ASSESSMENT OF HEALTH BENEFITS FROM USING BIODIESEL AS RESIDENTIAL HEATING OIL

National Biodiesel Board

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LIST OF ABBREVIATIONS AND ACRONYMS

AERMOD	American Meteorological Society/Environmental Protection Agency Regulatory Model
B[a]anthracene	Benz[a]anthracene
BenMAP-CE	Environmental Benefits Mapping and Analysis Program - Community Edition
CARB	California Air Resources Board
CMAQ	Community Multiscale Air Quality Model
CT	Census Tract
Cr(VI)	Hexavalent Chromium
CV	Contingent Valuation
D[a,h]anthracene	Dibenz[a,h]anthracene
DSN	Data Series Name
EIA	U.S. Energy Information Administration
HAP	Hazardous Air Pollutant
HARP	Hot Spots Analysis & Reporting Program
HRA	Health Risk Assessment
In[1,2,3-cd]pyr	Indeno[1,2,3-cd]pyrene
LPG	Liquified Petroleum Gas
NATA	National Air Toxics Assessment
NEI	National Emissions Inventory
NYCHA	New York City Housing Authority
OEHHA	(California) Office of Environmental Health Hazard Assessment
PAH	Polycyclic Aromatic Hydrocarbon
$PM_{2.5}$	Particulate Matter with an Aerodynamic Diameter of $\leq$2.5 microns
SEDS	State Energy Data System
TSD	Technical Support Document

U.S. EPA	United States Environmental Protection Agency
WTP	Willingness-to-Pay

1. EXECUTIVE SUMMARY

This report assesses the health benefits of substituting biomass-based diesel in residential space heating sources currently fueled by heating oil in select northeastern states. The emission sources, data sources, models, and analytical techniques for each urbanized area were selected to provide the most comprehensive, robust, and transparent analysis possible within the schedule and budget limitations of the approved project. For all locations, Trinity has attempted to identify the communities believed to be most impacted by the emission sources modeled and has highlighted the benefits of biomass-based biodiesel to those specific communities to the degree possible.

1.1 Analysis Technique

The general analysis technique is a simplified, air toxic-based health risk assessment (HRA) of specific residential heating oil combustion sources in the areas selected. The analyses do not attempt to replicate any existing HRA performed for a specific facility, correlate with monitored concentrations of specific pollutants, or quantify the full background health risk experienced in the area modeled. Rather, the analyses show the air toxic health risk benefits of fueling the modeled residential combustion sources with biomass diesel compared to petroleum-based distillate heating oil.

Because health risk is directly proportional to the established air pollutant toxicity values, the risk reduction percentage at any given receptor will be the same as the reduction in air pollutant toxicity from heating oil combustion compared to biomass-based diesel combustion. This analysis translates those changes in toxicity values into risk metrics, including reductions in cancer risk (per million people) and reduction in cancer burden.

1.2 Locations

The following locations were assessed for health risk reductions due to the use of biomass-based diesel in place of distillate oil for residential heating:

- New York City, New York
- Albany, New York
- Boston, Massachusetts
- New Haven, Connecticut; and
- Providence, Rhode Island

For all locations, Trinity modeled residential heating oil (distillate oil) combustion emissions as elevated volume sources, each a square mile in size (with the exception of New York City). Trinity located residential areas that use high amounts of heating oil and modeled the emissions in that area. With the exception of New York City, Trinity was not able to obtain residential heating oil inventories on a sufficiently granular level to model the exact heating oil emissions within a given square mile. Hence, the following assumptions were made for inventories that could only be found on the county and city-wide level:

- Heating oil usage is evenly distributed among the households that use distillate heating oil;
- The number of households using heating oil in a given census tract was used to scale heating oil usage in each census tract; and
- Health risk in each census tract was estimated based on the number of households using heating oil and the area of the census tract compared to the modeled, representative census tract.

1.3 Summary of Results

1.3.1 New York City (Bronx)

It is expected that the cancer risk associated with residential heating oil usage in the Sotomayor housing development in the Bronx lies somewhere between 1.7 and 23.3 excess cancer cases per million residents over a 70-year timeline. Assuming a full transition from residential distillate heating oil to biomass-based diesel, the baseline cancer risk in the Sotomayor development is reduced to a value between 0.4 and 3.4 excess cancer cases per million residents.

The total cancer burden (cancer risk multiplied by affected population) for all census tracts within a 5-mile radius of the Sotomayor development is 12 assuming the higher end of the risk range, with an expected reduction in cancer burden to a value of approximately 2 with the use of biomass-based diesel fuel for home heating oil combustion.

1.3.2 Albany, New York

It is expected that the cancer risk associated with residential heating oil usage in Albany census tract 17 lies somewhere between 0.3 and 1.7 excess cancer cases per million residents over a 70-year lifetime. Assuming a full transition from residential distillate heating oil to biomass-based diesel, the baseline cancer risk in Albany census tract 17 is reduced to a value between 0.1 and 0.3 excess cancer cases per million residents.

The total cancer burden for all census tracts within a 5-mile radius of Albany census tract 17 is less than 1 assuming the higher end of the risk range, with an expected reduction in cancer burden to a value that is much less than 1 with the use of biomass-based diesel fuel for home heating oil combustion.

1.3.3 Boston, Massachusetts

It is expected that the cancer risk associated with residential heating oil usage in Boston census tract 1105.01 lies somewhere between 0.9 and 21.8 excess cancer cases per million residents over a 70-year lifetime. Assuming a full transition from residential distillate heating oil to biomass-based diesel, the baseline cancer risk in Boston census tract 1105.01 is reduced to a value between 0.3 and 3.1 excess cancer cases per million residents.

The total cancer burden for all census tracts within a 5-mile radius of Boston census tract 1105.01 is 5 assuming the higher end of the risk range, with an expected reduction in cancer burden to a value that is much less than 1 with the use of biomass-based diesel fuel for home heating oil combustion.

1.3.4 New Haven, Connecticut

It is expected that the actual cancer risk of associated with residential heating oil usage in New Haven census tract 1419 lies somewhere between 0.3 and 7.4 excess cancer cases per million residents over a 70-year timeline. Assuming a full transition from residential distillate heating oil to biomass-based diesel, that baseline risk is reduced to a value between <0.1 and 1.1 excess cancer cases per million residents.

The total cancer burden for all of the census tracts within a 5-mile radius of census tract 1419 is <1, with an expected marginal reduction in cancer burden with the use of biomass-based diesel fuel for home heating oil combustion.

1.3.5 Providence, Rhode Island

It is expected that the actual cancer risk of associated with residential heating oil usage in Rhode Island census tract 21.01 lies somewhere between 0.5 and 11.3 excess cancer cases per million residents over a 70-year timeline. Assuming a full transition from residential distillate heating oil to biomass-based diesel, that baseline risk is reduced to a value between 0.1 and 1.6 excess cancer cases per million residents.

The total cancer burden for all of the census tracts within a 5-mile radius of Rhode Island census tract 21.01 is 1.2, with an expected reduction in cancer burden to a value of approximately <1 with the use of biomass-based diesel fuel for home heating oil combustion.

1.3.6 Valuation of Health Benefits

The monetary valuation of the health benefits associated with using biodiesel as a residential heating oil was determined to be as follows for the locations evaluated:

- Bronx area of New York City = $137 million
- Albany, NY = $1.2 million
- Boston, MA = $69.1 million
- New Haven, CT = $20.6 million
- Providence, RI = $21.3 million

1.4 Valuation of Health Benefits

The monetary valuation of the health benefits associated with using biodiesel as a residential heating oil was evaluated for each community. The benefits are based on reductions of ambient $PM_{2.5}$ concentrations as discussed within this report, coupled with the incidence/prevalence rates and population of the area. These benefits were calculated using U.S. EPA's BenMAP program, using inputs typically selected by CARB in demonstrating the benefits from their rulemakings. The overall benefit rates for each health endpoint are shown in Table 1-1, for both CARB valuations and those used in this report.

Table 1-1. Comparison of CARB versus BenMAP Valuation Results

Endpoint	CARB Valuation	BenMAP Valuation Used in this Report
Premature Mortality	$9,300,000 per death	$8,700,000 per death
Asthma Exacerbation	$52 per symptom day	$59 per symptom day
Minor Restricted Activity Days	$64 per day	$70 per day
Work Loss Days	$178 per day	$143 - $238 per day (depending on location)

1.5 Importance of Health Benefits to Environmental Justice Communities

The U.S. EPA defines environmental Justice (EJ) as "the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies."[1] One element of EJ is "The same degree of protection from environmental and health hazards."[2]

[1] See: Environmental Justice | US EPA

[2] Ibid.

As shown in the figures within this report, the health impacts of diesel emissions are disparately high in areas in close proximity to ports, railyards, distribution centers, freeways, and major roadways. These areas also frequently correspond to areas exhibiting elevated incidence rates of EJ metrics, such as:

- Asthma
- Low Birth Rate
- Cardiovascular Disease
- Low Education
- Linguistic Isolation
- Poverty
- Unemployment
- Housing Burden

These areas are also those with concentrated home heating oil usage. As such, EJ communities tend to be exposed to higher concentrations of home heating exhaust emissions in general.

The thrust of this study is to demonstrate the benefits of the substitution of biodiesel for home heating oil. The communities selected for this study were those identified to experience the highest emission rates, the highest ambient concentrations, and the highest risk levels due to home heating oil exhaust. As described within this report, these benefits are credited to residential home heating oil combustion. These benefits of biodiesel will therefore accrue to a much greater degree within EJ communities.

2.1 Health Risk of Residential Heating Oil Combustion

Distillate oil is widely used in many northeastern states to supply heat to homes. The individual chemical components generated from the combustion of residential heating oil have associated toxicity factors, and have been analyzed for associated health risks by the U.S. EPA. The following sections identify how the U.S. EPA and state agencies have reported on distillate oil combustion for residential heating and how the associated health risks are determined by the U.S. EPA.

2.1.1 U.S. EPA National Air Toxics Assessment

U.S. EPA determines county-wide health risks from residential heating oil combustion by quantifying the emissions of stationary nonpoint sources as part of the National Emission Inventory (NEI) dataset, which is subsequently evaluated in the National Air Toxics Assessment (NATA).

According to the 2014 NEI Technical Support Document[3] (TSD) in Table 4-70, non-wood residential heating by combustion of distillate oil was reported by some state, local, and tribal agencies. EPA estimates were also available for these sources. Table 4-71 outlines the agencies that reported data for non-wood residential heating emissions. For any state, local, or tribal agency that did not provide non-wood residential heating data, EPA estimates were utilized instead. According to the NEI TSD:

> *The general approach to calculating emissions for all fuel types is to take state-level fuel-specific (natural gas, distillate oil, kerosene, coal, and LPG) consumption from the EIA and allocate it to the county level. … County-level fuel consumption is multiplied by the emission factors to calculate emissions.*

Fuel type consumption by energy use sector was obtained from the State Energy Data System (SEDS) 2014 Consumption tables published by the U.S. Energy Information Administration (EIA). Distillate oil consumption is represented in the SEDS table by the Data Series Name (DSN). State-level fuel type consumption was allocated to each county using the U.S. Census Bureau's 2014 5-year estimate from its Census Detailed Housing report. These data include the number of housing units using a specific type of fuel for residential heating. State fuel type consumption was allocated to each county using the ratio of the number of houses burning natural gas, distillate oil, kerosene, or LPG in each county to the total number of houses burning natural gas, distillate oil, kerosene, or LPG in the state.

The NATA TSD states that the reported Hazardous Air Pollutant (HAP) emissions from the nonpoint 2014 NEI sources were modeled using a hybrid approach with the Community Multiscale Air Quality (CMAQ) and AERMOD models for the 52 most prevalent and high-risk toxics. Coarse, region-wide impacts were determined on a county level using 12-kilometer grids in the CMAQ model. AERMOD was utilized to generate near-field concentrations using gridded receptors (1 km in highly populated areas [>1 million population], 4 km in other areas), census block centroid receptors, and monitoring site receptors. These results were then weighted according to grid cell averages to determine census block and tract exposures for the 52 toxics. All other toxics were modeled directly using AERMOD.

The sections below review the information provided by specific agencies and how they were utilized to determine health risk impacts in this report.

[3] https://www.epa.gov/sites/production/files/2018-07/documents/nei2014v2_tsd_05jul2018.pdf

2.1.1.1 *New York*

Table 4-71 of the NEI TSD states that the New York State Department of Environmental Conservation provided 100% of the residential fuel oil combustion data to EPA for the NEI. Given the population density of New York, NY and Albany, NY, the 1 km grid cells were utilized in NATA.

2.1.1.2 *Massachusetts*

Table 4-71 of the NEI TSD states that the Massachusetts Department of Environmental Protection provided 100% of the residential fuel oil combustion data to EPA for the NEI. Given the population density of Boston, MA, the 1 km grid cells were utilized in NATA.

2.1.1.3 *Connecticut*

Table 4-71 of the NEI TSD does not list any Connecticut agency as reporting residential fuel oil consumption, indicating that EPA estimates were used. Given the population density of New Haven, CT, the 1 km grid cells were utilized in NATA.

2.1.1.4 *Rhode Island*

Table 4-71 of the NEI TSD does not list any Rhode Island agency as reporting residential fuel oil consumption, indicating that EPA estimates were used. Given the population density of Providence, RI, the 1 km grid cells were utilized in NATA.

2.1.2 Location Specific Health Risk Assessments

Given the coarse, county-wide approach to the NATA modeling, the associated health risk impacts with the NATA modeling do not have the capability to show local maxima. In order to determine local maxima and associated health risk reductions with a change to biodiesel combustion, analyses were conducted using AERMOD at each census tract using high resolution receptor grids, granular emissions data developed for each census tract, and California Air Resources Board's (CARB) Hotspots Analysis & Reporting Program (HARP) to generate estimated local health risk impacts at each location. The use of CARB's HARP program provides a high estimate for risk values, as the California Office of Environmental Health and Hazard Assessment (OEHHA) toxicity values are higher than EPA toxicity values, as outlined in Section 3.

3. TOXICITY OF HEATING OIL COMBUSTION COMPOUNDS

3.1 Toxicity of Heating Oil Combustion Compounds

Table 3-1 below lists the U.S. EPA and CARB toxicity “slope” factors for air toxic compounds released by combustion of residential heating oil. In general, the CARB toxicity factors are higher for all of the distillate oil combustion compounds, with the exception of Arsenic and Formaldehyde. Specifically, Hexavalent Chromium has the highest toxicity slope factor of all the pollutants and is 12.5 times higher than the equivalent EPA slope factor. Therefore, the use of CARB’s HARP program represents a high-end of health risks from residential heating oil combustion.

Table 3-1. Comparison of U.S. EPA and CARB Diesel Exhaust Toxicity Values

CAS	Pollutant	CARB Slope Factor (1/µg/m^3)	EPA Slope Factor (1/µg/m^3)	CARB vs EPA Value
75070	Acetaldehyde	0.0000027	0.0000022	123%
7440382	Arsenic	0.0033	0.0043	77%
56553	B[a]anthracene	0.00011	0.00006	183%
71432	Benzene	0.000029	0.0000078	372%
7440417	Beryllium	0.0024	0.0024	100%
7440439	Cadmium	0.0042	0.0018	233%
218019	Chrysene	0.000011	0.0000006	1833%
18540299	Cr(VI)	0.15	0.012	1250%
53703	D[a,h]anthracene	0.0012	0.0006	200%
50000	Formaldehyde	0.000006	0.000013	46%
193395	In[1,2,3-cd]pyr	0.00011	0.00006	183%
7439921	Lead	0.000012	0	N/A
91203	Naphthalene	0.000034	0.000034	100%
7440020	Nickel	0.00026	0.00024	108%

4. HEALTH RISK ASSESSMENT METHODOLOGY

The general analysis technique provides a simplified, partial ambient health risk assessment of specific residential heating oil sources in the areas selected. For no location does the analysis attempt to replicate an existing Health Risk Assessment (HRA) performed for a specific facility, correlate with monitored concentrations of specific pollutants, or quantify the full background risk experienced in the area modeled. Rather, the analyses show the health benefits of fueling the modeled residential sources with biomass-based diesel compared to distillate heating oil.

Because health risk is directly proportionate to the established toxicity values, the risk reduction percentage at any given receptor is the same as the reduction in toxicity of distillate oil compared to biomass-based diesel. This analysis translates those reduced toxicity values into easily understandable risk metrics, such as reductions in cancer risk (per million people).

4.1 Locations

The following locations were assessed:

- New York City, New York
- Albany, New York
- Boston, Massachusetts
- New Haven, Connecticut; and
- Providence, Rhode Island

For all locations, Trinity modeled residential heating oil emissions as area sources. Because of the distance limitations in AERMOD, specific areas within the cities were used to approximate the impacts to the city at large. Trinity targeted residential areas that use high amounts of heating oil.

4.2 Location No. 1: Bronx, New York

4.2.1 Data Sources and Emissions Inventories

The New York City Housing Authority (NYCHA) tracks heating oil consumption (in gallons) by borough and development for public housing developments within New York City.[4] Trinity used the NYCHA 2019 values since these contained the most recent and complete information to develop the emissions inventory. It was found that the Sotomayor housing development in the Bronx had the highest usage of residential heating oil in 2019, and this housing development is represented by census tract 36005004400 (see area in figure below denoted by blue outline).

