Health Consultation

PUBLIC COMMENT VERSION

Evaluation of Ethylene Oxide Concentrations in Outdoor

Air Near STERIGENICS

WILLOWBROOK, DUPAGE COUNTY,

ILLINOIS EPA FACILITY ID:

IL0000433594

NOVEMBER 17, 2023
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Prepared by the

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Agency for Toxic Substances and Disease Registry
Office of Community Health and Hazard Assessment
Eastern Section
Atlanta, Georgia 30333

Health Consultation: A Note of Explanation

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HEALTH CONSULTATION

Evaluation of Ethylene Oxide Concentrations in Outdoor Air Near

STERIGENICS

WILLOWBROOK, DUPAGE COUNTY, ILLINOIS

EPA FACILITY ID: IL0000433594

Prepared by the:

U.S. Department of Health and Human Services
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List of Abbreviations and Acronyms

ADAF	Age dependent adjustment factor
AQS	Air Quality System
ATSDR	Agency for Toxic Substances and Disease Registry
CI	Confidence interval
CREG	Cancer risk evaluation Guide
CV	Comparison value
DA	Duration adjustment
DHHS	U.S. Department of Health and Human Services
EPA	U.S. Environmental Protection Agency
EPC	Exposure point concentration
EtO	Ethylene Oxide
GAM	Generalized Additive Model
HMC	Hamiltonian monte carlo
IARC	International Agency for Research on Cancer
IDPH	Illinois Department of Public Health
ISCR	Illinois State Cancer Registry
IUR	Inhalation unit risk
LOESS	Locally estimated scatterplot smoothing
MDL	Method detection limit
MRL	Minimum Risk Level
NATA	National Air Toxics Assessment
NATTS	National Air Toxics Trends Stations
NESHAP	National Emission Standards for Hazardous Air Pollutants
NIOSH	National Institute for Occupational Safety and Health
NTP	National Toxicology Program
ROP	Residential occupancy period
SLAMS	State or Local Air Monitoring Stations
TRI	Toxics Release Inventory
UATS	Urban Air Toxics Strategy stations
UCL	Upper confidence limit
VOC	Volatile organic compound

1. Summary

Introduction

The Agency for Toxic Substances and Disease Registry (ATSDR) in Atlanta, Georgia, is a federal public health agency within the U.S. Department of Health and Human Services (DHHS). ATSDR's purpose is to serve the public by using the best science, taking responsive public health actions, and providing trusted health information to prevent people from coming into contact with harmful toxic substances. In 2018, the United States Environmental Protection Agency (U.S. EPA) requested that ATSDR review air modeling estimates of ethylene oxide (EtO) in outdoor air along with short term air monitoring data to assess potential risk from exposure to emissions from the Sterigenics medical sterilization facility in Willowbrook, IL. In response, ATSDR wrote a letter health consultation, released on July 26, 2018, which recommended that U.S. EPA conduct long-term EtO air monitoring near the Sterigenics facility ([ATSDR] 2018a, 2018b).

This ATSDR health consultation evaluates health risks from breathing EtO in outdoor air near the Sterigenics medical sterilization facility using longer-term air monitoring data collected by U.S. EPA between November 12, 2018 and March 31, 2019. The EtO monitoring occurred at eight air monitoring stations within a mile of the Sterigenics facility during: 1) the sterilization operations at Sterigenics (November 12, 2018 - February 15, 2019), and 2) during a 6-week post-closure period (February 16 - March 31, 2019). ATSDR evaluated outdoor EtO air concentrations to estimate exposure to EtO and the associated noncancer health effects and cancer risks to residents and off-site workers (people who work near but not at Sterigenics) within a mile of the Sterigenics facility. ATSDR also analyzed U.S. EPA's Air Quality System (AQS) EtO air monitoring data collected outdoors across the United States, which reflect background EtO concentrations in areas without known EtO sources. The Sterigenics facility in Willowbrook, IL was permanently closed in September 2019.

U.S. EPA detailed imprecision in the measured EtO concentrations near the method detection limit (MDL) and bias resulting from formation of EtO inside some canisters in two memos and an explainer document published in 2020-2021 ([U.S. EPA] 2021b; [U.S. EPA] 2021e; [U.S. EPA] 2021d). In response, ATSDR modeled the effects of canister type and holding time at two ambient air monitoring sites in Cook County, IL using a generalized additive model (GAM) that was fit using a Bayesian method to account for nondetects explicitly. The Cook County, IL site samples were analyzed at the same laboratory as the Willowbrook site data but were not near the Sterigenics site. The GAM model coefficients were used to adjust the Willowbrook data for the effects of holding time, analytical lag, and seasonality. These data were then used to estimate an exposure point concentration (EPC) by calculating a 95% upper confidence limit of the mean (95% UCL). ATSDR then used the 95% UCL of the adjusted EtO air concentrations to estimate lifetime excess cancer risks and noncancer health effects for Willowbrook residents and off-site workers during the operational and post-closure periods. ATSDR uses theoretical estimates of excess lifetime cancer risk as a tool for making public health conclusions and recommendations; these cancer risks are not an actual estimate of cancer cases in a community nor are they estimates of an individual's cancer risk.

After reviewing available data, ATSDR reached the following three health conclusions:

Conclusion 1

ATSDR concludes there is a concern for an increased lifetime risk of cancer associated with long-term EtO exposure for people who breathed the air within one mile of Sterigenics for years prior to February 15, 2019. The increased cancer risk is based on EtO concentrations measured in the air during sterilization operations and statistically adjusted for positive bias and seasonality.

Basis for Decision

- Breathing EtO in the air can cause cancer ([U.S. EPA] 2016). The best evidence of which cancers might be associated with breathing EtO comes from studies of workers exposed to high levels. Evidence from human epidemiological studies is strong but less than conclusive in associating specific cancers with EtO exposure ([U.S. EPA] 2016). Studies of a large cohort of workers observed a dose-response in the incidence of female breast cancer and breast cancer mortality in women (Steenland et al. 2003; Steenland, Stayner, and Deddens 2004). A study from the same cohort also found increased mortality in male workers from certain lymphoid cancers (non-Hodgkin lymphoma [also known as non-Hodgkin's lymphoma or NHL], myeloma, and lymphocytic leukemia as a group (Steenland, Stayner, and Deddens 2004; [U.S. EPA] 2016; [IARC] 2012).
- ATSDR estimated lifetime excess cancer risks from long-term EtO exposure while the Sterigenics facility was operating; the risks were based on EtO concentrations adjusted for positive bias within a mile of the facility between November 12, 2018 and February 15, 2019.
- The statistical adjustment (generalized additive model or GAM) did not remove all uncertainty associated with the positive sampling bias, but the adjustment did allow ATSDR to estimate cancer risks more accurately in order to make public health conclusions.
- All of U.S. EPA's air monitors were within 1 mile of Sterigenics. All monitors except the furthest air monitor had statistically significantly higher EtO air concentrations during operations compared to when Sterigenics was closed.
- During Sterigenics sterilization operations, EtO concentrations were highest at air monitoring stations closest to the facility and quickly decreased with distance from the facility.
- Residential lifetime excess cancer risks from long-term EtO exposure within 1 mile of the facility during operations ranged from 4 to 10 excess cancers in a population of 10,000, which led ATSDR to conclude there was a public health concern for increased cancer risk based on past exposure. Lifetime, excess cancer risks are estimates used to inform public health decision-making. They are not measurements of actual cases of cancer in a community.
- ATSDR estimated the cancer risks in this document assuming years of breathing the EtO concentrations EPA measured from November 2018-

February 2019. There is no long-term air monitoring data to assess EtO concentrations and associated cancer risk prior to November 2018. EtO emissions may have been greater in the past.

Conclusion 2

ATSDR concludes that people who breathed in EtO concentrations measured in the air near the Sterigenics facility when it was operating are not expected to be at risk for noncancer health effects due to EtO exposure.

Basis for Decision

- The highest measured average EtO air concentrations in residential and off-site worker locations during Sterigenics operations were well below noncancer health guidelines and significantly below the lowest concentrations that have been reported to result in noncancer health effects in scientific studies.
- People who lived, worked, went to school, shopped, or traveled near Sterigenics are not expected to have experienced noncancer health effects from exposure to EtO concentrations that were measured in the community based on EtO concentrations measured from November 2018-February 2019.

Conclusion 3

After Sterigenics stopped EtO sterilization operations on February 15, 2019, EtO concentrations in the air within a mile of the facility were similar to background levels observed across the United States. Lifetime excess cancer risk from EtO exposure for people living or working in Willowbrook after Sterigenics closed is similar to EtO-related cancer risk for people living or working in other areas without a major EtO source.

Basis for Decision

- EtO concentrations were lower and less variable after Sterigenics closed compared to when it was operating.
- Background outdoor air EtO concentrations were similar in the following locations:
    - All eight Willowbrook monitoring stations following the closure of Sterigenics,
    - Two Cook County background air monitoring stations,
    - Air quality monitoring stations across the United States in areas with no known source of EtO emissions.
- There are uncertainties associated with estimating cancer risk associated with background concentrations of EtO.

Next Steps

Emissions of EtO from the Sterigenics facility in Willowbrook have ceased as the facility is permanently closed. Consequently, additional steps to control exposure to EtO from this facility are not needed.

To address the method detection limit issue, U.S. EPA is working on developing new analytical methods to improve the sensitivity and accuracy of measuring low-level outdoor air EtO concentrations below background EtO levels. U.S. EPA is also conducting research on the factors contributing to positive bias of EtO concentrations measured air sampling collected in canisters and has developed new

air sampling and measurement method (method TO-15A) to reduce the influence of positive bias. (Whitaker et al. 2019)

ATSDR recommends:

- Concerned residents talk with their doctors about health concerns related to EtO exposures.
- U.S. EPA improve the analytical methods to accurately measure EtO at lower concentrations by lowering the EtO method detection limit and the impact of EtO canister effect.

For More Information:

If you have questions about this document or ATSDR's work on EtO in ambient air, call our toll-free number at 1-800-CDC-INFO and ask for information on the ATSDR health consultation on EtO concentrations in Willowbrook near the Sterigenics facility.

2. Purpose and Statement of Issues

This ATSDR health consultation evaluates health risks from EtO concentrations measured by the United States Environmental Protection Agency (U.S. EPA) in outdoor (ambient) air within a mile of the Sterigenics U.S., LLC medical sterilization facility in Willowbrook, IL during the operation of Sterigenics (November 12, 2018-February 15, 2019) and during a 6-week post-closure period (February 16-March 31, 2019). ATSDR also analyzed EtO air monitoring data that were collected across the United States, which reflect background EtO concentrations in areas without known EtO emission sources. The purposes of the document are:

- To evaluate inhalation of EtO in outdoor air for people who live (residential) and/or work (off-site worker) near the Sterigenics facility both during normal operations and after the facility closed.
- To estimate lifetime excess cancer risk and noncancer health effects from the EtO exposure.
- To understand whether Sterigenics contributed to EtO concentrations in outdoor air while it was operating.

In September 2020, U.S. EPA informed ATSDR of two issues that affect confidence in background levels of measured EtO concentrations using the U.S. EPA method for EtO lab analysis (U.S. EPA analytical method TO-15) ([U.S. EPA] 2021b; McClenny and Holdren 1999). The first issue is the uncertainty of measuring EtO concentrations near the method detection limit (MDL). ATSDR uses a health protective statistical approach and exposure assumptions in our calculations of EtO exposure to ensure our conclusions protect public health even when there are measurements of contaminants near or below the MDL.

The second issue is *positive bias* (artificially high EtO concentrations) in EtO concentrations collected and analyzed in some air sampling canisters using U.S. EPA method TO-15, Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air. U.S. EPA released two memoranda in May 2021 summarizing studies that demonstrate the formation and growth of EtO over time in clean canisters, called the "EtO canister effect" ([U.S. EPA] 2021e; [U.S. EPA] 2021d). In response, ATSDR conducted an independent analysis to estimate the impact of positive bias on the Willowbrook air sampling data using background EtO concentrations measured at two air quality monitoring stations in Cook County, IL. This analysis led to an adjustment of measured EtO concentrations in Willowbrook using a GAM which allowed for better estimates of EtO concentrations that people may have been

breathing in the community (See Analysis of Positive Bias and Seasonal Trends in Measured EtO Concentrations section, and Appendix D).

3. Background

On February 26, 2018, U.S. EPA Region 5 requested ATSDR review estimated EtO concentrations in outdoor air near Willowbrook, IL. ATSDR reviewed computer-modeled EtO concentrations. At ATSDR's request, U.S. EPA also collected EtO air measurements near the facility on May 16-18, 2018. ATSDR issued a letter health consultation report to U.S. EPA Region 5 based on the modeling and short-term air sampling on July 26, 2018 ([ATSDR] 2018a, 2018b).

One of the recommendations of that letter health consultation was that U.S. EPA work with Sterigenics to initiate long-term air monitoring. This health consultation analyzes EtO air monitoring data that U.S. EPA collected from November 2018 through March 2019.

3.1. Site Description and History

EtO is a highly flammable colorless gas classified as a volatile organic compound (VOC). It does not have an odor and would not be flammable at levels that have been measured in outdoor air in communities. EtO is commonly used in commercial sterilization facilities and hospitals to sterilize medical and plastic devices that cannot be sterilized by steam or radiation. It is also used to fumigate some food items such as spices, dried herbs, dried vegetables, and some nuts. Less than 1% of EtO used in industry worldwide is used in the sterilizing industry, but commercial sterilizers likely account for a significant portion of EtO air emissions in the United States ([U.S. EPA] 2017; [ATSDR] 2020). Most EtO is used to make other chemicals that go to manufacturing products such as antifreeze, textiles, plastics, detergents, and adhesives. U.S. EPA has measured EtO across the United States away from known sources.

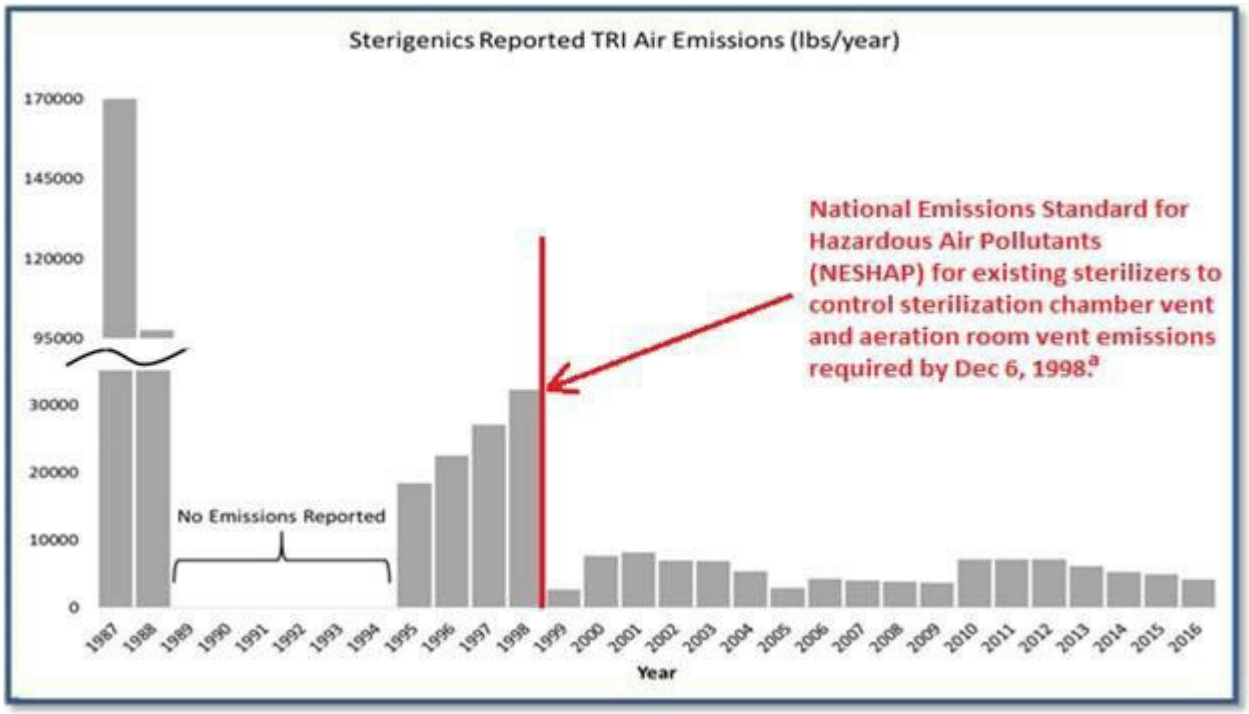
Sterigenics was a commercial sterilizing facility located in a mixed residential, commercial, and industrial area in Willowbrook, IL (see maps in Appendix A). At this location, Sterigenics injected EtO into sealed sterilization chambers to sterilize medical devices for designated periods of time, then moved sterilized products to aeration chambers prior to shipping products off-site.

3.1.1. Sterigenics Emissions and History

The sterilization chambers in the Willowbrook facility were contained in two buildings. Building 1 chambers were constructed in 1984, while Building 2 chambers were built in 1999 and 2012. Pollution control technology included acid water scrubbers and dry bed reactors that converted the EtO to ethylene glycol after the sterilization process ([Illinois EPA] 2015). Although back-vents on the units were historically uncontrolled, Sterigenics installed engineering controls to reroute EtO sterilization chamber back vent emissions to the existing control system at the end of July 2018 ([IARC] 2012). Despite the installation of back vent controls, the U.S. EPA air monitoring analyzed in this document revealed ongoing impacts to outdoor air quality from Sterigenics's fugitive EtO emissions. As a result, on February 15, 2019, the Illinois Environmental Protection Agency (Illinois EPA) Director issued a "Seal Order" to "prevent the commencement of any new sterilization cycles using ethylene oxide until measures are in place to prevent emissions of ethylene oxide that contribute to ambient levels of ethylene oxide which present a public health hazard to residents and off-site workers in the Willowbrook community" ([Illinois EPA] 2019b). According to an Illinois EPA inspection report, the last batch of sterilized material was shipped offsite on February 23, 2019 ([Illinois EPA] 2019b).

From 1987-2016 Sterigenics reported annual emissions estimates to the U.S. EPA's Toxic Release Inventory (TRI). TRI is a database of annual chemical emissions reported by industry and federal facilities. TRI emissions data are limited in that emissions may be estimated in a different fashion across different industries, facilities, and years. The emissions data are reported by volume of EtO emitted and cannot be used to estimate EtO concentrations in the community. Further, required reporting began in 1987 and does not include all facilities. Keeping its limitations in mind, data reported to TRI from Sterigenics indicate that EtO emissions were higher in Willowbrook for the early years of their operations until national emissions standards for hazardous air pollutants (NESHAP) for the sterilizer industry were established and implemented in 1999. Emissions at Sterigenics (Figure 1, below), show a marked decrease beginning in 1999 despite having opened operations in Building 2 that same year.

Figure 1. Historical EtO emissions from Sterigenics, LLC Willowbrook from the U.S. EPA Toxics Release Inventory



Data Source: U.S. EPA, Region 5. [a] U.S. EPA. 1997 (updated March 2004). Ethylene Oxide Commercial Sterilization and Fumigation Operations NESHAP Implementation Document. Office of Air Quality and Standards. Research Triangle Park, NC. EPA-456/R-97-004.

3.1.2. Sterigenics Closure

In June 2019, Illinois Senate Bill 1852, (the Matt Haller Act, or Public Act 101-0022) (Illinois General Assembly 2019) and Senate Bill 1854 (Public Act 101-0023) ("Amendment to The Environmental Protection Act, Public Act 101-0023" 2019) were passed, requiring 100% capture of all fugitive EtO emissions within a facility, a 99.9% reduction in stack emissions, and unannounced inspections of sterilizing facilities and ambient air testing for EtO throughout the state. In September 2019, Sterigenics was granted a construction permit to comply with the new Illinois Matt Haller Act state EtO emissions regulations, but later that month Sterigenics announced that due to an inability to renew its lease with

the property owner in Willowbrook, the facility will remain permanently closed (Sterigenics 2019; [Illinois EPA] 2019a).

3.2. U.S. EPA's 2016 Evaluation of the Inhalation Carcinogenicity of Ethylene Oxide

What we know about environmental contaminants changes as studies are conducted and we learn more about the toxic effects of pollutants in the body. For this reason, U.S. EPA periodically reassesses chemicals based on new scientific research. In December 2016, U.S. EPA finalized a toxicological review of human and animal health outcome studies of EtO exposure and concluded that EtO is "carcinogenic to humans" by inhalation route of exposure. According to EPA, in people employed in EtO-manufacturing facilities and in sterilizing facilities, there is "strong evidence of an increased risk of cancer of the lymphohematopoietic system", in particular for lymphoid cancer (i.e., non-Hodgkin lymphoma [NHL], myeloma, and lymphocytic leukemia) in males and breast cancer in females ([U.S. EPA] 2016).

When U.S. EPA conducted this review, they updated the inhalation unit risk (IUR) for evaluating the potential cancer risks posed by inhalation exposure to EtO. An IUR is an upper bound estimate of the increased cancer risk from inhalation exposure to a concentration of 1 microgram of EtO per cubic meter of air ($\mu g/m^3$) for a lifetime. The IUR can be multiplied by air concentrations (in $\mu g/m^3$) to estimate lifetime excess cancer risks from breathing EtO over a given number of years. The revised IUR assumes EtO is about 30 times more potent for adults and 60 times more potent for children than the former IUR. The IUR is based on a large high-quality occupational study of over 18,000 sterilization plant workers with a high-quality EtO exposure assessment for individual workers. More information about the studies that provided the basis for the IUR and cancers associated with breathing EtO is provided in the "Health Effects Evaluation" section. While the IUR can be used to estimate lifetime excess cancer risk to prioritize a population's risk of cancer from EtO exposure, it estimates theoretical cancer risks and cannot be used to predict an individual's risk of developing cancer.

3.3. U.S. EPA's National Air Toxics Assessment Report

The U.S. EPA National Air Toxics Assessment (NATA) was an ongoing review of air toxics in the United States. NATA was a screening tool for state, local, and tribal air agencies to identify which pollutants, emission sources, and places they may wish to study further to better understand any possible risks to public health from air toxics ([U.S. EPA] 2018). As of 2022, NATA has been replaced by a similar annual effort called the Air Toxics Screening Assessment ([U.S. EPA] 2022).

What is air modeling?

Air modeling is a tool used to understand how pollutants move through the air. If appropriate input data are available, computer models can be used to estimate pollution levels in the past and present. They may also tell us where pollution might move in the future.

NATA calculated theoretical risk using national air modeling of emissions from mobile sources (like cars, trucks, buses, and trains) as well as stationary sources (like factories, refineries, and power plants), yielding cancer risk and noncancer hazard estimates for census tracts, counties, and states. NATA was historically updated about every three years. The last NATA was issued on August 22, 2018 and can be found at https://www.epa.gov/national-air-toxics-assessment. The report released in 2018 is based on 2014 emissions, thus the report is called the "2014 National Air Toxics Assessment."

The 2014 NATA report identified new areas of the country with higher cancer risk from EtO exposures based on calculated theoretical lifetime excess cancer risk using the new IUR. Willowbrook was one of 25 areas around the country identified with cancer risks in at least one *census tract* (a geographic area the government uses to take a U.S. population census) that is higher than an excess cancer risk of 1 theoretical cancer cases in 10,000 exposed people. More information on the 2014 NATA's intended use and limitations is available at: https://www.epa.gov/sites/default/files/2018-08/documents/2014_nata_overview_fact_sheet.pdf.

Why do scientists need models?

Sometimes, we want to learn about past pollution—models can help us estimate past pollution levels. Other times, we only have samples for some of the places we want to learn about.
Models can also help us estimate pollution levels in areas where we didn't have samples. Models may also help us decide where to collect new samples.

Due to the findings of the NATA modeling, Illinois EPA and U.S. EPA Region 5 began working with Sterigenics in the spring of 2018 to reduce their emissions at the Willowbrook facility.

3.4. Community Description

The Village of Willowbrook, Illinois is a small, densely populated suburb in metropolitan Chicago, with approximately 9,200 residents. (U.S. Census 2020) Sterigenics is located in Willowbrook, with approximately 6,600 people living within 1 mile of the facility boundary (See Appendix A, Figure A-1, 2000 and 2010 census). LandScan analysis suggests that the number of people present within 1 mile of the facility increases from 5,869 at night to 15,120 during the day, which indicates people may come into the area for work, school, or other reasons during the day (see Figure A-2, day and nighttime populations for more explanation). There are four schools and one daycare facility within 1 mile of the facility.

According to the 2018 American Community Survey, Willowbrook residents are predominantly white (76.3%), non-Hispanic (93.6%), educated (91.5% graduated high school, and 51.8% graduated with a bachelor's degree or higher), and middle class (median household income in 2018 was about $71,574 per year). Approximately 19.2% of the population self-identify as Asian, and 3.7% as Black. (U.S. Census 2018)

3.5. Sampling Data

3.5.1. Air Monitoring Datasets Analyzed

In this health consultation, ATSDR evaluated the public health impact of EtO concentrations measured in outdoor air from various locations in and around Willowbrook. EtO samples in outdoor air are collected in stainless steel containers called "canisters". The EtO air monitoring data ATSDR evaluated include the following:

- U.S. EPA air sampling at eight air monitoring stations within about a mile of the Sterigenics facility in Willowbrook from November 2018 to March 2019.
- Illinois EPA Ambient Air Monitoring Network data for two Cook County locations (Schiller Park and Northbrook monitoring stations) from October 2018 to March 2021, considered as "background" in this report.

- Air sampling conducted by Village of Willowbrook from November 2018 and February 2019.
- Air sampling conducted by Village of Burr Ridge in November 2018.

To understand the contribution of facility emissions to total EtO exposure in the Willowbrook community, ATSDR evaluated EPA's EtO sample results when Sterigenics was operating ("operating period") and after the seal order when Sterigenics ceased sterilization operations on February 15, 2019 ("closure period"). ATSDR also evaluated data collected at two Illinois Ambient Air Monitoring Network locations in Cook County. These Cook County monitoring stations participate in two of U.S. EPA's national monitoring programs and measure EtO concentrations (among other pollutants) away from known industrial sources of EtO. EtO data collected from these two sites is available in U.S. EPA's Air Quality System (AQS) air pollution data repository. The characteristics of EtO air monitoring evaluated in this health consultation are presented in Table 1. The quality assurance plan for the U.S. EPA investigation in Willowbrook can be found at https://www.epa.gov/il/sterigenics-willowbrook-facility-quality-assurance-project-plan-and-sampling-plan.

