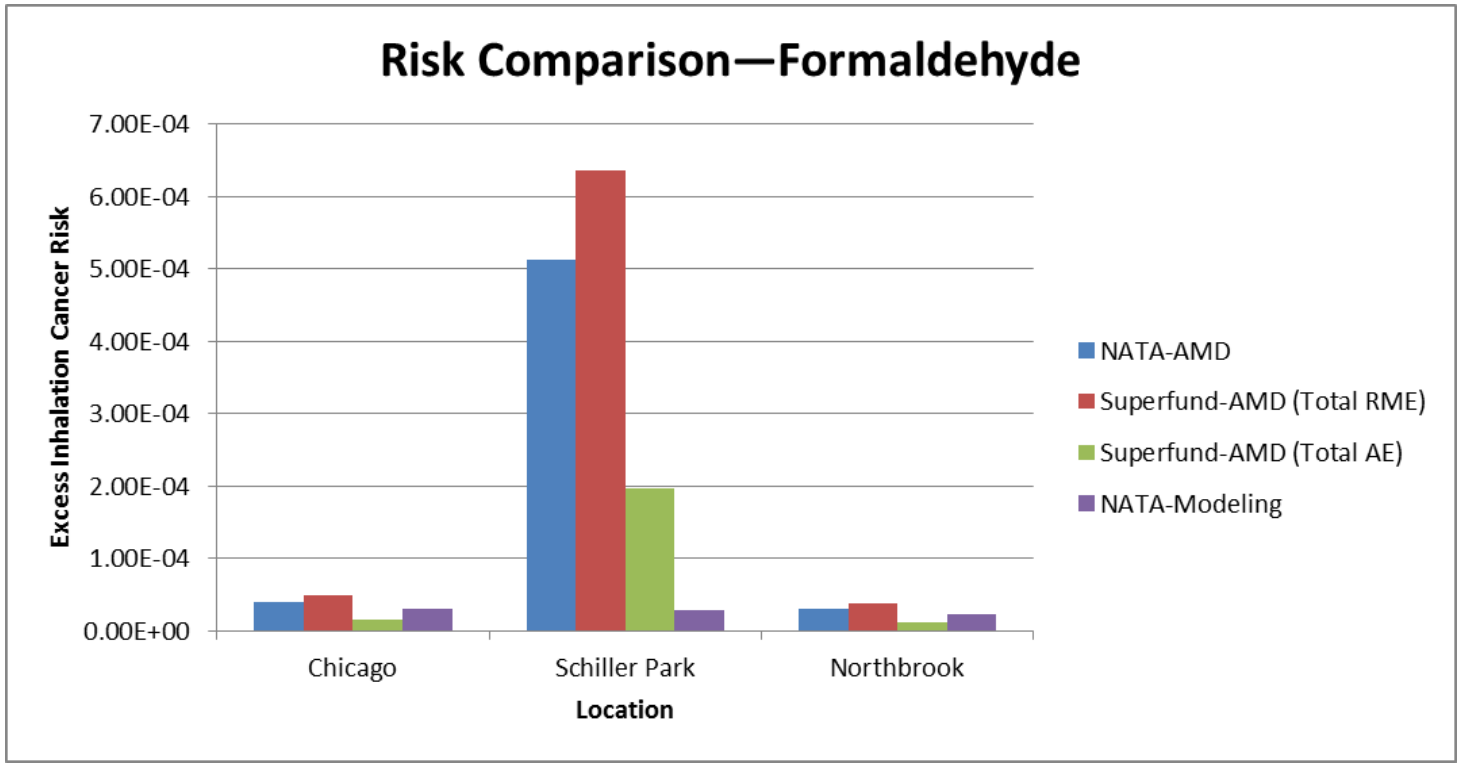

Figure 13. Comparison of inhalation ECR estimates across all approaches employed—formaldehyde.

Superfund-AMD: EPA Superfund approach to calculating ECR based on AMD.
NATA-AMD: NATA approach to calculating ECR based on AMD.
NATA-Modeling: NATA approach to calculating ECR based on air quality and HEM techniques.