[4] https://data.cityofnewyork.us/Housing-Development/Heating-Oil-Consumption-And-Cost-2010-2020-/bhwu-wuzu

Figure 4-1. Location of Sotomayor Housing Development, Bronx, NY

Emission factors specific to distillate oil combustion from EPA's 2017 National Emissions Inventory Technical Support Document (April 2020) for the source category "Residential Heating – Coal, Distillate Oil, Kerosene, Natural Gas, and LPG" were used to calculate $PM_{2.5}$ and toxic emission rates as follows:[5]

$$Heating\ Oil\ Uage\ \left(\frac{gallons}{year}\right) \times Emission\ Factor\ \left(\frac{lb}{1{,}000\ gal}\right) \times \frac{1\ year}{8{,}760\ hours} = Emission\ Rate\ \left(\frac{lbs}{hour}\right)$$

4.2.2 Model

Ambient concentrations from the above sources were determined using USEPA's approved AERMOD Modeling System. The model utilized local surface and upper air meteorological data processed using EPA AERMINUTE and AERMET meteorological data processors, along with preprocessed terrain data prepared by the United States Geological Survey. To provide a refined analysis of local maxima, the emission sources are modeled as a polygon area source with the dimensions of the census tract modeled. However, due to the geographic scale of the modeling domain, a simplified approach was utilized (e.g., buildings and structures will not be independently modeled).

Table 4-1 below indicates the source parameters used for census tract ID 36005004400, representing the Sotomayor housing development.

Table 4-1. Sotomayor Housing Development Modeling Parameters

Source ID	X (m)	Y (m)	Elevation (m)	Emission Rate (g/m^2-s)	Release Height (m)	Initial Vert. Dimension (m)
AREAPOLY	595,308.8	4,519,948	4.84	6.67E-06	9.144	0

Given that most of the Sotomayor housing development contains apartment buildings with multiple floors, a 30-foot release height was utilized for the polygon area source with no initial vertical dimension. This does not account for buoyancy from plume rise, but it is consistent with EPA NATA modeling procedures of this source type. The vertices for the polygon area source are represented in Table A-1 of Appendix A.

The emission rate for the polygon area source is equal to one over the area of the polygon, representing a unit emission rate of 1 g/s. This unit emission rate was run for 8,760 hours, and the resulting period file concentration, representing the average concentration at each receptor over the 5-years of meteorological data, was used to generate ground level concentrations for each individual pollutant. The ground level concentrations and associated health risk impacts were determined using CARB's HARP tool, which implements the OEHHA risk analysis methodology. Risk was determined in terms of excess cancer risk above baseline values due to distillate oil combustion.

[5] See document titled "Residential Heating NEMO 2017 FINAL_4-2 update" located at: ftp://newftp.epa.gov/air/nei/2017/doc/supporting_data/nonpoint/

4.3 Location No. 2: Albany, New York

4.3.1 Data Sources and Emissions Inventories

In order to determine the heating oil usage in a given area, the heating oil use was first determined from the NEI data on a county-wide basis. The NEI data provides annual emissions from various source categories, and hence, the $PM_{2.5}$ annual emissions from the home heating oil combustion category were used to back-calculate the annual heating oil usage using the $PM_{2.5}$ emission factor for home heating oil combustion (units of lbs/1,000 gallons).[6]

Trinity identified areas that had high usages of heating oil utilizing U.S. Census data which tracks total number of homes that use heating oil within a given census tract.[7] Trinity identified census tract 17 as having a high proportion of homes that use heating oil. The number of houses within the census tract that use heating oil was then divided by the total number of homes in the county that use heating oil to determine the percent usage of heating oil within the census tract. That percentage was then multiplied by the county-wide total residential heating oil usage to determine how much residential heating oil is used within census tract 17 as shown below:

$$\frac{Number\ of\ Homes\ within\ Tract\ 17\ that\ use\ Heating\ Oil}{Total\ number\ of\ Homes\ within\ County\ that\ use\ Heating\ Oil} \times Countywide\ Heating\ Oil\ Usage\ \left(\frac{gallons}{year}\right) = Heating\ Oil\ Usage\ within\ Tract\ 17\ \left(\frac{gallons}{year}\right)$$

This approach assumes that each home in the county that uses heating oil uses the same amount of home heating oil. Lastly, emission factors from the 2017 NEI were used to calculate $PM_{2.5}$ and toxic emission rates as follows:[8]

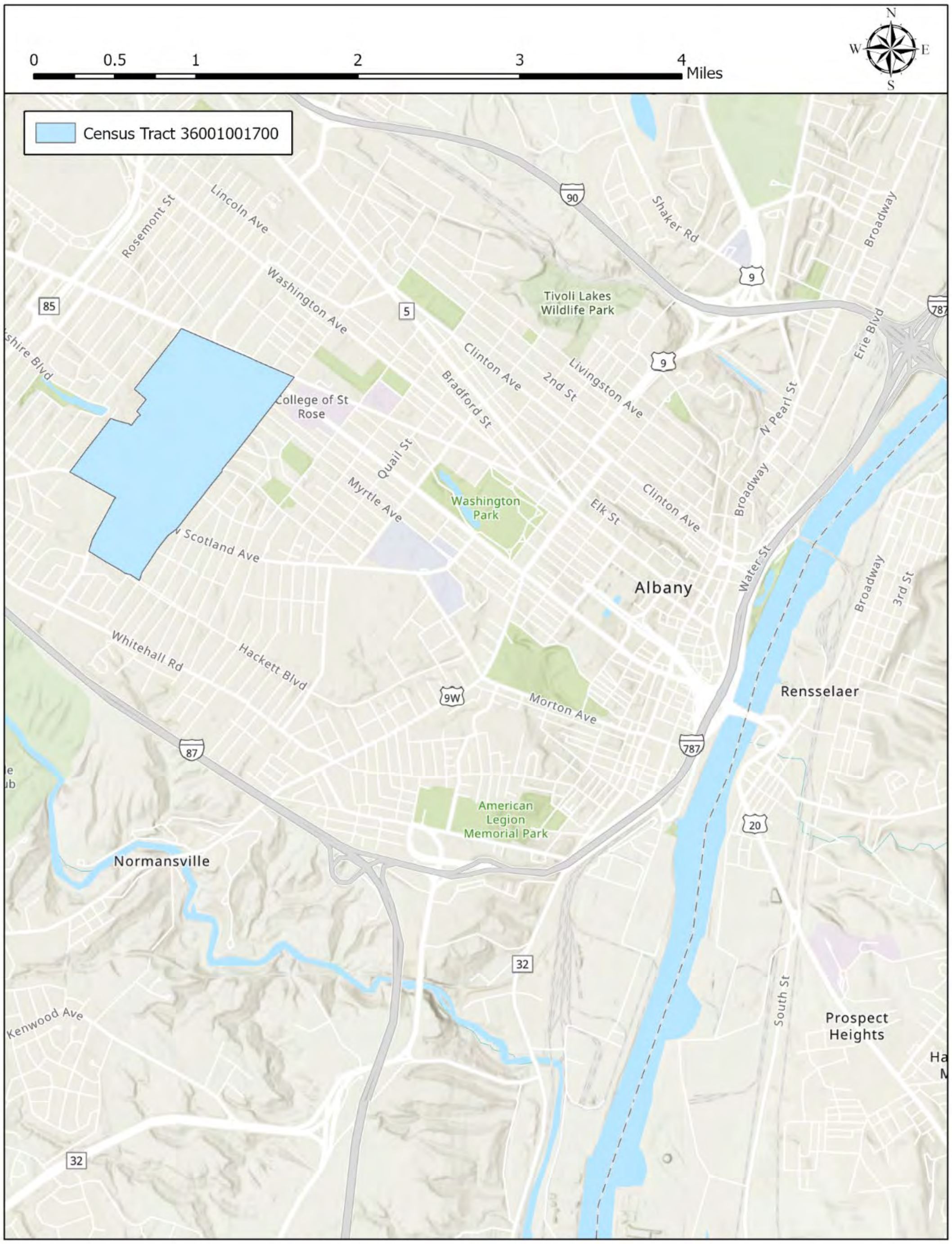
$$Heating\ Oil\ Uage\ \left(\frac{gallons}{year}\right) \times NEI\ Emission\ Factor\ \left(\frac{lb}{1{,}000\ gal}\right) \times \frac{1\ year}{8{,}760\ hours} = Emission\ Rate\ \left(\frac{lbs}{hour}\right)$$

[6] See document titled “Residential Heating NEMO 2017 FINAL_4-2 update” located at: ftp://newftp.epa.gov/air/nei/2017/doc/supporting_data/nonpoint/

[7] United States Census Bureau, Table B25040, 2017: ACS 1-Year Estimates Detailed Tables

[8] See document titled “Residential Heating NEMO 2017 FINAL_4-2 update” located at: ftp://newftp.epa.gov/air/nei/2017/doc/supporting_data/nonpoint/

Figure 4-2. Location of Albany, NY Census Tract 17



4.3.2 Models

Ambient concentrations from the above sources were determined using USEPA's approved AERMOD Modeling System. The model utilized local surface and upper air meteorological data processed using EPA AERMINUTE and AERMET meteorological data processors, along with preprocessed terrain data prepared by the United States Geological Survey. To provide a refined analysis of local maxima, the emission sources are

modeled as a polygon area source with the dimensions of the census tract modeled. However, due to the geographic scale of the modeling domain, a simplified approach was utilized (e.g., buildings and structures will not be independently modeled).

Table 4-2 below indicates the source parameters used for Albany census tract 17.

Table 4-2. Census Tract 17 Modeling Parameters

Source ID	X (m)	Y (m)	Elevation (m)	Emission Rate (g/m^2-s)	Release Height (m)	Initial Vert. Dimension (m)
AREAPOLY	597,760	4,723,759	74.01	7.32E-07	0	0

Given that most of the sources from the Albany census tract are from single-story residences, a 0-foot release height was utilized for the polygon area source with no initial vertical dimension. This does not account for buoyancy from plume rise, but it is consistent with EPA NATA modeling procedures of this source type.

There are 115 vertices utilized to develop the polygon area source census tract 17, which are included in appendix table A-2.

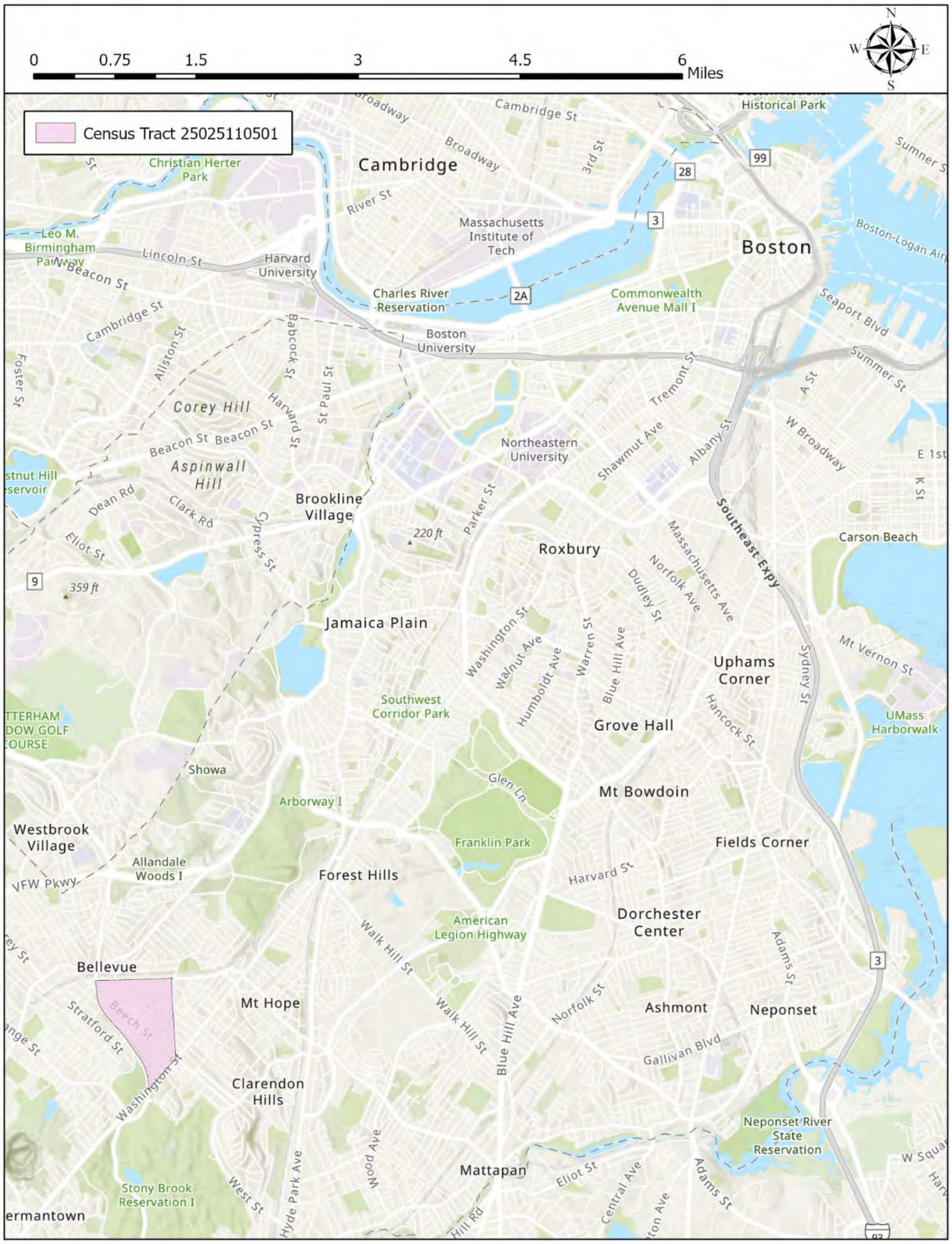
The emission rate for the polygon area source is equal to one over the area of the polygon, representing a unit emission rate of 1 g/s. This unit emission rate was run for 8,760 hours, and the resulting period file concentration, representing the average concentration at each receptor over the 5-years of meteorological data, was used to generate ground level concentrations for each individual pollutant. The ground level concentrations and associated health risk impacts were determined using CARB's HARP tool, which implements the OEHHA risk analysis methodology. Risk was determined in terms of excess cancer risk above baseline values due to distillate oil combustion.

4.4 Location No. 3: Boston, Massachusetts

4.4.1 Data Sources and Emissions Inventories

The same emission inventory calculation approach was used as described for Location No. 2, except that the Boston census tract used was 1105.01.

Figure 4-3. Location of Boston, MA Census Tract 1105.01



4.4.2 Models

Ambient concentrations from the above sources were determined using USEPA's approved AERMOD Modeling System. The model utilized local surface and upper air meteorological data processed using EPA AERMINUTE and AERMET meteorological data processors, along with preprocessed terrain data prepared by the United States Geological Survey. To provide a refined analysis of local maxima, the emission sources are

modeled as a polygon area source with the dimensions of the census tract modeled. However, due to the geographic scale of the modeling domain, a simplified approach was utilized (e.g., buildings and structures will not be independently modeled).

Table 4-3 below indicates the source parameters used for Boston census tract 1105.01.

Table 4-3. Census Tract 1105.01 Modeling Parameters

Source ID	X (m)	Y (m)	Elevation (m)	Emission Rate (g/m^2-s)	Release Height (m)	Initial Vert. Dimension (m)
AREAPOLY	322,921	4,683,764	43.73	1.56E-06	0	0

Given that most of the sources from the Boston census tract are from single-story residences, a 0-foot release height was utilized for the polygon area source with no initial vertical dimension. This does not account for buoyancy from plume rise, but it is consistent with EPA NATA modeling procedures of this source type.

There are 81 vertices utilized to develop the polygon area source census tract 1105.01, which are included in appendix table A-3.