Table 1. Characteristics of EtO air monitoring.

Investigation	Dates of collection	Number of monitoring locations	Number of valid samples
U.S. EPA, Sterigenics operational period	November 13, 2018 – February 15, 2019	8	265
U.S. EPA, Sterigenics closed	February 16, 2019 – March 31, 2019	8	165
Village of Willowbrook: November 2018 and February 2019 (combined indoor and outdoor samples)	November, 2018 and February 2109	11	31
Village of Burr Ridge: November 2018	November, 2018	8	8
Illinois EPA Ambient Air Monitoring Network, Cook County locations	October 2018 – March 2021	2	231

3.5.2. Issues Affecting the Uncertainty in Background EtO Measurements in Ambient Air

U.S. EPA has described two issues that affect confidence in the accuracy of measured EtO concentrations using the U.S. EPA method for EtO lab analysis (U.S. EPA analytical method TO-15). The first issue is the uncertainty of measuring EtO concentrations near the method detection limit (MDL). The second issue is from positive sampling bias from canister growth of EtO ([U.S. EPA] 2021b). Positive sampling bias is the artificially high measurement and reporting of EtO concentrations in some outdoor air sampling collected and analyzed in canisters using U.S. EPA method TO-15. U.S. EPA discovered positive sampling bias when quality assurance tests discovered the presence of low concentrations of EtO in some cleaned canisters, including canisters used to sample air in Willowbrook. Positive sampling bias is caused by the formation and growth of EtO in canisters which is being called the "canister effect,"

and results in reported concentrations of EtO that are higher than the true amount in the outdoor air being sampled.

In general, canisters are stainless steel and are lined with a coating (*inert* lining) on the inside that should not react to the pollutants being sampled in air. However, U.S. EPA found that certain types of lining on the inside surface of stainless-steel canisters can react with humidified air, causing the formation and growth of EtO over time. U.S. EPA's May 2021 memos summarize a study finding unacceptably high positive bias in several new electropolished canisters ([U.S. EPA] 2021e; [U.S. EPA] 2021d). These findings are described in more detail in Appendix E. The implication of the canister effect is that it adds EtO to an air sample, causing the measured concentrations of EtO during analysis to be quantified at a higher concentration than what is actually in the air, leading to the reporting of inaccurately high measurements of EtO concentrations (positive sampling bias).

U.S. EPA reported that even though the impact of the positive bias on measured EtO concentrations is expected to be relatively small, the positive bias coupled with the greater variability of measuring low concentrations near the method detection limit imposes significant uncertainty and less confidence in the accuracy of low-level EtO concentrations ([U.S. EPA] 2021b). U.S. EPA therefore concluded they do not have enough confidence in monitoring measurements of background EtO concentrations to use them to estimate risk ([U.S. EPA] 2021b).

U.S. EPA is continuing to investigate the formation and growth of EtO in some canisters, and the impact the positive bias has on the measurement of low-level EtO concentrations near the detection limit. U.S. EPA has updated the analytical method, method TO-15A, in part to identify canisters with positive bias and to lower the method detection limit.

3.6. Key Questions Guiding the ATSDR Analysis

Before analyzing the data sets mentioned above, ATSDR focused on a few important questions to guide the assessment. These questions included:

1. How might factors other than facility emissions affect EtO concentrations measured in the outdoor air?
2. What are the reasonable EPCs and resulting risk of health effects for residents and off-site workers using the EtO sample results at the eight U.S. EPA sampling locations near Sterigenics?
3. Are there identifiable spatial, temporal, weather, or other factors that impact the assessment of human exposure to EtO near the Sterigenics facility in Willowbrook?
4. Is EtO consistently found in different areas of Illinois and the country, and how do the concentrations compare to the data collected by U.S. EPA in Willowbrook from November 2018 – March 2019?
5. How does the positive bias from the "canister effect" impact Willowbrook EtO concentrations and our understanding of exposure to emissions from Sterigenics?

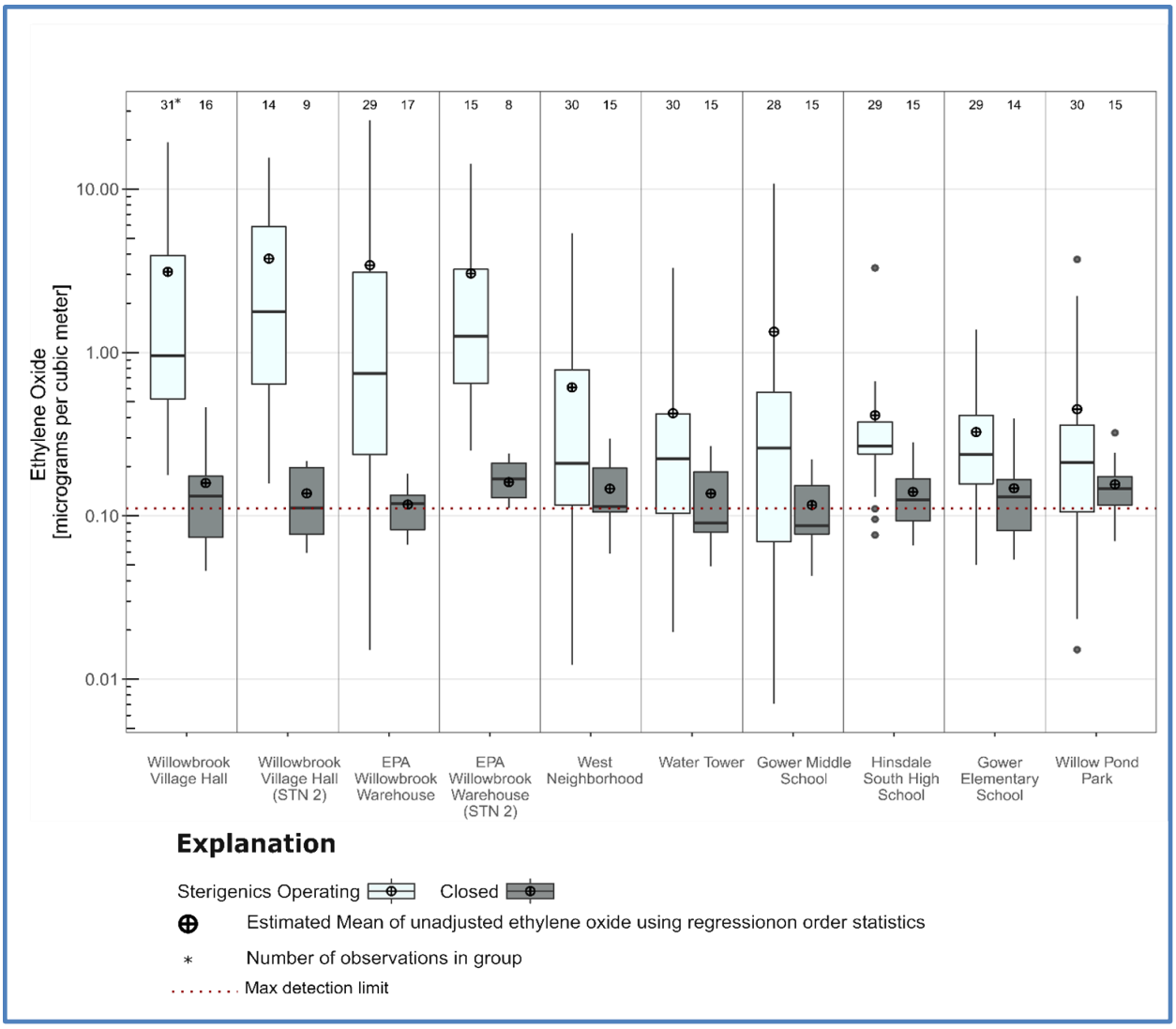
To answer these questions, we analyzed the datasets individually and together using the R statistical computing environment ("The R Project for Statistical Computing"). The technical details of the statistical approach and findings are presented in the Appendixes.

4. Scientific Evaluation

4.1. General Trends: U.S. EPA Measured EtO Concentrations in Willowbrook, IL

Boxplots show the spread of the unadjusted measured EtO outdoor air concentrations (as reported by the analytical laboratory) collected by U.S. EPA at eight locations within a mile of the Sterigenics facility during operations and post-closure (Figure 2). Median EtO concentrations values, which are less prone to influence of outliers, during the Sterigenics operational period ranged from 0.21 µg/m^3 to 1.78 µg/m^3. During the post-closure period, the median EtO concentrations ranged from 0.09 µg/m^3 to 0.15 µg/m^3, and all eight locations reported lower and more consistent outdoor EtO concentrations with less variability than EtO concentrations collected during facility operations. The median background EtO concentrations measured post-closure were similar to median EtO background concentrations measured at monitoring stations across the United States (see Appendix D, Table D-1). The measured EtO concentrations presented in Figure 2 are summarized in Tables B-1 and B-2 in Appendix B. Data collected by Villages of Willowbrook and Burr Ridge did not have enough samples to for a robust statistical or spatial trends analysis.

Figure 2. Operational (November 13, 2018- February 15, 2019) versus post-closure (February 16, 2019 – March 31, 2019) unadjusted measured EtO concentrations at U.S. EPA air monitoring stations in Willowbrook, IL.



For explanation of boxplots see Appendix F

4.1.1. Time and Spatial Trends: U.S. EPA Measured EtO Concentrations in Willowbrook

4.1.1.1. Effects of time on EPA EtO measurements

Using statistical tests described in Appendix C, the U.S. EPA EtO air sample results were significantly higher during the operating period as compared to the post-closure period. These trends can be visualized when plotting measured EtO concentrations over time at U.S. EPA air monitoring stations from the beginning to the end of the U.S. EPA air monitoring. In Figure 3, the U.S. EPA air monitoring stations to the west are color coded yellow (Village Hall, West Neighborhood, Hinsdale South High School, and Gower Elementary), monitoring stations to the southeast are blue (Warehouse and Gower Middle School), and monitoring stations to the north are pink (Water Tower and Willow Pond Park). In Figure 3, time plots for each monitoring station are stacked by direction from Sterigenics, then stacked

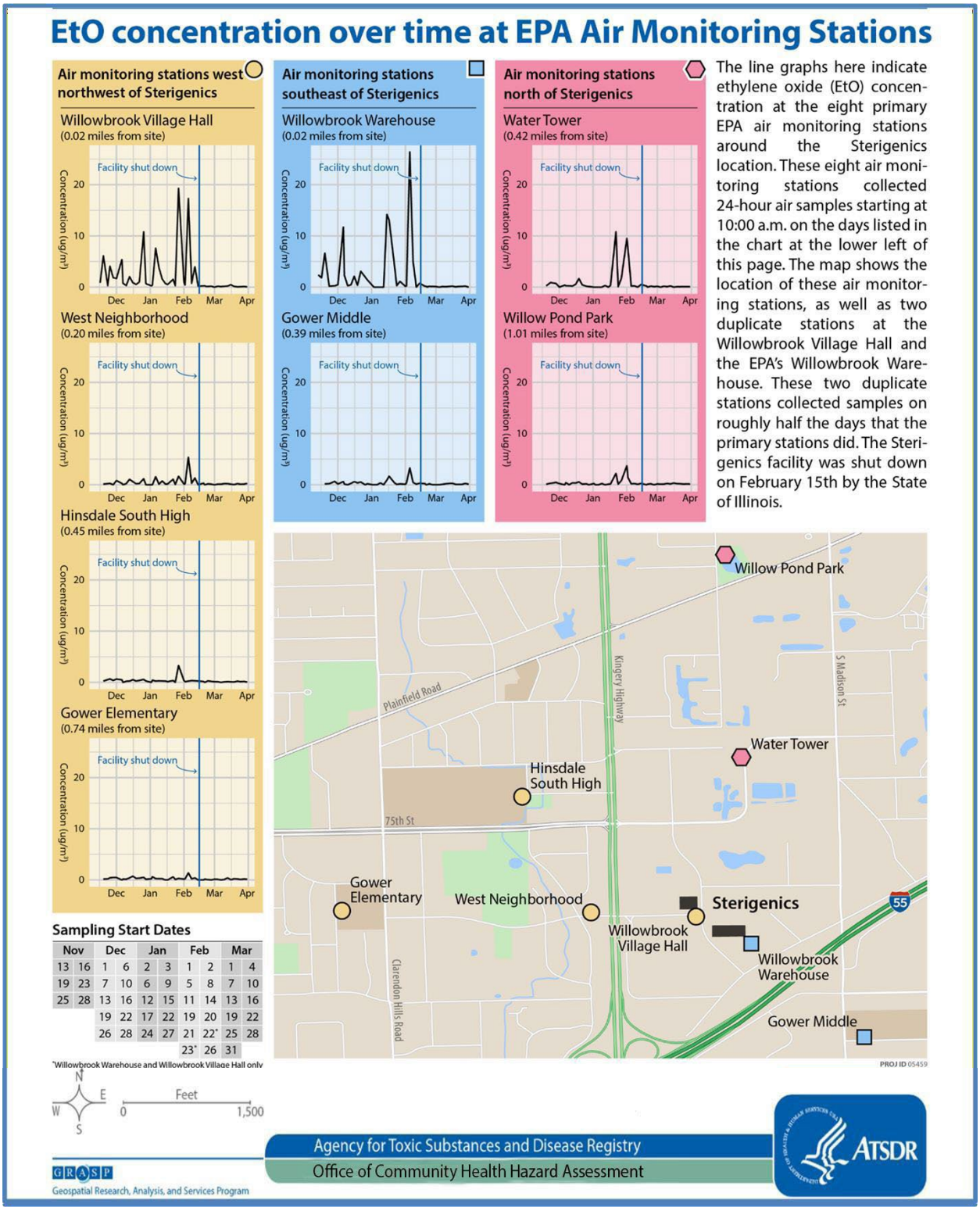
by distance, with the closest monitor to Sterigenics at the top. The vertical blue line in the time plots designates February 15, 2019, when the sterilization operations at Sterigenics resumed.

Time trends analysis supports the conclusion that Sterigenics was the predominant local source of EtO in Willowbrook when the facility was in operation. When evaluating data from monitors in the same general direction from Sterigenics, the trends over time are identical. In addition, the EtO concentrations at specific locations decrease with distance, suggesting they are all impacted by the same source. These time trends also show that ambient EtO concentrations dropped markedly and there was less variation in EtO concentrations across all monitoring stations after Sterigenics stopped operating.

4.1.1.2. Effects of location and winds on EPA EtO measurements

ATSDR compared the EPA EtO sampling results at each of the stations and evaluated the differences in EtO after the shutdown of sterilization operations at Sterigenics (Appendix C). During sterilization operations, all stations had different EtO concentrations, with higher measurements nearest to the facilities.

Figure 3. Time trends of EtO concentrations at U.S. EPA air monitoring stations in Willowbrook, IL.



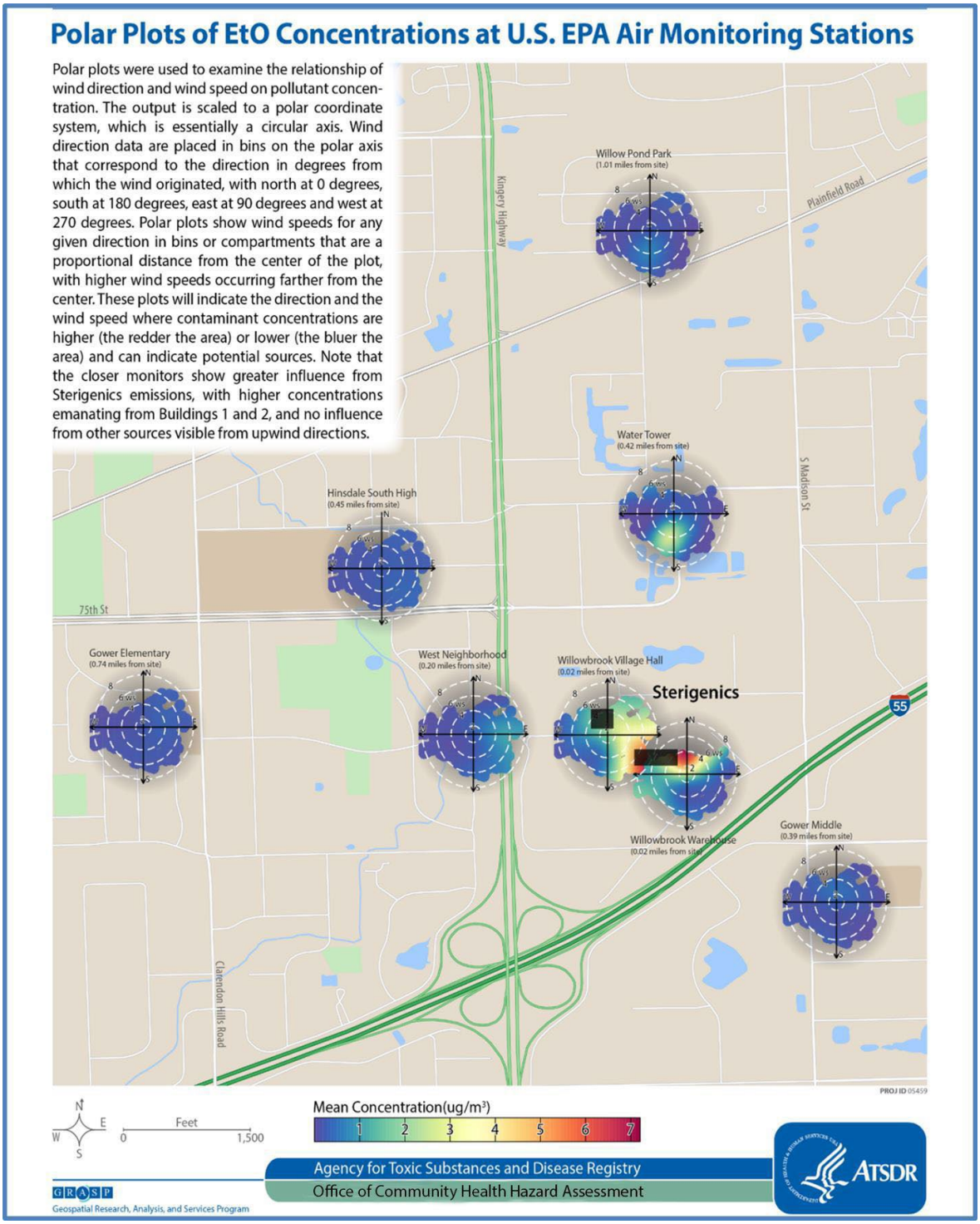
In Figure 4, polar plots display the relationship of average EtO concentration to wind direction, on the polar axis, and wind speed, on the radial axis. When each sample location's EtO polar plot is superimposed over a map, these plots can give insight into the potential source(s) of contaminants (note, wind direction on these plots indicate the direction that winds are blowing *from,* and distance from center indicate higher wind speeds). Higher average EtO concentrations by wind direction and the wind speed are indicated by redder colors, while lower average EtO is indicated by blue. For this assessment, we created a map of all the air monitoring stations with polar plots and looked at air monitors in similar wind directions.

The polar plots in Figure 4 indicate Sterigenics is a major local source of EtO. During Sterigenics operations, the polar plots at the nearest sampling sites had higher EtO when winds were blowing towards them from the Sterigenics plant. This pattern was present in other more distant sampling sites, but the average EtO decreased substantially with distance from the facility. Additional maps with polar plots grouped by direction from the facility are presented in Appendix C. ATSDR did not develop polar plots for the closure period because the sample locations' EtO concentrations post-closure were not significantly different, and there were only a limited amount of sampling data available.

In summary, time and spatial plots of EtO concentrations collected during normal site operations suggest that Sterigenics was the major source of EtO detected during the ambient air monitoring in Willowbrook, IL because

1. Ambient concentrations of EtO quickly decreased with distance (0.2 mile to 1.0 mile) from Sterigenics facilities during the period it was operational.
2. Ambient concentrations of EtO dropped markedly and were less variable at each monitoring station after Sterigenics closed on February 15, 2019.
3. Post-closure EtO concentrations were similar to concentrations measured at background stations in other locations across the United States.

Figure 4. Polar plots of EtO concentrations at U.S. EPA air monitoring stations in Willowbrook, IL: November 2018-February 2019



4.1.2. Analysis of Bias and Seasonal Trends in Measured EtO Concentrations

As discussed previously, U.S. EPA has observed that in the presence of humid air, some cleaned air sampling canisters appear to form EtO through chemical reactions between humidified air and the type of internal, inert surface lining of the canister (canister lining). Samples collected and analyzed for EtO have one of three internal surface lining types (electropolished, proprietary SUMMA®, or silicon-ceramic linings) which influence the growth of EtO from these chemical reactions. The length of time between when a sample is collected and when it is analyzed (the holding time) is believed to facilitate more EtO growth in affected canisters because there is more time for EtO to react with the lining of the can. This EtO growth and formation in affected canisters, called the *EtO canister effect*, results in a positive sampling bias, which is measured concentrations of EtO that are higher than what is actually present in the sampled air. Besides canister lining and holding time, EtO has been observed to fluctuate by season (higher in summer months) in canisters less affected by positive bias. Since Willowbrook data were collected over four months from the fall to the spring, an adjustment considering the effect of season was necessary.

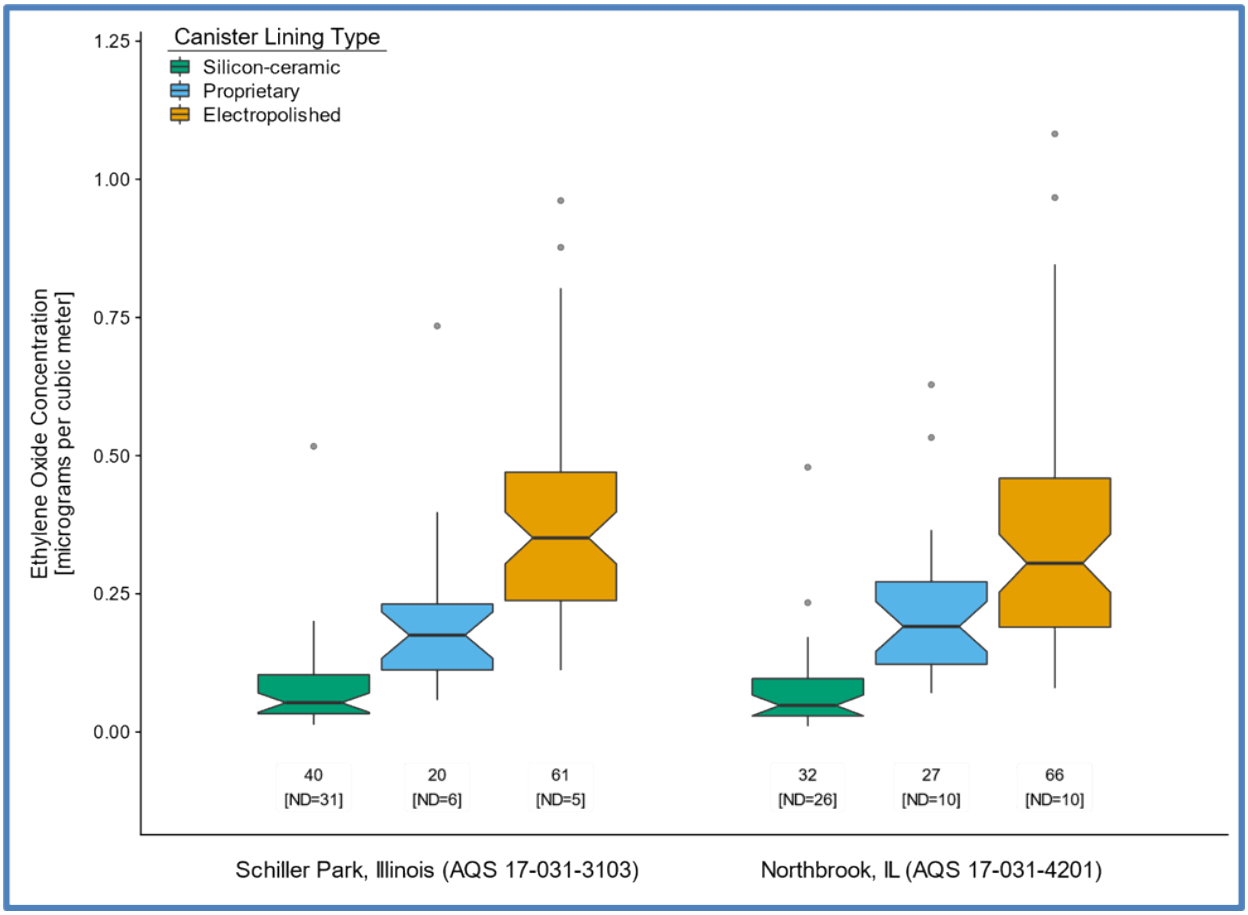
Using a GAM, ATSDR estimated the effect of canister lining type, sample holding time, and seasonality in the measured EtO concentrations in a dataset from two Cook County monitoring stations not impacted by known EtO sources. Analysis of the samples from Cook County were conducted at the same sample laboratory as the EPA EtO samples from Willowbrook. ATSDR then used the estimated GAM coefficients to adjust the EPA EtO sampling data at Willowbrook. The adjusted EtO concentrations were used to evaluate the potential health effects of breathing EtO in Willowbrook. Additional details of this modeling process are described in Appendix E.

4.1.2.1. Canister lining

The majority of the canisters used to collect EtO air samples at the background Cook County monitoring stations had an electropolished lining. The geometric mean background EtO concentrations detected by electropolished and SUMMA® canisters were 4.5 and 2.8 times higher, respectively, than the geometric mean EtO detected by silicon-ceramic canisters ($p < 0.001$) (Figure 5). The geometric mean of EtO concentrations measured by electropolished canisters was 1.6 times higher than that of the SUMMA® canisters ($p < 0.001$).