V. DISCUSSION

This comprehensive evaluation of emissions characteristics and risk estimates indicates that although the 2005 NATA can guide future public health protection policy in order to reduce the health risk burden in specific locations, the ECR estimates presented in the 2005 NATA should only be used in relative risk analysis and should be used with caution. The emissions estimates at the county level help to identify the specific source categories with the highest emissions and specific geographical areas that are burdened with the highest pollution. In Cook County, it is apparent that the area non-point sources contribute the most to the overall emissions; however, that is not the case in other counties in Illinois. Many rural counties are experiencing higher emissions from point sources due to the presence of large factories. Also, the strong influence of on-road emissions is apparent in more urban locations than rural locations. A study utilizing the 2002 NATA indicated that emissions from mobile and area (nonpoint) sources in Minnesota was responsible for greater estimated human health risk than those from point sources (Pratt, Dymond, and Elickson, 2012). This finding is somewhat consistent with our results based on analysis of the 2005 NATA, since non-point sources are the major contributors to air pollution in Cook County in comparison to other counties in Illinois and the area nonpoint and mobile sources are the risk drivers.

Chemical-specific emissions estimates indicate that toluene and methanol contribute the most to the overall emissions in Cook County at 22% and 10% respectively. Other chemicals contributing greater than 5% include m-xylene, 2,2,4-Trimethylpentane, benzene and xylene (mixture). These chemicals should be closely monitored to determine whether emissions reduction strategies through regulatory and voluntary emissions control programs are successful in reducing the ambient levels of

these pollutants. In addition, additional air-pollution reduction strategies should be developed and implemented to achieve further emissions and exposure reductions.

The chemical-specific risk estimates indicate that formaldehyde and benzene contributed the most to the overall inhalation cancer risk in Cook County. Other notable contributions include naphthalene, acetaldehyde, 1,4,- dichlorobenzene, and tetrachloroethylene, all contributing greater than 5% to the overall cancer risk. Finding the top contributing chemicals can help focus on areas where specific efforts for emissions, exposure, and risk-reduction practices can be implemented. We identified 22 census tracts located in Cook County that have an excess inhalation cancer risk greater than or equal to $1x10^{-4}$, which should be targeted for exposure and risk reduction to reduce the overall cancer risk burden on the population. Also, a more complex analysis that takes the land characteristics, socioeconomic variables, and cancer incidence rates in those specific census tracts into account should be performed to determine if there is any correlation and if there are specific risk factors.

To support the modeled concentration results for the risk calculation comparison, a report was created by the EPA to summarize and present findings from the model-to-monitor study results for the EPA 2005 NATA. This report found that there was a good agreement (i.e., interquartile values within a factor of two) between the ambient concentrations and the NATA 2005 model for acetaldehyde, arsenic, benzene, carbon tetrachloride, formaldehyde, methyl chloride, and toluene (Eastern Research Group, 2010). These results further strengthen the risk estimates concluded in this study, with the concentration estimates being extremely important in the comparison.

The analysis of the 2002 NATA by Logue et al. (2011) found that there was variability across chemicals in the strength of NATA to predict risks, concentrations, and exposures. In order to further evaluate the validity of this hypothesis for the current NATA, we estimated ECRs using AMD for the concentration term by following the 2005

NATA's approach as well as the approach taken by the EPA Superfund Risk Assessment program. We also compared these ECRs based on monitoring data against the ECR estimates of the 2005 NATA derived using air quality and HEM. Based on the comparison of risk calculations and concentrations from the 2005 NATA, this observation is still apparent; however, there are still a few similarities. The EPA total RME ECR estimates for benzene were the highest in Schiller Park and Northbrook across all risk calculation techniques at those locations and the highest risk estimates at each location for formaldehyde. However, Chicago had the highest cancer risk from benzene based on the NATA modeling results. There were also differences in risk severity between the results for the EPA Superfund AE approach based on AMD and the results for the NATA modeling approach, with the EPA Superfund AE resulting in the lowest risk estimates for both chemicals at each monitoring station except for formaldehyde at the Schiller Park location. We should caution that these ECR results are limited to only two chemicals. The addition of inhalation cancer risks posed by other carcinogens found in the list of 177 HAPs that formed the basis of NATA cancer risk analysis would result in higher risk than what is presented in this study.