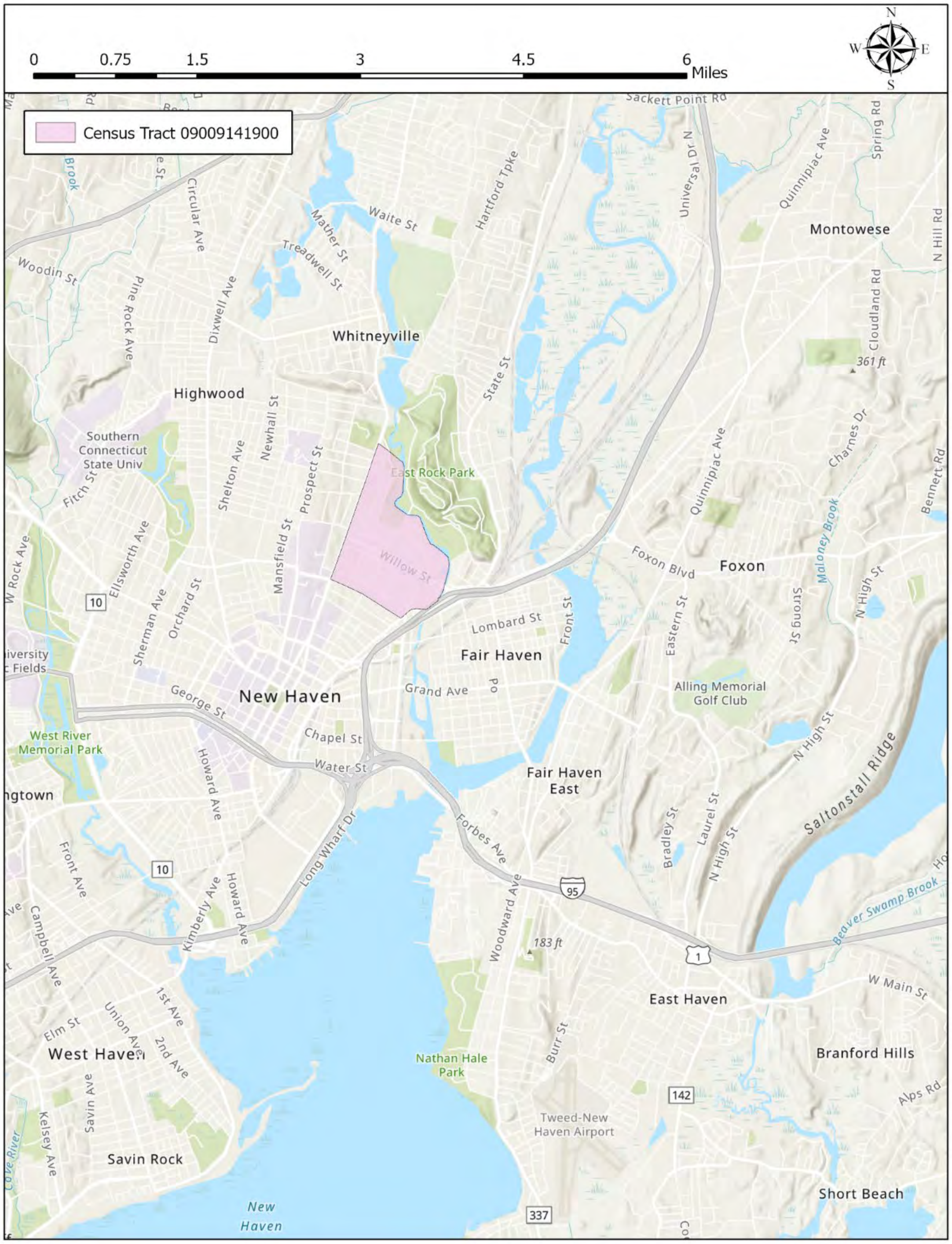
The emission rate for the polygon area source is equal to one over the area of the polygon, representing a unit emission rate of 1 g/s. This unit emission rate was run for 8,760 hours, and the resulting period file concentration, representing the average concentration at each receptor over the 5-years of meteorological data, was used to generate ground level concentrations for each individual pollutant. The ground level concentrations and associated health risk impacts were determined using CARB's HARP tool, which implements the OEHHA risk analysis methodology. Risk was determined in terms of excess cancer risk above baseline values due to distillate oil combustion.

4.5 Location No. 4: New Haven, Connecticut

4.5.1 Data Sources and Emissions Inventories

The same emission calculation methodology was used as described for Location No. 2, except that the New Haven census tract used was 1419.

Figure 4-4. Location of New Haven, CT Census Tract 1419



4.5.2 Models

Ambient concentrations from the above sources were determined using USEPA's approved AERMOD Modeling System. The model utilized local surface and upper air meteorological data processed using EPA AERMINUTE and AERMET meteorological data processors, along with preprocessed terrain data prepared by the United States Geological Survey. To provide a refined analysis of local maxima, the emission sources are

modeled as a polygon area source with the dimensions of the census tract modeled. However, due to the geographic scale of the modeling domain, a simplified approach was utilized (e.g., buildings and structures will not be independently modeled).

Table 4-4 below indicates the source parameters used for New Haven census tract 1419.

Table 4-4. Census Tract 1419 Modeling Parameters

Source ID	X (m)	Y (m)	Elevation (m)	Emission Rate (g/m^2-s)	Release Height (m)	Initial Vert. Dimension (m)
AREAPOLY	674,213	4,576,424	13.7	7.48E-07	0	0

Given that most of the sources from the New Haven census tract are from single-story residences, a 0-foot release height was utilized for the polygon area source with no initial vertical dimension. This does not account for buoyancy from plume rise, but it is consistent with EPA NATA modeling procedures of this source type.

There are 111 vertices utilized to develop the polygon area source census tract 1419, which are included in appendix table A-4.

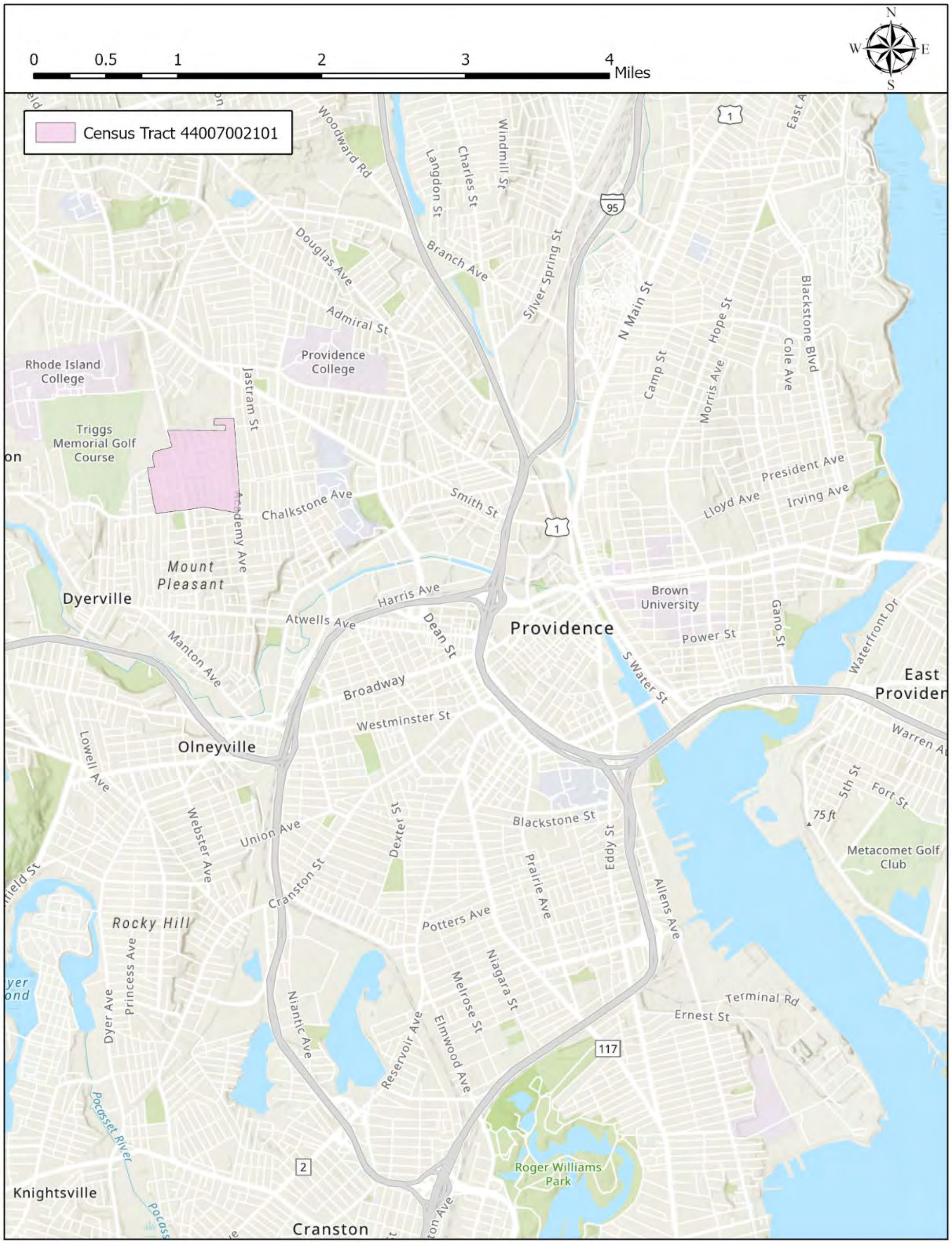
The emission rate for the polygon area source is equal to one over the area of the polygon, representing a unit emission rate of 1 g/s. This unit emission rate was run for 8,760 hours, and the resulting period file concentration, representing the average concentration at each receptor over the 5-years of meteorological data, was used to generate ground level concentrations for each individual pollutant. The ground level concentrations and associated health risk impacts were determined using CARB's HARP tool, which implements the OEHHA risk analysis methodology. Risk was determined in terms of excess cancer risk above baseline values due to distillate oil combustion.

4.6 Location No. 5: Providence, Rhode Island

4.6.1 Data Sources and Emissions Inventories

The same emission calculation approach was used as described for Location No. 2, except that the Providence census tract used was 21.01.

Figure 4-5. Location of Providence, RI Census Tract 21.01



4.6.2 Models

Ambient concentrations from the above sources were determined using USEPA's approved AERMOD Modeling System. The model utilized local surface and upper air meteorological data processed using EPA AERMINUTE and AERMET meteorological data processors, along with preprocessed terrain data prepared by the United States Geological Survey. To provide a refined analysis of local maxima, the emission sources are

modeled as a polygon area source with the dimensions of the census tract modeled. However, due to the geographic scale of the modeling domain, a simplified approach was utilized (e.g., buildings and structures will not be independently modeled).

Table 4-5 below indicates the source parameters used for Providence census tract 21.01.

Table 4-5. Census Tract 21.01 Modeling Parameters

Source ID	X (m)	Y (m)	Elevation (m)	Emission Rate (g/m^2-s)	Release Height (m)	Initial Vert. Dimension (m)
AREAPOLY	296272	4634459	33.9	2.15E-06	0	0

Given that most of the sources from the Providence census tract are from single-story residences, a 0-foot release height was utilized for the polygon area source with no initial vertical dimension. This does not account for buoyancy from plume rise, but it is consistent with EPA NATA modeling procedures of this source type.

There are 78 vertices utilized to develop the polygon area source census tract 1419, which are included in appendix table A-5.

The emission rate for the polygon area source is equal to one over the area of the polygon, representing a unit emission rate of 1 g/s. This unit emission rate was run for 8,760 hours, and the resulting period file concentration, representing the average concentration at each receptor over the 5-years of meteorological data, was used to generate ground level concentrations for each individual pollutant. The ground level concentrations and associated health risk impacts were determined using CARB's HARP tool, which implements the OEHHA risk analysis methodology. Risk was determined in terms of excess cancer risk above baseline values due to distillate oil combustion.

4.7 Valuation of Health Benefits

The monetary valuation of health benefits from using biodiesel was evaluated using U.S. EPA's Environmental Benefits Mapping and Analysis Program - Community Edition (BenMAP), Version 1.5.0.[9] BenMAP is capable of calculating the reduction in incidence or prevalence of negative health impacts associated with a corresponding reduction in ambient $PM_{2.5}$ concentration. BenMAP also allows for the valuation of these reductions based on the use of user-specified valuation functions.

The methodology contained within BenMAP is routinely used by CARB to estimate the health benefits of various rulemaking activities aimed at reducing $PM_{2.5}$ emissions.[10] For this reason, the assumptions and model inputs that were selected for this analysis are based on CARB's methodology as described in detail in Appendix J of the California Truck and Bus Initial Statement of Reasons[11] (except as noted).

[9] https://www.epa.gov/benmap

[10] https://ww2.arb.ca.gov/resources/documents/carbs-methodology-estimating-health-effects-air-pollution

[11] https://ww3.arb.ca.gov/regact/2010/truckbus10/correctedappj.pdf

4.7.1 Geography, Incidence/Prevalence, and Population

For each community, health benefits were calculated on a census tract basis, with total benefits equaling the aggregation of all census tracts within each analysis community. Incidence/prevalence rates were selected from BenMAP default data sets. The population dataset was derived from U.S. Census data at the smallest geographic unit, which is the county level. The analysis selected included a population growth estimate to reflect the 2020 calendar year.

4.7.2 Health Impacts

The health impacts analyzed consisted of the following:

- Premature Mortality (all causes).
- Asthma Exacerbation (including cough, shortness of breath, and wheeze)—together taken to mean, “asthmas attacks.”
- Acute respiratory symptoms resulting in “minor restricted activity days.”
- Work loss days.

The above health impacts, or “endpoints” are those routinely used by CARB during their rulemaking, and hence were used for this analysis.

For each endpoint, BenMAP requires the user to select one or more health impact functions. Each health impact function option represents a technical study reflecting the relationship between $PM_{2.5}$ concentrations and the health impact “endpoint” that is being studied. With regard to the above health impact endpoints, the studies relied upon were selected based on those used in the CARB analyses previously stated, to the degree possible.

Specifically, for the endpoint of “premature death” (which includes cancer deaths), the analysis relied upon the study *Pope et al., 2002*, which is a study CARB has primarily relied upon. For the asthma exacerbation endpoint, the study CARB relied upon is not included within BenMAP. Hence, all available studies related to asthma endpoints were “pooled” using that functionality of BenMAP. For acute respiratory symptoms resulting in minor restricted activity days, the analysis relied upon the study *Ostro and Rothschild, 1989*. And finally, for work loss days, the study *Ostro, 1987* was selected, which is also a study CARB has primarily relied upon.

It is important to note that the endpoint of premature deaths calculated by BenMAP is not equivalent to the cancer burden values discussed in this report. This is because the endpoint of premature death includes all causes, including both lung cancer and ischemic heart disease. In contrast, the metric of cancer burden includes all types of cancers attributed to PM2.5 exposure. Likewise, cancer burden relates to incidence rate of cancer, which is not the same as the premature death endpoint. Many cancer cases do not result in death, and hence, cancer burden reductions will always be higher than avoided premature deaths calculated by BenMAP.

4.7.3 Valuation Functions

Valuation functions assign a value to each health impact “endpoint.” Of the above health impacts, reduced premature mortality will always dominate the overall benefit value under any scenario. However, to document the use of BenMAP, it is important to document the valuation functions used for each endpoint included in this project.

- For the endpoint of premature mortally, the BenMAP standard valuation function “based on 26 value-of-life studies” was selected.

- For the health impact endpoint of asthma exacerbation, all of the available health impact functions within BenMAP were pooled to derive a result.

- For the acute respiratory endpoint of minor restricted activity days, the standard EPA valuation function of “WTP: 1 day, CV studies” was selected.

- For the endpoint of work loss days, the standard EPA valuation function of median work loss days, county specific was selected.

4.7.4 General Valuation Results

Specific results are provided below in Section 6 for each community. In a general, it is noted that the overall value of benefits is sensitive to (i) the extent of geographic area analyzed, and (ii) the population living within the same extents. That is, analyses performed over a broader area, and encompassing a greater population, will produce greater benefits.

5. HEALTH RISK ASSESSMENT RESULTS

5.1 Location No. 1: Bronx, New York

5.1.1 NATA Modeling

According to the 2014 NATA report, the total cancer risk determined for census tract ID 36005004400, representing the Sotomayor housing development, was 1.7 cases per million residents. The six major drivers of this risk were Arsenic, Beryllium, Cadmium, Hexavalent Chromium, Formaldehyde, and Nickel. Additionally, a full change from traditional residential fuel oil to biomass-based diesel represents a 17% reduction in volatile organic compound emissions and an 86% reduction in particulate metal emissions.[12] In total, a full switch from residential fuel oil to biomass diesel represents a baseline risk change from 1.7 cases per million residents to 0.4 cases per million residents, a 1.3 case per million resident reduction. Table 5-1 below shows the detailed NATA cancer risk values and associated reductions.

Table 5-1. NATA Risk Reduction for Sotomayor Housing Development, NYC

Pollutant Name	NATA Cancer Risk (1 in 10^6)	% Reduction	Reduced Risk (1 in 10^6)
1,3-Butadiene	5.0E-03	17%	4.1E-03
Acetaldehyde	8.5E-03	17%	7.1E-03
Arsenic Compounds (Inorganic Including Arsine)	1.7E-01	86%	2.3E-02
Benzene	1.4E-02	17%	1.2E-02
Benzyl Chloride	3.0E-04	17%	2.5E-04
Beryllium Compounds	4.0E-01	86%	5.7E-02
Bromoform	3.7E-07	17%	3.1E-07
Chromium VI (Hexavalent)	2.1E-01	86%	3.0E-02
Cadmium Compounds	3.9E-01	86%	5.4E-02
Ethylbenzene	8.4E-05	17%	7.0E-05
Ethylene Dibromide (Dibromoethane)	1.3E-05	17%	1.1E-05
Formaldehyde	2.3E-01	17%	1.9E-01
Methyl Tert-Butyl Ether	8.0E-08	17%	6.6E-08
Nickel Compounds	2.5E-01	86%	3.5E-02
Naphthalene	2.7E-02	17%	2.3E-02
PAHs	6.9E-04	17%	5.8E-04
Total	**1.7**	**74%**	**0.4**

[12] *Analysis of Fuel Cycle Energy Use and Greenhouse Gas Emissions from Residential Heating Boilers*, National Oilheat Research Alliance (NORA), June 2018, at 104 ("The fine particulate (PM2.5) emissions for the liquid fuel fired heating systems demonstrate the very strong linear relationship between the fine particulate emissions and the sulfur content of the liquid fuels being studied as illustrated in Figure 75 which clearly shows the linear relationship between the measured mass of fine particulates per unit of energy...These results show that as sulfur decreases, the PM2.5 emissions are reduced in a linear manner within the sulfur content range tested"). While B100 might be expected to have virtually no PM2.5 emissions, to be conservative this study assumes an 86% reduction in particulates for B100, in line with a reduction in sulfur by switching from 100% petroleum distillate (typically 7-8 ppm sulfur content) to 100% biodiesel (typically 1 ppm sulfur content or less).