If there is no bias by canister lining and no EtO source, the background EtO concentrations in outdoor air samples from these monitoring stations should all be approximately in the same range. However, as shown in Figure 5, in over two years of data collection at the two Cook County stations, the highest EtO concentrations were measured in canisters that have electropolished lining and the lowest EtO concentrations were measured in silicon-ceramic lined canisters. Proprietary SUMMA® canisters have EtO concentrations somewhere in the middle of the ranges of electropolished and silicon-ceramic canisters.

Figure 5. Range of EtO concentrations at Cook County, IL background air monitoring stations by canister lining (October 2018-March 2021)



For explanation of boxplots see Appendix F

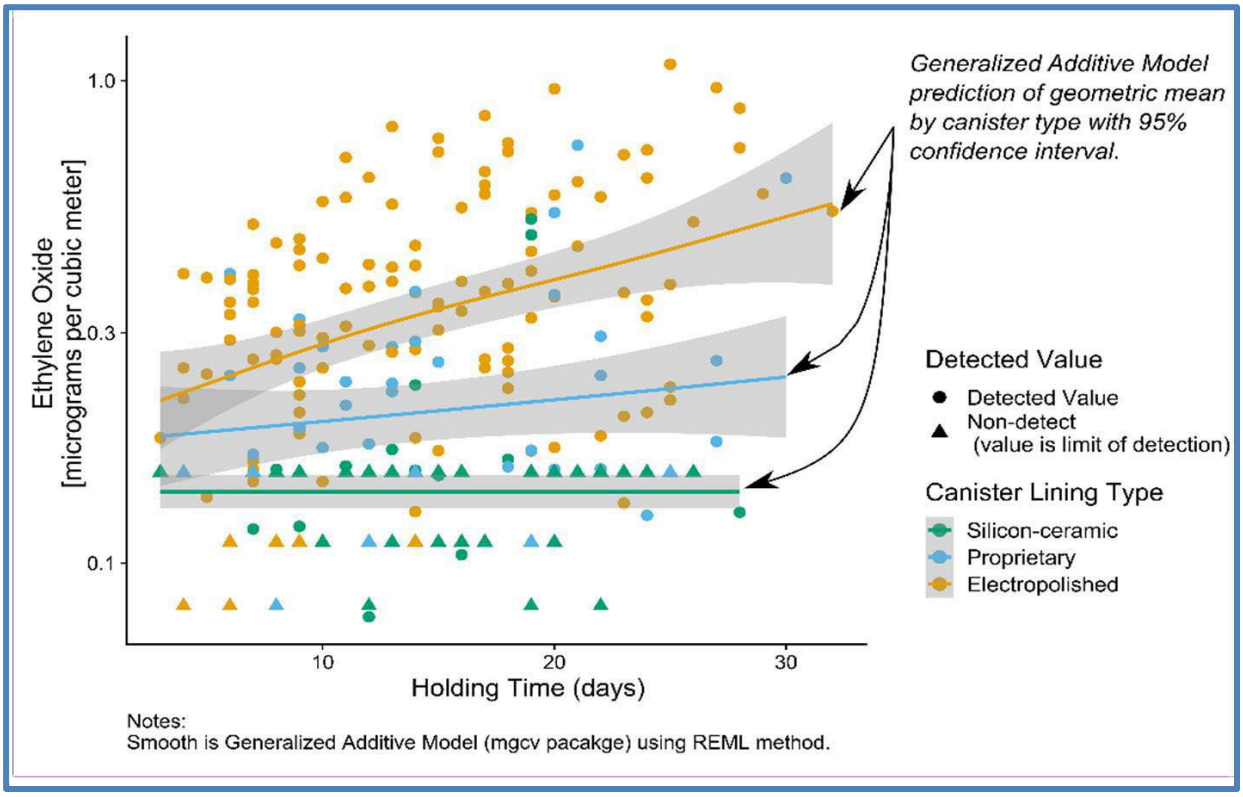
4.1.2.2. Holding time

Background samples in Cook County had median holding times nearly three times that of samples collected in Willowbrook (Table 2). The GAM assessment of the impact of holding time by the various canister types in Cook County is visualized in Figure 6. The lines in Figure 6 (referred to as "smooths") are model-estimated trends of EtO concentrations by holding time in each canister type. The grey shading around each line, which is the 95% confidence interval, reflects the uncertainty in that estimate. The GAM assessment suggests there is an exponential relationship between EtO concentrations and holding time in the electropolished canisters (Figure 6). This means that the model predicts that the EtO concentration would be expected to rise faster as the holding time gets longer in electropolished canisters.

Table 2. Characteristics of valid Cook County and Willowbrook air monitoring samples by canister lining type and holding times

Lining	Sample Set	Number of Samples [below detection limit]	Percent of Canisters	Median Holding Time (days)	Median Ethylene Oxide (micrograms per cubic meter)
Electropolished	Illinois EPA/Cook County Site	124 [12]	53.7%	14	0.347
Electropolished	EPA Willowbrook Post Closure	71 [10]	51.1%	5	0.150
Proprietary	Illinois EPA/Cook County Site	45 [14]	19.5%	13	0.179
Proprietary	EPA Willowbrook Post Closure	46 [16]	33.1%	5	0.102
Silicon-Ceramic	Illinois EPA/Cook County Site	62[48]	26.8%	15	0.077
Silicon Ceramic	EPA Willowbrook Post Closure	22[8]	15.8%	5	0.0804

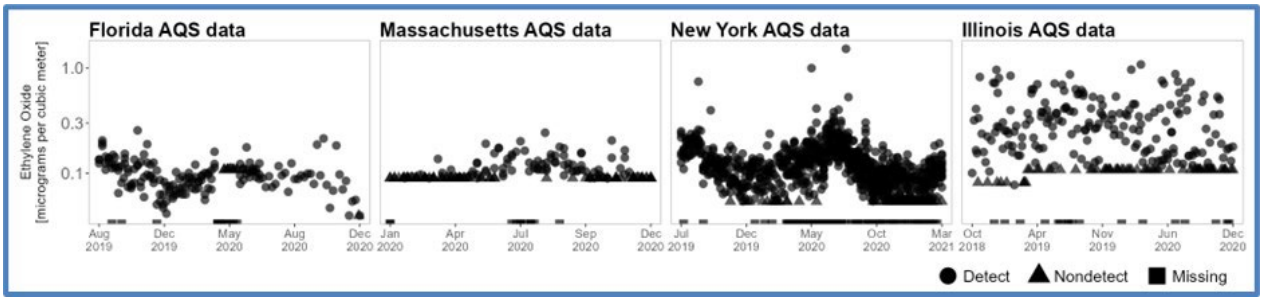
Figure 6. GAM-estimated trend in ethylene oxide concentrations in Cook County canisters by holding time



4.1.2.3. Seasonal pattern

EtO concentrations from the two Illinois sites do not have a seasonal trend (Figure 7). EtO measurements at other states, such as Florida, Massachusetts, and New York, have a seasonal trend and much less variability or "noise" in measured background EtO (Figure 7; Appendix D). This trend, where EtO rises in late spring/summer, is present at all 12 New York monitoring stations as well as the two Florida monitoring stations regardless of their location in the state. Florida and New York exclusively use their own silicon-ceramic lined canisters and analyze their samples in a state lab, so the type of canister and the analytical method are identical for every EtO sample analyzed. ATSDR believes the seasonal trend in background air concentrations could be observed in those three states because electropolished canisters and SUMMA® proprietary canisters are not used in those states' air monitoring programs. In Illinois and other state monitoring programs, a seasonal trend is not as obvious in measured data, likely because the effect of positive bias obscures the trend.

Figure 7. Example of EtO concentration trends in areas without known EtO sources, silicon-ceramic canisters at Florida, Massachusetts, New York versus mixed canisters at two Cook County, IL monitoring stations



4.1.2.4. Trends in GAM adjustment of Cook County EtO sites

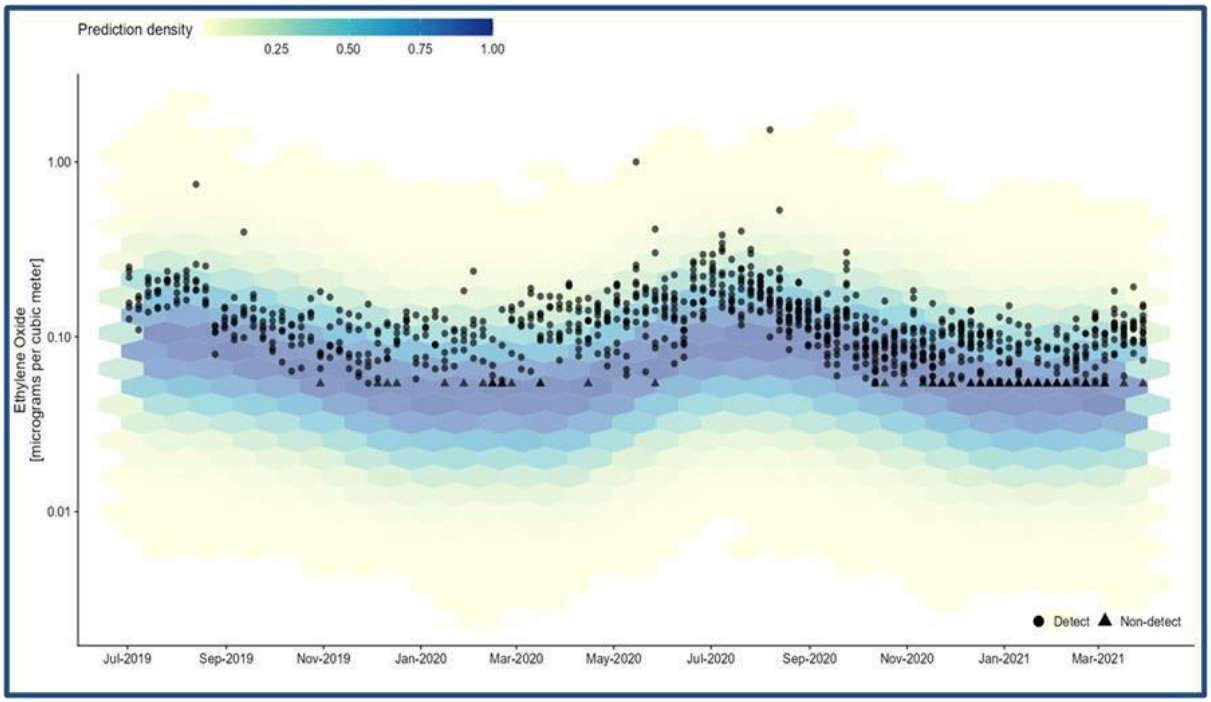
The Cook County background EtO concentrations, after using the GAM to adjust for canister type and holding time, also had a seasonal trend, which was similar to the New York EtO dataset's seasonal trend (Figure 8). The fact that New York, Florida, Massachusetts, and adjusted Cook County EtO data all follow a similar seasonal pattern indicates that background EtO appears to be ubiquitous with seasonal trending. These trends may be attributed to a variety of potential factors including atmospheric chemical reactions (possibly with co-pollutants), solar radiation, other meteorologic factors (humidity, temperature, etc.), biologic sources, and perhaps uncharacterized industrial emissions. Sample collection date serves as a stand-in for the potential seasonal and climate variables that may influence EtO concentrations. Therefore, the GAM adjustment approach used in this health consultation is suitable for adjusting EtO data with GAM developed with climatically similar background data.

4.1.3. Trends in GAM adjustment of EPA EtO data

Using the GAM fit to Cook County data, ATSDR adjusted the measured EtO concentrations in the U.S. EPA Willowbrook air samples for the effects of canister lining type, holding time, and season. Figure 9 shows the reported data trend line over time of measured EtO concentrations (blue line) and the adjusted EtO concentration trend line (mustard line) over time by U.S. EPA Willowbrook air monitor location. The gray fills around each trend line is the 95% confidence interval (CI) of the trend line. Figure 9 also shows the EtO concentration trend lines by air monitoring station location from closest to the Sterigenics facility to furthest (left to right and top to bottom).

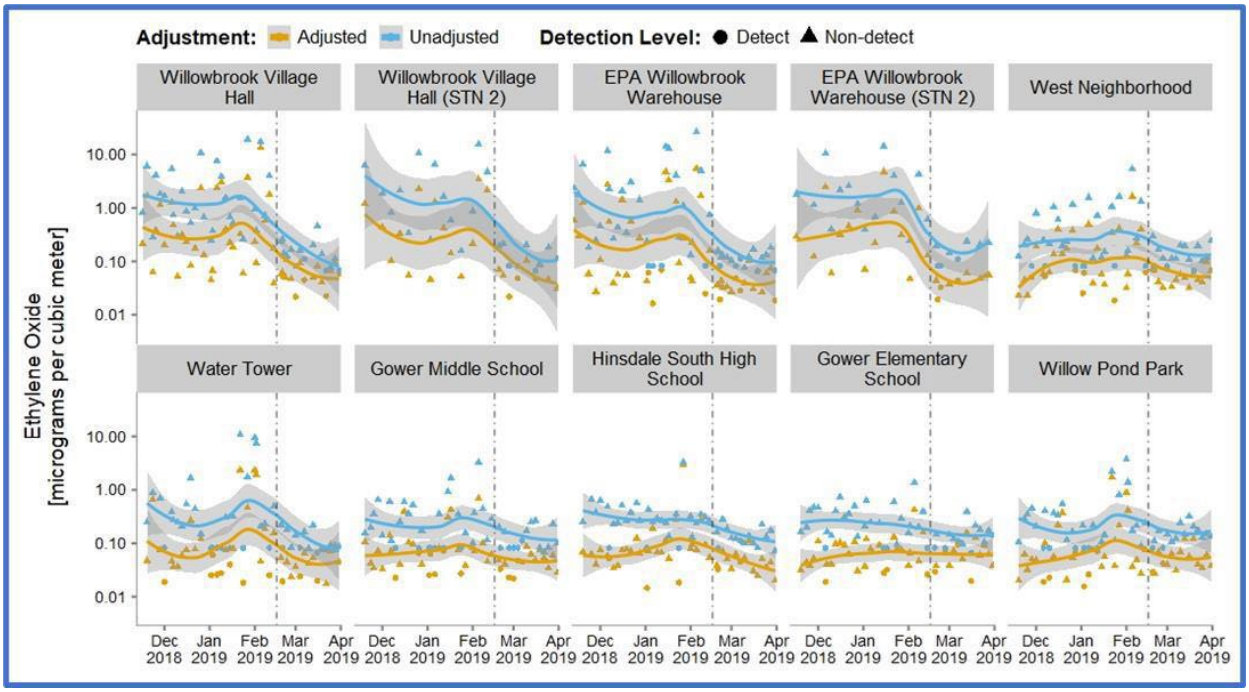
Statistical testing (Wilcoxon rank sum test, see Appendix C for technical details) of GAM adjusted EtO concentrations determined all monitoring stations with the exception of the station farthest from the facility (Willow Pond Park, 1 mile from Sterigenics) had higher EtO concentrations when Sterigenics was open compared to when it was shut down, $p<0.05$ (See Table C-1 and Figure C-1 in Appendix C). The greatest post-closure decreases in concentrations occurred at the closest sites. Over eight days following the Sterigenics facility closure on February 15, 2019, sterilized material left aeration chambers at the facility. During this time, there was a rapid reduction in EtO concentrations, particularly for air monitoring stations nearest Sterigenics.

Figure 8. New York background EtO concentrations imposed over model-predicted smoothed Cook County, IL background EtO concentrations



Explanation: New York background ambient EtO air data are collected with only silicon ceramic canisters; the Prediction Density is the density of 1000 predictions of silicon-ceramic canisters with 7 days holding time using the model developed with Illinois AQS data using can lining type, holding time, and cyclic seasonal trend of Julian days (day of the year from 1 to 365). Higher density means more probable prediction given the model.

Figure 9. Time trend of measured and adjusted EtO concentrations at U.S. EPA monitoring stations in Willowbrook, IL (November 2018-March 2019)



Explanation: Time series of adjusted (in yellow) and unadjusted (in blue) at each EPA EtO air monitoring station. A vertical dotted line marks facility closure. Both adjusted and unadjusted concentrations tended to be lower and less variable after the facility closed at the closest monitoring stations. Adjusted concentrations were lower than unadjusted concentrations.

In summary, the GAM controls for the effects of canister lining, holding time, and season to adjust EtO concentrations of non-silicon ceramic canisters to EtO concentrations as if they were collected in silicon-ceramic canisters with no holding time or seasonal effect. The model allows us to compare EtO concentrations measured in samples collected in canisters with different types of linings and during different seasons. For example, the unadjusted background mean EtO concentrations in Cook County are twice as high as the unadjusted background mean EtO concentrations in Willowbrook air samples collected after Sterigenics closed (post-closure period). However, GAM adjusted mean background EtO concentrations in Willowbrook and Cook County are very similar because the model controls for canister and seasonal differences between the two sites (Table 3). Comparison of the predictions of the GAM adjusted EtO concentrations and unadjusted EtO concentrations using censored regression model suggest that canister lining accounts for 41% of the variability in the unadjusted EtO concentrations, while holding time and seasonality account for 5% and 2%, respectively.

4.1.4. Summary Findings of ATSDR's Analysis of Bias and Seasonal Trends

ATSDR evaluated the positive bias in measured EtO concentrations by analyzing canister lining type and holding time for the eight U.S. EPA Willowbrook monitoring stations and two Cook County background stations with no known sources. We also evaluated and controlled for the effect of seasonality in our assessment of positive bias. From this analysis, we conclude:

1. Relative to air samples collected with silicon-ceramic canisters, air samples collected in canisters with electropolished lining have the highest positive EtO bias. Canisters with proprietary lining also exhibit a positive bias.

2. There is an exponential relationship in electropolished canisters between the holding time and the EtO measurements in air samples collected; this relationship is not significant in proprietary SUMMA® canisters or in silicon-ceramic canisters.
3. Seasonality is observed in the background outdoor EtO concentrations with samples collected in silicon-ceramic lined canisters.
4. ATSDR generated a Bayesian fitted GAM that controlled for the effects of canister lining, holding time, and season, yielding adjusted time trends that reveal seasonal variability in ambient EtO concentrations.
5. The GAM adjustment to the U.S. EPA EtO concentrations measured in air samples collected in Willowbrook removes the canister effect from the dataset and produces more accurate estimates of EtO concentrations.

In general, our process of evaluating positive bias and estimating GAM adjusted EtO concentrations in Willowbrook allow us to better define EtO exposures and thus health risks.

Table 3. Comparison of measured and GAM adjusted mean background EtO concentrations at Cook County Sites and Willowbrook Sites during the 6-week post-closure period

Monitoring Station	Mean* EtO- All canister types	Mean* EtO Silicon-Ceramic canisters	Adjusted mean* EtO- All canister types
Cook-Northbrook	0.269 (n=125; 25 NDs)	0.079	0.070
Cook-Schiller Park	0.286 (n=106; 7 NDs)	0.104	0.077
Willowbrook- post-closure	0.135 (n=122; 28 NDs)	0.091	0.055

**Units of mean/adjusted mean are in micrograms per cubic meter. Unadjusted censored EtO concentrations were imputed using robust regression on order statistics. Additional information in Table E-3.*

4.2. Outdoor Air Evaluation

4.2.1. Screening Analysis

ATSDR screened chemicals for further evaluation by comparing EtO concentrations against ATSDR health-based comparison values (CVs). ATSDR inhalation CVs are health-protective air concentrations for a given duration of exposure to the contaminant that are not expected to cause harmful health effects. CVs may be developed for acute (less than 2 weeks), intermediate (2 weeks up to 1 year) or chronic (1 year or more) exposure durations.

Exposure to chemical concentrations detected below ATSDR's CVs are not expected to cause harmful health effects in people. Therefore, concentrations below CVs are not evaluated further. Contaminant concentrations that exceed CVs do not indicate that a health risk is likely but rather that the pollutant should be evaluated further to determine the potential public health impact.

The ATSDR CV for chronic exposure to EtO is the ATSDR cancer risk evaluation guide (CREG) based on U.S. EPA's IUR for EtO. ATSDR CREGs are estimates of the carcinogen concentrations that could cause one additional case of cancer in one million people exposed over a lifetime. The CREG for EtO considers early-life susceptibility to EtO and applies weighting factors known as age-dependent adjustment factors (ADAFs), as EtO has been designated as a mutagen (a chemical that causes genetic mutations). ATSDR's CREG for EtO is 0.00021 µg/m^3.

The ATSDR acute and intermediate CVs for EtO are based on ATSDR's acute and intermediate minimal risk levels (MRLs). An inhalation MRL is an estimate of the contaminant concentration that someone can breathe over a specific duration that is not expected to cause noncancer health effects. ATSDR's acute MRL is 720 µg/m^3 and the intermediate MRL is 126 µg/m^3 ([ATSDR] 2020).

In Table 4, ATSDR compared EtO concentrations averaged over the appropriate duration of exposure to each CV. The maximum 24-hour concentration at each U.S. EPA monitoring station in Willowbrook was compared to the acute CV and the maximum 2-week rolling average was compared to the intermediate CV. No EtO concentrations at the monitoring stations exceeded the acute or intermediate MRL. Therefore, acute and intermediate exposure to EtO concentrations in Willowbrook do not pose a public health hazard and are not evaluated further. For chronic EtO exposure, ATSDR screened 95% UCL EtO concentrations at each monitoring station against the ATSDR CREG for EtO. The CREG was exceeded at all monitoring stations. Therefore, additional health evaluation of the potential health risks associated with chronic exposure to EtO in Willowbrook follows below.

Table 4. Screening of measured EtO concentrations at U.S. EPA air monitoring stations in Willowbrook, Illinois during normal Sterigenics sterilization operations against ATSDR comparison values for EtO

U.S. EPA Air Monitoring Station	Chronic Average EtO [95 UCL]* (µg/m^3) †	ATSDR CREG‡: 0.00021 (µg/m^3)	Intermediate Highest 2-week Average EtO (µg/m^3)	ATSDR Intermediate MRL§: 126 µg/m^3	Acute Max 24-hour Average EtO (µg/m^3)	ATSDR Acute MRL: 720 µg/m^3
Gower Elementary	0.32 [0.41]	Exceeds CREG	0.17	No exceedance	1.38	No exceedance
Gower Middle	0.42 [0.62]	Exceeds CREG	0.23	No exceedance	3.29	No exceedance
Hinsdale South	0.41 [0.62]	Exceeds CREG	0.91	No exceedance	3.29	No exceedance
Water Tower	1.33 [2.29]	Exceeds CREG	1.77	No exceedance	10.8	No exceedance
West Neighborhood	0.60 [0.93]	Exceeds CREG	0.60	No exceedance	5.35	No exceedance
Willow Pond Park	0.44 [0.68]	Exceeds CREG	0.79	No exceedance	3.71	No exceedance
Village Hall	3.12 [4.56]	Exceeds CREG	4.27	No exceedance	19.3	No exceedance
Willowbrook Warehouse	3.42 [5.39]	Exceeds CREG	3.61	No exceedance	26.4	No exceedance

* *95 UCL - 95% upper confidence limit (UCL) of the full study duration mean*

† *Micrograms per cubic meter*

‡ *ATSDR cancer risk evaluation guide, chronic comparison value for cancer*

§ *ATSDR minimal risk level*

4.2.2. Health Evaluations

GAM adjusted data were used to estimate EPCs for EtO concentrations at each of the eight U.S. EPA air monitoring stations located within a mile of the Sterigenics facility (See Table 5). ([ATSDR] 2019) ATSDR calculated EtO EPCs during Sterigenics's operational time period and during the 6-week post-closure time period for residential and off-site worker exposure settings.

Most information on health effects from chronic inhalation exposure to EtO is derived from animal studies or epidemiological and case studies of workers in occupational settings. Further, most studies of chronic occupational EtO exposures are on cancer endpoints. This section presents ATSDR's in-depth review of the health effects (both noncancer and cancer) from chronic inhalation of EtO.

4.2.2.1. Noncancer Health Effects Evaluation

ATSDR reviewed the noncancer health effects observed in animal studies on chronic exposure to EtO. Breathing EtO at very high levels may affect several different body systems. Four chronic animal inhalation studies are reported in ATSDR's Toxicological Profile for Ethylene Oxide. These studies demonstrated adverse effects in the hematological (splenic hematopoiesis), musculoskeletal (myopathy), endocrine (adrenal gland hyperplasia), and male reproductive systems (reduced sperm count/motility), and reduced body weight gain at duration-adjusted EtO concentrations at 18,000 to 37,800 µg/m^3. The limitations in these animal studies prevented ATSDR from deriving a chronic inhalation MRL for EtO ([ATSDR] 2020).

Some of the effects observed in these chronic animal studies are supported by intermediate duration animal studies reported in the toxicological profile. Reduced body weight gain and reduced survival in the offspring of pregnant rodents were observed at a slightly lower duration-adjusted concentration (12,000 µg/m^3) in an intermediate study. No effects were observed at a duration-adjusted concentration of 3,800 µg/m^3 in the same study.

Case studies in workers exposed to several thousand times higher than concentrations measured in Willowbrook reported neuropathy (weakness, numbness, and pain in the extremities), impaired hand-eye coordination, cognitive dysfunction (deficits in normal thought function), memory loss, headache, and hand numbness. These studies were not used to derive a chronic MRL because they do not have adequate exposure-response data and were considered insufficient to establish a causal relationship between chronic EtO exposure and neurological effects in humans ([ATSDR] 2020).

Possible associations between breathing EtO at work and pregnancy loss have been explored in epidemiological studies of sterilizer workers. Limitations in these studies preclude drawing conclusions about whether EtO can cause miscarriage or other harmful effects related to pregnancy ([ATSDR] 2020).

The highest GAM adjusted EtO EPC was 2.3 µg/m^3 at any U.S. EPA air monitoring station in Willowbrook while Sterigenics was operating. The highest EtO EPC in Willowbrook is more than 5,000 times less than the lowest EtO concentration (12,000 µg/m^3) where health effects were observed in animal studies. ATSDR therefore concludes that noncancer health effects are not expected for people in the Willowbrook community near the Sterigenics facility.

4.2.2.2. Cancer Evaluation

Various agencies have determined that EtO is a human carcinogen, including the National Toxicology Program (NTP) at the National Institutes of Environmental Health Sciences, U.S. EPA, and the International Agency for Research on Cancer (IARC). ([NTP] 2021; [U.S. EPA] 2016; [IARC] 2012).