Figures 14 and Figure 15 show the spatial trend in ECR estimates across different risk assessment approaches adopted for benzene and formaldehyde, respectively. For benzene, location-specific ECR is the highest at the Schiller Park sampling station, across all approaches utilizing the EPA monitoring data, as shown in Figure 14. However, the NATA modeling approach found Chicago to have the highest risk. For this location, the NATA model results may have been unable to account for the lake breezes dispersing the benzene emissions.

These spatial differences in the ECR (i.e., an order of magnitude) across the census tracts studied could also be an artifact of small sample size or could be due to errors in emission inventories and/or sampling and laboratory protocols. Future analysis

of traffic density data and mobile-source risk contributions near this air-monitoring location should be performed to determine whether traffic and vehicle emissions are indeed leading to an increased concentration of benzene and elevated cancer risks in the Schiller Park census tract in which the air monitoring is located. Such a study should also assess the interaction between mobile-source emissions and exposures and associated ECR spatially using GIS techniques. For formaldehyde, as shown in Figure 15, the ECR estimates based on AMD collected at the Schiller Park location were of concern, with all three approaches adopted resulting in a cancer risk greater than the cancer risk acceptability threshold of $1x10^{-4}$. This may stem from sampling stations being in close proximity to O'Hare airport and adjacent highways. Future temporal analysis across more current years at this location should be performed in order to determine if the formaldehyde concentrations and associated risks are still indeed elevated.

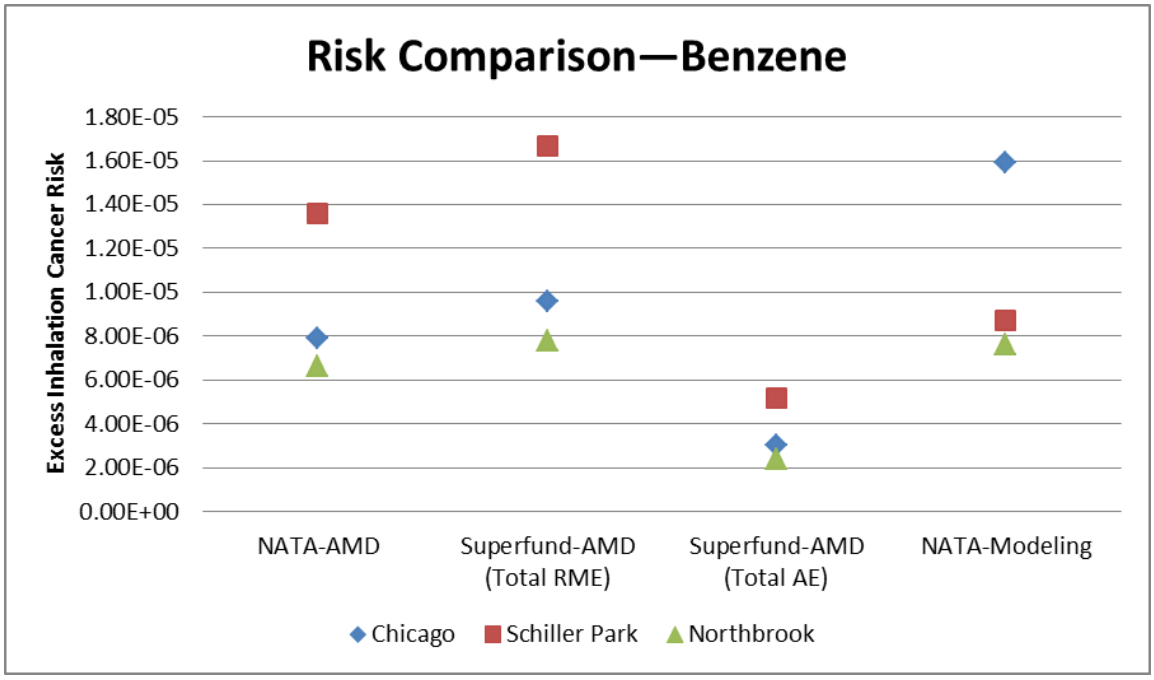

Figure 14. Inhalation ECR trends across air monitoring station locations and ECR estimation approaches—benzene.