5.1.2 Census-Specific Modeling

Utilizing the emission rates outlined in Section 4.3.1, a modeling analysis specific to the Sotomayor Housing Development (census tract ID 36005004400) was completed. The three major drivers of this risk analysis were Arsenic, Cadmium, and Hexavalent Chromium. In this scenario, the baseline risk levels were substantially higher at 23.3 cases per million residents. This difference is accounted for both by a larger representation of metal emissions from a more refined emissions inventory, and higher pollutant toxicity values derived by OEHHA as used in the HARP analysis. With the associated volatile and metal risk reduction from a full switch to biomass-based diesel, the baseline risk is reduced to an average total risk of 3.4 cases per million residents, representing a reduction of 19.9 cases per million residents. The table below shows the detailed modeled cancer risk values and associated reductions.

Table 5-2. Census-Specific Modeling for Sotomayor Housing Development, NYC

Name	AERMOD Conc. (µg/m3)	HARP Risk	Reduction	Reduced Risk
Acetaldehyde	1.43E-03	1.3E-02	17%	1.1E-02
Arsenic	1.63E-04	9.8	86%	1.4
B[a]anthracene	1.16E-06	3.71E-03	86%	5.2E-04
Benzene	6.22E-05	5.6E-03	17%	4.6E-03
Beryllium	1.22E-04	0.9	86%	0.1
Cadmium	1.22E-04	1.6	86%	0.2
Cr(VI)	2.20E-05	10.4	86%	1.5
Chrysene	6.91E-07	2.2E-04	86%	3.1E-05
D[a,h]anthracene	4.85E-07	6.2E-03	86%	8.7E-04
Formaldehyde	9.59E-03	0.2	17%	0.1
In[1,2,3-cd]pyr	6.22E-07	1.98E-03	86%	2.8E-04
Lead	3.67E-04	0.1	86%	1.6E-02
Naphthalene	3.28E-04	3.5E-02	86%	4.9E-03
Nickel	1.22E-04	0.1	86%	1.4E-02
Total	**N/A**	**23.3**	**85.4%**	**3.4**

5.1.3 Bronx, NY Health Risk Summary

Given the conservative nature of the OEHHA health risk values utilized in the HARP software, and the coarse, county-wide review of the NATA report, it is expected that the actual cancer risk of associated with residential heating oil usage in the Sotomayor housing development (census tract ID 36005004400) lies somewhere between 1.7 and 23.3 excess cancer cases per million residents over a 70-year timeline. Utilizing 17% and 86% reductions for volatile and metal toxics emissions, respectively, assuming a full transition from residential distillate heating oil to biomass-based diesel, that baseline risk is reduced to a value between 0.4 and 3.4 excess cancer cases per million residents.

5.1.4 Extrapolation of Risk Results to Other Similar Housing Areas

Risk results from the Sotomayor housing development can be extrapolated to the larger surrounding areas with similar housing densities utilizing a “density factor”, which is the ratio of households utilizing fuel oils (945 for Sotomayor) divided by area (265,578 square meters for Sotomayor). This data can be used to extrapolate the Sotomayor risk results to other areas based on the ratio of the Sotomayor "density factor" and associated risk (23.3 in one million) to other census tract "density factors" as follows, where Census Tract is abbreviated as CT:

Equation 1. Census Tract Density Factor

$$Density\ Factor_{CT\ X} = \frac{Homes\ Using\ Heating\ Oil_{CT\ X}}{Area\ (m^2)_{CT\ X}} / \frac{Homes\ Using\ Heating\ Oil_{Sotomayor\ CT}}{Area\ (m^2)_{Sotomayor\ CT}}$$

Equation 2. Unit Risk Factor

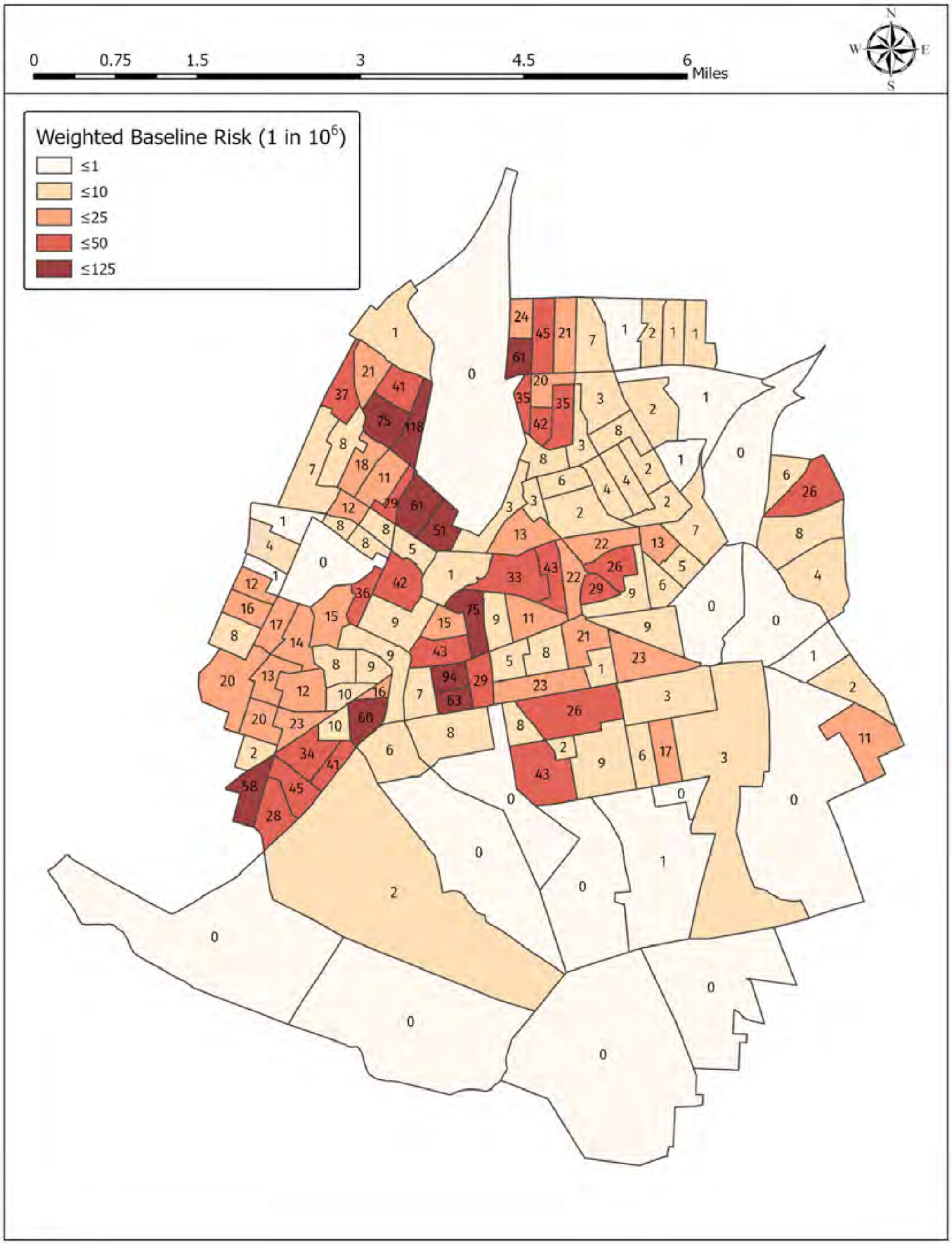
$$Unit\ Risk\ (\frac{Risk}{Homes\ Using\ Heating\ Oil}) = \frac{Risk_{Sotomayor\ CT}}{Homes\ Using\ Heating\ Oil_{Sotomayor\ CT}}$$

Equation 3. Extrapolated Census Tract Risk

$$Risk_{CT\ X} = Homes\ Using\ Heating\ Oil_{CT\ X} * Unit\ Risk\ Factor * Density\ Factor_{CT\ X}$$

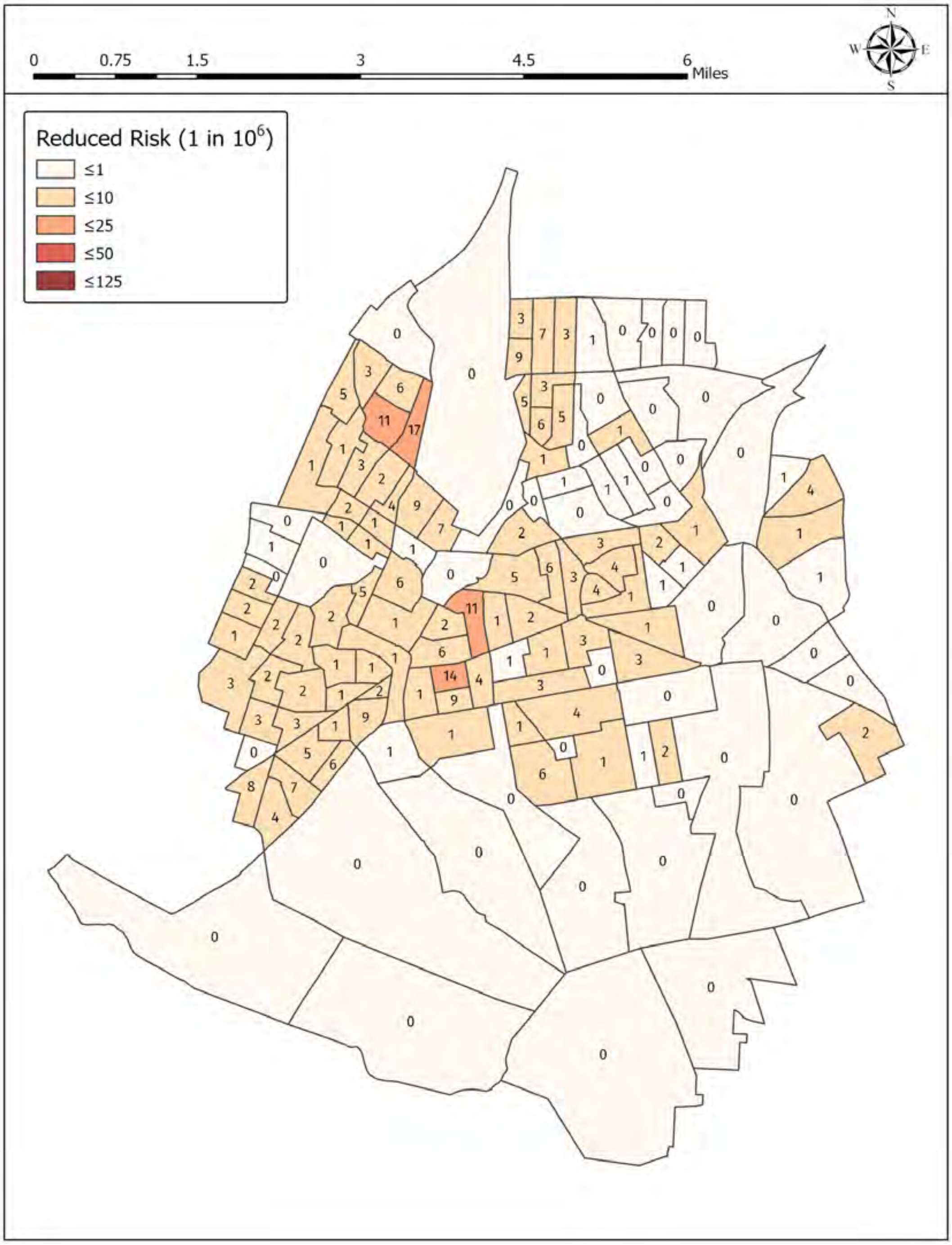
In this case, Sotomayor has 945 houses burning distillate oil and an area of 265,578 square meters, so a density factor of 0.00356 fuel oil houses per meter squared. This factor, combined with Sotomayor's unit risk factor of 0.02461 (23.3 per million cases/945 houses), can then be multiplied by the number of residences using heating oil in any other nearby census tract to get an estimated risk due to distillate oil combustion in that tract. The figure below shows the calculated risk per million residents due to distillate oil combustion in the vicinity (~5 mile diameter area) of the Bronx near the Sotomayor housing development. The Sotomayor development is outlined in blue.

Figure 5-1. Risk Due to Home Heating Oil Combustion in the Bronx, NYC



The figure below shows the reduction in risk due to the conversion to biomass-based diesel fuel for the same 5-mile diameter area surrounding the Sotomayor development.

Figure 5-2. Reduced Risk Due to Biodiesel Heating Oil Combustion in the Bronx, NYC



The reduction in “cancer burden”, which is just each respective census tract risk multiplied by the census tract population divided by 1 million, can be determined from this same data. The maximum baseline cancer burden is 1.0 for census tract 36005039300, compared to the Sotomayor development cancer burden of 0.1, indicating that this census tract could expect 1 person to develop cancer over a 70-year lifetime due to exposure to distillate oil combustion within that census tract alone. The total cancer burden for all of the census tracts in the selected 5-mile radius is 12, with an expected reduction in cancer burden to a value of approximately 2 with the use of biomass-based diesel fuel for home heating oil combustion.

5.1.5 Valuation of Health Benefits

The health benefits of reduced $PM_{2.5}$ exposure were modeled using USEPA's Ben-MAP according to the methodology described under Section 4,7. The results are shown in Table 5-3 below.

Table 5-3. Valuation of Reduced Incidence Benefits, Bronx, NYC

Endpoint	Reduced Incidence	Benefit Value
Premature Mortality	15.5	$135,249,595
Asthma Exacerbation	10,848	$638,975
Minor Restricted Activity Days	11,889	$827,239
Work Loss Days	2,034	$291,321
Total		**$137,007,131**

5.2 Location No. 2: Albany, New York

5.2.1 NATA Risk Reduction for Census Tract 17 in Albany, NY

According to the 2014 NATA report, the non-wood fuel consumption cancer risk determined for census tract 17, representing Albany, NY, was 0.3 cases per million residents. The six major drivers of this risk were Arsenic, Beryllium, Cadmium, Hexavalent Chromium, Formaldehyde, and Nickel. Additionally, a full change from traditional residential fuel oil to biomass-based diesel represents a 17% reduction in volatile organic compound emissions and an 86% reduction in particulate metal emissions.[13] In total, a full switch from residential fuel oil to biomass diesel represents a baseline risk change from 0.3 cases per million residents to 0.1 cases per million residents, a 0.2 case per million resident reduction. Table 5-4 below shows the detailed NATA cancer risk values and associated reductions.

Table 5-4. NATA Risk Reduction for Census Tract 17 in Albany, NY

Pollutant Name	NATA Cancer Risk (1 in 10^6)	% Reduction	Reduced Risk (1 in 10^6)
1,3-Butadiene	1.2E-03	17%	9.6E-04
Acetaldehyde	1.5E-03	17%	1.2E-03
Arsenic Compounds(Inorganic Including Arsine)	4.2E-02	86%	5.8E-03
Benzene	3.4E-03	17%	2.8E-03
Benzyl Chloride	9.9E-05	17%	8.3E-05
Beryllium Compounds	4.9E-02	86%	6.9E-03
Bromoform	1.3E-07	17%	1.1E-07
Chromium VI (Hexavalent)	1.3E-02	86%	1.8E-03

[13] Ibid.

Pollutant Name	NATA Cancer Risk (1 in 10^6)	% Reduction	Reduced Risk (1 in 10^6)
Cadmium Compounds	5.4E-02	86%	7.6E-03
Ethylbenzene	2.3E-05	17%	1.9E-05
Formaldehyde	2.4E-02	17%	2.0E-02
Methyl Tert-Butyl Ether	2.8E-08	17%	2.3E-08
Nickel Compounds	6.0E-02	86%	8.5E-03
Naphthalene	4.5E-03	17%	3.7E-03
PAHs	1.6E-04	17%	1.3E-04
Total	**0.3**	**77%**	**0.1**

5.2.2 Census-Specific Modeling

Utilizing the emission rates outlined in Section 4.3.1, a modeling analysis specific to census tract 17was completed. The three major drivers of this risk analysis were Arsenic, Cadmium, and Hexavalent Chromium. In this scenario, the baseline risk levels were higher at 1.7 cases per million residents. This difference is accounted for both by a larger representation of metal emissions from a more refined emissions inventory, and higher pollutant toxicity values derived by OEHHA as used in the HARP analysis. With the associated volatile and metal risk reduction from a full switch to biomass-based diesel, the baseline risk is reduced to an average total risk of 0.3 cases per million residents, representing a reduction of 1.4 cases per million residents. The table below shows the detailed modeled cancer risk values and associated reductions.

Table 5-5. HARP Risk Reduction for Census Tract 17 in Albany, NY

Name	AERMOD Conc. (µg/m3)	HARP Risk	Reduction	Reduced Risk
Acetaldehyde	1.58E-04	1.5E-03	17%	1.2E-03
Arsenic	1.80E-05	0.2	86%	2.9E-02
B[a]anthracene	1.29E-07	3.3E-05	86%	4.6E-06
Benzene	6.86E-06	6.5E-04	17%	5.4E-04
Beryllium	1.35E-05	0.1	86%	1.5E-02
Cadmium	1.35E-05	0.2	86%	2.8E-02
Cr(VI)	2.44E-06	1.2	86%	0.2
Chrysene	7.65E-08	2.9E-06	86%	4.1E-07
D[a,h]anthracene	5.35E-08	2.1E-04	86%	2.9E-05
Formaldehyde	1.06E-03	2.1E-02	17%	1.8E-02
In[1,2,3-cd]pyr	6.86E-08	2.5E-05	86%	3.5E-06
Lead	4.07E-05	1.6E-03	86%	2.3E-04
Naphthalene	3.61E-05	4.2E-03	86%	5.9E-04
Nickel	1.35E-05	1.2E-02	86%	1.6E-03
Total	**N/A**	**1.7**	**85.1%**	**0.3**

5.2.3 Albany, NY Health Risk Summary

Given the conservative nature of the OEHHA health risk values utilized in the HARP software, and the coarse, county-wide review of the NATA report, it is expected that the actual cancer risk associated with residential heating oil usage in the census tract 17 lies somewhere between 0.3 and 1.7 excess cancer cases per million residents over a 70-year timeline. Utilizing 17% and 86% reductions for volatile and metal toxics emissions, respectively, assuming a full transition from residential distillate heating oil to biomass-based diesel, that baseline risk is reduced to a value between 0.1 and 0.3 excess cancer cases per million residents.