In December 2016, U.S. EPA finalized the Evaluation of the Inhalation Carcinogenicity of Ethylene Oxide report that provides scientific support and rationale for the hazard and a dose-response assessment pertaining to the carcinogenicity from chronic inhalation exposure to EtO. ([U.S. EPA] 2016). This report concluded that EtO is carcinogenic to humans by the inhalation route. This conclusion was based on studies in workers that were less than conclusive on their own, extensive evidence of carcinogenicity in animals, evidence that EtO mutates DNA and evidence that EtO causes events that can lead to cancer in humans.

The report also describes the development of U.S. EPA's IUR for evaluating the potential cancer risks posed by inhalation exposure to EtO. The IUR was derived from combined risk estimates for lymphoid cancer mortality and breast cancer incidence from EtO exposure based on the data from a National Institute for Occupational Safety and Health (NIOSH) epidemiologic study of over 18,000 plant workers (45% male, 55% female) at 14 EtO sterilization facilities between 1940 and 1988 ([U.S. EPA] 2016; [NIOSH] 2004). U.S. EPA used this epidemiologic study to develop the IUR because it is a high-quality large size cohort design with males and females, adequate follow-up, absence of known confounding exposures, and individual worker exposure estimates from a high-quality exposure assessment ([U.S. EPA] 2016). Workers were exposed to a measured geometric mean EtO concentration of 4,000 $\mu g/m^3$ and a modeled geometric mean of 2,100 $\mu g/m^3$ (Hornung et al. 1994). ATSDR uses U.S. EPA's IUR of 2.99 x 10^{-3} to calculate the ATSDR CV (CREG) for cancer effects and to estimate lifetime excess cancer risks.

Steenland et al. (2004) evaluated cancer mortality in the entire NIOSH cohort of 18,235 men and women workers. There were no statistically significant increases in mortality in the overall cohort from any cancer compared to the general U.S. population. Workers with the highest cumulative exposures and longest latency (time EtO exposure and observed mortality) had statistically significant excess mortality for lymphoid cancers (non-Hodgkin lymphoma, myeloma, and lymphocytic leukemia) in males and female breast cancer. Mortality from non-Hodgkin lymphoma was statistically significantly elevated in the highest exposure group compared to the U.S. population, but there were not statistically significant elevations for myeloma or lymphocytic leukemia individually (Steenland, Stayner, and Deddens 2004).

Steenland et al. (2003) studied female breast cancer incidence in a subset of the original NIOSH cohort described above; this cohort included 7,576 women who were employed at one the 14 sterilization facilities for at least one year. The authors concluded the data suggest that EtO exposure is associated with breast cancer, but the causal interpretation is weakened due to some inconsistences in exposure-response trends, possible biases due to lack of response from study participants, and incomplete cancer ascertainment (Steenland et al. 2003).

Mikoczy et al. (2011) studied mortality and incidence from breast and lymphohematopoietic cancers in 2,171 male and female Swedish workers in sterilizing facilities over 34 years (1972–2006). The study indicated that was a positive-response relationship with breast cancer with increased rate ratios for the upper two quartiles of cumulative exposure (Mikoczy et al. 2011).

The low-level outdoor air EtO concentrations measured in Willowbrook are over a thousand times lower than EtO concentrations that workers were exposed to in the worker studies described above. However, these occupational epidemiologic studies represent health effects that occurred in people exposed to high levels of EtO at work over a long period of time. There have not been studies evaluating the health effects from community exposures to low-level EtO concentrations, which would include sensitive populations such as developing babies (in utero) and young children. Worker studies provide the best available information about the risk of cancer due to EtO exposure.

Lifetime Excess Cancer Risk Calculations using Exposure Point Concentrations

For the purposes of estimating a lifetime excess cancer risk from chronic exposure to EtO concentrations in Willowbrook, ATSDR used reasonable maximum exposure (RME) assumptions about how long, how often, and how much EtO residents and off-site workers may breathe. For a residential scenario, ATSDR's RME scenario is a continuous residential exposure duration of 24 hours a day for 33 years over a lifetime of 78 years. For EtO, ATSDR calculates lifetime cancer risks based on 33 years of residential exposure using age-dependent adjustment factors (ADAFs). ADAFs are used to weight risk for exposure of the youngest age ranges (infants and children) to mutagenic compounds like EtO. Mutagens are pollutants that can cause changes in the DNA of the exposed individual which can result in cancer or other serious health effects. Pollutants that cause cancer from a mutagenic mode of action may result in a higher risk of cancer for children exposed in early life than for adults. For an off-site worker scenario (workers who regularly work near, but not at, Sterigenics), ATSDR assumed an RME of 8.5-hour workday, 250 days a year, for 20 years. See Appendix F for RME assumptions, ADAFs, U.S. EPA IUR, and formulas used to calculate lifetime cancer risks for residential and off-site workers exposure scenarios.

The estimated lifetime excess cancer risks based on long-term residential and off-site worker EtO exposure scenarios at each monitoring station during Sterigenics operations are a concern for increased cancer risk (See Table 5). All the lifetime cancer risk estimates are greater than or equal to 1 in 10,000 (greater than 1 additional cancer case among 10,000 exposed individuals). The residential lifetime cancer risk estimates range from a maximum of 10 in 10,000 to 4 in 10,000. The maximum off-site worker lifetime cancer risk is 4 in 10,000 exposed workers with a low of 1 in 10,000 exposed workers (Table 5).

These theoretical lifetime excess cancer risk estimates are in addition to the lifetime background cancer risk for the general population. Lifetime excess cancer risk estimates are a tool used for assessing potential community health impacts from environmental exposures and for deciding whether public health actions are needed to protect health, and do not predict actual cancer risk for individuals or represent incidence rates of cancer in the Willowbrook community. Any cancer risk from EtO would be in addition to existing risk of cancer due to individual or lifestyle factors. Lifetime cancer risks estimated based on EPA's IUR are calculated based on conservative assumptions and are intended to be greater than the actual risk of cancer in a community based on a given EtO concentration.

For the purpose of comparison, the estimated lifetime cancer risks for residents and off-site workers from EtO exposure during Sterigenics operations at each monitoring stations are presented with estimated lifetime cancer risks at the same monitoring stations during the post-closure time period.

During the post-closure period, the GAM adjusted EtO EPCs, and the associated cancer risk estimates represent background levels similar to those found in many locations across the United States. The maximum residential and off-site worker lifetime cancer risks during Sterigenics's operational period are similar but slightly lower than the estimated cancer risk reported in the ATSDR July 26, 2018 letter health consultation to U.S. EPA at approximately the same locations. Regardless of the canister effect and its influence on air measurements reported, EtO emissions from Sterigenics during operations resulted in higher lifetime excess cancer risk than that posed by post-closure background conditions.

From these cancer risks, ATSDR concludes that while Sterigenics was operating, long-term exposure to EtO air concentrations in Willowbrook was a concern for increased risk of lymphoid and breast cancers for residents living within a mile of the facility and off-site workers within half a mile of the facility. After Sterigenics stopped EtO sterilization operations and no longer emitted EtO emissions on February 15, 2019, EtO air concentrations and the lifetime cancer risk for people living or working in Willowbrook are similar to background EtO concentrations and related cancer risks found in many locations across the United States away from known EtO sources.

Table 5. GAM – adjusted EtO EPC and lifetime excess cancer risk at U.S. EPA air monitoring stations in Willowbrook during Sterigenics operational period and post-closure

Monitoring Station (Distance from Sterigenics Facility)	Scenario	Operational Period GAM Adjusted EPC, (µg/m³)*	Post-Closure GAM Adjusted EPC, (µg/m³)	Operational Lifetime Excess Cancer Risk‡	Post-closure Lifetime Excess Cancer Risk
West Neighborhood (0.20 mile)	Residential	0.37	0.07	10 in 10,000	2 in 10,000
Gower Middle (0.39 mile)	Residential	0.19	0.06	6 in 10,000	2 in 10,000
Hinsdale South High (0.45 mile)	Residential	0.42	0.06	10 in 10,000	2 in 10,000
Gower Elementary (0.74 mile)	Residential	0.13	0.09	4 in 10,000	3 in 10,000
Willow Pond Park (1.01 miles)	Residential	0.33	0.07	10 in 10,000	2 in 10,000
Warehouse (0.02 mile) †	Off – site worker	1.66	0.05	3 in 10,000	0.1 in 10,000
Village Hall (0.02 mile) †	Off – site worker	2.30	0.08	4 in 10,000	0.1 in 10,000
Water Tower (0.42 mile)	Off – site worker	0.65	0.06	1 in 10,000	0.1 in 10,000

EtO air monitoring data used for lifetime excess cancer risk calculations are from U.S. EPA EtO samples collected between November 12, 2018 and March 31, 2019.

** Adjusted refers to GAM adjusted EtO concentrations modeled to remove the positive bias and seasonal effect. EPC stands for exposure point concentration calculated using the 95% upper confidence limit of the mean and is reported in units of micrograms per meter cubed (µg/m³)*

† Where there were two co-located air monitors, we report the higher of the two EPCs and lifetime cancer risks in this table.

‡ In EtO datasets with more uncertainty due to variability in the EtO concentrations, the EtO EPCs calculated using 95% UCL of the mean tend to be higher than the sample mean EtO concentration compared to a dataset with lower variability. For this reason, the EPC is not meant to be used for comparing risk between monitoring stations. Even though EPCs and cancer risk are not necessarily highest at the closest monitoring stations, ATSDR observed that in general, EtO concentrations during the operational period decreased with distance from the facility within the same wind direction.

4.3. Evaluation of Health Outcome Data

4.3.1. Lifetime U.S. Population Risk of Cancer

The lifetime risk of developing cancer in the United States is 1 in 2 males and 1 in 3 females for all invasive cancers (American Cancer Society 2023). An individual's cancer risk depends on many potential risk factors, including age, gender, genetic predisposition (such as BRCA or Lynch Syndrome gene mutations), environmental/occupational exposures, and lifestyle behaviors (e.g., smoking, diet). Information about the risk factors for specific types of cancer are available at the National Cancer Institute (National Cancer Institute 2015) and the American Cancer Society (American Cancer Society 2023).

4.3.2. Illinois Department of Public Health (IDPH) Cancer Incidence Assessment

Based on ATSDR's recommendation in the July 2018 letter health consultation, the IDPH Division of Epidemiologic Studies conducted a cancer incidence assessment to determine if there is elevated cancer incidence in the population surrounding the Sterigenics facility in Willowbrook, Illinois. This type of assessment is not intended to and cannot determine cause-and-effect relationship with site related contaminants but rather is a screening to identify unusual patterns. IDPH obtained cancer cases from the Illinois State Cancer Registry (ISCR) for diagnosis years 1995-2015. In the assessment, two study groups were identified: 1) study area 1 was comprised of cases in nine census tracts immediately surrounding the Sterigenics facility; 2) study area 2 was comprised of an area approximating the entire 60527 zip code. The population comprising study area 1 was included in study area 2. The IDPH cancer incidence assessment report was released on March 29, 2019 ([IDPH] 2019).

The IDPH Cancer Incidence Assessment near Sterigenics, Willowbrook, Illinois (1995-2015) states the following:

"In conclusion, this cancer assessment examined a number of cancer sites that included cancers that have a recognized association with EtO (lymphohematopoietic and breast cancers), and other common cancer sites that have no such association with EtO, in both adult and pediatric surrounding the Sterigenics facility in Willowbrook, Illinois, over the years 1995 through 2015. For lymphohematopoietic and breast cancers the study found increases in Hodgkin lymphoma, and in recent years, non-Hodgkin lymphoma. Pediatric lymphoma was also elevated during the study period. For other common cancer sites, the study found increased cancer in prostate for males, and increased cancers of the pancreas, ovary, and bladder in females. However, many apparent differences and inconsistences existed between genders, across study areas, and among cancer sites. A number of limitations in methodology and data also exist. Future studies with larger populations and preferably involving multiple EtO emissions sites are strongly recommended to confirm this assessment's findings." ([IDPH] 2019)

4.4. Summary of Limitations and Uncertainties

The limitations and uncertainties of this health consultation include:

1. U.S. EPA method TO-15 used to collect and analyze air samples for EtO in ambient air has MDLs about 200 times higher than ATSDR's screening comparison value for cancer. Concentrations of EtO lower than the MDL cannot be reliably measured and may be of public health concern.

2. Some canisters used in U.S. EPA method TO-15 to collect and analyze air samples for EtO in ambient air had positive sampling bias resulting from EtO growth inside canisters which causes inaccuracy and uncertainty in some samples reported in the data analyzed in this document. ATSDR adjusted the site data using a GAM; the exact effects between the Illinois AQS data and the EPA Willowbrook data may not be identical.

3. In November 2018, U.S. EPA reported that they had discovered a potential for trans-2-butene to co-elute with EtO during lab analysis, possibly resulting in inaccurate EtO measurements. This potential interference resulted in an adjustment in the way samples were analyzed to ensure appropriate reporting of EtO concentrations. Subsequent testing rarely detected trans-2-butene and when it was detected, it was at very low concentrations (detected in trace amounts). The subsequent sampling also validated the range of EtO previously reported in U.S. EPA's May 2018 sampling. Further, ATSDR analyzed differences in samples with and without co-elutants and did not identify a statistically significant difference in those with trans-2-butene present.

4. EPA has noted that EtO sample results near the MDL using Method-TO-15 can be imprecise. Furthermore, several EtO results were reported as below MDL, particularly in the AQS samples and during the period when the Sterigenics facility was closed. Sample results below the detection limit are common for almost any chemical detected near its specific MDL. As such, the EPCs used followed the ATSDR's Public Health Assessment Guidance Manual and the ATSDR Exposure Point Concentrations Guidance for Discrete Sampling ([ATSDR] 2019; [ATSDR] 2022). These guidance documents recommended statistical approaches for estimating EPCs by calculating 95% UCLs of the mean using statistical methods that explicitly account for nondetect results, while also reducing the chance that the EPCs are underestimated due to imprecision in sampling and measurement of contamination.

5. EtO air sampling data were available from eight U.S. EPA air monitoring stations near Sterigenics in Willowbrook, IL for a total of five months. Ideally, the characterization of chronic exposures is based on data collected over longer durations that can reflect seasonal and temporal variability.

6. Due to a lack of long-term EtO air monitoring data prior to 2018-2019, we cannot fully evaluate historical trends or chronic exposures in the community to quantify past lifetime cancer risks. TRI data suggest emissions were likely higher prior to 1999. However, TRI data were inconsistently reported in the past and cannot be used to directly assess community exposure.

7. The U.S. EPA IUR is based on occupational cohorts of healthy workers exposed over many years to EtO concentrations that were thousands of times higher than EtO concentrations detected in the ambient air of communities near commercial sterilizers (Steenland, Stayner, and Deddens 2004; Steenland et al. 2003). There is significant uncertainty in using high concentrations in worker studies to estimate lifetime cancer risk at the much lower EtO concentrations measured in Willowbrook and for more sensitive sub-populations like children. Cancer risks estimated using ATSDR's methodology detailed in the ATSDR Guidance for Inhalation Exposures are conservative (health protective) to account for these uncertainties ([ATSDR] 2021).

8. There is a data gap in humans for how lower EtO exposures affects development of adverse health outcomes, especially in utero and in young children. Young children may be particularly susceptible to adverse health effects from EtO exposure. ATSDR uses U.S. EPA's ADAFs to

calculate lifetime excess lifetime cancer risk that accounts for the greater cancer risk for children exposed to mutagenic compounds.

4.5. Addressing Community Medical Concerns

ATSDR recommends that community members who are concerned about EtO exposures or have health-related questions talk with their doctor. Important additional steps in maintaining health and detecting problems early include keeping up to date with regular checkups and recommended age-appropriate medical screening tests (e.g., breast cancer screening recommended by the U.S. Preventive Services Taskforce) and being evaluated by their doctor between checkups if unusual symptoms or concerns arise.

Healthcare providers seeking more information and guidance about EtO exposure and potential health effects can consult with experts trained in environmental medicine located at:

University of Illinois at Chicago
Great Lakes Center for Reproductive and Children's Environmental Health
Website: https://childrensenviro.uic.edu/
Phone: 866-967-7337 **Email:** ChildrensEnviro@uic.edu

In addition to advice from their doctor, individuals or concerned community members seeking more information can also contact experts using the phone number or email above.

5. Conclusions

ATSDR evaluated U.S. EPA EtO air monitoring data collected from November 2018 through March 2019 to assess cancer and noncancer risks for Willowbrook residents and off-site workers (people who work in the area, but not at Sterigenics) while Sterigenics was operating and after it closed. Sterigenics has not operated in Willowbrook since February 15, 2019 and will no longer operate at that location. ATSDR calculated lifetime excess cancer risks using GAM adjusted EtO concentrations to account for the effects of canister lining, holding time and seasonality. ATSDR used theoretical estimates of lifetime excess cancer risk as a tool for deciding whether public health actions are needed to protect health. These cancer risks are not an actual estimate of cancer cases in a community and do not represent an individual's cancer risk. After reviewing the results of our evaluation of available data, we arrived at three conclusions.

Conclusion 1: ATSDR concludes there is a concern for an increased lifetime risk of cancer associated with long-term EtO exposure for people who breathed the air within one mile of Sterigenics for years prior to February 15, 2019. The increased cancer risk is based on EtO concentrations measured in the air during sterilization operations and statistically adjusted for positive bias and seasonality.

Basis for Decision:

- Breathing EtO in the air can cause cancer ([U.S. EPA] 2016). The best evidence of which cancers might be associated with breathing EtO comes from studies of workers exposed to high levels. Evidence from human epidemiological studies is strong but less than conclusive in associating specific cancers with EtO exposure ([U.S. EPA] 2016). Studies of a large cohort of workers observed a dose-response in the incidence of female breast cancer and breast cancer mortality

in women (Steenland et al. 2003; Steenland, Stayner, and Deddens 2004). A study from the same cohort also found increased mortality in male workers from certain lymphoid cancers (non-Hodgkin lymphoma [also known as non-Hodgkin's lymphoma or NHL], myeloma, and lymphocytic leukemia) as a group
(Steenland, Stayner, and Deddens 2004; [U.S. EPA] 2016; [IARC] 2012).

- ATSDR estimated lifetime excess cancer risks from long-term EtO exposure while the Sterigenics facility was operating; the risks were based on EtO concentrations adjusted for positive bias within a mile of the facility between November 12, 2018 and February 15, 2019.
- The statistical adjustment (generalized additive model or GAM) did not remove all uncertainty associated with the positive sampling bias, but the adjustment did allow ATSDR to estimate cancer risks more accurately in order to make public health conclusions.
- All of U.S. EPA's air monitors were within 1 mile of Sterigenics. All monitors except the furthest air monitor had statistically significantly higher EtO air concentrations during operations compared to when Sterigenics was closed.
- During Sterigenics sterilization operations, EtO concentrations were highest at air monitoring stations closest to the facility and quickly decreased with distance from the facility.
- Residential lifetime excess cancer risks from long-term EtO exposure within 1 mile of the facility during operations ranged from 4 to 10 excess cancers in a population of 10,000, which led ATSDR to conclude there was a public health concern for increased cancer risk based on past exposure. Lifetime, excess cancer risks are estimates used to inform public health decision-making. They are not measurements of actual cases of cancer in a community.
- ATSDR estimated the cancer risks in this document assuming years of breathing the EtO concentrations EPA measured from November 2018-Februrary 2019. There is no long-term air monitoring data to assess EtO concentrations and associated cancer risk prior to November 2018. EtO emissions may have been greater in the past.

Conclusion 2: ATSDR concludes that people who breathed in EtO concentrations measured in the air near the Sterigenics facility when it was operating are not expected to be at risk for noncancer health effects due to EtO exposure.

Basis for Decision:

- The highest measured average EtO air concentrations in residential and off-site worker locations during Sterigenics operations were well below noncancer health guidelines and significantly below the lowest concentrations that have been reported to result in noncancer health effects in scientific studies.
- People who lived, worked, went to school, shopped, or traveled near Sterigenics are not expected to have experienced noncancer health effects from exposure to EtO concentrations that were measured in the community based on EtO concentrations measured from November 2018-February 2019.

Conclusion 3: After Sterigenics stopped EtO sterilization operations on February 15, 2019, EtO concentrations in the air within a mile of the facility were similar to background levels observed across the United States. Lifetime excess cancer risk from EtO exposure for people

living or working in Willowbrook after Sterigenics closed is similar to EtO-related cancer risk for people living or working in other areas without a major EtO source.

Basis for Decision:

- EtO concentrations were lower and less variable after Sterigenics closed compared to when it was operating.
- Background outdoor air EtO concentrations were similar in the following locations:
  - All eight Willowbrook monitoring stations following the closure of Sterigenics,
  - Two Cook County background air monitoring stations,
  - Air quality monitoring stations across the United States in areas with no known source of EtO emissions.
- There are uncertainties associated with estimating cancer risk associated with background concentrations of EtO.

6. Recommendations

Emissions of EtO from the Sterigenics facility in Willowbrook have ceased as the facility is permanently closed. Consequently, additional steps to control exposure to EtO from this facility are not needed.

To address the method detection limit issue, U.S. EPA is working on developing new analytical methods to improve the sensitivity and accuracy of measuring low-level outdoor air EtO concentrations below background EtO levels. U.S. EPA is also conducting research on the factors contributing to positive bias of EtO concentrations measured air sampling collected in canisters and has developed new air sampling and measurement method (method TO-15A) to reduce the influence of positive bias (Whitaker et al. 2019).

ATSDR recommends:

- Concerned residents talk with their doctors about health concerns related to EtO exposures.
- U.S. EPA improve the analytical methods to accurately measure EtO at lower concentrations by lowering the EtO method detection limit and the impact of EtO canister effect.

For More Information:

If you have questions about this document or ATSDR's work on EtO in ambient air, call our toll-free number at 1-800-CDC-INFO and ask for information on the ATSDR health consultation on EtO concentrations in Willowbrook near the Sterigenics facility.

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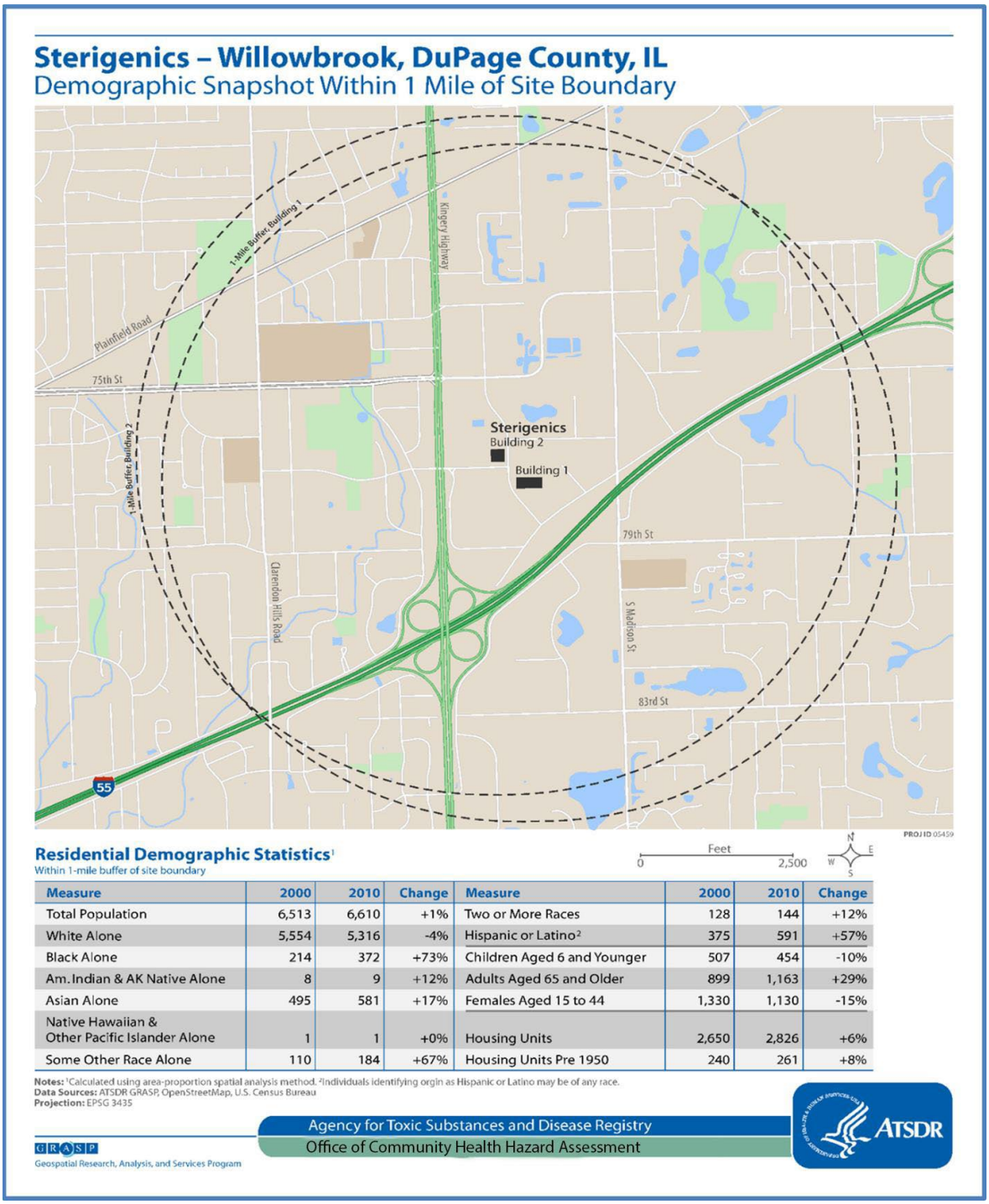
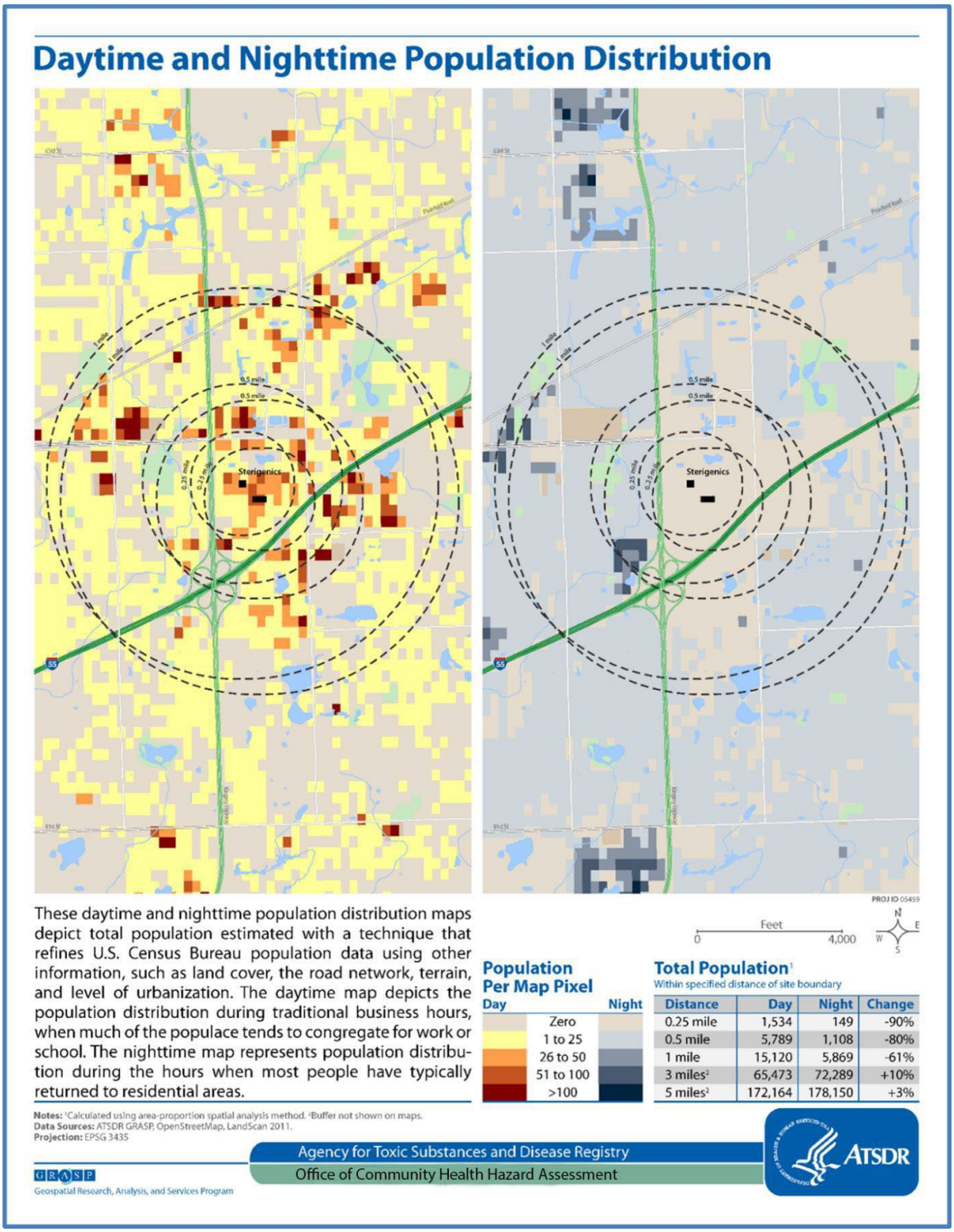
Appendix A. Area Demographic Maps