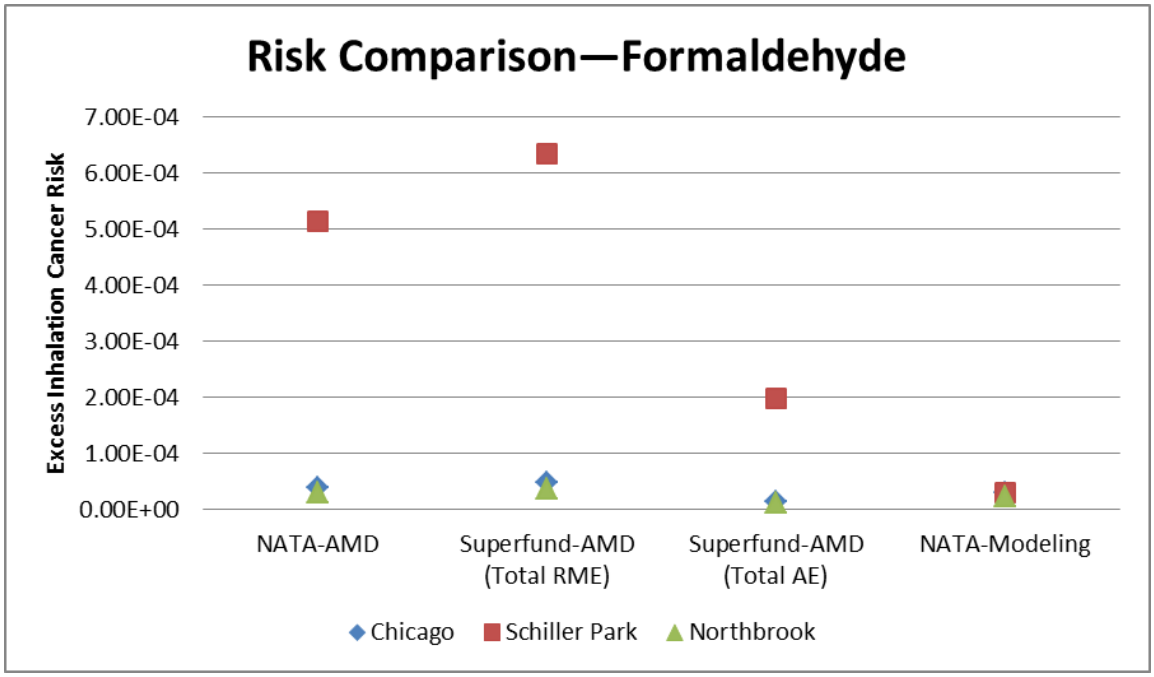

Figure 15. Inhalation ECR trends across air monitoring station locations and ECR estimation approaches—formaldehyde.

The EPA monitoring results for benzene and formaldehyde indicate temporal trends that can be utilized for future sampling strategies and further strengthen the EPA current sampling timeline. Figures 16 and 17 illustrate the monthly averages for benzene and formaldehyde in 2005 at all three EPA sampling locations within Cook County. It is apparent that the monitoring results indicate trends in monthly averages.