5.2.4 Extrapolation of Risk Results to Other Similar Housing Areas

Risk results from census tract 17 can be extrapolated to the larger surrounding areas with similar housing densities utilizing a “density factor”, which is the ratio of households utilizing fuel oils (165 for census tract 17) divided by area (1,367,250 square meters for census tract 17). This data can be used to extrapolate the Albany risk results to other areas based on the ratio of the Albany “density factor” and associated risk (1.7 in one million) to other census tract “density factors” as follows, where Census Tract is abbreviated as CT:

Equation 4. Census Tract Density Factor

$$Density\ Factor_{CT\ X} = \frac{Homes\ Using\ Heating\ Oil_{CT\ X}}{Area\ (m^2)_{CT\ X}} / \frac{Homes\ Using\ Heating\ Oil_{CT\ 17}}{Area\ (m^2)_{CT\ 17}}$$

Equation 5. Unit Risk Factor

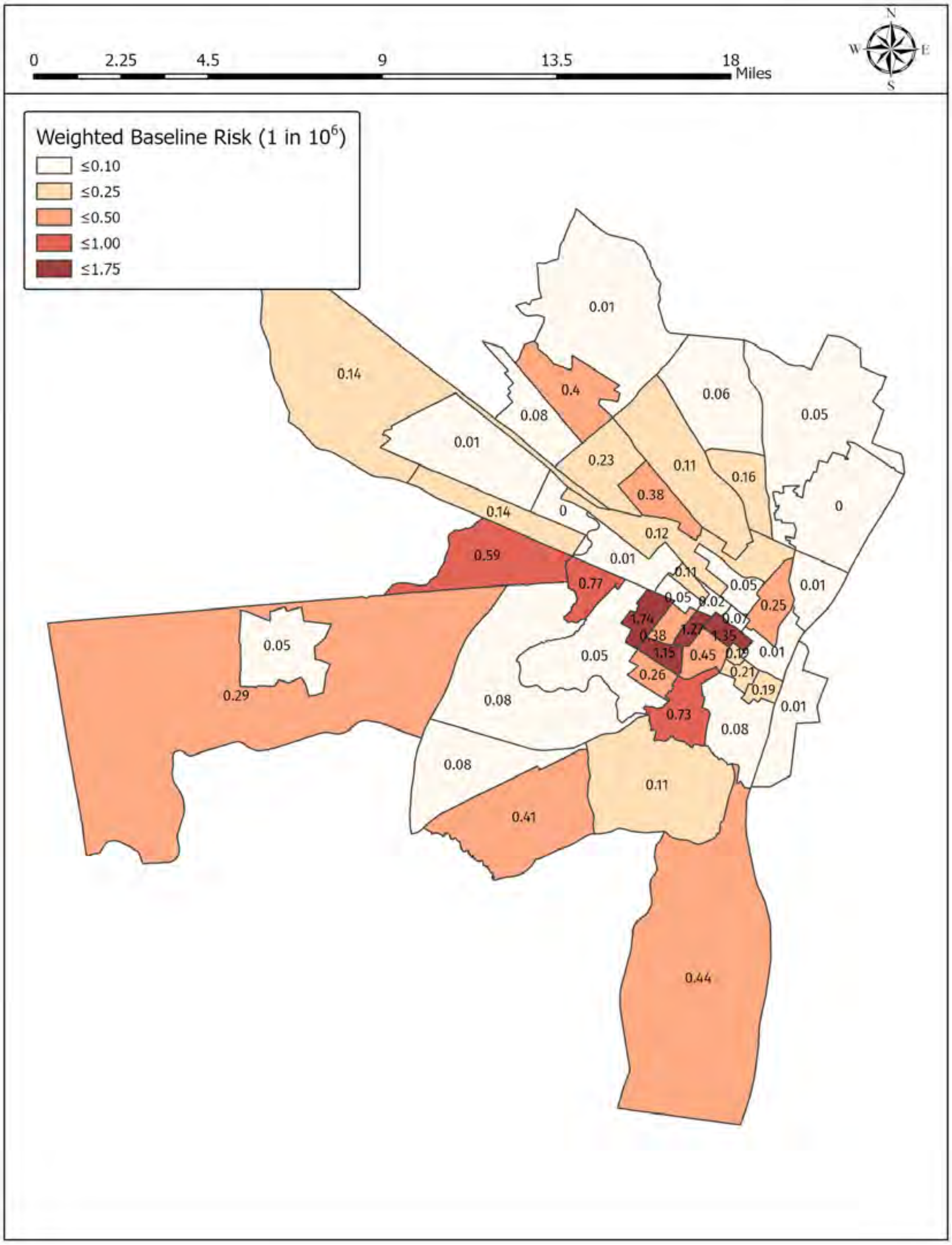
$$Unit\ Risk\ (\frac{Risk}{Homes\ Using\ Heating\ Oil}) = \frac{Risk_{CT\ 17}}{Homes\ Using\ Heating\ Oil_{CT\ 17}}$$

Equation 6. Extrapolated Census Tract Risk

$$Risk_{CT\ X} = Homes\ Using\ Heating\ Oil_{CT\ X} * Unit\ Risk\ Factor * Density\ Factor_{CT\ X}$$

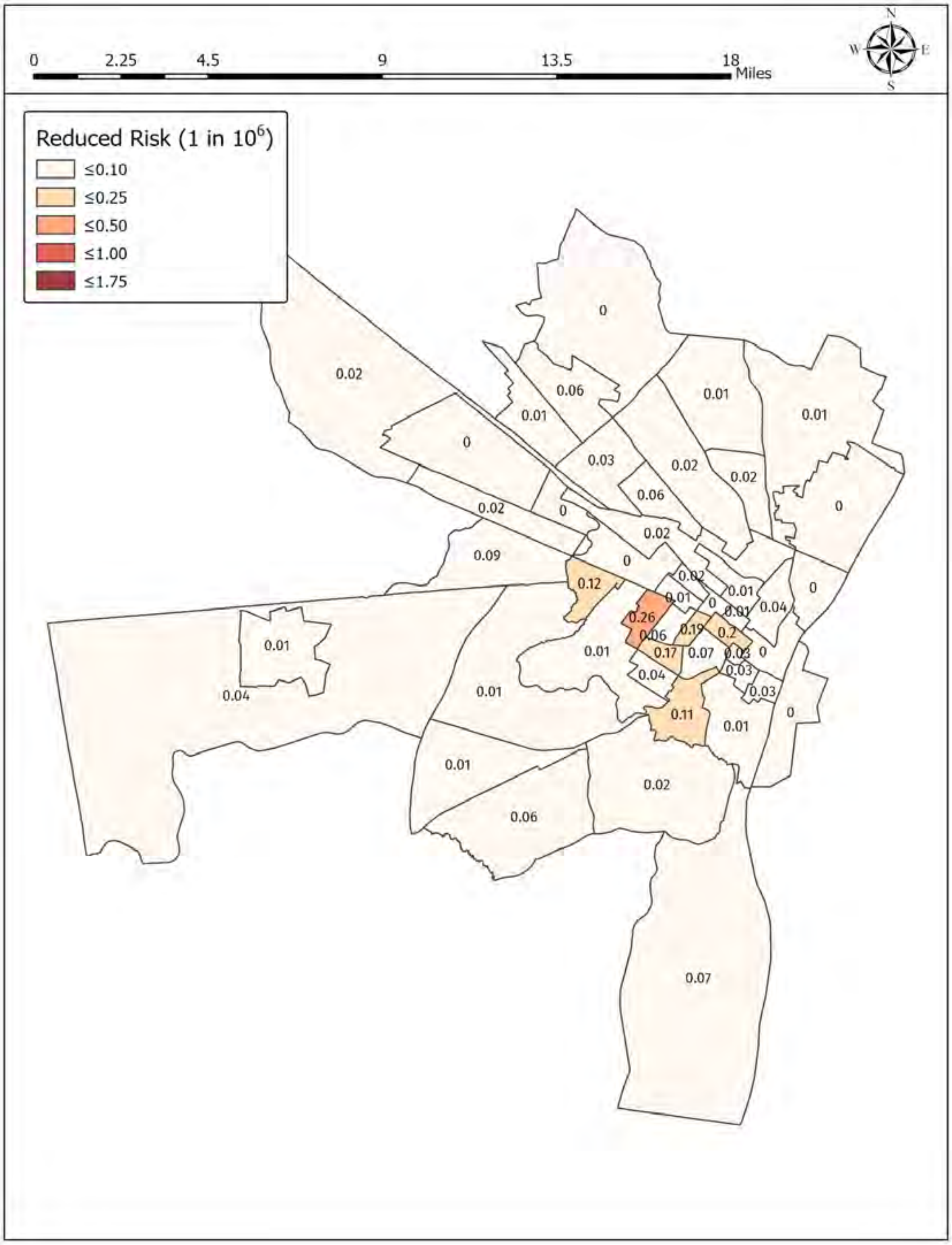
In this case, census tract 17 has 165 houses burning distillate oil and an area of 1,367,250 square meters, so a density factor of 0.00012068 fuel oil houses per meter squared. This factor, combined with census tract 17‘s unit risk factor of 0.010519307 (1.7 per million cases/165 houses), can then be multiplied by the number of residences using heating oil in any other nearby census tract to get an estimated risk due to distillate oil combustion in that tract. The figure below shows the calculated risk per million residents due to distillate oil combustion in the vicinity (~5 mile diameter area) of the Albany area near census tract 17.

Figure 5-3. Risk Due to Home Heating Oil Combustion in Albany, NY



The figure below shows the reduction in risk due to the conversion to biomass-based diesel fuel for the same 5-mile diameter area surrounding census tract 17.

Figure 5-4. Risk Reduction Due to Biodiesel Heating Oil Combustion in Albany, NY



The reduction in “cancer burden”, which is just each respective census tract risk multiplied by the census tract population divided by 1 million, can be determined from this same data. The maximum baseline cancer burden is 0.008 for census tract 17, which is the census tract used to develop the analysis, indicating that this census tract could expect <1 person to develop cancer over a 70-year lifetime due to exposure to distillate oil combustion within that census tract. The total cancer burden for all of the census tracts in the selected 5-mile radius is also <1, with a negligible reduction in cancer burden with the use of biomass-based diesel fuel for home heating oil combustion.

5.2.5 Valuation of Health Benefits

The health benefits of reduced $PM_{2.5}$ exposure were modeled using USEPA's Ben-MAP according to the methodology described under Section 4.7. The results are shown in Table 5-6 below.

Table 5-6. Valuation of Reduced Incidence Benefits, Albany, NY

Endpoint	Reduced Incidence	Benefit Value
Premature Mortality	0.1	$1,224,296
Asthma Exacerbation	65	$3,854
Minor Restricted Activity Days	87	$6,056
Work Loss Days	15	$2,772
Total		$1,236,978

5.3 Location No. 3: Boston, Massachusetts

5.3.1 NATA Modeling

According to the 2014 NATA report, the fuel oil cancer risk determined for census tract 1105.01, representing Boston, was 0.9 cases per million residents. The six major drivers of this risk were Arsenic, Beryllium, Cadmium, Hexavalent Chromium, Formaldehyde, and Nickel. Additionally, a full change from traditional residential fuel oil to biomass-based diesel represents a 17% reduction in volatile organic compound emissions and an 86% reduction in particulate metal emissions.[14] In total, a full switch from residential fuel oil to biomass diesel represents a baseline risk change from 0.9 cases per million residents to 0.3 cases per million residents, a 0.6 case per million resident reduction. Table 5-5 below shows the detailed NATA cancer risk values and associated reductions.

Table 5-7. NATA Risk Reduction for Census Tract 1105.01

Pollutant Name	NATA Cancer Risk (1 in 10^6)	% Reduction	Reduced Risk (1 in 10^6)
1,3-Butadiene	1.9E-03	17%	1.6E-03
Acetaldehyde	6.2E-03	17%	5.1E-03
Arsenic Compounds(Inorganic Including Arsine)	3.1E-01	86%	4.3E-02
Benzene	4.6E-03	17%	3.8E-03
Beryllium Compounds	1.3E-01	86%	1.9E-02
Chromium VI (Hexavalent)	1.2E-01	86%	1.7E-02
Cadmium Compounds	1.1E-01	86%	1.5E-02
Ethylbenzene	3.2E-05	17%	2.7E-05
Formaldehyde	1.8E-01	17%	1.5E-01

[14] Ibid.

Pollutant Name	NATA Cancer Risk (1 in 10^6)	% Reduction	Reduced Risk (1 in 10^6)
Nickel Compounds	3.7E-02	86%	5.1E-03
Naphthalene	1.5E-02	17%	1.3E-02
PAHs	2.8E-04	17%	2.3E-04
Total	**0.9**	**70%**	**0.3**

5.3.2 Census-Specific Modeling

Utilizing the emission rates outlined in Section 4.3.1, a modeling analysis specific to census tract 1105.01 was completed. The three major drivers of this risk analysis were Arsenic, Cadmium, and Hexavalent Chromium. In this scenario, the baseline risk levels were substantially higher at 21.8 cases per million residents. This difference is accounted for both by a larger representation of metal emissions from a more refined emissions inventory, and higher pollutant toxicity values derived by OEHHA as used in the HARP analysis. With the associated volatile and metal risk reduction from a full switch to biomass-based diesel, the baseline risk is reduced to an average total risk of 3.1 cases per million residents, representing a reduction of 18.7 cases per million residents. The table below shows the detailed modeled cancer risk values and associated reductions.

Table 5-8. Census-Specific Modeling for Census Tract 1105.01

Name	AERMOD Conc. (µg/m3)	HARP Risk	Reduction	Reduced Risk
Acetaldehyde	8.67E-04	7.8E-03	17%	6.5E-03
Arsenic	9.90E-05	13.3	86%	1.9E+00
B[a]anthracene	7.08E-07	4.5E-03	86%	6.3E-04
Benzene	3.76E-05	3.4E-03	17%	2.8E-03
Beryllium	7.43E-05	0.6	86%	7.8E-02
Cadmium	7.43E-05	1.0	86%	1.4E-01
Cr(VI)	1.34E-05	6.6	86%	0.9
Chrysene	4.18E-07	2.7E-04	86%	3.7E-05
D[a,h]anthracene	2.94E-07	6.9E-03	86%	9.6E-04
Formaldehyde	5.81E-03	1.1E-01	17%	9.1E-02
In[1,2,3-cd]pyr	3.76E-07	2.4E-03	86%	3.4E-04
Lead	2.23E-04	1.6E-01	86%	2.3E-02
Naphthalene	1.99E-04	2.1E-02	86%	3.0E-03
Nickel	7.43E-05	6.1E-02	86%	8.5E-03
Total	**N/A**	**21.8**	**85.6%**	**3.1**

5.3.3 Boston, MA Health Risk Summary

Given the conservative nature of the OEHHA health risk values utilized in the HARP software, and the coarse, county-wide review of the NATA report, it is expected that the actual cancer risk of associated with residential heating oil usage in census tract 1105.01 lies somewhere between 0.9 and 21.8 excess cancer cases per million residents over a 70-year timeline. Utilizing 17% and 86% reductions for volatile and metal toxics emissions, respectively, assuming a full transition from residential distillate heating oil to biomass-based diesel, that baseline risk is reduced to a value between 0.3 and 3.1 excess cancer cases per million residents.