Figure A-1. Residential demographic statistics near Sterigenics in Willowbrook, IL



Measure	2000	2010	Change	Measure	2000	2010	Change
Total Population	6,513	6,610	+1%	Two or More Races	128	144	+12%
White Alone	5,554	5,316	-4%	Hispanic or Latino²	375	591	+57%
Black Alone	214	372	+73%	Children Aged 6 and Younger	507	454	-10%
Am. Indian & AK Native Alone	8	9	+12%	Adults Aged 65 and Older	899	1,163	+29%
Asian Alone	495	581	+17%	Females Aged 15 to 44	1,330	1,130	-15%
Native Hawaiian & Other Pacific Islander Alone	1	1	+0%	Housing Units	2,650	2,826	+6%
Some Other Race Alone	110	184	+67%	Housing Units Pre 1950	240	261	+8%

Figure A-2. Population density near Sterigenics in Willowbrook, IL: daytime and nighttime



Appendix B. Summary of Outdoor EtO Concentrations in Willowbrook

Outdoor EtO air data used to characterize health risks

U.S. EPA collected 24-hour EtO air samples in Willowbrook at eight locations using ten air monitors (two were collocated for quality assurance purposes). Samples were collected from November 12, 2018 – March 31, 2019, with a consistent collection frequency of either every 3rd day for primary monitors, or every sixth day for two co-located monitors. Intermittent samples were collected in some locations outside of this schedule. The U.S. EPA data also includes EtO concentrations that occurred after Sterigenics EtO sterilization operations were sealed, or involuntarily closed, on February 15, 2019 (see Tables B-1 and B-2).

Because some of the measured EtO concentrations were below analytic detection limits, ATSDR calculated summary statistics after estimating non-detect values using robust regression on order statistics (Helsel 2012). This statistical approach computes regression statistics to estimate the percentiles of the censored (non-detected) measurements. For each U.S. EPA air monitoring station in Willowbrook, ATSDR calculated the median, mean, and 95% CI (Manly 2007) to ensure that exposures are not underestimated due to sampling errors ([U.S. EPA] 2015; [ATSDR] 2019; Millard 2013).

The measured outdoor air EtO concentrations are subject to positive bias from the canister effect and to seasonal variation. To account for positive bias and seasonality, ATSDR used a GAM to adjust measured EtO concentrations in Willowbrook. The GAM adjusted EtO concentrations were used to calculate lifetime excess cancer risks from long-term EtO exposure. See GAM adjusted EPC in Table F-3. See Appendix E: Analysis of EtO Positive Bias and Seasonality for an explanation of the GAM adjustment to the measured EtO concentrations. See Appendix C, Figure C-1 for a visual comparison of GAM adjusted EtO concentrations by monitoring station and operating period.

Table B-1. Descriptive statistics of U.S. EPA measured 24-hour EtO outdoor air concentrations in Willowbrook during Sterigenics operations, November 13, 2018 – February 15, 2019 (µg/m^3)

Station	Number of Samples [Valid]	Number Samples Below Detection Limit	EtO Concentration Range	Median Concentration [Interquartile Range]	Mean Concentration [95% Confidence Interval]
Gower Elementary	32[29]	4	<0.08 – 1.38	0.237 [0.157--0.411]	0.32 [0.24 – 0.43]
Gower Middle	32[30]	7	<0.08 – 3.29	0.197 [0.101 – 0.439]	0.42 [0.24 – 0.68]
Hinsdale South High	32[29]	3	<0.08 – 3.29	0.267 [0.239 – 0.376]	0.41 [0.28 – 0.64]
Water Tower	32[28]	8	<0.08 – 10.8	0.248 [< 0.082 – 0.535]	1.33 [0.43 – 2.51]
West Neighborhood	32[30]	7	<0.08 – 5.35	0.205 [0.115 – 0.804	0.60 [0.32 – 1.01]
Willow Pond Park	32[30]	6	<0.08 – 3.71	0.211 [0.105 – 0.36]	0.44 [0.22 – 0.74]
Willowbrook Village Hall	32[31]	0	0.18 – 19.3	0.954 [0.517 – 3.98]	3.12 [1.66 – 4.85]
Willowbrook Village Hall 2*	14[14]	0	0.16 – 15.6	1.65 [0.591 – 5.31]	3.75 [1.66 – 6.37]
Willowbrook Warehouse	32[29]	4	<0.08 – 26.4	0.745 [0.237 – 3.09]	3.42 [1.57 – 5.79]
Willowbrook Warehouse 2*	17[15]	0	0.25 – 14.3	1.26 [0.609– 4.05]	3.04 [1.33 – 5.3]

* *Collocated duplicate monitor.*

Table B-2. Descriptive statistics of measured U.S. EPA 24-hour EtO outdoor air concentrations in Willowbrook during the post-closure period after Sterigenics stopped operations, February 16 – March 31, 2019 (µg/m3)

Station	Number of samples [Valid]	Number of Samples Below Detection Limit	EtO Concentration Range	Median Concentration [Interquartile Range]	Mean Concentration [95% Confidence Interval]
Gower Elementary	15[14]	4	<0.11 – 0.39	0.124 [< 0.067 – 0.174]	0.14 [0.11-0.19]
Gower Middle	15[15]	5	<0.11 – 0.27	0.0839 [0.0815 – 0.202]	0.13 [0.10-0.18]
Hinsdale South High	15[15]	2	<0.11 – 0.28	0.125 [0.102 –0.175]	0.14[0.11-0.17]
Water Tower	15[15]	3	<0.08 – 0.22	0.0871 [0.0793 – 0.165]	0.11 [0.09-0.15]
West Neighborhood	15[15]	3	<0.08 – 0.30	0.114 [0.102 –0.197]	0.14 [0.11-0.18]
Willow Pond Park	15[15]	2	<0.08 – 0.32	0.147 [0.111 –0.177]	0.15 [0.13-0.19]
Village Hall	17[16]	4	<0.11 – 0.46	0.128 [0.0781 – 0.166]	0.15 [0.11-0.21]
Village Hall (2)*	9[9]	3	<0.08 – 0.22	0.112 [< 0.067 – 0.197]	0.13 [0.08-0.22]
Warehouse	17[17]	5	<0.11 – 0.18	0.119 [0.0754 – 0.134]	0.12 [0.10-0.14]
Warehouse (2) *	8[8]	3	<0.11 – 0.24	0.144 [< 0.082 – 0.206]	0.17 [0.13 – 0.23}

* *Collocated duplicate monitor.*

Outdoor EtO air data used to evaluate spatial trends in addition to the U.S. EPA air sampling

Other datasets used in the spatial assessment of EtO, but not risk characterization, are described below.

Village of Burr Ridge: The Village of Burr Ridge collected eight 24-hour samples on November 13, 2018. These data were used in a spatial analysis of EtO concentrations in outdoor air (Figure C-3) but were too limited to be used in the risk characterization in this document or to draw public health conclusions because repeated measurements were not made over time (see Table B-3).

Table B-3. Burr Ridge measured 24-hour EtO outdoor air concentrations from sampling on November 13, 2019 (µg/m^3)

Number of Stations*	Number of Samples [Valid]	Number of Samples Below Detection Limit	EtO Concentration Range	Median EtO Concentration [Interquartile Range]
8	8[8]	0	0.12 – 0.40	0.21 [0.20–0.24]

* *Eight stations were sampled once on November 13, 2019 – data are combined for summary purposes*

Village of Willowbrook: The Village of Willowbrook collected 24-hour samples in both indoor and outdoor locations. Sampling occurred on November 16 and February 5-17, 2019. These data were used

in an overall trends curve of concentration versus distance (Figure C-3). While some of these samples were taken close to the Sterigenics facility and were used in the spatial analysis of EtO concentrations in outdoor air (Figure C-3), they were not collected on a routine basis and over enough time to represent long-term exposure for risk characterization in the health evaluation (see Table B-4). Therefore, these data were not used to estimate cancer risks or make public health conclusions.

Table B-4. City of Willowbrook measured 24-hour EtO outdoor air concentrations for two sampling events: November 16, 2018 and February 5-17, 2019 (µg/m^3)

Station	Indoor or Outdoor	Number Below Detection Limit	Samples [Valid]	EtO Concentration Range	Median [Interquartile Range]
Community Park	Outdoor	0	1[1]	0.14–0.14	— *
Gower Elementary	Outdoor	0	5[5]	0.2–3.1	0.62 [0.23–0.7]
Gower Elementary	Indoor	0	4[4]	0.07–0.32	0.085 [0.07–0.155]
Gower Middle	Outdoor	0	5[5]	0.08–6.12	0.39 [0.33–1.1]
Gower Middle	Indoor	0	4[4]	0.29–0.49	0.395 [0.328–0.46]
Hinsdale South	Outdoor	0	1[1]	0.12–0.12	—
Hinsdale South	Indoor	0	5[5]	0.08–0.45	0.23 [0.15–0.25]
Public Works	Outdoor	0	5[5]	0.09–1	0.38 [0.27–0.61]
Residential Indoor	Indoor	0	2[2]	0.31–0.67	—
Residential Outdoor	Outdoor	0	2[2]	0.14–0.15	—
Village Hall	Outdoor	0	5[5]	0.36–38	1.4 [0.58–9.2]
Village Hall	Indoor	0	15[15]	0.34–72	2.7 [0.87–35]
West Swim	Outdoor	0	1[1]	0.1–0.1	—
West Swim	Indoor	0	1[1]	0.25–0.25	—
Willow Pond	Outdoor	0	1[1]	0.08–0.08	—
Willowbrook Police Department	Outdoor	0	5[5]	0.39–320	2 [0.43–160]
Willowbrook Police Department	Indoor	0	16[16]	0.22–250	5.8 [1.25–24]

** Median and interquartile range not calculated due to small sample size*
Note that monitoring data reported by U.S. EPA noted substantial differences in concentration from what was reported inside and outside City (Village) Hall. For example, when 54 µg/m^3 was reported in the 2/11-2/12/2019 sample, two collocated EPA monitors at Village Hall reported 3.98 and 4.75 µg/m^3, respectively, at Village Hall stations 1 and 2. Differences were also noted on other dates. Since the concentrations reported at U.S.EPA monitoring stations agree and are collocated, ATSDR is defaulting to those stations for risk evaluation purposes.

Appendix C. Time and Spatial Analysis

Time Trends of outdoor EtO air concentrations in Willowbrook

To evaluate EtO concentration over time, ATSDR compared the outdoor air EtO concentrations (both measured and adjusted) at each U.S. EPA air monitoring station during Sterigenics operations (November 13, 2018-February 15, 2019) and post-closure (February 16-March 31, 2019) using boxplots and the Wilcoxon rank sum test. ATSDR also used a Kruskal Wallis rank test to evaluate differences in measured median EtO concentrations at U.S. EPA monitoring stations. There are statistical differences between the EtO concentrations at the U.S. EPA stations when the facility was operating (Kruskal Wallis $p < 0.001$), but post-closure there was not a significant difference detected between stations ($p = 0.55$). This finding indicates that none of the U.S. EPA stations were relatively more impacted by any other potential sources of EtO in the community.

The Wilcoxon rank-sum test showed the U.S. EPA data by station showed significant ($p<0.05$) decreases in EtO concentrations at seven of the eight locations during the post-closure period compared to the sampling data during Sterigenics operating period. Using the Hodges-Lehman estimator of median differences, the nearest stations to the facility generally experiencing the greatest decrease (Table C-1). Using the adjusted data, a similar pattern was noted, although the degree of effect of the shutdown was diminished, possibly due to differences in detection limits relative to the data after adjustment. Overall, the levels of EtO dropped post-closure after the Seal Order was issued on February 15, 2019 and Sterigenics's EtO sterilization operations in Willowbrook ended.

Table C-1. Results of Wilcoxon rank sum tests comparing outdoor EtO air concentrations (both measured and adjusted) at U.S. EPA monitoring stations when Sterigenics was open (November 12, 2018-February 15, 2019) versus when Sterigenics was closed (February 16-March 2019).

Monitoring Station (Distance from Sterigenics)	Adjusted Hodges Lehmann Estimator	Adjusted W Statistic	Adjusted P-value*	Measured Hodges Lehmann Estimator	Measured P-value*
Warehouse (0.02 mi)	-0.0971	128	<0.01	-0.347	<0.001
Warehouse STN 2 (0.02 mi)	-0.322	6.0	<0.01	-1.16	<0.001
Village Hall (0.02 mi)	-0.242	36	<0.01	-0.827	<0.001
West Neighborhood (0.20 mi)	-0.00006	144.1	<0.01	-0.0807	<0.01
Gower Middle (0.39 mi)	-0.00380	119.0	<0.01	-0.064	0.01
Water Tower (0.42 mi)	-0.00002	153.0	0.04	-0.149	<0.01
Hinsdale South High (0.45 mi)	-0.0218	87.5	<0.01	-0.142	<0.001
Gower Elementary (0.74 mi)	-0.00003	163.0	0.067	-0.103	<0.01
Willow Pond Park (1.01 mi)	-0.00007	203.5	0.19	-0.0395	0.16

* *A p-value <0.05 indicates a statistically significant difference between operational and post closure data.*

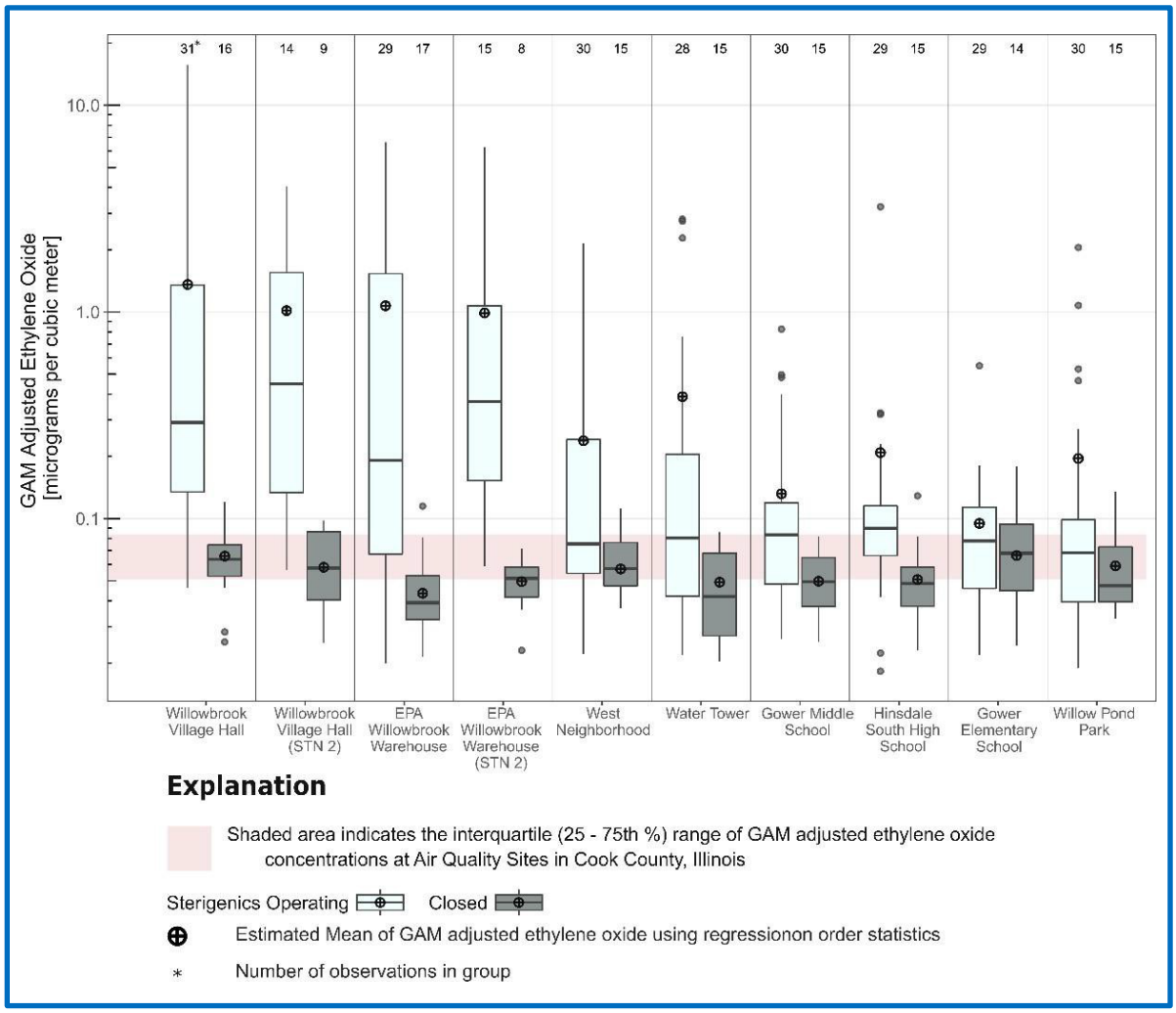
Figure C-1 shows the distribution of outdoor GAM adjusted EtO air concentrations while the facility was operational (light blue) and after its closure (dark gray) at each monitoring station using *boxplots*.

Boxplots show the *distribution* or spread of EtO air concentrations at each of the U.S EPA monitoring stations. The dark line in the middle is the *median value* (the number that separates the lower half and higher half of the data set, or 50th percentile), while the top of the box is the *third quartile* (75th percentile) and the bottom of the box is the *first quartile* (the 25th percentile). The lines extend to EtO concentrations that are considered part of the distribution. The dots at the top or bottom of the boxplot are EtO concentrations considered infrequently high or low measurements (statistical outliers) for the EtO concentrations at that monitor.

Figure 2 in the text (in the "General Measured Data Trends" section) presents a comparable boxplot for measured EtO concentrations. The interpretation of boxplot in Figure 1 is similar to the interpretation of Figure C-1 described above. Both plots (Figure 2 and Figure C-1) demonstrate that concentrations dropped after Sterigenics closed, especially at the closest monitoring stations. Concentrations at all monitoring stations were lower in Figure C-1 (displaying GAM adjusted data) compared to Figure 1 (displaying measured data) because the GAM adjusted limited the influence of positive bias on EtO concentrations.

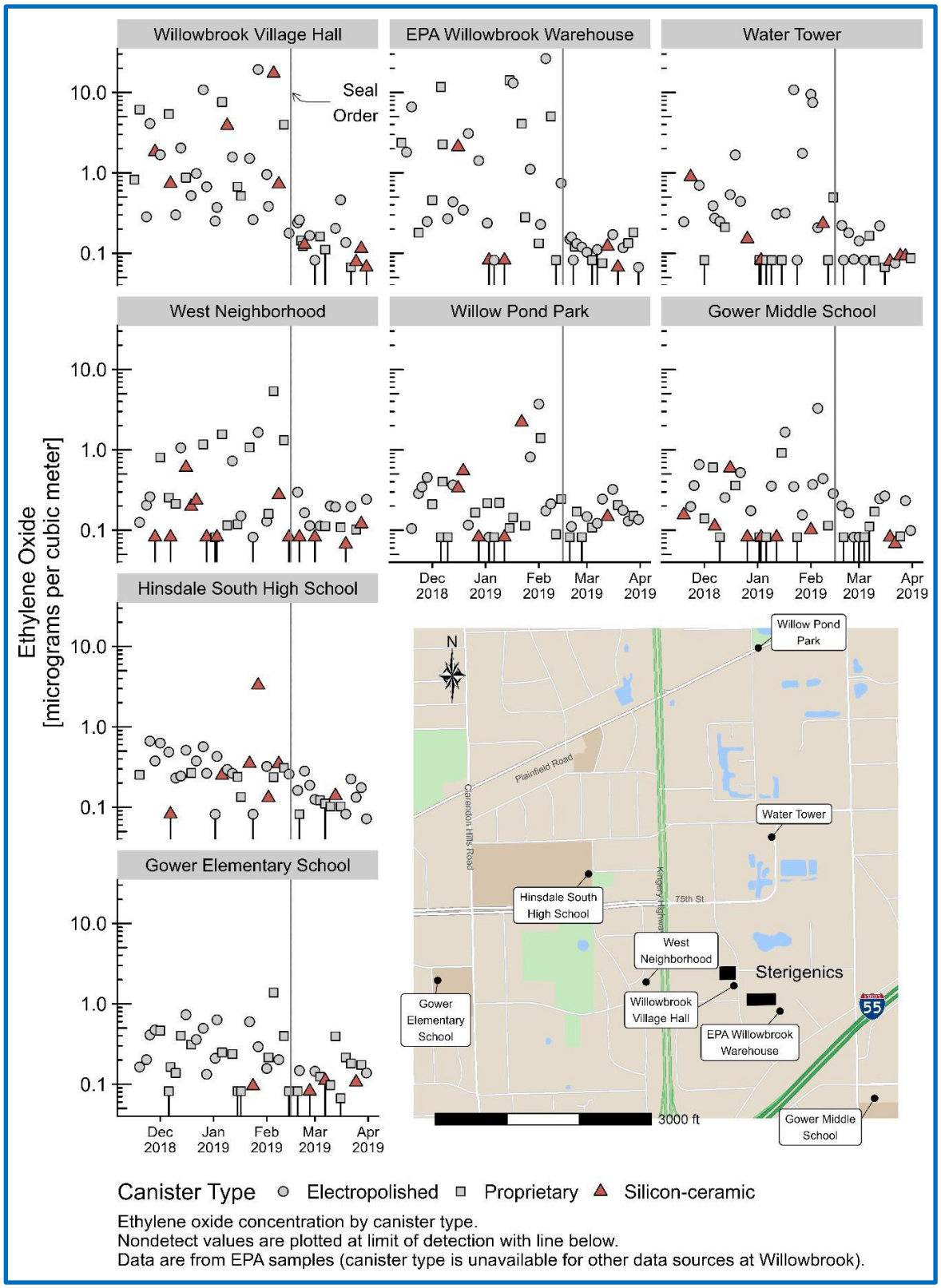
Figure C-2 plots measured EtO concentration by date and canister type at each monitoring station. Plots are grouped by direction of the monitoring station from Sterigenics and sorted from closest monitoring stations at the top to farther monitoring stations below. There is a great deal of scatter (variability) in the concentrations data when Sterigenics is operating, but after the facility closed on February 15, 2019, EtO concentrations were substantially reduced and there is less variability in the concentrations (Figure C-2). In general, Figures C-1 and C-2 visualize the impact from Sterigenics emissions on the outdoor EtO concentrations measured in Willowbrook

Figure C-1. Comparison of GAM adjusted outdoor EtO (µg/m³) air concentrations at U.S. EPA monitoring stations during Sterigenics's operating period (pre-Seal Order) and post-closure period (post-Seal Order): November 2018-March 2019



For explanation of boxplots see Appendix F

Figure C-2. Measured outdoor EtO air concentrations at U.S. EPA monitoring stations by date and canister type (November 2018-March 2019).