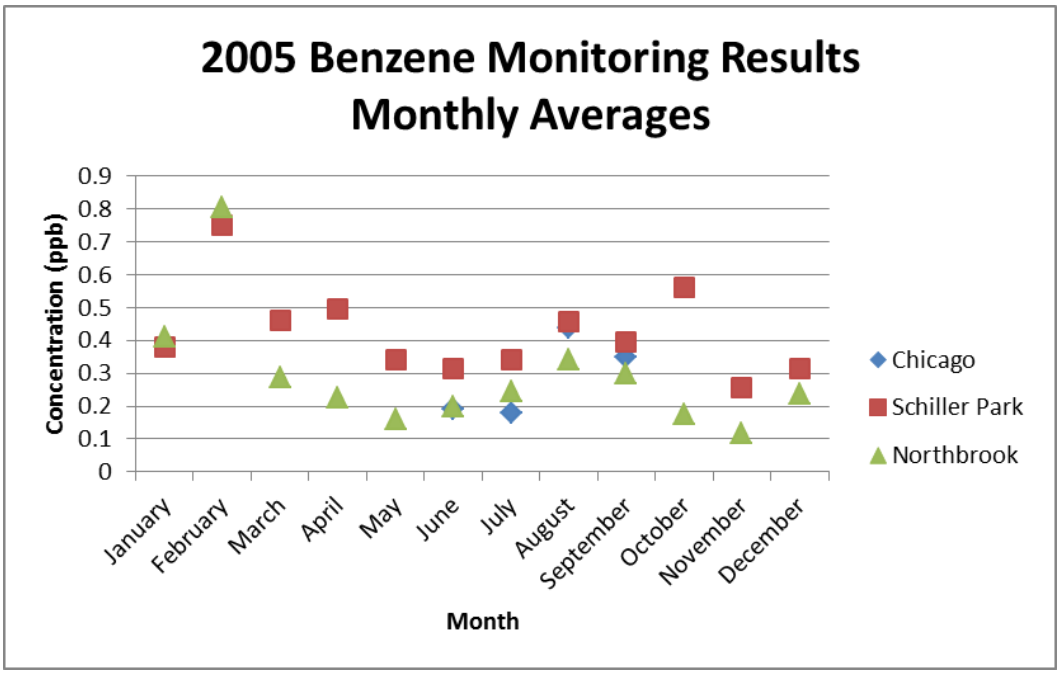

Figure 16. Monthly averages of benzene monitoring results at three locations within Cook County in 2005.

From 2003–2006, Illinois EPA (IEPA) conducted the IEPA's Large Area Monitoring Program (LAMP) project, which was designed to test an innovative diffusion tube technology for measuring concentrations of benzene, ethyl benzene, toluene, and xylene (BETX), and perform a saturation study that would permit preliminary characterization of BETX concentrations throughout the Greater Chicago Metropolitan area. The 2003 LAMP project was deemed successful in that it found the diffusion tube technology to provide highly correlated results to those obtained using field deployed gas chromatography. The 2005 Phase II portion of this study indicated that the Northbrook and Chicago BETX concentrations were very comparable; however, the Schiller Park concentrations were found to be much higher. The IEPA concluded that the Northbrook and Chicago locations are likely representative of a significant portion of urbanized areas, while Schiller Park may be more representative of areas near major

expressways and airports. Temporally, the IEPA found that the months with the highest concentrations were January–February and August–September, with the lowest months being March and April. Benzene and 1,3-butadiene, two mobile-source air toxics, show cool season peaks on the national scale as well (USEPA, 2009). This could be the reason for the low benzene risk results in the Chicago location because the monitoring results were only for the summer months.

The LAMP study results from 2005 and the monitoring results from 2005 are extremely similar. Figure 16 illustrates that the Schiller Park location had the highest benzene results in 2005, and the months with the highest concentrations for all sampling stations were January, February, August, September, and October. This further strengthens the importance of sampling during peak months and helps to pinpoint areas of concern including major expressways and airports.

