San Francisco Citywide Health Risk Assessment: Technical Support Documentation

September 2020

San Francisco Department of Public Health
San Francisco Planning Department
Ramboll

POPULATION HEALTH DIVISION
SAN FRANCISCO DEPARTMENT OF PUBLIC HEALTH

San Francisco Planning

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Acronyms and Abbreviations

AADT	annual average daily traffic
AERMAP	AERMOD terrain preprocessing program
AERMET	AERMOD meteorological preprocessing program
AERMOD	American Meteorological Society/EPA Regulatory Model Improvement Committee Regulatory Mode
ASF	age sensitivity factor
BAAQMD	Bay Area Air Quality Management District
CALINE	3 third generation of the California Department of Transportation Roadway Model
Caltrans	California Department of Transportation
CARB	California Air Resources Board
CEIDARS	California Emissions Inventory Development and Reporting System
CHNA	Community Health Needs Assessment
CPF	cancer potency factor
CPU	central processing unit
DBR	daily breathing rate
DPM	diesel particulate matter
EMFAC	California State emissions factor model for on-road mobile sources
GDF	gas dispensing facility
g/s	g/s grams/second
HRA	health risk assessment
ISC	Industrial Source Complex
m	meters
m/s	meters per second
mph	miles per hour
NAD83	North American Datum of 1983
NEI	National Emissions Inventory
OGV	ocean going vessel
PAH	polycyclic aromatic hydrocarbons
PM	particulate matter
$PM_{2.5}$	fine particulate matter with aerodynamic diameter equal to or less than 2.5 microns
PSD	prevention of significant deterioration
Rcaline	version of CALINE run under the statistical programming language R
SCRAM	US EPA Support Center for Regulatory Air Models
SF Bar Pilots	San Francisco Bar Pilots
SF-CHAMP	San Francisco County Chained Activity Modeling Process
SFDPH	San Francisco Department of Public Health
SFPLAN	San Francisco Planning Department
SRTM	Shuttle Radar Topography Mission
TAC	toxic air contaminant
TIGER	Topographically Integrated Geographic Encoding and Referencing
TOG	total organic gases
USEPA	United States Environmental Protection Agency
UTM	Universal Transverse Mercator
VI	vulnerability index
VMT	vehicle miles traveled
WGS84	World Geodetic System of 1984

1. Introduction

This document describes technical work performed to support San Francisco's citywide health risk assessment modeling (Citywide HRA). The objective of the technical work was to identify and map regions of the city where current residents are exposed to higher levels of air pollution and where future residents, in new developments projects, may also be exposed. To identify areas with elevated air pollutant concentrations and higher population exposures, *air pollution dispersion modeling* played a central role. Dispersion modeling applies a time-averaged, simplified representation of turbulent, atmospheric transport to approximate how pollutants are carried, mixed, and diluted by the local winds. Critical inputs to the dispersion models are estimates of emissions from major air pollution sources and source characteristics. The technical support documentation therefore highlights how emissions of major source categories were inventoried, as well as which dispersion models were used and how they were applied.

Air pollutants considered in the dispersion modeling analysis were emissions of *primary* particulate matter (PM) from many major source categories and emissions of *primary* toxic air contaminants (TAC) with documented cancer toxicities. The qualifier "primary" signifies that only compounds emitted directly were considered. Furthermore, these compounds were assumed to be nonreactive. Compounds formed in the atmosphere from emissions of other pollutants, so-called *secondary* pollutants, were not included in this analysis. Secondary air pollutants were not considered in part because their formation involves complex chemical reactions that are not accounted for in the dispersion models applied in this analysis and in part because near-source exposures tend to be driven by emissions of primary pollutants; whereas, secondary pollutants form downwind of sources and tend to be more regionally distributed. The emissions estimates and modeling analyses were developed for a development year of 2020, which serves as an update to the prior development year of 2014.[1]

The development of the technical foundation that supports the Citywide HRA, was a collaborative effort. Roadway activity developed from San Francisco Chained Activity Modeling Process (SF-CHAMP) for on-road cars and trucks provided an initial blueprint, which built on analyses supporting San Francisco's Article 38, a City ordinance that recognizes the health benefits of requiring particulate matter filtration for new developments near busy roadways. The Bay Area Air Quality Management District (BAAQMD) built upon this initial effort by including additional stationary and mobile sources of air pollution and by substantially increasing the number of receptor points included for evaluation in the modeling analysis. Ramboll US Corporation (Ramboll) contributed to both emissions and modeling efforts associated with mobile and maritime sources. The San Francisco Planning and Health departments provided careful review of modeling inputs and results and helpful suggestions for improvements.

The subsections below, which comprise the technical support documentation, describe the development of the emissions inventory (Section 2), discuss other air dispersion modeling inputs and system configuration (Section 3), outline methods used to generate concentrations and cancer risk estimates from modeling output (Section 4), present modeling results and findings (Section 5), and discuss sources of uncertainty in the methods applied (Section 6).

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[1] The technical document supporting the prior Community Risk Reduction Plan modeling for development year 2014 is documented in the San Francisco Community Risk Reduction Plan: Technical Support Document, prepared by Bay Area Air Quality Management District (BAAQMD), San Francisco Department of Public Health (SF DPH), & San Francisco Planning Department (SF Planning). 2012.