Spatial trends of outdoor EtO air concentrations in Willowbrook

Figures C-3, C-4 and C-5 display the polar plots displayed in Figure 4 but grouped by direction. These figures give a more detailed view of each polar plot and the relationships between plots that are closer and further away in the same direction from the facility. The impact of distance on concentration are plotted for all datasets to show the decrease with distance in ambient concentrations with the various sampling locations. Locally Weighted Smoothing (LOESS) plots show the relationship between variables and trends; here, the trend demonstrates a decrease in EtO concentrations with distance (Figure C-6).

Figure C-3. Polar plots for U.S. EPA western sampling locations: November 2018-February 2019.

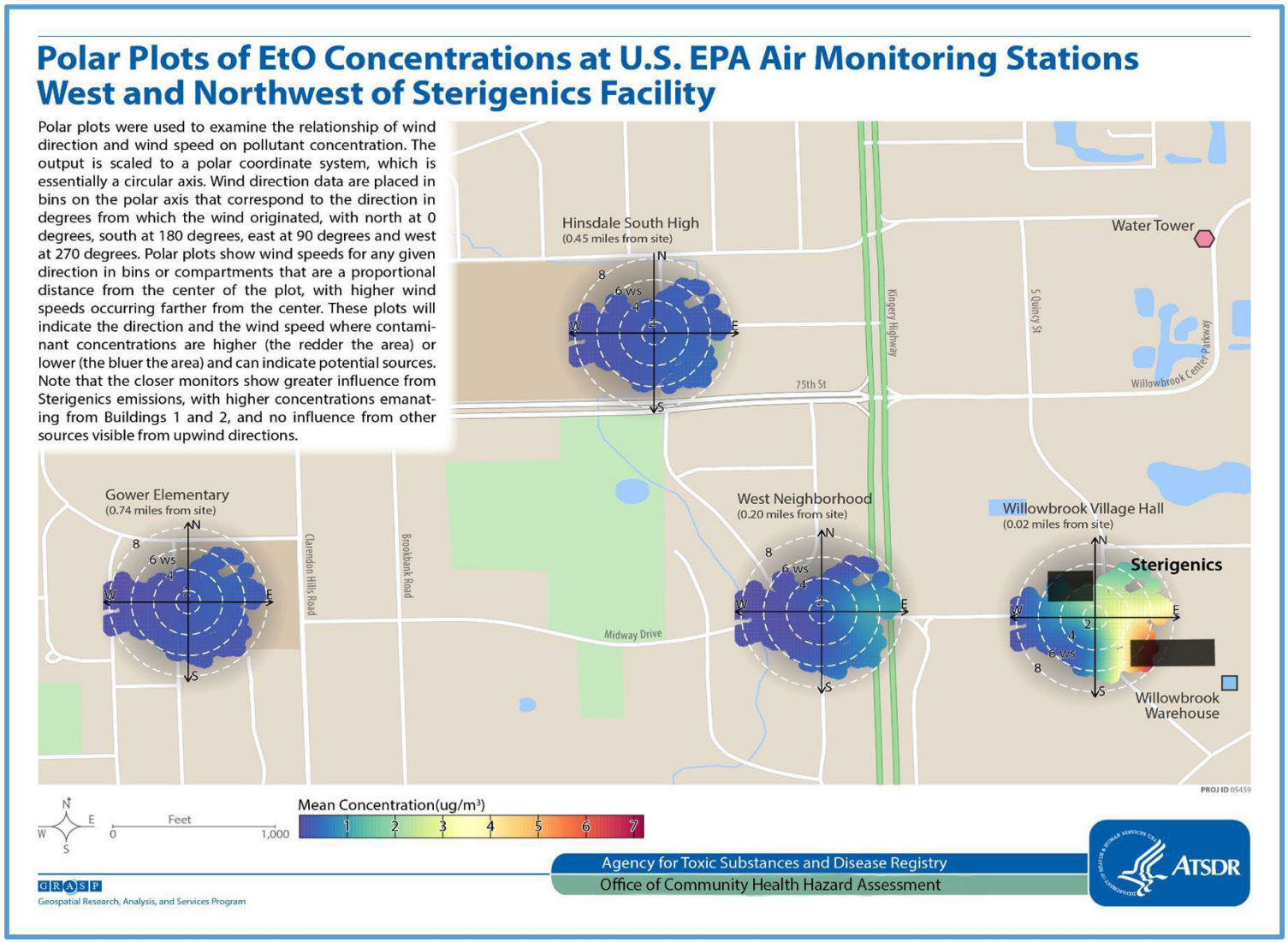


Figure C-4. Polar plots for U.S. EPA southeast sampling locations: November 2018-February 2019.

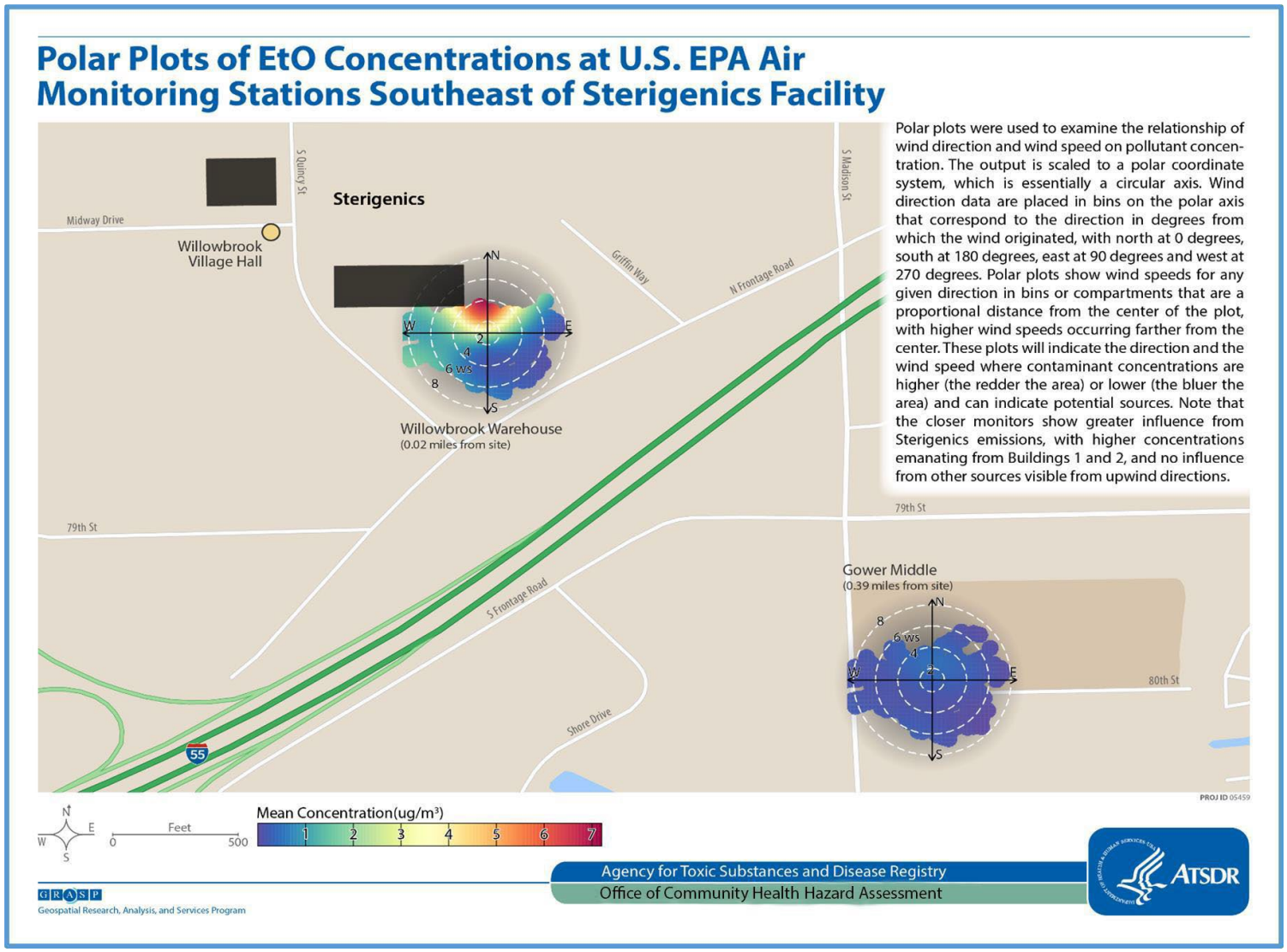


Figure C-5. Plots for U.S. EPA northern sampling locations: November 2018-February 2019.

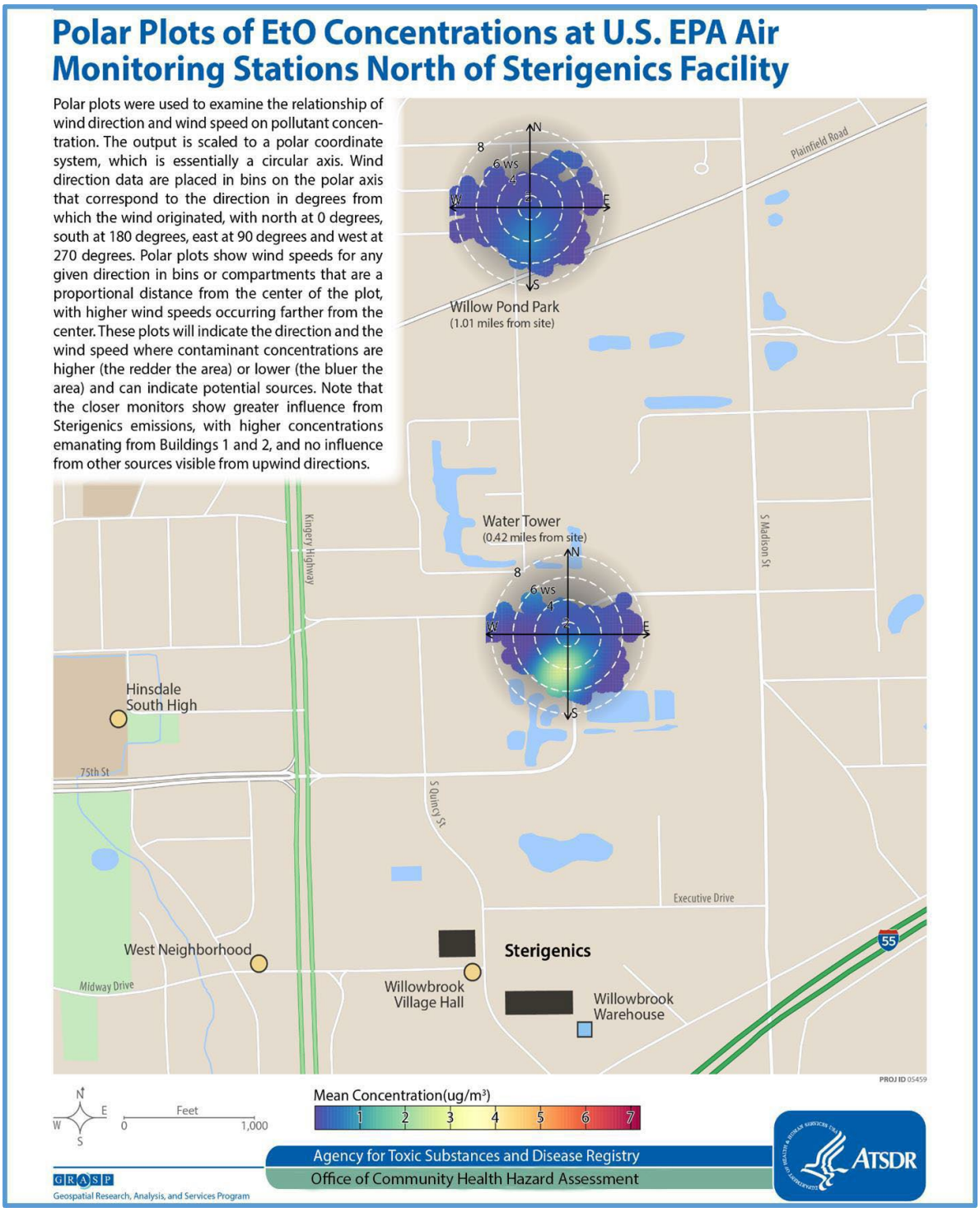
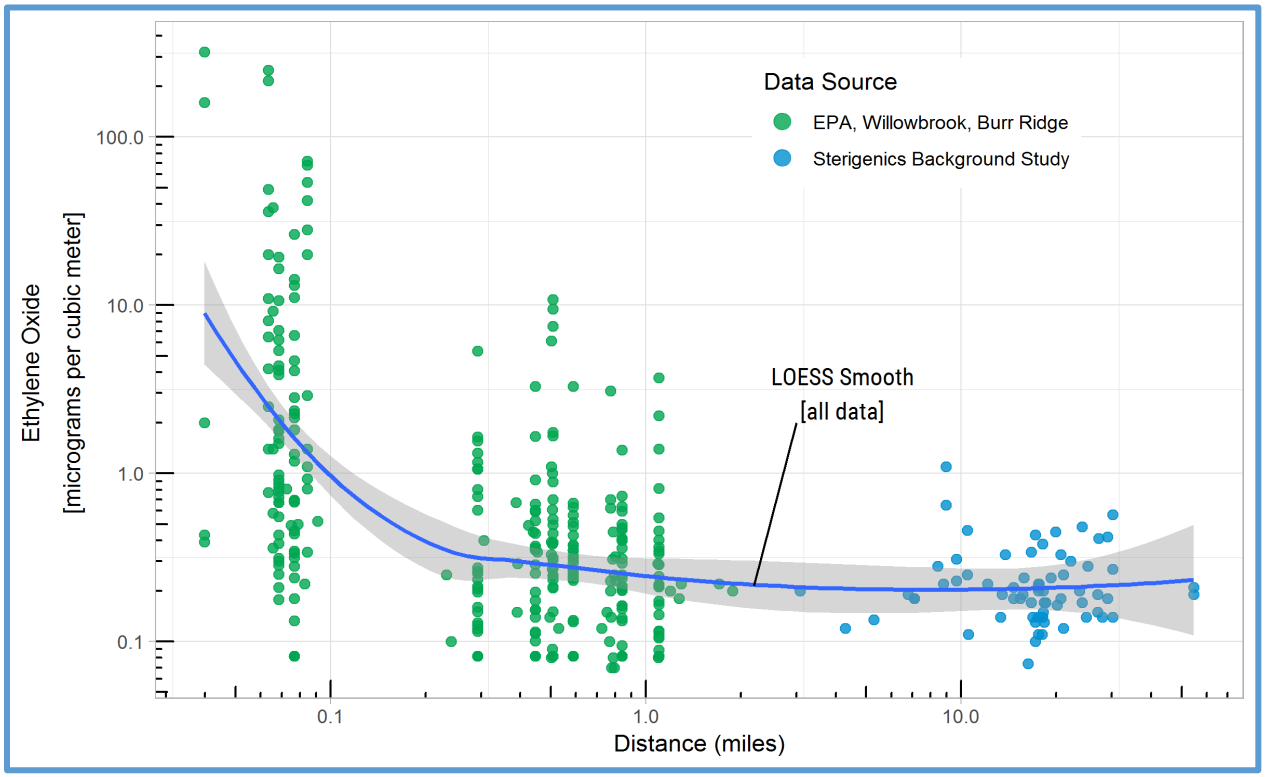


Figure C-6. Plots of measured outdoor EtO air concentrations with distance from Sterigenics in Willowbrook (November 2018-March 2019).

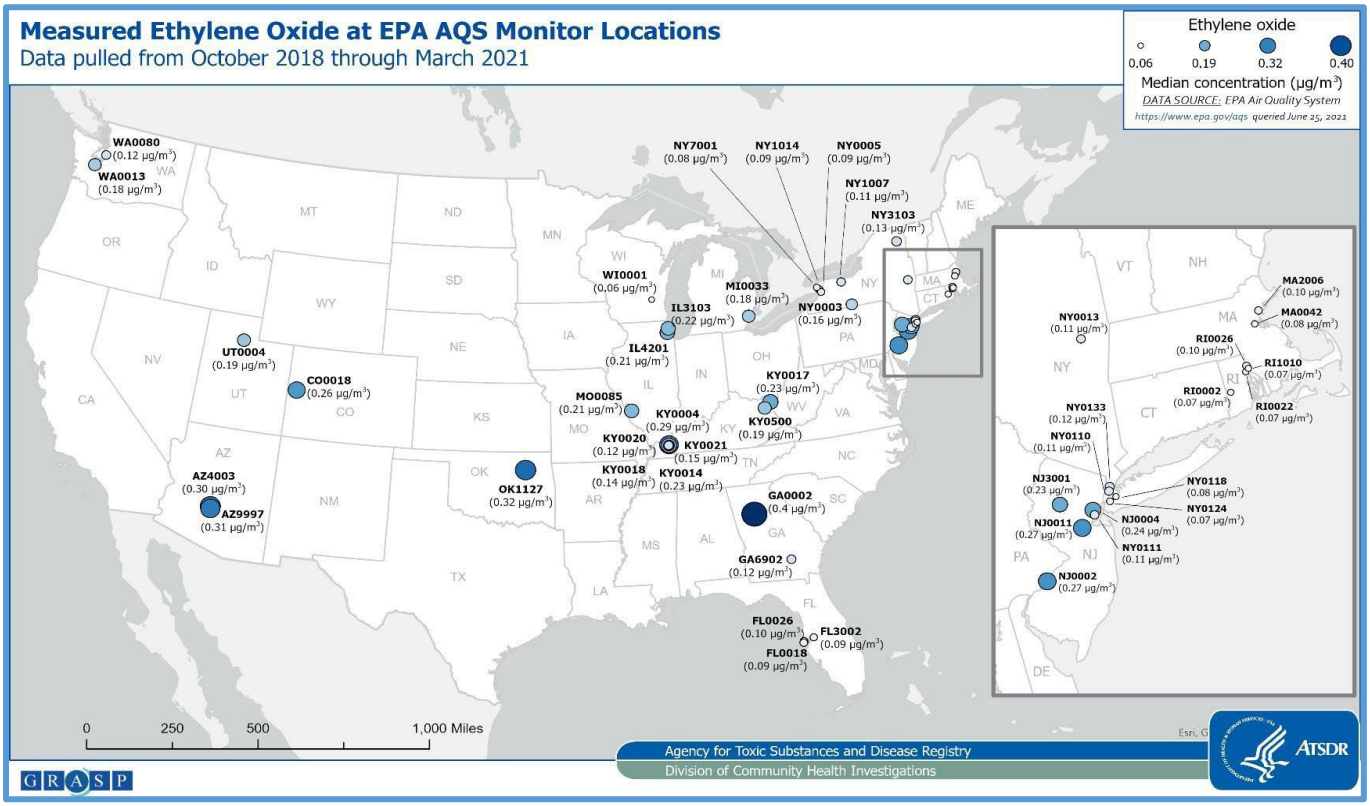


Appendix D. Outdoor EtO Concentrations in Illinois and Across the United States

To evaluate background outdoor EtO concentrations both in Illinois and across the United States, ATSDR accessed EtO data from U.S. EPA's Air Quality System (AQS). AQS contains ambient air pollution data collected by EPA, state, local, and tribal air pollution control agencies from thousands of monitors. AQS also contains meteorological data, descriptive information about each monitoring station (including its geographic location and its operator), and data quality assurance/quality control information ([U.S. EPA] 2021a). ATSDR examined EtO concentrations for air monitoring stations identified by U.S. EPA as Urban Air Toxics Strategy stations (UATS), National Air Toxics Trends stations (NATTS), or State and Local Air Monitoring Stations (SLAMS) that are intended to inform national ambient air quality for hazardous air pollutants in areas not believed directly impacted by industrial pollutants.

EtO air concentrations in this dataset were initially collected and analyzed using EPA's method TO-15, with gradual adoption of method TO-15a beginning after the new method was published in September 2019. We evaluated data from 48 stations in 16 states collected between 2018 and the spring of 2021. These national data show a wide range of median background EtO concentrations of 0.064-0.340 µg/m^3 at each of the monitoring stations (Figure D-1, Table D-1).

Figure D-1. National air monitoring stations reporting median measured EtO concentrations between October 2018 and March 2021.



Data are unadjusted. Median EtO concentrations may be influenced by the EtO canister effect, described below.

Table D-1. Descriptive statistics of measured EtO air concentrations detected at AQS air monitoring stations across the United States (µg/m3)[*] 2018-2021[†].

State (Station ID)	Number of Samples [Number Detected][*]	Median	Median 95% CI	Range
Arizona (04-013-4003)	60[49]	0.280	0.230 – 0.380	< 0.108 – 0.826
Arizona (04-013-9997)	131 [107]	0.320	0.250 – 0.390	< 0.108 – 1.420
Colorado (08-077-0018)	113[89]	0.230	0.180 – 0.300	< 0.108 – 1.375
Florida (12-103-0018)	59[56]	0.088	0.074 – 0.097	< 0.014 – 0.205
Florida (12-103-0026)	64[59]	0.086	0.072 – 0.100	< 0.108 – 0.256
Florida (12-057-3002)	96[89]	0.079	0.070 – 0.088	< 0.108 – 0.214
Georgia (13-089-0002)	61[58]	0.340	0.200 – 0.460	< 0.051 – 6.102
Georgia (13-069-0002)	9[5]	0.063	0.048 – 0.980	< 0.051 – 2.772
Illinois (17-031-3103)	129[92]	0.180	0.150 – 0.250	< 0.108 – 0.961
Illinois (17-031-4201)	148[103]	0.180	0.140 – 0.250	< 0.108 – 1.082
Kentucky (21-139-0004)	27[26]	0.290	0.200 – 0.340	< 0.108 – 0.828
Kentucky (21-157-0014)	30[26]	0.230	0.170 – 0.320	< 0.108 – 1.424
Kentucky (21-019-0017)	6[6]	0.230	0.085 – 0.660	0.085 – 0.662
Kentucky (21-157-0018)	24[11]	0.120	0.076 – 0.180	< 0.108 – 0.367
Kentucky (21-157-0020)	20[7]	0.064‡	0.033 – 0.130	< 0.108 – 0.380
Kentucky (21-157-0021)	26[11]	0.095‡	0.048 – 0.290	< 0.108 – 1.512
Kentucky (21-043-0500)	137[99]	0.180	0.140 – 0.220	< 0.108 – 0.864
Massachusetts (25-025-0042)	70[30]	0.081	0.069 – 0.094	< 0.090 – 0.740
Massachusetts (25-021-2004)	63[37]	0.099	0.071 – 0.120	< 0.090 – 0.824
Massachusetts (25-009-2006)	76[45]	0.094	0.082 – 0.100	< 0.090 – 0.216
Michigan (26-163-0015)	7[1]	NA	NA	< 0.108 – 0.232
Michigan (26-163-0033)	131[92]	0.170	0.140 – 0.200	< 0.108 – 1.051
Missouri (29-510-0085)	128[96]	0.200	0.170 – 0.230	< 0.108 – 0.923
New Jersey (34-007-0002)	103[82]	0.250	0.190 – 0.300	< 0.108 – 0.920
New Jersey (34-039-0004)	87[64]	0.250	0.180 – 0.300	< 0.108 – 0.706
New Jersey (34-023-0011)	107[80]	0.250	0.170 – 0.310	< 0.108 – 1.426
New Jersey (34-027-3001)	101[67]	0.200	0.150 – 0.280	< 0.108 – 0.841
New York (36-101-0003)§	87[86]	0.160	0.140 – 0.170	< 0.054 – 0.402
New York (36-101-0003)§	67[66]	0.140	0.120 – 0.150	< 0.054 – 0.319
New York (36-029-0005)	76[59]	0.096	0.081 – 0.110	< 0.054 – 0.411
New York (36-001-0013)	100[93]	0.110	0.098 – 0.130	< 0.054 – 0.744
New York (36-005-0110)	94[90]	0.110	0.100 – 0.120	< 0.054 – 0.303
New York (36-085-0111)	70[68]	0.110	0.100 – 0.130	< 0.054 – 1.526
New York (36-047-0118)	47[38]	0.095	0.078 – 0.120	< 0.054 – 0.629
New York (36-081-0124)	115[91]	0.080	0.069 – 0.093	< 0.054 – 0.253
New York (36-005-0133)	119[119]	0.120	0.110 – 0.130	0.066 – 0.219
New York (36-055-1007)	117[100]	0.110	0.098 – 0.120	< 0.054 – 0.397
New York (36-029-1014)	78[66]	0.100	0.090 – 0.120	< 0.054 – 1.000
New York (36-063-7001)	54[42]	0.089	0.075 – 0.110	< 0.054 – 0.183
Oklahoma (40-143-1127)	41[26]	0.280	0.210 – 0.400	< 0.108 – 0.787
Pennsylvania (42-003-0008)	13[6]	0.130*	0.073 – 0.420	< 0.108 – 0.578
Rhode Island (44-003-0002)	59[32]	0.092	0.062 – 0.100	< 0.090 – 0.569
Rhode Island (44-007-0022)	58[32]	0.072	0.064 – 0.090	< 0.090 – 0.450
Rhode Island (44-007-0026)	57[32]	0.099	0.085 – 0.100	< 0.090 – 0.1746
Rhode Island (44-007-1010)	60[25]	0.076	0.071 – 0.100	< 0.090 – 0.464

State (Station ID)	Number of Samples [Number Detected]*	Median	Median 95% CI	Range
Utah (49-011-0004)	117[77]	0.180	0.140 – 0.230	< 0.108 – 1.386
Washington (53-067-0013)	47[32]	0.180	0.120 – 0.240	< 0.108 – 0.769
Washington (53-033-0080)	110[59]	0.110	0.090 – 0.130	< 0.108 – 0.679
Wisconsin (55-027-0001)	56[6]	0.068*	0.054 – 0.087	< 0.108 – 0.320
Wisconsin (55-079-0010)	14[1]	NA	NA	< 0.108 – 0.203

**µg/m³micrograms per cubic meter*
† http://www.epa.gov/aqs
‡ less than 50% of samples were above the detection limit.
§ Note that New York station 0003 had noticeably higher EtO measurements than other New York stations. This station is at an atmospheric research facility, in a remote, high elevation forested area.
Censored data were imputed using robust regression on order statistics. Valid samples are samples not flagged as invalid in AQS; detected values are those reported above detection limits or alternate detection limits.