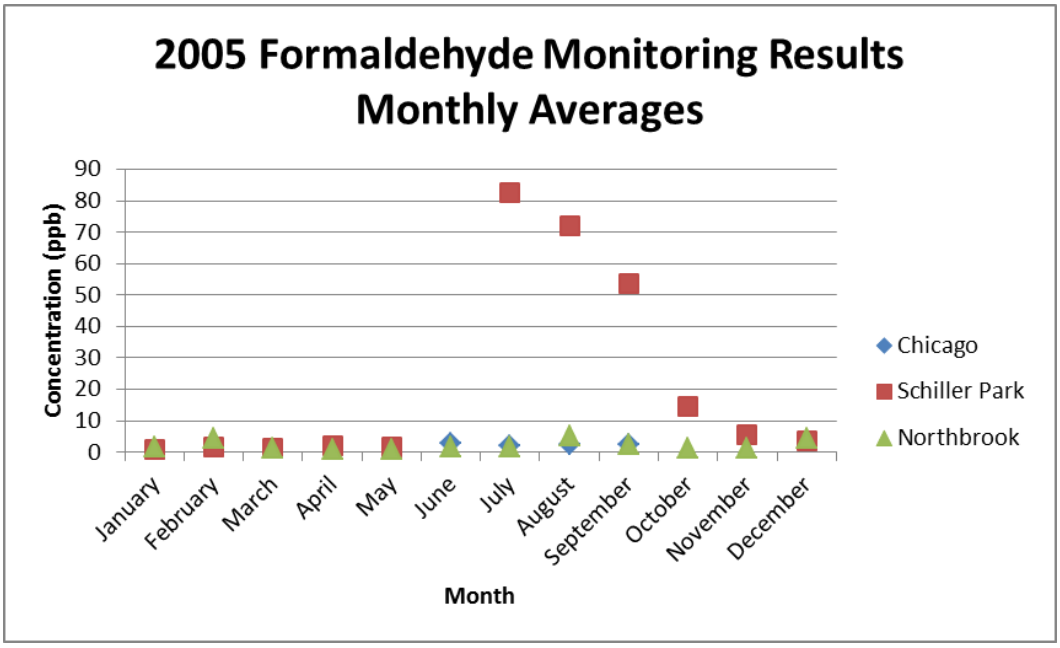

Figure 17. Monthly averages of formaldehyde monitoring results at three locations within Cook County in 2005.

Figure 17 clearly indicates that the Schiller Park location had the highest formaldehyde monitoring results in 2005. This was also concluded in an EPA Chicago O'Hare Airport Air Toxic Monitoring Program performed in 2000, where the EPA, in measuring the airborne levels of various contaminants in the vicinity of O'Hare as well as other locations in the Chicago area to assess airport related emissions, found acetaldehyde and formaldehyde to be the highest at the two O'Hare Airport sites than at any of the other three Chicago area sites (IEPA, 2002). These results indicate that the major source of aldehyde emissions in any large metropolitan area come from mobile sources. Illustrated in both Figure 17 and current literature, the summer months tend to have an increased concentration of formaldehyde due to its dependence on sunlight. It has been estimated that 85%–95% of formaldehyde concentrations originate from secondary photochemical production, supporting the observed warm season peak. (USEPA, 2009; Grosjean, Swanson, and Ellis, 2002).

Our results should give the impetus for future research focusing on uncovering the influence of roadway emissions and traffic density on elevated concentrations and cancer risk estimates; correlation between cancer incidence at the census-tract level and census-tract level cancer risk estimates; the evaluation of effectiveness of the maximum achievable control technology standards in reducing air toxics emitted from a variety of sources; comparison between the NATA modeling results with both deterministic (as we performed here) and probabilistic risk assessment methods utilizing Monte Carlo simulation in order to better characterize variability and uncertainty in ECR estimates; and correlations between high HAP emissions and cancer risks in areas with low socioeconomic status.

Associations between cancer risk estimates and race/ethnicity have been reported in the literature. For example, a case study examined the relationship between NATA data for emissions and cancer risks and race, ethnicity, and socioeconomic status

in order to determine whether potential health risks from exposure to hazardous air pollutants in the state of Florida disproportionately impact certain race/ethnicity and socioeconomic classes. This study found that locations with a higher proportion of African American residents had significantly greater cancer risk from exposure to air toxics in 97% of the census tracts, and those areas with a higher proportion of Hispanic residents indicated a greater risk in 65% of the state. However, there was variability between the cities and counties throughout the state (Gilbert and Chakraborty, 2011). Also, an environmental justice study conducted in El Paso County, Texas, found that, in analyzing traditional environmental justice variables (race, age, and income), Hispanic ethnic status was associated with significantly higher relative cancer risk from exposure to air toxics while White racial status is associated with significantly lower relative risk (Collins et al., 2011). These studies show that the data similar to the EPA's NATA could not only be utilized to guide future air-pollution control policy but also to develop hypothesis for potential association between health effects and air toxic emissions/exposures.

Both this study and the NATA results have limitations that must be addressed before interpretation. The limitations of this study include:

- The inability to determine a temporal trend in risk estimates using the NATA because of the restriction to the assessment year.
- Uncertainty and variability in the risk calculations including variations in where people live, their levels of activity, degree of susceptibility or sensitivity.
- The use of the proper EPA exposure factors when calculating the lifetime average daily dose and cumulative risk for the location and population of interest.