5.3.4 Extrapolation of Risk Results to Other Similar Housing Areas

Risk results from census tract 1105.01 can be extrapolated to the larger surrounding areas with similar housing densities utilizing a “density factor”, which is the ratio of households utilizing fuel oils (438 for census tract 1105.01) divided by area (647,837 square meters for census tract 1105.01). This data can be used to extrapolate the risk results to other areas based on the ratio of the census tract 1105.01 “density factor” and associated risk (21.8 in one million) to other census tract “density factors” as follows, where Census Tract is abbreviated as CT:

Equation 7. Census Tract Density Factor

$$Density\ Factor_{CT\ X} = \frac{Homes\ Using\ Heating\ Oil_{CT\ X}}{Area\ (m^2)_{CT\ X}} / \frac{Homes\ Using\ Heating\ Oil_{CT\ 1105.01}}{Area\ (m^2)_{CT\ 1105.01}}$$

Equation 8. Unit Risk Factor

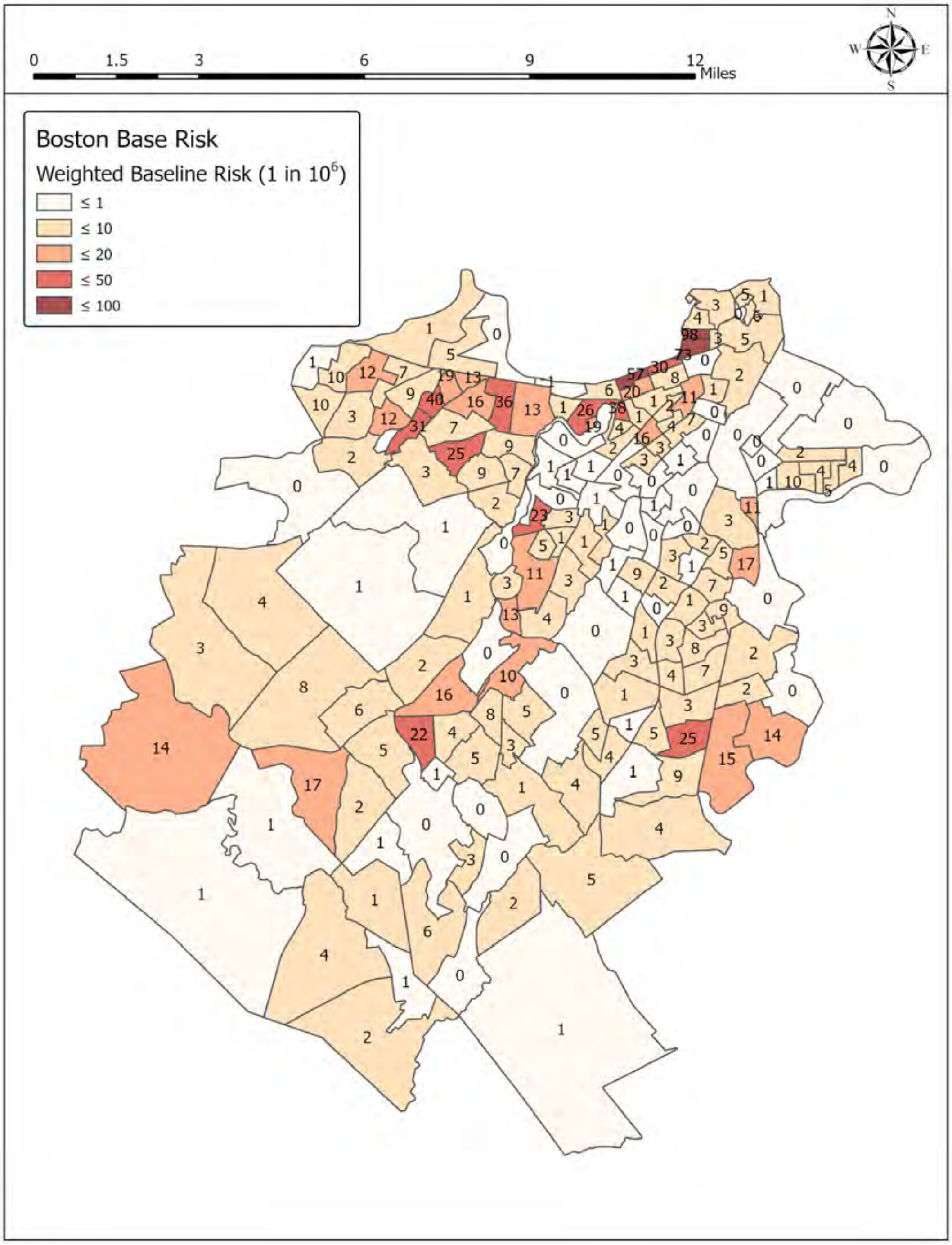
$$Unit\ Risk\ (\frac{Risk}{Homes\ Using\ Heating\ Oil}) = \frac{Risk_{\ CT\ 1105.01}}{Homes\ Using\ Heating\ Oil_{\ CT\ 1105.01}}$$

Equation 9. Extrapolated Census Tract Risk

$$Risk_{CT\ X} = \ Homes\ Using\ Heating\ Oil_{CT\ X} * Unit\ Risk\ Factor * Density\ Factor_{CT\ X}$$

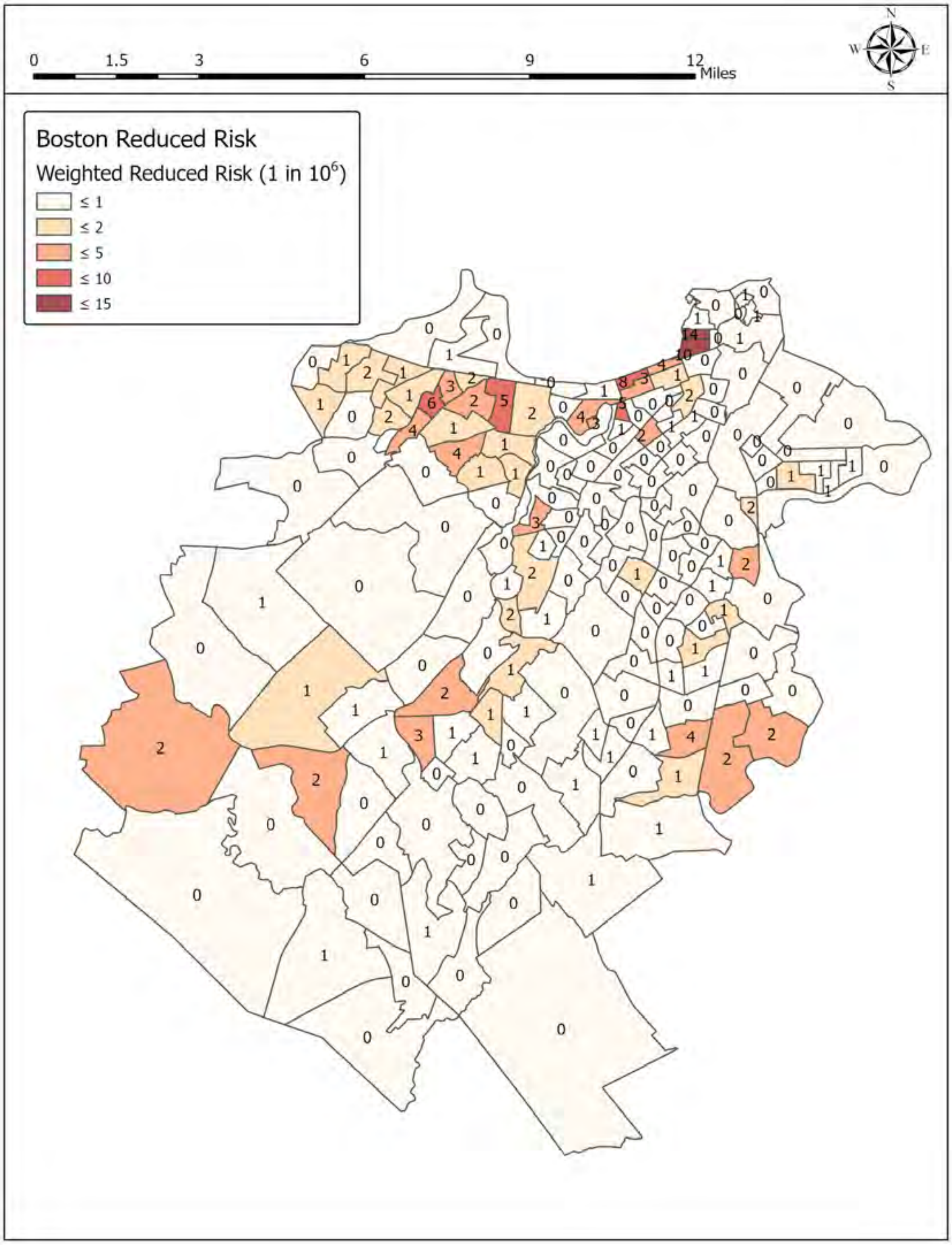
In this case, census tract 1105.01 has 438 houses burning distillate oil and an area of 647,837 square meters, so a density factor of 0.0068 fuel oil houses per meter squared. This factor, combined with census tract 1105.11’s unit risk factor of 0.04988 (21.8 per million cases/438 houses), can then be multiplied by the number of residences using heating oil in any other nearby census tract to get an estimated risk due to distillate oil combustion in that tract. The figure below shows the calculated risk per million residents due to distillate oil combustion in the vicinity (~5 mile diameter area) of the Boston area near census tract 1105.01.

Figure 5-5. Risk Due to Home Heating Oil Combustion in Boston, MA



The figure below shows the reduction in risk due to the conversion to biomass-based diesel fuel for the same 5-mile diameter area surrounding Boston.

Figure 5-6. Reduced Risk Due to Biodiesel Heating Oil Combustion in Boston, MA



The reduction in “cancer burden”, which is just each respective census tract risk multiplied by the census tract population divided by 1 million, can be determined from this same data. The maximum baseline cancer burden is 0.4 for census tract 25025020200, compared to the cancer burden of 0.1 for census tract 1105.01, indicating that this census tract could expect <1 person to develop cancer over a 70-year lifetime due to exposure to distillate oil combustion within that census tract alone. The total cancer burden for all of the census tracts in the selected 5-mile radius is 5, with an expected reduction in cancer burden to a value of approximately <1 with the use of biomass-based diesel fuel for home heating oil combustion.

5.3.5 Valuation of Health Benefits

The health benefits of reduced $PM_{2.5}$ exposure were modeled using USEPA's Ben-MAP according to the methodology described under Section 4,7. The results are shown in Table 5-3 below.

Table 5-9. Valuation of Reduced Incidence Benefits, Boston, MA

Endpoint	Reduced Incidence	Benefit Value
Premature Mortality	7.8	$68,257,253
Asthma Exacerbation	4,143	$244,037
Minor Restricted Activity Days	5,876	$408,864
Work Loss Days	1,003	$238,376
Total		**$69,148,530**

5.4 Location No. 4: New Haven, Connecticut

5.4.1 NATA Modeling

According to the 2014 NATA report, the total cancer risk determined for census tract ID 90091419000, representing New Haven, was 0.3 cases per million residents. The six major drivers of this risk were Arsenic, Beryllium, Cadmium, Hexavalent Chromium, Formaldehyde, and Nickel. Additionally, a full change from traditional residential fuel oil to biomass-based diesel represents a 17% reduction in volatile organic compound emissions and an 86% reduction in particulate metal emissions.[15] In total, a full switch from residential fuel oil to biomass diesel represents a baseline risk change from 0.3 cases per million residents to <0.1 cases per million residents, a 0.2 case per million resident reduction. Table 5-7 below shows the detailed NATA cancer risk values and associated reductions.

Table 5-10. NATA Risk Reduction for Census Tract 1419

Pollutant Name	NATA Cancer Risk (1 in 10^6)	% Reduction	Reduced Risk (1 in 10^6)
1,3-Butadiene	1.2E-03	17%	1.0E-03
Acetaldehyde	1.9E-03	17%	1.5E-03
Arsenic Compounds(Inorganic Including Arsine)	1.3E-01	86%	1.9E-02
Benzene	3.6E-03	17%	3.0E-03
Beryllium Compounds	5.4E-02	86%	7.6E-03
Chromium VI (Hexavalent)	5.1E-02	86%	7.1E-03
Cadmium Compounds	5.1E-02	86%	7.1E-03
Ethylbenzene	2.3E-05	17%	1.9E-05

[15] Ibid.

Formaldehyde	3.2E-02	17%	2.6E-02
Nickel Compounds	1.3E-02	86%	1.8E-03
Naphthalene	6.3E-03	17%	5.3E-03
PAHs	1.9E-04	17%	1.6E-04
Total	**0.35**	**77%**	**0.08**

5.4.2 Census-Specific Modeling

Utilizing the emission rates outlined in Section 4.3.1, a modeling analysis specific to census tract 1419 was completed. The three major drivers of this risk analysis were Arsenic, Cadmium, and Hexavalent Chromium. In this scenario, the baseline risk levels were substantially higher at 7.4 cases per million residents. This difference is accounted for both by a larger representation of metal emissions from a more refined emissions inventory, and higher pollutant toxicity values derived by OEHHA as used in the HARP analysis. With the associated volatile and metal risk reduction from a full switch to biomass-based diesel, the baseline risk is reduced to an average total risk of 1.1 cases per million residents, representing a reduction of 6.3 cases per million residents. The table below shows the detailed modeled cancer risk values and associated reductions.

Table 5-11. Census-Specific Modeling for Census Tract 1419

Name	AERMOD Conc. (µg/m3)	HARP Risk	Reduction	Reduced Risk
Acetaldehyde	4.55E-04	4.1E-03	17%	3.4E-03
Arsenic	5.21E-05	3.1	86%	4.4E-01
B[a]anthracene	3.72E-07	1.2E-03	86%	1.7E-04
Benzene	1.98E-05	1.8E-03	17%	1.5E-03
Beryllium	3.89E-05	0.3	86%	4.1E-02
Cadmium	3.89E-05	0.5	86%	7.3E-02
Cr(VI)	7.01E-06	3.3	86%	0.5
Chrysene	2.20E-07	7.0E-05	86%	9.8E-06
D[a,h]anthracen	1.54E-07	2.0E-03	86%	2.8E-04
Formaldehyde	3.06E-03	5.8E-02	17%	4.8E-02
In[1,2,3-cd]pyr	1.98E-07	6.3E-04	86%	8.8E-05
Lead	1.17E-04	3.7E-02	86%	5.1E-03
Naphthalene	1.04E-04	1.1E-02	86%	1.6E-03
Nickel	3.89E-05	3.2E-02	86%	4.4E-03
Total	**N/A**	**7.4**	**85.4%**	**1.1**

5.4.3 New Haven, CT Health Risk Summary

Given the conservative nature of the OEHHA health risk values utilized in the HARP software, and the coarse, county-wide review of the NATA report, it is expected that the actual cancer risk of associated with residential heating oil usage in census tract 1419 lies somewhere between 0.3 and 7.4 excess cancer cases per million residents over a 70-year timeline. Utilizing 17% and 86% reductions for volatile and metal toxics emissions, respectively, assuming a full transition from residential distillate heating oil to biomass-based diesel, that baseline risk is reduced to a value between <0.1 and 1.1 excess cancer cases per million residents.

5.4.4 Extrapolation of Risk Results to Other Similar Housing Areas

Risk results from census tract 1419 can be extrapolated to the larger surrounding areas with similar housing densities utilizing a “density factor”, which is the ratio of households utilizing fuel oils (563 for census tract 1419) divided by area (1,301,209 square meters for census tract 1419). This data can be used to extrapolate the risk results to other areas based on the ratio of the census tract 1419 “density factor” and associated risk (7.4 in one million) to other census tract “density factors” as follows, where Census Tract is abbreviated as CT:

Equation 10. Census Tract Density Factor

$$Density\ Factor_{CT\ X} = \frac{Homes\ Using\ Heating\ Oil_{CT\ X}}{Area\ (m^2)_{CT\ X}} / \frac{Homes\ Using\ Heating\ Oil_{CT\ 1419}}{Area\ (m^2)_{Sotomayor\ CT\ 1419}}$$

Equation 11. Unit Risk Factor

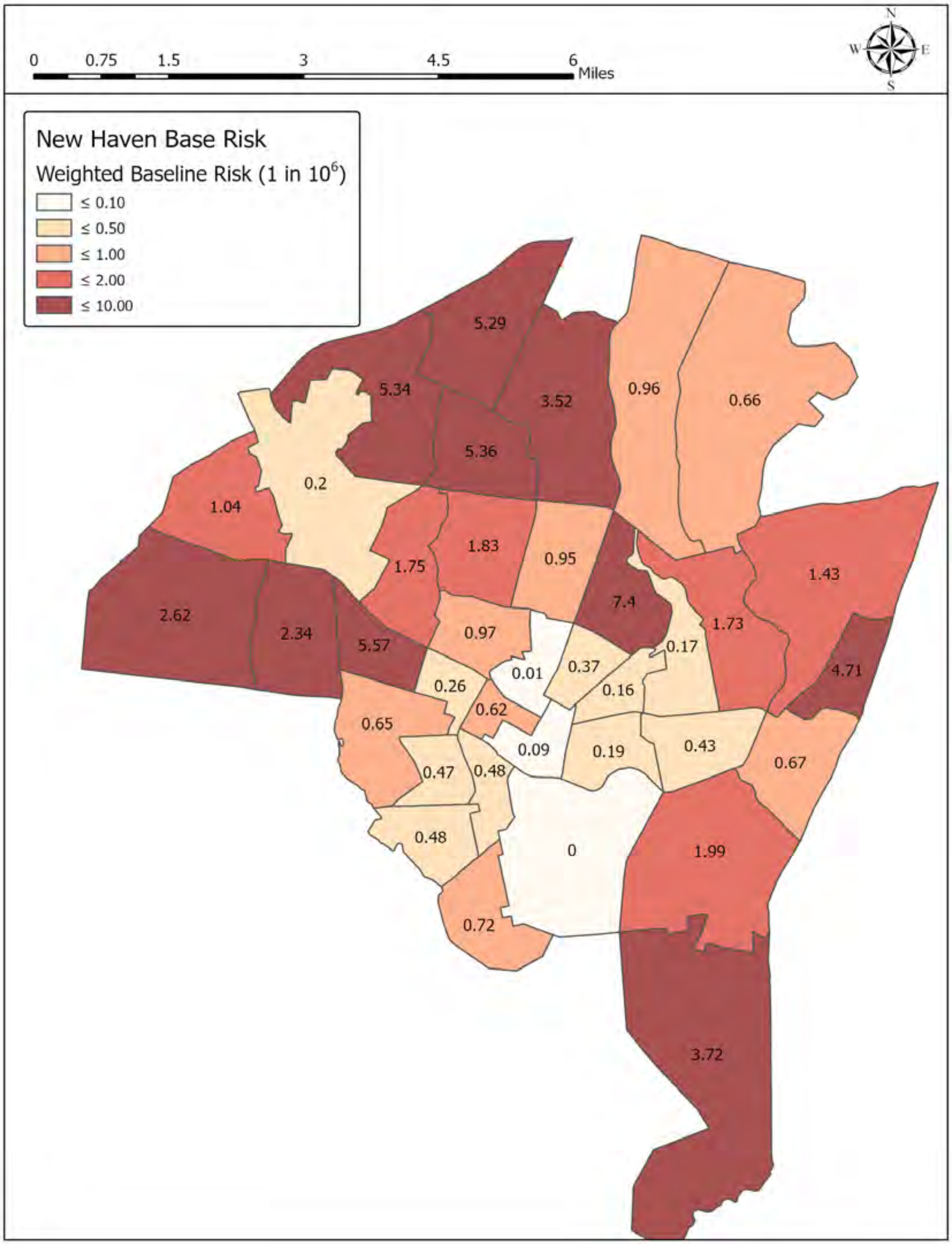
$$Unit\ Risk\ (\frac{Risk}{Homes\ Using\ Heating\ Oil}) = \frac{Risk_{CT\ 1419}}{Homes\ Using\ Heating\ Oil_{CT\ 1419}}$$