ATSDR evaluated background outdoor air EtO concentrations in multiple states to inform the health assessment evaluation of EtO concentrations in Willowbrook, Illinois. In Figure D-2, EtO air concentrations from individual AQS monitoring stations in Florida and New York are visualized to illustrate seasonal patterns in background EtO air concentrations. EtO concentrations in these states, measured exclusively using silicon-ceramic canisters, show far less variability (EtO median concentrations of 0.08-0.16 µg/m^3) than states, such as Illinois, that used different types of canisters for ambient air quality measurements. EtO concentrations in Florida and New York (Figures D-2 and D-3) follow a seasonal pattern, with EtO concentrations rising in early summer, peaking in mid-summer, then declining in the fall. Note Massachusetts also exclusively uses silicon-ceramic canisters and also showed a peak in the mid-summer EtO concentrations, but the seasonal pattern in the winter months was not as visually apparent due to higher MDLs (Figures D-4 and D-5). The EtO concentrations at these stations stay relatively stable and low through winter and spring. Higher EtO concentrations are observed in these stations in the spring/summer, regardless of where in the state the monitor was located. However, because the Cook County sites used all three canister types, this trend is not distinguishable in Illinois (Figure D-4). This visual trend is clearer when each state's AQS EtO concentrations are aggregated into a single image (see Figure D-5). In contrast, EtO samples collected using mixed canister types (all states except Florida, Massachusetts, and New York) tended to exhibit higher and more variable EtO concentrations and did not exhibit a clear seasonal pattern. This observation warrants investigation into potential atmospheric reactions or biologic/unidentified industrial sources of background EtO in ambient air. Identifying information on how much of a pollutant is present in areas removed from sources ("background") is an important aspect of assessing excess exposure resulting from known industrial sources. Prior to U.S. EPA's initiation of national analysis of EtO in fall of 2018, there was little information about what constitutes "normal", "background", or "non-source identified" EtO concentrations in ambient air across the United States in the scientific literature.

EPA's canister analysis resulted in additional understanding of limitations in using existing U.S. EPA method TO-15 to analyze EtO concentrations in ambient air and an understanding of pollutants that interfere (EtO co-elutants). In September 2019, U.S. EPA released an updated analytical method (TO-15a) that can identify positive EtO bias in air samples from the formation and growth of EtO in a canister due to reactions between evacuated air and the lining of some canisters. U.S. EPA is working to improve the analytical methods to measure EtO accurately, reduce EtO formation in canisters, find more sensitive methods to measure EtO with lower MDLs.

In May 2021 ([U.S. EPA] 2021d; [U.S. EPA] 2021e) , U.S. EPA reported to ATSDR that sampling canisters with silicon-ceramic lining performed better and had less positive bias and EtO generation than electropolished canisters. They observed a 7 to 10-fold increase in EtO concentration in new "clean" electropolished canisters over a 4-5 week hold time, while far fewer silicon-ceramic canisters had detectable EtO over that time period. Further, they recommended the use of humidified zero air in lieu of nitrogen to better detect the "canister effect" in clean canisters. U.S. EPA reported in April of 2021 that the updated analytical requirements in method TO-15A are expected to improve ([U.S. EPA] 2021c).

- Canister qualification/certification through the use of humidified zero air versus nitrogen.
- More stringent canister cleanliness acceptance limits.
- TO-15A is better tailored to identify and remove problematic canisters from EtO sampling.

For these reasons, the evaluation of measured EtO concentration data without analyzing the positive bias caused by EtO canister effect makes it difficult to determine whether detections of EtO concentrations in an air sample are a product of the EtO canister effect (positive bias) or if EtO was actually ubiquitously present at low concentrations. Prior to the identification of this issue, different types of canisters (e.g., silicon-ceramic, SUMMA canister proprietary lining, and electropolished) were used interchangeably when sampling for EtO in outdoor air with method TO-15.

Figure D-2. Florida AQS EtO concentrations over time at 3 stations in 2 counties.

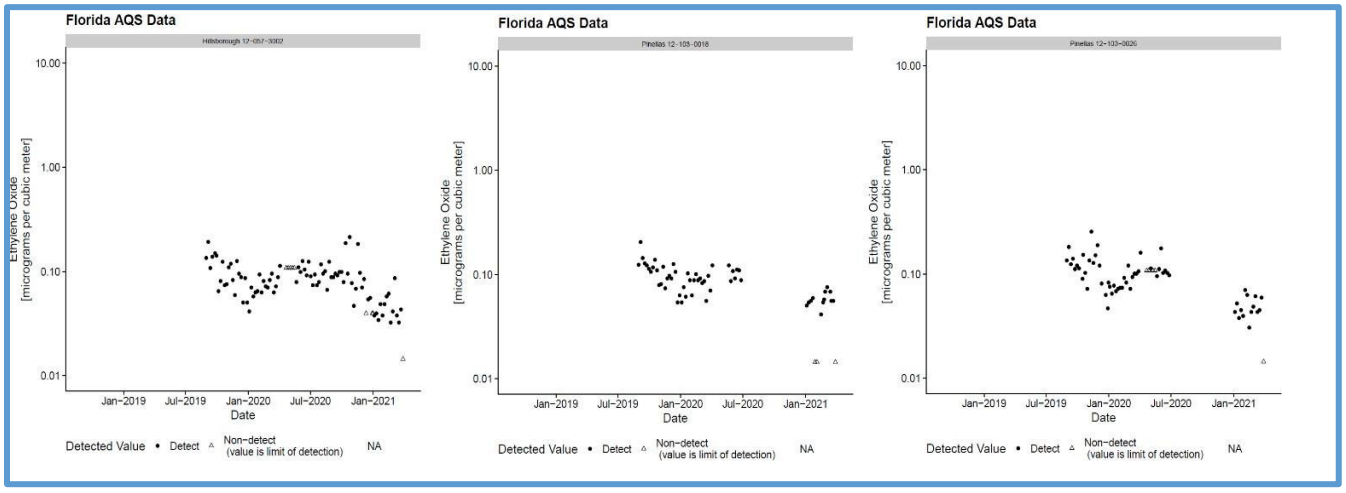


Figure D-3. All New York AQS EtO concentrations over time at 12 stations in 10 counties.

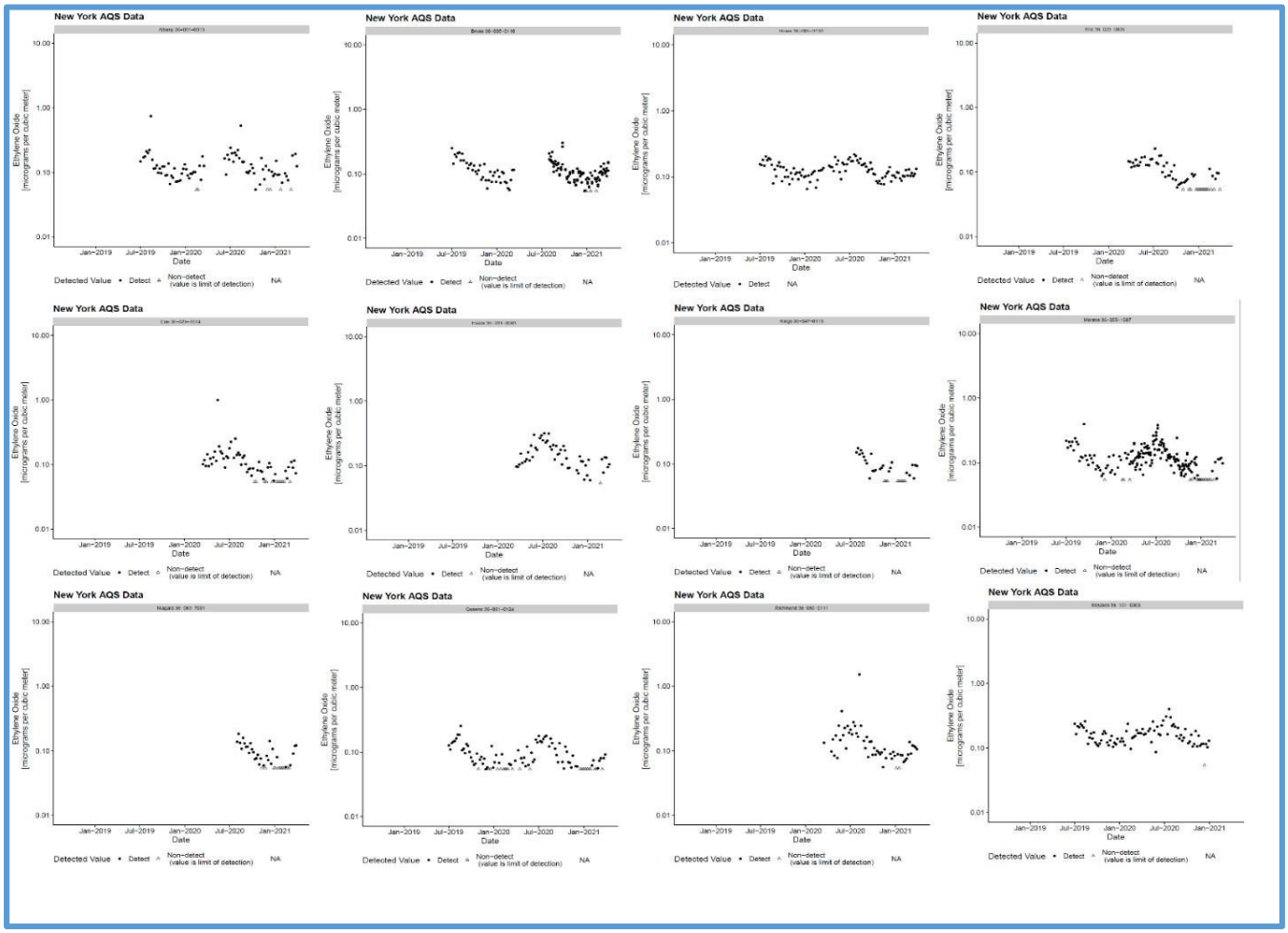


Figure D-4. EtO concentrations over time in areas without EtO sources: silicon-ceramic canisters at Florida, New York, and Massachusetts AQS sites vs. mixed canisters at Illinois AQS sites.

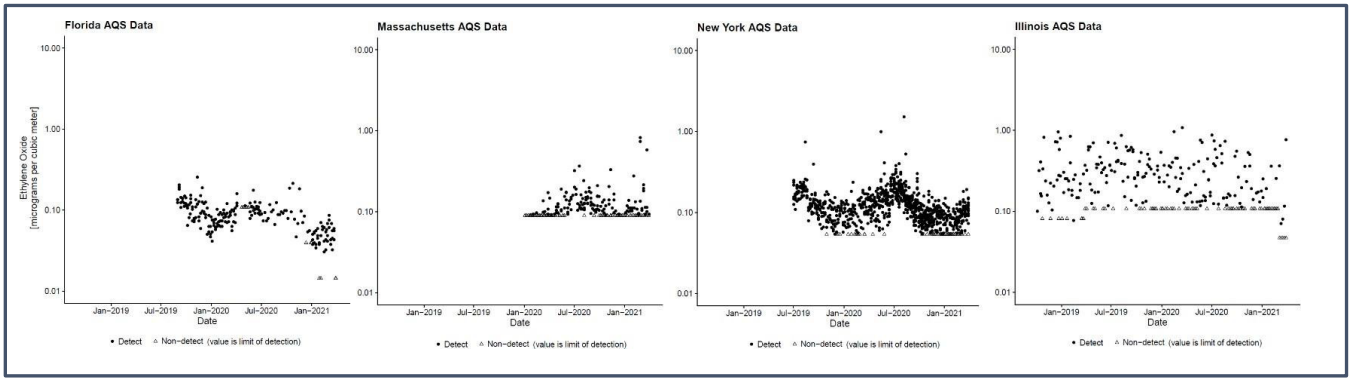
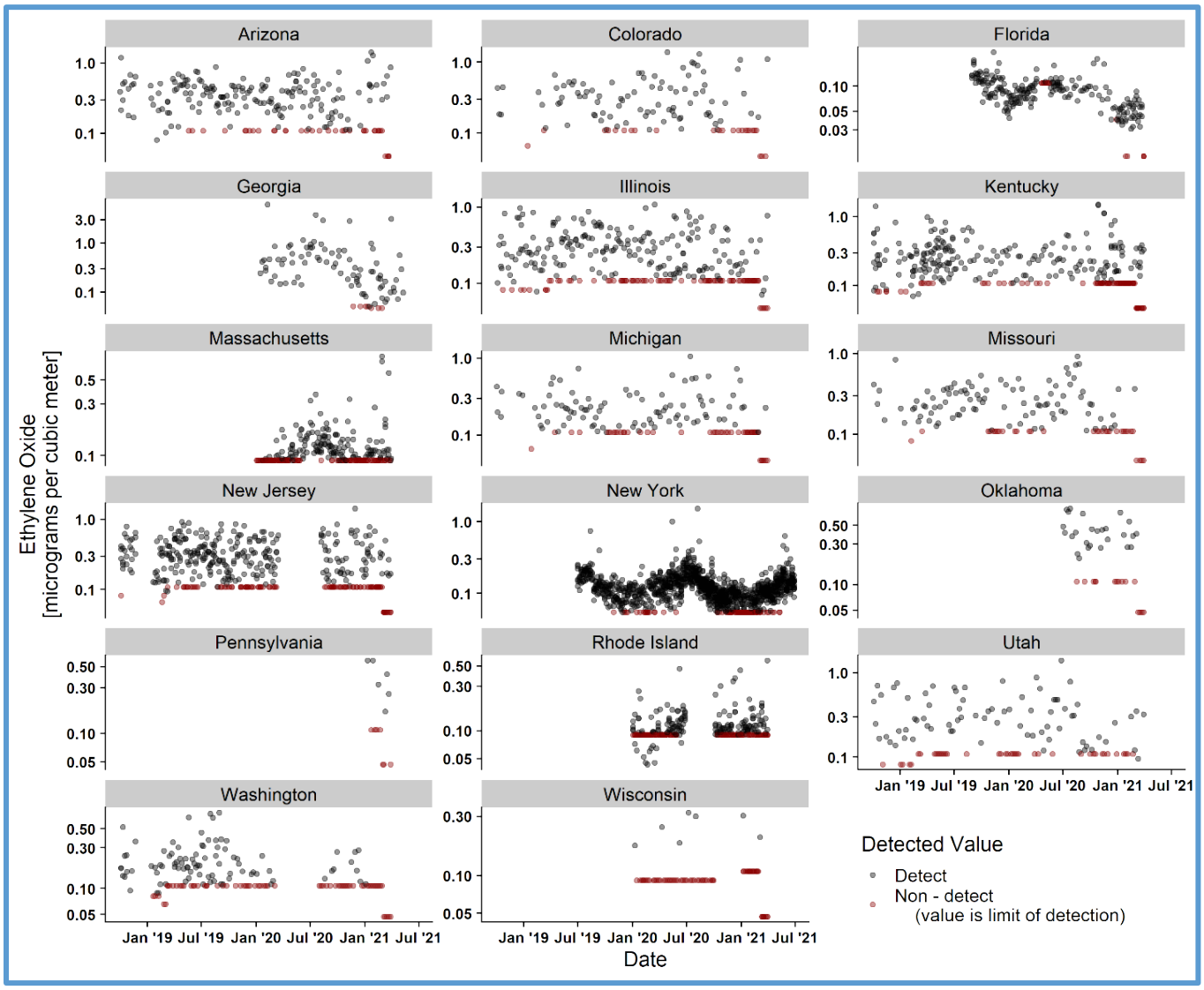


Figure D-5. Aggregated AQS EtO concentrations collected by state (October 2018-March 2021)



source: www.epa.gov/aqs

Appendix E. ATSDR'S Analysis of EtO Positive Bias and Seasonality

In some canisters the canister effect causes positive EtO bias which results in higher reported EtO concentrations than are actually present in the outdoor air sample. In this section, we describe a Bayesian fitted generalized additive model (GAM) which was used to adjust EtO concentrations in the Willowbrook dataset by controlling for canister lining type and holding time within the context of an apparent seasonal effect. This approach, which subtracts the modeled positive bias effects of lining type, holding time, and season from measured EtO concentrations in air samples collected in non-silicon-ceramic canisters, is appropriate to quantify EtO concentrations and trends for site-specific assessments when sufficient local background EtO air quality monitoring data exists.

Data used to build the model

To evaluate ambient EtO concentrations both in Illinois and across the United States, ATSDR accessed data from U.S. EPA's AQS. As a referent of background EtO exposure in areas unaffected by EtO sources, ATSDR evaluated EtO concentrations collected at two Illinois ambient air quality monitoring stations (the Northbrook and Schiller Park ambient air monitoring stations) within Cook County, IL between October 2018 and March 2021. The differences in EtO concentrations between the two sites is small and not statistically significant (Wilcoxon Rank Sum p = 0.5, Hodges-Lehmann estimator: 0.00002, 95% CI of the -0.0008 – 0.003 $\mu g/m^3$). Therefore, we combined data from these two stations for the purposes of building the GAM that corrects for effects of canister linings, holding time, and seasonality on EtO concentration in air samples from non-silicon-ceramic canisters. ATSDR applied the GAM, built with robust Cook County background EtO data, to the measure Willowbrook EtO concentrations to remove the noise of the canister effect and better estimate EtO concentrations and resulting health implications for cancer and noncancer health effects and trends in the data. ATSDR received lab reports and canister identifying information from U.S. EPA and its contract lab, Eastern Research Group.

Methods

Software:

ATSDR used R statistical software to analyze EtO concentrations reported in the Willowbrook (DuPage County, IL) air samples as well as background EtO air data collected in Illinois and in other states. R version 4.1.2 with analytical packages NADA 1.6; NADA-2 1.0.2; tidyverse 1.3.1; mgcv 1.8-35; brms 2.16.3; tidybayes 3.0.1; EnvStats 2.4, bayestestR 0.11.5, asbio 1.7, and effect size 0.6.0.1 were used for statistical modeling and generating all tables and figures in this report. The details of the statistical approach for this assessment are presented below.

Bayesian fitted GAM:

ATSDR used Hamiltonian Monte Carlo (HMC) based Bayesian analysis to develop models describing the effects of canister lining type, sample holding time, and seasonality on observed levels of EtO at the two Cook County monitoring stations. The R brms package was used to interface with the Stan platform (version 2.21.0). The Stan/brms computational framework supplies robust Bayesian inference as well as methods for explicit treatment of censored data (Kurz 2021). ATSDR used Stan because it could formulate the model to explicitly describe censoring (non-detects) of the ethylene oxide results. ATSDR considered nine candidate models and compared them with each other using Bayes Factors (Makowski et al. 2019; Makowski, Ben-Shachar, and Lüdecke 2019) to assess the relative predictive power of the

models to each other. HMC was performed with default weak priors and with 4 chains, 20,000 burn in and 20,000 post burn in samples, with a thinning of 10.

Results of the GAM adjustment

ATSDR observed the influence of lining type, holding time, and seasonality on the measured background EtO concentrations in the Cook County, Illinois air monitoring stations. In comparison to states that only used electropolished canisters (Florida, Massachusetts, and New York), Illinois and other states had no discernable seasonal pattern, and generally higher reported EtO measurements. ATSDR evaluated the optimal model of holding time, canister type, and seasonal effects in a stepwise fashion. Our final model (presented here) represents the optimal configuration of these variables that was generalizable to the data at Willowbrook; the model had the highest Bayes factor.

To better estimate the seasonal effect in the Cook County background EtO concentrations, ATSDR:

- modeled the holding time smooth terms as interactive linear terms because there was no evidence of nonlinear effects (because the model with smooths showed a near linear term in the GAM).
- because we observed seasonality in the silicon ceramic AQS data, ATSDR used a cyclic spline based smooth of the effect of Julian day using a cyclic spline.
- The model is (note the star * is an interactive term):
  *log(EtO) ~ sample holding time * canister lining type + s(Julian day) + error*

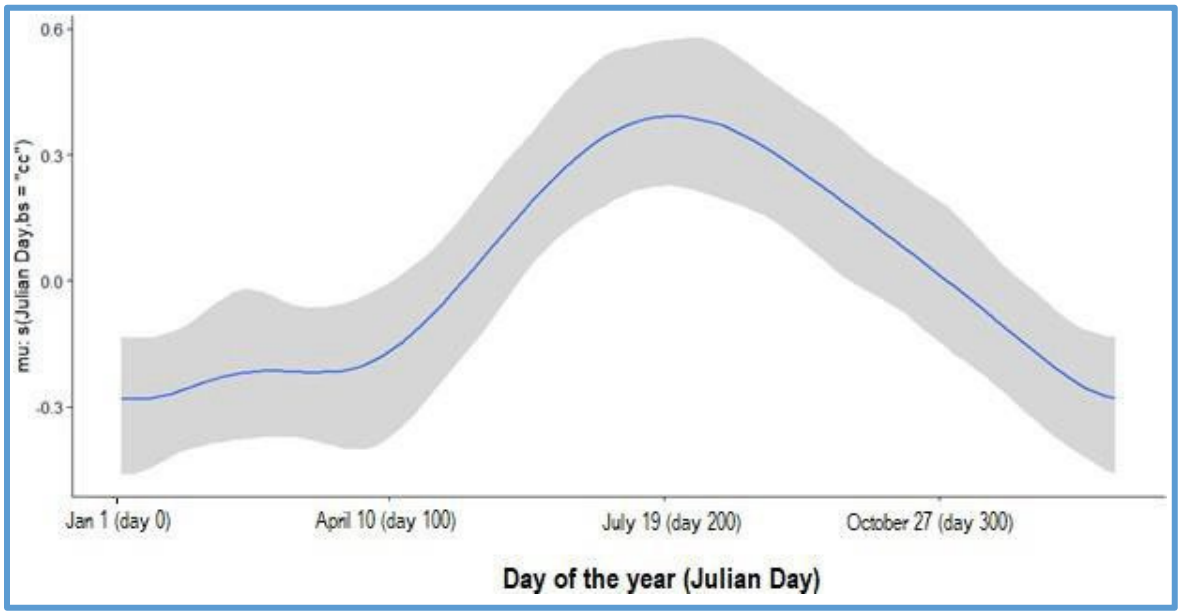
The GAM had an adjusted r-squared suggesting that about 49% of the EtO concentrations reported were explained by canister lining type, sample holding time, and seasons in the Cook County background EtO data we evaluated (See Table E-1 and Figure E-1).

Table E-1. GAM coefficients: linear interaction of holding time by canister lining type and smoothed date (parametric coefficients) using Cook County air quality monitoring sites (October 2018-March 2020)

Coefficient	Median Estimate	95% Credible Interval	Probability of Direction	Rhat	Effective Sample Size
Intercept	-2.77	[-3.41, -2.21]	100%	1.000	7798
Sample holding time	0.01	[-0.03, 0.05]	76.29%	1.000	7725
Proprietary lining	0.64	[-0.12, 1.33]	95.96%	1.000	7773
Electropolished lining	0.99	[0.38, 1.65]	99.95%	1.000	7832
Interaction of lag: proprietary lining	0.02	[-0.02, 0.07]	78.72%	1.000	7746
Interaction of lag: electropolished lining	0.03	[-0.01, 0.07]	93.64%	1.000	7640

Median estimate is median of HMC posterior. 95% Credible interval is the shortest interval that contains 95% of the posterior distribution and represents the uncertainty of the parameter estimate. Probability of Direction is an index which can range from 50% to 100% that measures the probability that an effect is in a particular direction. Rhat is measure of convergence of the HMC chains and should be 1 or close to 1. Effective Sample Size is the number of independent samples with similar estimation power as the 8000 samples in HMC simulation. Model was built using Cook County background monitoring sites from the Illinois Ambient Air Monitoring Network.

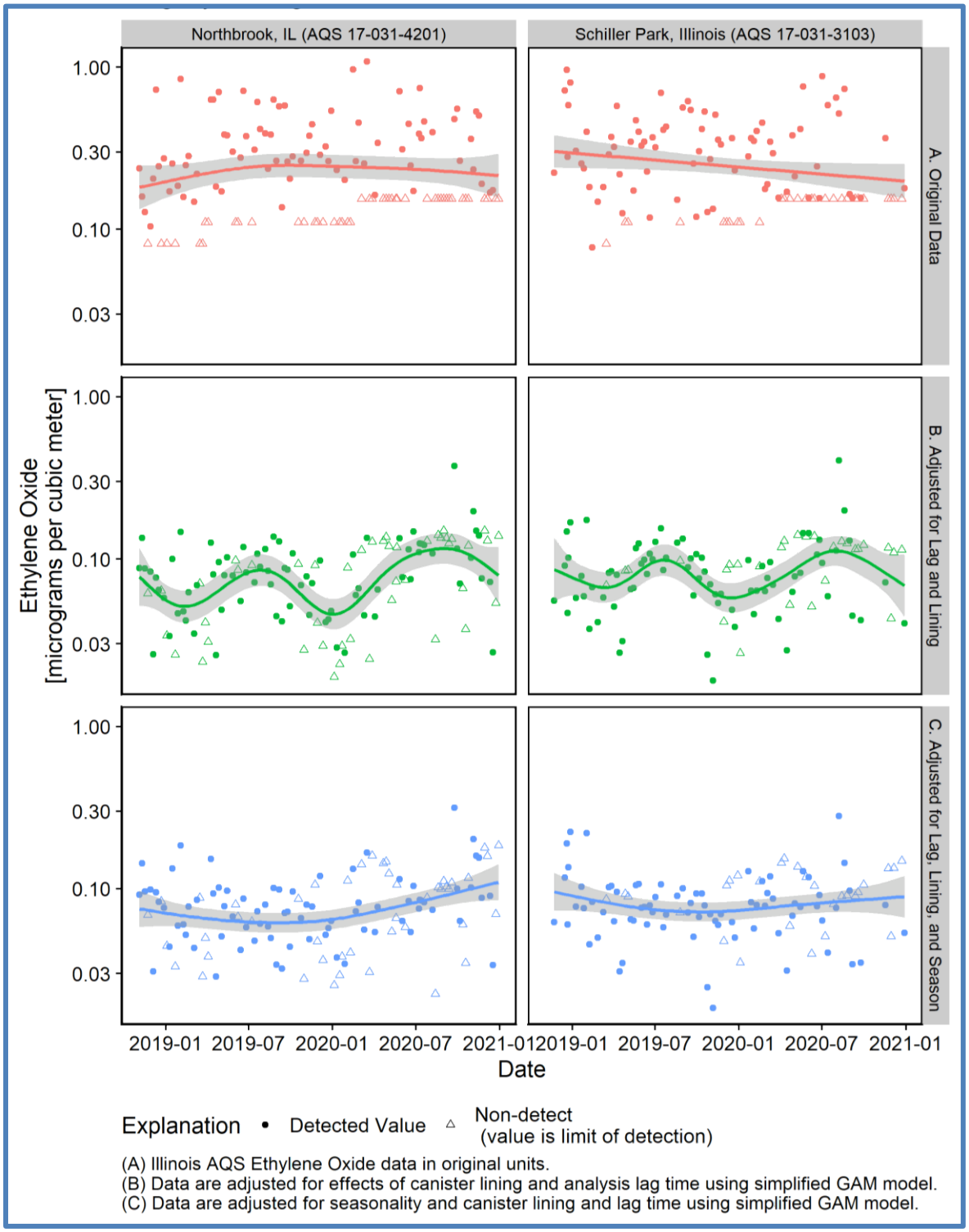
Figure E-1. Smooth effect of *Julian Day* (day of the year from 1 to 365): Cook County, IL background air monitoring stations (October 2018-March 2021).