The limitations presented with the 2005 NATA include:

- It applies to only geographical areas.
- Does not reflect exposure and risk from all compounds
- Does not reflect all pathways of exposure
- Reflects only outdoor air, does not fully capture variation in background ambient air concentrations.
- Might systematically underestimate ambient air concentrations, based on assumptions where data is missing.
- Contains uncertainty (ICF International, 2011)

Our goals, in general, should aid in steering the scientific and regulatory debate on future environmental management policies, rules, and regulations for cancer-causing chemicals; degree of effectiveness of the current air-pollution control technologies and policies; identification of areas with high air toxic exposures and inhalation cancer risks; and technical input to public health agencies about potential environmental justice areas for targeted interventions. These important issues are highlighted in our study using two of the highest contributors to cumulative cancer risk in Cook County, Illinois (i.e., benzene and formaldehyde.)

Although EPA's NATA was very beneficial for performing air quality as well as excess cancer risk analysis spatially, we advocate that EPA's NATA cancer risk results should only be used to evaluate relative risks across different geographic areas. Furthermore, EPA should not develop any air-pollution control and management policy based on NATA ECR results. The discrepancy that we found between the ECR estimates based on NATA modeling approach (i.e., lowest) and the ECR estimates

based on air-quality monitoring data approaches (both NATA approach and EPA Superfund approach) provide a rationale for not developing exposure control and/or public health protection policy for cancer risk reduction based on NATA results. We advocate personal sampling studies or saturation community-based monitoring in urban, suburban, industrial, rural, and background airsheds to determine exposure concentration of air toxics, along with descriptive epidemiology studies utilizing GIS analysis for hypothesis development and risk factor determination and observational epidemiology studies (case-control or cohort) for dose-response relationship development for potential health effects. The data produced from these studies should be synthesized and a scientific weight of evidence analysis should be performed to assess carcinogenic effects of air toxics on human populations, including susceptible populations. Such a database would lead to the development of effective carcinogenic air-toxic exposure and cancer risk reduction measures and public health policy development.

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VITA

NAME:	Frank J. Pagone
EDUCATION:	MS Industrial Hygiene, University of Illinois at Chicago, Chicago, IL, Expected Summer 2013.
	BS General Health Science, Purdue University, West Lafayette, Indiana, 2009
HONORS:	2nd Place Winner of the 2013 Masters Level Student Poster Competition at the Air and Waste Management Association106th Annual Conference and Exhibition, Chicago, IL, 2013
	Award of Appreciation at the American Industrial Hygiene Association Annual Conference and Exposition, Social Concerns Committee, Student Poster Session, Montreal, QC, 2013
	Award of Appreciation at the American Industrial Hygiene Association Annual Conference and Exposition, Social Concerns Committee, Student Poster Session, Indianapolis, IN, 2012
PROFESSIONAL MEMBERSHIP:	American Industrial Hygiene Association American Society of Safety Engineers Public Health Student Association Air and Waste Management Association
POSTER PRESENTATIONS:	Air and Waste Management Association 106th Annual Conference and Exhibition, Student Poster Competition, Chicago, IL, 2013
	American Industrial Hygiene Conference and Exposition, Student Poster Presentations, Montreal, QC, 2013
	University of Illinois at Chicago Student Research Forum, Student Poster Presentations, Chicago, IL, 2013
	University of Illinois at Chicago School of Public Health 8th Annual Student Research/Practice Awards Day, Student Poster Presentations, Chicago, IL 2013
	University of Illinois at Chicago 5th Annual Minority Health in the Midwest Conference, Student Poster Presentations, Chicago, IL 2013
	American Industrial Hygiene Conference and Exposition, Student Poster Presentations, Indianapolis, IN, 2012

University of Illinois at Chicago School of Public Health 7th Annual Student Research/Practice Awards Day, Student Poster Presentations, Chicago, IL 2012

American Industrial Hygiene Association Student Night, Student Poster Presentations, LaGrange, IL, 2012

CERTIFICATIONS: OHSA 10-hr Construction Safety Certification
40-hr Hazardous Materials Safety Training
50-hr American Red Cross First Responder Course