Equation 12. Extrapolated Census Tract Risk

$$Risk_{CT\ X} = Homes\ Using\ Heating\ Oil_{CT\ X} * Unit\ Risk\ Factor * Density\ Factor_{CT\ X}$$

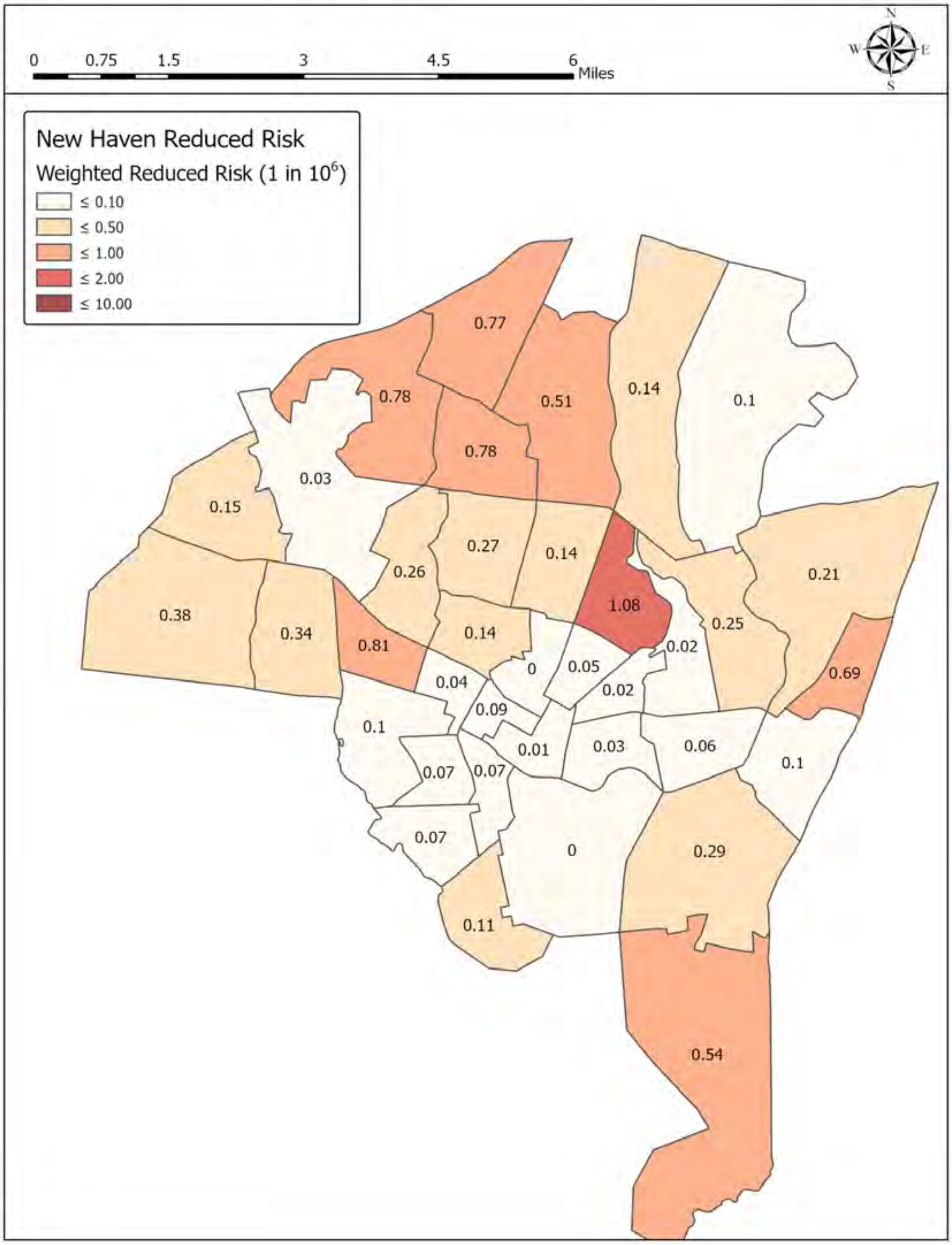
In this case, census tract 1419 has 563 houses burning distillate oil and an area of 1,301,209 square meters, so a density factor of 0.00043 fuel oil houses per meter squared. This factor, combined with census tract 1419’s unit risk factor of 0.01315 (7.4 per million cases/563 houses), can then be multiplied by the number of residences using heating oil in any other nearby census tract to get an estimated risk due to distillate oil combustion in that tract. The figure below shows the calculated risk per million residents due to distillate oil combustion in the vicinity (~5 mile diameter area) of the New Haven area near census tract 1419.

Figure 5-7. Risk due to Home Heating Oil Combustion in New Haven, CT



The figure below shows the reduction in risk due to the conversion to biomass-based diesel fuel for the same 5-mile diameter area surrounding census tract 1419.

Figure 5-8. Reduced Risk Due to Biodiesel Heating Oil Combustion in New Haven, CT



The reduction in "cancer burden", which is just each respective census tract risk multiplied by the census tract population divided by 1 million, can be determined from this same data. The maximum baseline cancer burden is <0.1 for all census tracts, indicating that all census tracts could expect <1 person to develop cancer over a 70-year lifetime due to exposure to distillate oil combustion. The total cancer burden for all of the census tracts in the selected 5-mile radius is also <1, with an expected marginal reduction in cancer burden with the use of biomass-based diesel fuel for home heating oil combustion.

5.4.5 Valuation of Health Benefits

The health benefits of reduced $PM_{2.5}$ exposure were modeled using USEPA's Ben-MAP according to the methodology described under Section 4.7. The results are shown in Table 5-12 below.

Table 5-12. Valuation of Reduced Incidence Benefits, New Haven, CT

Endpoint	Reduced Incidence	Benefit Value
Premature Mortality	2.3	$20,413,656
Asthma Exacerbation	1,073	$63,195
Minor Restricted Activity Days	1,380	$96,001
Work Loss Days	232	$46,899
Total		**$20,619,751**

5.5 Location No. 5: Providence, Rhode Island

5.5.1 NATA Modeling

According to the 2014 NATA report, the total cancer risk determined for census tract ID 44007002101, representing Providence, was 0.5 cases per million residents. The six major drivers of this risk were Arsenic, Beryllium, Cadmium, Hexavalent Chromium, Formaldehyde, and Nickel. Additionally, a full change from traditional residential fuel oil to biomass-based diesel represents a 17% reduction in volatile organic compound emissions and an 86% reduction in particulate metal emissions. In total, a full switch from residential fuel oil to biomass diesel represents a baseline risk change from 0.5 cases per million residents to 0.1 cases per million residents, a 0.4 case per million resident reduction. below shows the detailed NATA cancer risk values and associated reductions.

Table 5-13. Risk Reduction for Census Tract 21.01

Pollutant Name	NATA Cancer Risk (1 in 10^6)	% Reduction	Reduced Risk (1 in 10^6)
1,3-Butadiene	5.1E-04	17%	4.3E-04
Acetaldehyde	1.2E-03	17%	1.0E-03
Arsenic Compounds(Inorganic Including Arsine)	1.9E-01	86%	2.6E-02
Benzene	2.4E-03	17%	2.0E-03
Beryllium Compounds	8.2E-02	86%	1.1E-02
Chromium VI (Hexavalent)	4.5E-02	86%	6.3E-03
Cadmium Compounds	6.1E-02	86%	8.5E-03
Ethylbenzene	8.1E-06	17%	6.7E-06
Formaldehyde	4.9E-02	17%	4.1E-02
Nickel Compounds	1.8E-02	86%	2.6E-03
Naphthalene	5.0E-03	17%	4.1E-03
PAHs	9.5E-05	17%	7.9E-05
Total	**0.5**	**77%**	**0.1**

5.5.2 Census-Specific Modeling

Utilizing the emission rates outlined in Section 4.3.1, a modeling analysis specific to census tract 21.01 was completed. The three major drivers of this risk analysis were Arsenic, Cadmium, and Hexavalent Chromium. In this scenario, the baseline risk levels were substantially higher at 11.3 cases per million residents. This difference is accounted for both by a larger representation of metal emissions from a more refined emissions inventory, and higher pollutant toxicity values derived by OEHHA as used in the HARP analysis. With the associated volatile and metal risk reduction from a full switch to biomass-based diesel, the baseline risk is reduced to an average total risk of 1.6 cases per million residents, representing a reduction of 9.7 cases per million residents. The table below shows the detailed modeled cancer risk values and associated reductions.

Table 5-14. Census-Specific Modeling for Census Tract 21.01

Name	AERMOD Conc. (µg/m3)	HARP Risk	Reduction	Reduced Risk
Acetaldehyde	4.47E-04	4.0E-03	17%	3.3E-03
Arsenic	5.11E-05	6.9	86%	9.6E-01
B[a]anthracene	3.65E-07	2.3E-03	86%	3.3E-04
Benzene	1.95E-05	1.7E-03	17%	1.4E-03
Beryllium	3.83E-05	0.3	86%	4.0E-02
Cadmium	3.83E-05	0.5	86%	7.2E-02
Cr(VI)	6.89E-06	3.4	86%	0.5
Chrysene	2.17E-07	1.4E-04	86%	1.9E-05
D[a,h]anthracen	1.52E-07	3.5E-03	86%	5.0E-04
Formaldehyde	3.00E-03	5.7E-02	17%	4.7E-02

In[1,2,3-cd]pyr	1.95E-07	1.2E-03	86%	1.7E-04
Lead	1.15E-04	8.4E-02	86%	1.2E-02
Naphthalene	1.03E-04	1.1E-02	86%	1.5E-03
Nickel	3.83E-05	3.1E-02	86%	4.4E-03
Total	**N/A**	**11.3**	**85.6%**	**1.6**

5.5.3 Providence, RI Health Risk Summary

Given the conservative nature of the OEHHA health risk values utilized in the HARP software, and the coarse, county-wide review of the NATA report, it is expected that the actual cancer risk of associated with residential heating oil usage in census tract 21.01 lies somewhere between 0.5 and 11.3 excess cancer cases per million residents over a 70-year timeline. Utilizing 17% and 86% reductions for volatile and metal toxics emissions, respectively, assuming a full transition from residential distillate heating oil to biomass-based diesel, that baseline risk is reduced to a value between 0.1 and 1.6 excess cancer cases per million residents.

5.5.4 Extrapolation of Risk Results to Other Similar Housing Areas

Risk results from census tract 21.01 can be extrapolated to the larger surrounding areas with similar housing densities utilizing a “density factor”, which is the ratio of households utilizing fuel oils (250 for census tract 21.01) divided by area (465,411 square meters for census tract 21.01). This data can be used to extrapolate the risk results to other areas based on the ratio of the census tract 21.01 “density factor” and associated risk (11.3 in one million) to other census tract “density factors” as follows, where Census Tract is abbreviated as CT:

Equation 13. Census Tract Density Factor

$$Density\ Factor_{CT\ X} = \frac{Homes\ Using\ Heating\ Oil_{CT\ X}}{Area\ (m^2)_{CT\ X}} / \frac{Homes\ Using\ Heating\ Oil_{CT\ 21.01}}{Area\ (m^2)_{CT\ 21.01}}$$

Equation 14. Unit Risk Factor

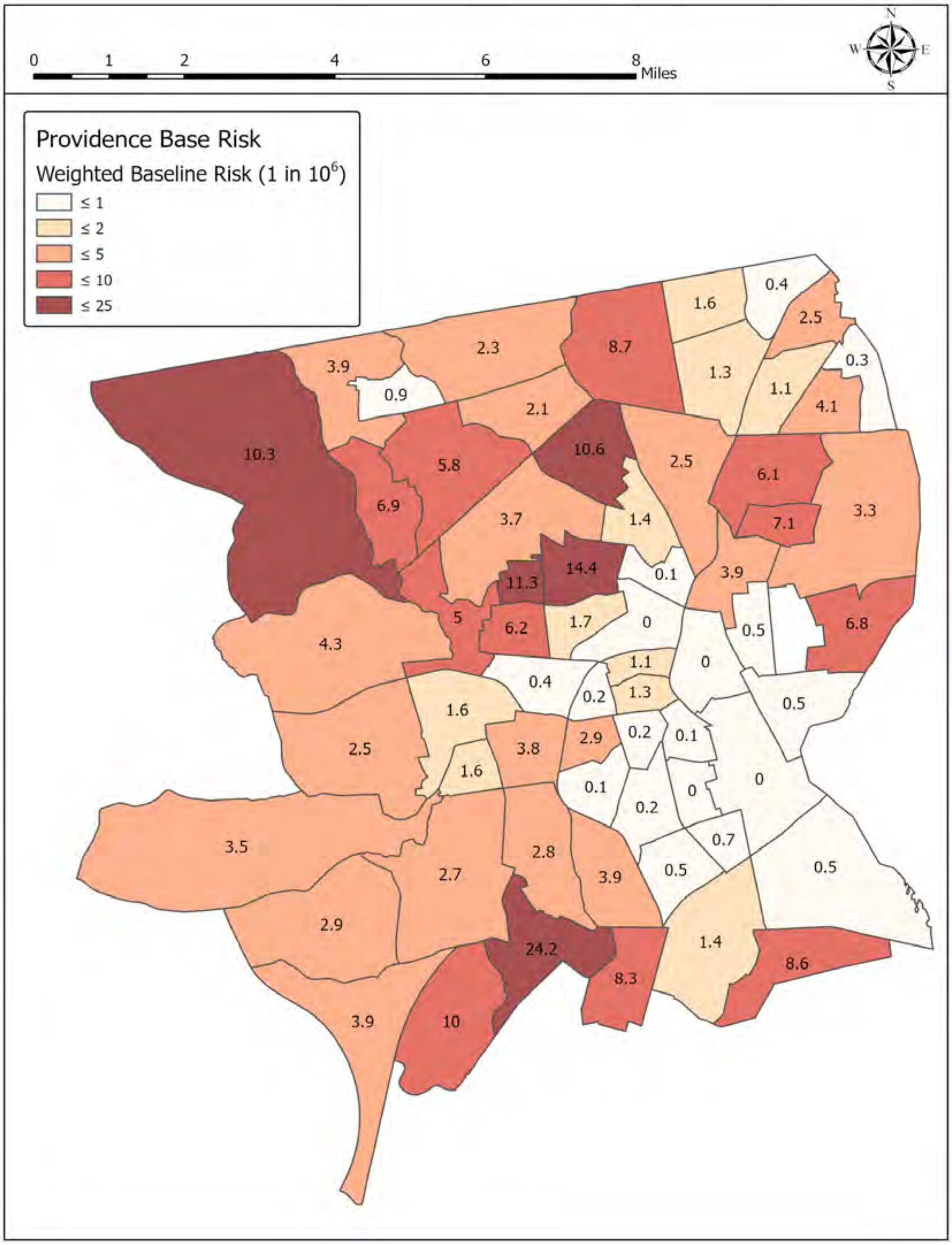
$$Unit\ Risk\ (\frac{Risk}{Homes\ Using\ Heating\ Oil}) = \frac{Risk_{Sotomayor\ CT}}{Homes\ Using\ Heating\ Oil_{CT\ 21.01}}$$

Equation 15. Extrapolated Census Tract Risk

$$Risk_{CT\ X} = Homes\ Using\ Heating\ Oil_{CT\ X} * Unit\ Risk\ Factor * Density\ Factor_{CT\ X}$$