Using the coefficients of the GAM, we adjusted the EtO concentrations from the two Illinois Ambient Air Monitoring Network background monitoring stations in Cook County collected between October 2018 and March 2021 for canister type, holding time, and seasonality (Figure E-2). To show the relative influence of each factor on measured values of EtO, we highlight:

- the original measured EtO concentrations in the top two panels in red, which have little or no pattern.
- the GAM-adjusted data in the middle panels in green, where the model is controlling for canister lining type and sample holding time, which reveals the seasonality of EtO concentrations at the two Illinois background sites.
- the GAM-adjusted data in the bottom panels in blue, where the model is controlling for lining type, sample holding time, and season, revealing an estimated background concentration if these factors were not present.

Figure E-2. Comparison of measured EtO concentrations to GAM-adjusted EtO concentrations at two Illinois AQS background monitoring stations in Cook County.



Explanation: Using the coefficients of the GAM, we adjusted the EtO concentrations from the two Illinois Ambient Air Monitoring Network background monitoring stations in Cook County collected between October 2018 and March 2021 for canister type, holding time, and seasonality (Figure E2). To show the relative influence of each factor on measured values of EtO, we highlight: • the original measured EtO concentrations in red, which have little or no pattern. • the GAM-adjusted data in green, where the model is controlling for canister lining type and sample holding time, which reveals the seasonality of EtO concentrations at the two Illinois background sites. the GAM-adjusted data in blue, where the model is controlling for lining type, sample holding time, and season, revealing an estimated background concentration if these factors were not present.

Table E-2 shows how the GAM model predicts background EtO concentration *if all the samples were collected with silicon-ceramic canisters* (the preferred canister for EtO quantification). For the two Illinois Ambient Air Monitoring Network sites in Cook County, the overall mean was 0.28 µg/m^3 (unadjusted) with a GAM-predicted mean (controlling for can type, holding time, and season) of 0.073 µg/m^3; note that the mean of all silicon-ceramic lined canisters for these sites is 0.098 µg/m^3, although this is imputed using ROS with data that are 77% non-detect, which would make these estimates approximate. The model estimated mean and median concentrations of EtO in Cook County are below EPA's MDL. A GAM was chosen in part to account for the effects on model estimates introduced by values below the MDL (censored values).

Table E-2. Comparison of measured and GAM-adjusted background EtO concentrations [±]

Site	Measured Mean EtO- All Canister Types (µg/m^3)	Measured Mean EtO Silicon-Ceramic (µg/m^3)	Measured Median EtO Silicon-Ceramic (µg/m^3)	GAM-Adjusted Mean EtO (µg/m^3)	GAM-Adjusted Median EtO (µg/m^3)
Northbrook, IL	0.269 (n=125; 46 NDs; 95% CI: 0.233 – 0.309)	0.079 (n=32; 26 NDs; 95% CI: 0.0513– 0.122)	0.0480 (95% CI: 0.0307 – 0.0821)	0.0696 (95% CI: 0.0623 – 0.078)	0.0578 (95% CI: 0.0555 – 0.0637)
Schiller Park, IL	0.286 (n=106; 28 NDs; 95% CI: 0.249 – 0.327)	0.104 (n=30; 22 NDs; 95% CI: 0.081 – 0.133)	0.0821 (95% CI: 0.0646 – 0.116)	0.0773 (95% CI: 0.0695 - 0.0861)	0.0677 (95% CI: 0.0645 – 0.0766)
Cook County[§]	0.277 (n=231; 74 NDs; 95% CI: 0.25 – 0.306)	0.0983 (n=62; 48 NDs; 95% CI: 0.072 – 0.125)	0.0768 (95% CI: 0.0608 – 0.0964)	0.0732 (95% CI 0.0679- 0.0791)	0.0626 (95% CI 0.0607– 0.0672)
New York (12 sites) [¶]	See Median (n=1162; 104 NDs)	See Median (n=1162; 104 NDs)	0.0801-0.150 (95% CI range 0.0695-0.158)	N/A	N/A
Florida (3 sites)	See Median (n=213;16 NDs)	See Median (n=213;16 NDs)	0.079-0.086 (95% CI range 0.070-0.097)	N/A	N/A
Massachusetts (3 sites)	See Median (n=209;97 NDs)	See Median (n=209;97 NDs)	0.081-0.099 (95% CI range 0.069-0.100)	N/A	N/A

[±] Measured, censored data were imputed using robust regression on order statistics.
[§] Cook County based on combined data from Northbrook and Schiller Park
[¶] Note that New York station 0003 had noticeably higher EtO measurements than other New York stations. This station is at an atmospheric research facility, in a remote, high elevation forested area.

Comparing seasonality in the Illinois GAM model to 12 aggregated New York site trends

To illustrate the seasonality in background EtO air concentrations from IL (GAM adjusted for canister type and holding time) and New York (measured using silicon-ceramic canister), the Illinois GAM-adjusted data were overlaid with New York background data in Figure 7. New York was used in this figure because there are 12 sites across the state that allow a robust comparison of this seasonality to the Illinois GAM-adjusted EtO concentrations. Both states showed similar seasonality, with EtO peaking in July and lowest in winter months. This trend is also noticeable in unadjusted data in Florida, and to a lesser extent in a few other states.

Summary of ATSDR's canister effect analysis

The GAM ATSDR utilized to adjust for canister lining type, holding time, and seasonality estimated that canisters with electropolished lining and proprietary lining demonstrated the greatest positive EtO bias relative to silicon-ceramic canisters (~169% and 89%, respectively). The model has terms for an exponential growth of EtO concentrations in the time elapsed between sample collection and sample analysis (i.e., sample "holding time"). While a small amount of bias has been observed in canisters with proprietary lining ("SUMMA canisters") and silicon-ceramic lining, they do not show as much growth over time as electropolished canisters. We found that electropolished canisters reported the highest bias (~3.0% EtO increase per day of holding time), followed by the proprietary SUMMA canisters (~2.0% EtO increase per day of holding time), with silicon-ceramic canisters showing the least bias (~1.0% EtO increase per day of holding time) (Table E-1). After controlling for the canister lining and sampling holding time, the adjusted background EtO data in Cook County showed a seasonable effect (high in summer and low in winter). The seasonal trending is nearly identical to that observed in 12 New York and three Florida background air quality monitoring sites where data are collected exclusively in silicon-ceramic canisters. Our GAM estimates median background EtO concentrations are approximately 0.06 $\mu g/m^3$ at the Cook County ambient air monitoring stations. A review of national data suggests median background EtO concentrations in Illinois are similar at other air quality monitoring sites where silicon-ceramic canisters are exclusively used (MA, NY, FL). These findings warrant additional investigation into the potential mechanisms that would explain ubiquitous and seasonally trending background concentrations of EtO. Our findings also support adjusting for canister effect bias when using a canister sampling fleet with multiple canister lining types.

ATSDR evaluated canister characteristics and holding time for two Cook County background air monitoring station and U.S. EPA air monitoring stations near the former Sterigenics facility in Willowbrook, IL. From this analysis, we conclude:

1. Canisters with electropolished lining have the highest positive EtO bias, followed by canisters with proprietary lining, and silicon-ceramic canisters have the least EtO bias over time. This relationship appears to be exponential in electropolished canisters and warrants adjustment of non-silicon-ceramic canister data to correct the canister effect bias in datasets with mixed canister lining types.

2. Seasonality is observed in background EtO concentrations from monitoring locations with samples collected in silicon-ceramic lined canisters.

3. ATSDR generated a Bayesian GAM that controlled for the effects of canister lining type and holding time, yielding adjusted time trends that show a seasonal trend of EtO.

4. The GAM adjusted mean background EtO concentration in Cook County was approximately 0.073 $\mu g/m^3$, which appears to be similar to New York (0.115 $\mu g/m^3$) and Florida (0.09 $\mu g/m^3$). Further, the seasonal effect revealed in the Cook County GAM adjusted EtO concentrations appears to occur during the same months as that observed in these states.

5. Investigation of ubiquitous EtO in the atmosphere is warranted; seasonal trending suggests that EtO can be produced to some extent by atmospheric chemical reactions, possibly with co-pollutants, solar radiation, or other meteorologic factors (humidity, temperature, etc.), biologic sources, or perhaps uncharacterized industrial emissions.

GAM-adjustment effect on ATSDR's Sterigenics (Willowbrook, IL) assessment

ATSDR used the GAM to adjust EtO concentrations detected in outdoor air in Willowbrook during the operation of Sterigenics (Nov 12, 2018-Feb 15, 2019) and during a 6-week period post-closure (Feb 16-Mar 31, 2019).

Table E-3 compares the GAM-adjusted means and medians to mean and median silicon-ceramic canisters, demonstrating that adjusted concentrations are similar to concentrations measured in silicon-ceramic canisters. During operations, closer monitoring stations had higher EtO concentrations (Figure C-6). The mean and median EtO concentrations in silicon-ceramic canisters were therefore likely influenced by which monitoring stations has the most silicon-ceramic canisters. ATSDR weighted monitoring stations by the number of silicon-ceramic samples per location for the operational mean estimate to calculate the GAM-adjusted mean and median. This allowed the silicon-ceramic mean and median concentrations to be more comparable to the GAM-adjusted mean and median. Because statistical analysis of post-closure data revealed no significant differences in concentration between the 8 monitoring stations, we combined data from monitoring stations during the shutdown period. This allowed for a more robust estimate of the mean and median silicon-ceramic EtO concentrations in a dataset that had a limited number of silicon-ceramic canister results. During shutdown the unadjusted mean was 0.135 µg/m^3 and the GAM-adjusted mean was 0.0545 µg/m^3. The unadjusted silicon-ceramic mean during shutdown was 0.091 µg/m^3. During Sterigenics operations, we calculated a mean (weighted by number of silicon-ceramic canisters at each monitoring station) of 0.439 µg/m^3 – the unadjusted silicon-ceramic canister mean was 0.951 µg/m^3.

The smaller difference between the shutdown period of GAM-adjusted and silicon-ceramic means and larger difference during site operations is in large part due to the very small number of silicon-ceramic canisters by station during site operations. Post-closure data were aggregated (Table E-3), resulting in a larger number of samples, both for silicon-ceramic (n=22) and non-silicon-ceramic canisters (n=117), whereas sites during operations had between 0 and 5 silicon-ceramic canisters at each of the 8 sampling locations. The presence of fewer silicon-ceramic canisters results in higher variability in concentration due to the influence of wind speed and wind direction, distance, and direction from the site. This means that the post-closure GAM-adjusted data are much more similar to silicon-ceramic canisters because there were more silicon-ceramic canisters upon which to base the model adjustments.

Table E-3. Comparison of central tendency statistics: measured and GAM-adjusted EtO concentrations at U.S. EPA monitoring stations in Willowbrook by Sterigenics operational status (November 2018-March 31, 2019).

Monitoring Station	Measured All Canister Types Mean EtO (µg/m^3)	Measured Silicon-Ceramic Mean EtO (µg/m^3)	Measured Silicon-Ceramic Median EtO (µg/m^3)	GAM-Adjusted Mean EtO (µg/m^3)	GAM-Adjusted Median EtO (µg/m^3)
Willowbrook-Closed	0.135 (n=122; 28 NDs; 95% CI: 0.124 – 0.149)	0.0909 (95% CI: 0.078 – 0.106)	0.0804 (95% CI: 0.0696-0.114)	0.0545 (95% CI: 0.0497 – 0.0596)	0.0462 (95% CI: 0.0425 – 0.0531)
Willowbrook-Operational	1.26 (n=236; 39 NDs; 95% CI: 0.888 – 1.68)	0.951 (95% CI: 0.339–1.97)	0.176 (95% CI: 0.0634 – 0.347)	0.439*	0.116*

** weighted mean by number of silicon-ceramic samples per monitoring station*

As with the Cook County dataset, we adjusted the Willowbrook EtO concentrations by canister lining type, holding lag time, and season. ATSDR's lifetime cancer risk calculations changed slightly with the GAM-adjustments for site-specific data.

Table E-4 compares the measured and GAM-adjusted mean EtO concentrations, EtO EPCs (95% upper confidence limit of the mean (UCL)) and lifetime excess cancer risks at the residential (West Neighborhood) and occupational (Village Hall) monitoring stations closest to Sterigenics facility during the Sterigenics operational and post-closure time periods. The mean EtO concentrations and EPCs were greater during the operational time period compared to the post-closure time period at both stations whether measured or GAM-adjusted EtO concentrations are compared. GAM-adjusted concentrations were used to calculate cancer risk in the final analysis because they give a more accurate estimates of cancer risk and the difference in cancer risk when Sterigenics was operating and when it closed.

Table E-4. Measured and GAM-adjusted EtO concentrations and lifetime excess cancer risks at the closest residential and occupational air monitors during Sterigenics post-closure and Sterigenics operational time periods.

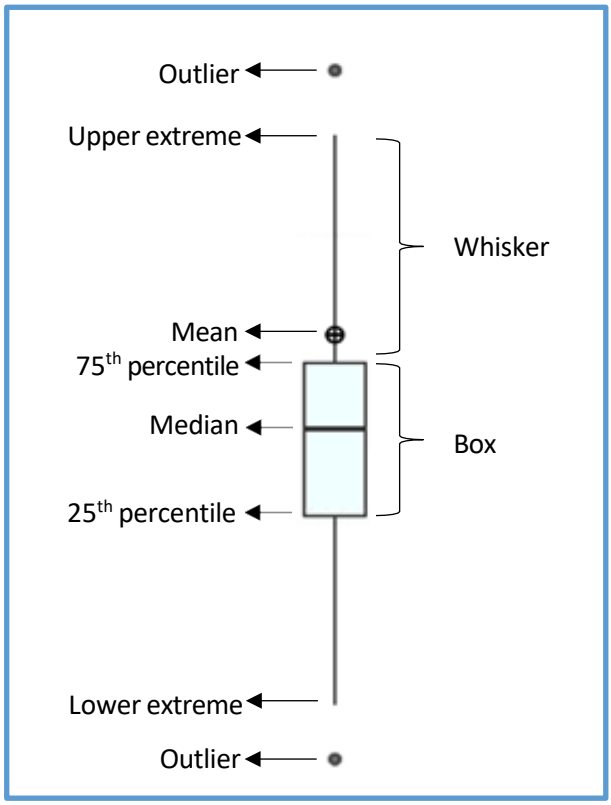
Monitoring Station	Measured Mean	GAM-Adjusted Mean	Measured EPC*	GAM-Adjusted EPC*	Cancer Risk, Measured EPC (per 10,000)†
Residential: OPERATIONAL (West Neighborhood)	0.600	0.240	0.939	0.369	30
Residential: POST-CLOSURE (West Neighborhood)	0.144	0.057	0.176	0.066	5
Occupational: OPERATIONAL (Village Hall)	3.12	1.36	4.58	2.34	9
Occupational: POST-CLOSURE (Village Hall)	0.153	0.064	0.198	0.077	0.4

**The EPC is the exposure point concentration based on the 95% upper confidence limits of the means and was used to calculate the lifetime excess cancer risks*

†Lifetime excess cancer risks based on measured and GAM-adjusted EPCs

Appendix F. Explanation of Boxplots

Figure F-1. Components of a boxplot



A boxplot is a chart that visualizes the distribution of a dataset. The components of a boxplot represent summary statistics of the dataset. The components include:

- The **median** is the 50th percentile, meaning half the data is greater and half of the data is less than the median. It is represented by the line inside the box.
- The **box** is bounded by the **75th percentile** (value that is greater than three quarters of the data) at the top and **25th percentile** (value that is greater than one quarter of the data) at the bottom. The length of the box is equal to the **interquartile range (IQR)**, which is the difference of the 75th percentile minus the 25th percentile.
- The upper and lower **whisker** connect the box with the upper and lower extremes, respectively. The whisker is never longer than 1.5 times the IQR (or 1.5 times the length of the box)
- **Outliers** are values in the dataset that are either greater than the 75th percentile + 1.5 * IQR or less than the 25the percentile – 1.5 * IQR and are represented by dots above or below the upper or lower extreme.

- The value of the upper and lower **extremes** depends on whether or not the dataset contains upper and lower outliers. If there are upper and lower outliers in the dataset, as in the example in Figure F-1 then the upper extreme will be equal to the 75th percentile + 1.5*IQR and the lower extreme will be equal to the 25th percentile – 1.5* IQR. In a dataset with no outliers, the upper extreme would be equal to the maximum value and the lower extreme would be equal to the minimum value.
- The **mean,** represented here by a circle with a cross in the middle, is the average value of the dataset.

Boxplots can help give an at-a-glance sense of several characteristics of the data. Representing boxplots from different datasets side by side as is done in Figure 2 in this document can give a sense of whether observations taken at different times or in different places tended to be higher or lower than one another. It can give a sense of how much variation is in the dataset. Variation is a measure of how different observations in a dataset are from each other. More variable datasets will have longer boxes and whiskers. The boxplot can also give a sense of whether data is skewed. For example, a boxplot with a long upper whisker, a shorter lower whisker and a median towards the bottom of the box indicates that values less than the median tend to be closer together whereas higher values greater than the median can be much higher and more spread apart.

Appendix G. Lifetime Excess Cancer Risk Evaluation

Residential scenarios

To evaluate cancer risk from chronic exposure to EtO concentrations in residential area of Willowbrook, ATSDR calculated lifetime excess cancer risks using a default RME residential scenario. We use an average life expectancy value of 78 years, a 33-year residential occupancy period (ROP) (time from a person moving into a residence to the time the person moves out) and a continuous exposure assumption of 24 hours a day, 365 days a year. Sterigenics operated approximately 34 years in this community from 1985-2019. The EPCs used are GAM adjusted 95% UCL of the mean EtO concentration at each U.S. EPA air monitoring station during normal Sterigenics operations from the November 13, 2018 to February 15, 2019 and during the post-closure period from February 16, 2019 to March 30, 2019.

Because EtO is a mutagenic compound, ATSDR also uses age-dependent adjustment factors (ADAF) to weight early life exposure of children to EtO in the residential scenario. EtO has three ADAFs with different age ranges and a duration adjustment (DA) to adjust for the 33 years of residential exposure from birth (See Table F-1). When applying the ADAFs, ATSDR calculated partial cancer risks by age range at each U.S. EPA monitoring station by multiplying the ADAF for each age range by the U.S. EPA IUR (2.99×10^{-3}), the ATSDR EtO EPC (95% UCL) at each monitoring station, and the duration adjustment by age range (Table F-1). The total lifetime excess cancer risk at each monitoring station is calculated by adding the three partial cancer risks by age range.

Table G-1. Calculation of partial cancer risk by age for the residential EtO exposure scenario. Total lifetime cancer risk is a sum of partial cancer risks by age.

Age Range	ADAF*	U.S. EPA IUR†	EPC ‡ (µg/m³)	Duration Adjustment (DA)	Partial Cancer Risk by Age Range
0 to <2 yrs	10	2.99×10^{-3}	*Site-specific*	2 years/78 years	= ADAF*IUR*EPC*DA
2 to <16 yrs	3	2.99×10^{-3}	*Site-specific*	14 years/78 years	= ADAF*IUR*EPC*DA
16 to 33 yrs	1	2.99×10^{-3}	*Site-specific*	17 years/78 years	= ADAF*IUR*EPC*DA

** Age-dependent adjustment factors*
† United States Environmental Protection Agency's inhalation unit risk
‡ Exposure point concentration in micrograms per meter cubed

Table G-2 gives an example of how the ATSDR EPC and residential RME assumptions (33 years of exposure from birth with continuous exposure) were used to calculate the cancer risk for the West Neighborhood monitoring site. The partial cancer risks by age range are summed to get the total cancer risk for the monitoring site. For the West Neighborhood monitoring site, the sum of the partial cancer risks in Table G-2 is 11.2 lifetime, excess estimated cases of cancer out of 10,000 people who are exposed according to ATSDR's RME exposure assumptions. Lifetime, excess cancer risks are rounded down to 1 significant digit, so 11.2 is rounded down to 10 in 10,000. Cancer risks of 15 or greater would be rounded up to 20.

Table G-2. Calculation of partial cancer risk by age for the residential EtO exposure scenario. Total lifetime cancer risk is a sum of partial cancer risks by age.

Age Range	ADAF*	U.S. EPA IUR†	EPC‡ (95% UCL) (µg/m³)	Years Exposed	Years Lifetime	Duration Adjustment (DA) Factor	Partial Cancer Risk by Age Range *(ADAF)x(IUR)x(EPC)x (DA)*
0 to <2 yrs	10	2.99×10^{-3}	0.369	2	78	0.0256 (2 years/78 years)	2.8 in 10,000
2 to <16 yrs	3	2.99×10^{-3}	0.369	14	78	0.1795 (14 years/78 years)	6.0 in 10,000
16 to 33 yrs	1	2.99×10^{-3}	0.369	17	78	0.2179 (17 years/78 years)	2.4 in 10,000

**Age-Dependent Adjustment Factors*
†United States Environmental Protection Agency's Inhalation Unit Risk
‡Exposure Point Concentration in micrograms per meter cubed

Commercial/industrial off-site worker scenarios

To evaluate cancer risk from chronic exposure to EtO concentrations in commercial and industrial areas of Willowbrook, ATSDR calculated lifetime excess cancer risks using a default RME for an off-site worker scenario. ATSDR assumed a full-time worker RME scenario of 8.5 hours a day, 5 days a week, 50 weeks per year for 20 years ([ATSDR] 2021). These RME assumptions were used to calculate the exposure factor for estimating lifetime cancer risk from chronic EtO exposure. Note that "off-site" worker refers to people whose workplaces are near Sterigenics but not at Sterigenics.

Willowbrook Lifetime Excess Cancer Risks

Table G-3 on the next page presents estimated lifetime excess cancer risks for residential and off-site worker exposures during Sterigenics operations from the November 13, 2018 to February 15, 2019 and during the post-closure period from February 16, 2019 to March 30, 2019 using the assumptions defined above. The lifetime cancer risk estimate is a tool used for public health decision making and does not represent the actual cases or incidence rates of cancer in the Willowbrook community.

ATSDR used the 95% UCL of GAM adjusted EtO concentrations to calculate EPCs at each of the eight U.S. EPA air monitoring stations located within a mile of the Sterigenics facility for operations and post-closure. The GAM adjusted concentrations are less subject to positive bias than measured EtO concentrations. The lines of evidence supporting this approach are discussed in more detail in Appendix E.

It is important to note that as EPCs, the 95% UCL used in this report is statistically generated based on the mean value at each site. It represents a number that we believe with 95% confidence that the true

mean value will not exceed. This statistic is generated taking into consideration the variability (spread) of the concentrations reported at each site. If the data have high variability, the value of the true mean is more uncertain. As a result, the EPC in that case will be higher than the sample mean, compared to a site with lower variability.

Table G-3. GAM – adjusted EtO EPC and lifetime excess cancer risk at U.S. EPA air monitoring stations in Willowbrook during Sterigenics operational period and post-closure.

Monitoring Station (Miles from Sterigenics Facility)	Scenario	Operational Adjusted EPC[*,†,‡] (µg/m³)	Closed Adjusted EPC[*] (µg/m³)	Operational Lifetime Cancer Risk[‡]	Closed Lifetime Cancer Risk
West Neighborhood (0.20 mile)	Residential	0.37	0.07	10 in 10,000	2 in 10,000
Gower Middle (0.39 mile)	Residential	0.19	0.06	6 in 10,000	2 in 10,000
Hinsdale South High (0.45 mile)	Residential	0.42	0.06	10 in 10,000	2 in 10,000
Gower Elementary (0.74 mile)	Residential	0.13	0.09	4 in 10,000	3 in 10,000
Willow Pond Park (1.01 miles)	Residential	0.33	0.07	10 in 10,000	2 in 10,000
Warehouse (0.02 mile [+])	Off – site worker	1.66	0.05	3 in 10,000	0.1 in 10,000
Village Hall (0.02 mile)	Off – site worker	2.30	0.08	4 in 10,000	0.1 in 10,000
Water Tower (0.42 mile)	Off – site worker	0.65	0.06	1 in 10,000	0.1 in 10,000

EtO air monitoring data used for lifetime excess cancer risk calculations are from U.S. EPA EtO samples collected between November 12, 2018 and March 31, 2019.

[*] *Adjusted refers to GAM adjusted EtO concentrations modeled to remove the positive bias and seasonal effect. EPC stands for exposure point concentration calculated using the 95% upper confidence limit of the mean and is reported in units of micrograms per meter cubed* (µg/m3)

[†] *Where there were two co-located air monitors, we report the higher of the two lifetime cancer risks in this table.*

[‡] *In EtO datasets with more uncertainty due to variability in the EtO concentrations, the EtO EPCs calculated using 95% UCL of the mean tend to be higher than the sample mean EtO concentration compared to a dataset with lower variability. For this reason, the EPC is not meant to be used for comparing risk between monitoring stations. Even though EPCs and cancer risk are not necessarily highest at the closest monitoring stations, ATSDR observed that in general, EtO concentrations during the operational period decreased with distance from the facility within the same wind direction.*

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