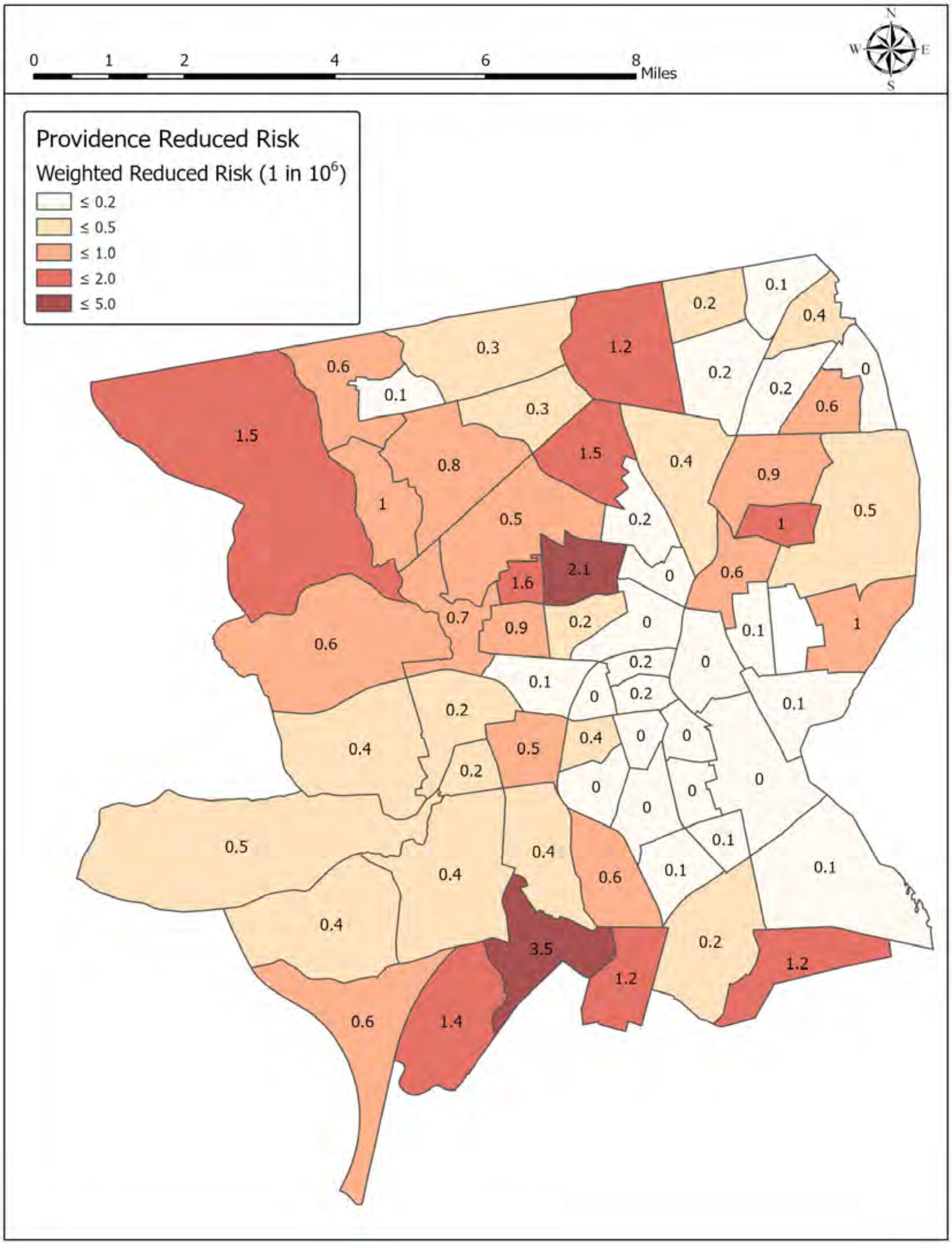
In this case, census tract 21.01 has 250 houses burning distillate oil and an area of 465,511 square meters, so a density factor of 0.00054 fuel oil houses per meter squared. This factor, combined with census tract 21.01’s unit risk factor of 0.04511 (11.3 per million cases/250 houses), can then be multiplied by the number of residences using heating oil in any other nearby census tract to get an estimated risk due to distillate oil combustion in that tract. The figure below shows the calculated risk per million residents due to distillate oil combustion in the vicinity (~5 mile diameter area) of the Providence area near census tract 21.01.

Figure 5-9. Risk due to Home Heating Oil Combustion in Providence, RI



The figure below shows the reduction in risk due to the conversion to biomass-based diesel fuel for the same 5-mile diameter area surrounding census tract 21.01.

Figure 5-10. Reduced Risk due to Biodiesel Heating Oil Combustion in Providence, RI



The reduction in “cancer burden”, which is just each respective census tract risk multiplied by the census tract population divided by 1 million, can be determined from this same data. The maximum baseline cancer burden is 0.2 for census tract 44007014000, compared to the cancer burden of <0.1 for census tract 21.01, indicating that this census tract could expect <1 person to develop cancer over a 70-year lifetime due to exposure to distillate oil combustion within that census tract alone. The total cancer burden for all of the census tracts in the selected 5-mile radius is 1.2, with an expected reduction in cancer burden to a value of approximately <1 with the use of biomass-based diesel fuel for home heating oil combustion.

5.5.5 Valuation of Health Benefits

The health benefits of reduced $PM_{2.5}$ exposure were modeled using USEPA's Ben-MAP according to the methodology described under Section 4.7. The results are shown in Table 5-15 below.

Table 5-15. Valuation of Reduced Incidence Benefits, Providence, RI

Endpoint	Reduced Incidence	Benefit Value
Premature Mortality	2.4	$21,118,265
Asthma Exacerbation	1,190	$70,121
Minor Restricted Activity Days	1,514	$105,367
Work Loss Days	256	$44,501
Total		**$21,338,254**

APPENDIX A. TABLES

Table A-1. Sotomayor Housing Development Vertex Coordinates

Vertex ID	X (m)	Y (m)
1	595308.8	4,519,948.0
2	595,877.4	4,520,044.7
3	595,829.0	4,520,280.6
4	595,148.3	4,520,154.4
5	595,308.8	4,519,948.0

Table A-2. Census Tract 17 Vertex Coordinates

Vertex ID	X (m)	Y (m)
1	597,760	4,723,759
2	597,678	4,723,647
3	597,766	4,723,601
4	598,003	4,723,472
5	598,009	4,723,469
6	598,017	4,723,465
7	598,013	4,723,461
8	598,008	4,723,458
9	597,925	4,723,299
10	597,903	4,723,258
11	597,868	4,723,193
12	597,856	4,723,168
13	597,851	4,723,158
14	597,847	4,723,148
15	597,834	4,723,102
16	597,825	4,723,072
17	597,836	4,723,065
18	597,878	4,723,041
19	597,950	4,722,997
20	598,018	4,722,959
21	598,065	4,722,932
22	598,095	4,722,912
23	598,102	4,722,913
24	598,118	4,722,908
25	598,129	4,722,906
26	598,136	4,722,903
27	598,190	4,722,869
28	598,194	4,722,866
29	598,199	4,722,863
30	598,211	4,722,905
31	598,217	4,722,922
32	598,255	4,722,981
33	598,318	4,723,081
34	598,350	4,723,125
35	598,378	4,723,162
36	598,400	4,723,190
37	598,411	4,723,201
38	598,462	4,723,240

Vertex ID	X (m)	Y (m)
39	598,477	4,723,257
40	598,580	4,723,394
41	598,649	4,723,482
42	598,714	4,723,569
43	598,793	4,723,668
44	598,792	4,723,680
45	598,797	4,723,689
46	598,862	4,723,770
47	598,920	4,723,845
48	598,929	4,723,856
49	598,944	4,723,876
50	598,996	4,723,945
51	599,030	4,723,989
52	599,052	4,724,020
53	599,106	4,724,092
54	599,153	4,724,152
55	599,248	4,724,279
56	599,263	4,724,298
57	599,278	4,724,319
58	599,293	4,724,340
59	599,311	4,724,362
60	599,148	4,724,429
61	599,049	4,724,471
62	599,020	4,724,482
63	598,993	4,724,495
64	598,956	4,724,511
65	598,945	4,724,516
66	598,926	4,724,523
67	598,902	4,724,533
68	598,868	4,724,546
69	598,859	4,724,550
70	598,817	4,724,567
71	598,732	4,724,602
72	598,717	4,724,608
73	598,701	4,724,616
74	598,682	4,724,623
75	598,588	4,724,662
76	598,532	4,724,684
77	598,479	4,724,706
78	598,473	4,724,698

Vertex ID	X (m)	Y (m)
79	598,436	4,724,645
80	598,364	4,724,551
81	598,324	4,724,498
82	598,307	4,724,475
83	598,274	4,724,433
84	598,178	4,724,307
85	598,144	4,724,263
86	598,143	4,724,259
87	598,145	4,724,255
88	598,158	4,724,245
89	598,188	4,724,220
90	598,222	4,724,190
91	598,229	4,724,185
92	598,161	4,724,097
93	598,171	4,724,089
94	598,179	4,724,082
95	598,184	4,724,076
96	598,187	4,724,071
97	598,188	4,724,066
98	598,183	4,724,064
99	598,176	4,724,061
100	598,170	4,724,056
101	598,123	4,723,994
102	598,111	4,724,003
103	598,102	4,724,006
104	598,052	4,724,018
105	598,001	4,724,033
106	597,971	4,724,044
107	597,962	4,724,030
108	597,960	4,724,028
109	597,954	4,724,019
110	597,932	4,723,988
111	597,921	4,723,975
112	597,885	4,723,927
113	597,831	4,723,856
114	597,791	4,723,804
115	597,760	4,723,759

Table A-3. Census Tract 1105.01 Vertex Coordinates

Vertex ID	X (m)	Y (m)
1	322,921	4,683,764
2	322,927	4,683,658
3	322,938	4,683,561
4	322,946	4,683,530
5	322,946	4,683,527
6	322,957	4,683,498
7	322,971	4,683,469
8	322,975	4,683,461
9	322,976	4,683,458
10	322,996	4,683,423
11	323,027	4,683,376
12	323,052	4,683,344
13	323,083	4,683,308
14	323,095	4,683,294
15	323,119	4,683,268
16	323,143	4,683,240
17	323,157	4,683,224
18	323,196	4,683,177
19	323,220	4,683,146
20	323,223	4,683,141
21	323,232	4,683,131
22	323,238	4,683,123
23	323,251	4,683,104
24	323,258	4,683,093
25	323,304	4,683,020
26	323,328	4,682,981
27	323,348	4,682,955
28	323,394	4,682,888
29	323,425	4,682,833
30	323,443	4,682,791
31	323,460	4,682,742
32	323,473	4,682,672
33	323,478	4,682,626
34	323,479	4,682,610
35	323,478	4,682,563
36	323,478	4,682,548
37	323,507	4,682,575
38	323,510	4,682,580

Vertex ID	X (m)	Y (m)
39	323,532	4,682,606
40	323,565	4,682,645
41	323,606	4,682,689
42	323,648	4,682,735
43	323,676	4,682,765
44	323,688	4,682,780
45	323,726	4,682,821
46	323,775	4,682,874
47	323,788	4,682,890
48	323,784	4,682,942
49	323,781	4,683,032
50	323,778	4,683,118
51	323,775	4,683,146
52	323,776	4,683,154
53	323,775	4,683,195
54	323,772	4,683,246
55	323,774	4,683,261
56	323,769	4,683,347
57	323,768	4,683,374
58	323,763	4,683,483
59	323,763	4,683,558
60	323,759	4,683,673
61	323,758	4,683,726
62	323,758	4,683,749
63	323,762	4,683,759
64	323,775	4,683,771
65	323,758	4,683,771
66	323,711	4,683,769
67	323,674	4,683,767
68	323,617	4,683,765
69	323,592	4,683,765
70	323,517	4,683,764
71	323,404	4,683,764
72	323,298	4,683,764
73	323,202	4,683,763
74	323,158	4,683,764
75	323,135	4,683,763
76	323,084	4,683,764
77	323,046	4,683,764
78	323,026	4,683,764

Vertex ID	X (m)	Y (m)
79	322,980	4,683,765
80	322,953	4,683,764
81	322,921	4,683,764

Table A-4. Census Tract 1419 Vertex Coordinates

Vertex ID	X (m)	Y (m)
1	674,213	4,576,424
2	674,179	4,576,329
3	674,256	4,576,298
4	674,361	4,576,255
5	674,396	4,576,239
6	674,503	4,576,192
7	674,538	4,576,177
8	674,577	4,576,154
9	674,692	4,576,084
10	674,731	4,576,061
11	674,747	4,576,051
12	674,796	4,576,021
13	674,813	4,576,011
14	674,831	4,576,000
15	674,886	4,575,968
16	674,904	4,575,958
17	674,970	4,575,917
18	674,981	4,575,925
19	675,012	4,575,953
20	675,022	4,575,962
21	675,078	4,576,011
22	675,101	4,576,020
23	675,113	4,576,022
24	675,145	4,576,026
25	675,228	4,576,022
26	675,239	4,576,021
27	675,254	4,576,019
28	675,281	4,576,039
29	675,310	4,576,064
30	675,314	4,576,068
31	675,332	4,576,081
32	675,336	4,576,085
33	675,352	4,576,097
34	675,368	4,576,110
35	675,376	4,576,116
36	675,384	4,576,122
37	675,381	4,576,154
38	675,382	4,576,156

Vertex ID	X (m)	Y (m)
39	675,396	4,576,152
40	675,433	4,576,227
41	675,444	4,576,274
42	675,461	4,576,342
43	675,488	4,576,458
44	675,498	4,576,527
45	675,479	4,576,608
46	675,415	4,576,665
47	675,310	4,576,740
48	675,287	4,576,742
49	675,248	4,576,811
50	675,157	4,577,041
51	675,127	4,577,058
52	675,096	4,577,060
53	675,023	4,577,064
54	675,017	4,577,064
55	674,984	4,577,088
56	674,930	4,577,123
57	674,916	4,577,131
58	674,881	4,577,160
59	674,873	4,577,200
60	674,899	4,577,236
61	674,939	4,577,263
62	674,962	4,577,312
63	674,960	4,577,396
64	674,962	4,577,417
65	674,969	4,577,547
66	674,970	4,577,568
67	674,970	4,577,569
68	674,967	4,577,596
69	674,956	4,577,628
70	674,951	4,577,644
71	674,950	4,577,648
72	674,921	4,577,666
73	674,908	4,577,677
74	674,781	4,577,776
75	674,677	4,577,847
76	674,671	4,577,828
77	674,665	4,577,812
78	674,652	4,577,770

Vertex ID	X (m)	Y (m)
79	674,646	4,577,750
80	674,643	4,577,741
81	674,634	4,577,714
82	674,630	4,577,704
83	674,628	4,577,697
84	674,620	4,577,674
85	674,618	4,577,666
86	674,611	4,577,645
87	674,592	4,577,581
88	674,585	4,577,560
89	674,577	4,577,534
90	674,552	4,577,453
91	674,543	4,577,426
92	674,533	4,577,397
93	674,503	4,577,308
94	674,493	4,577,278
95	674,479	4,577,234
96	674,437	4,577,103
97	674,423	4,577,060
98	674,412	4,577,026
99	674,379	4,576,927
100	674,368	4,576,894
101	674,363	4,576,876
102	674,345	4,576,821
103	674,339	4,576,802
104	674,333	4,576,784
105	674,315	4,576,730
106	674,309	4,576,712
107	674,251	4,576,537
108	674,217	4,576,434
109	674,216	4,576,428
110	674,215	4,576,426
111	674,213	4,576,424

Table A-5. Census Tract 21.01 Vertex Coordinates

Vertex ID	X (m)	Y (m)
1	296,272	4,634,459
2	296,267	4,634,458
3	296,275	4,634,398
4	296,281	4,634,363
5	296,284	4,634,339
6	296,292	4,634,296
7	296,295	4,634,277
8	296,300	4,634,242
9	296,303	4,634,223
10	296,305	4,634,210
11	296,314	4,634,152
12	296,320	4,634,118
13	296,327	4,634,077
14	296,364	4,634,081
15	296,388	4,634,083
16	296,425	4,634,087
17	296,448	4,634,089
18	296,472	4,634,091
19	296,508	4,634,095
20	296,580	4,634,102
21	296,613	4,634,105
22	296,644	4,634,109
23	296,658	4,634,111
24	296,670	4,634,113
25	296,709	4,634,117
26	296,716	4,634,118
27	296,732	4,634,120
28	296,778	4,634,111
29	296,839	4,634,099
30	296,902	4,634,084
31	296,925	4,634,079
32	296,965	4,634,072
33	297,012	4,634,062
34	297,028	4,634,188
35	297,029	4,634,227
36	297,028	4,634,262
37	297,026	4,634,329
38	297,018	4,634,514

Vertex ID	X (m)	Y (m)
39	297,016	4,634,545
40	297,016	4,634,557
41	297,013	4,634,602
42	297,005	4,634,787
43	297,001	4,634,851
44	296,923	4,634,852
45	296,865	4,634,854
46	296,847	4,634,853
47	296,836	4,634,847
48	296,834	4,634,827
49	296,833	4,634,800
50	296,922	4,634,797
51	296,926	4,634,795
52	296,930	4,634,790
53	296,928	4,634,752
54	296,873	4,634,754
55	296,835	4,634,755
56	296,808	4,634,756
57	296,738	4,634,759
58	296,668	4,634,762
59	296,598	4,634,765
60	296,522	4,634,767
61	296,444	4,634,769
62	296,473	4,634,653
63	296,478	4,634,629
64	296,452	4,634,622
65	296,351	4,634,599
66	296,337	4,634,595
67	296,331	4,634,592
68	296,327	4,634,590
69	296,324	4,634,585
70	296,322	4,634,582
71	296,319	4,634,574
72	296,315	4,634,557
73	296,314	4,634,546
74	296,315	4,634,539
75	296,315	4,634,529
76	296,327	4,634,466
77	296,303	4,634,462
78	296,272	4,634,459