2. Emissions Inventory

This section presents a summary of the emissions inventory developed for the Citywide HRA. Each subsection presents the methodology for generating estimates of annual emissions for the source categories modeled, including:

- On-road mobile sources—cars and trucks—on freeways and surface streets with traffic volumes of more than 1,000 vehicles per day (Section 2.1),
- Permitted stationary sources, including gasoline dispensing stations, prime and standby diesel generators, wastewater treatment plants, recycling facilities, dry cleaners, large boilers, and other industrial facilities (Section 2.2),
- Caltrain passenger diesel locomotives (Section 2.3),
- Ships and harbor craft, including ocean going vessels, cruise ships, excursion boats, and tug boats (Section 2.4), and
- Ferry boats (Section 2.5).

Source categories of emissions not included in the Citywide HRA analysis are

- Residential wood burning from fireplaces and wood stoves,
- Commercial and residential cooking,
- Indirect sources that generate vehicle trips such as distribution centers, retail centers, and postal service stations; and
- Construction emissions.[2]

These categories are potentially important sources of PM and TACs on a citywide scale, but are either difficult to analyze, such as in the case of wood burning and cooking (widely distributed and poorly known locations), were judged to be less important than similar sources that are included, such as the case of indirect sources (whose contribution is small compared to freeway and street traffic), or are temporary or intermittent emissions sources that are widely distributed, as is the case for construction emissions.

Annual emissions estimates were developed for the following years, representing the most recent data available:

- On-road mobile sources: Year 2020 (SFCHAMP 2015model run)
- Permitted, stationary sources: Year 2014
- Caltrain passenger diesel locomotives: Year 2014
- Ships and harbor craft: Year 2017
- Ferry boats: Year 2017

Emissions estimates were generated for the following directly emitted pollutants that have been identified in previous studies (Cohen and Pope 1995, Krewski et al. 2009, HEI 2010) as having significant health impacts:

- Fine particulate matter ($PM_{2.5}$, particles with diameter less than 2.5 micrometers),
- Diesel particulate matter (DPM),
- Other carcinogenic air contaminants, including exhaust and evaporative emissions from gas-powered vehicles, such as benzene and 1,3-butadiene; benzene and ethylbenzene from gas stations and polycyclic aromatic hydrocarbons (PAHs) from industrial sources.

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[2] Emissions from construction projects are difficult to quantify because construction activity is sporadic and emission factors vary depending on the type of equipment and phase of construction. Challenges arise in forecasting an accurate equipment list, engine year of the equipment, and the hours of equipment operation.

2.1 Roadways

State highways and surface streets in San Francisco are a significant source of fine PM and TAC air pollution. Emissions from cars and trucks in the urban environment occur in close proximity to sensitive receptors and have been shown to have a high ratio of inhaled to emitted pollutants (*intake fraction*; Marshall et al. 2005). The Citywide HRA analysis applied dispersion modeling for freeways and surface streets with traffic volumes of more than 1,000 vehicles per day or more, including all motor vehicle types.

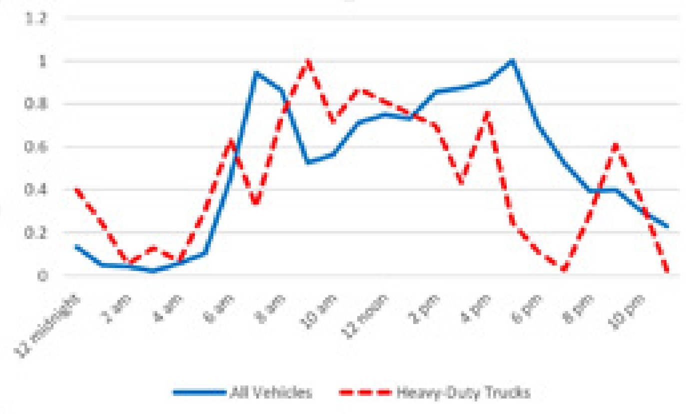
Activity Data:

For estimating emissions from on-road mobile sources, roadway activity data were generated using SF-CHAMP, developed for the San Francisco County Transportation Authority to provide detailed forecasts of travel demand for planning studies and city projects (Outwater and Charlton 2006). SF-CHAMP (version 2015), the official travel forecasting tool for San Francisco, is an activity-based model that predicts future travel patterns for the city. Traffic for year 2020 was used to model vehicle emissions along each link of the 2020 roadway network.

SF-CHAMP includes estimates of vehicle counts based on road types (i.e., residential, thoroughfare, arterial, and freeways) for cars, trucks, and buses. The California Air Resources Board (CARB) has adopted several key regulations designed to reduce diesel exhaust from heavy duty trucks that transports goods within the Bay Area. In order to ensure that the Citywide HRA captures these reductions, SF Planning provided heavy duty and medium duty truck fractions for each neighborhood in San Francisco. BAAQMD then matched each truck fraction by roadway type for each neighborhood to develop vehicle-specific emissions along each roadway. Truck-restricted streets were assumed to have no truck activity.

Average speeds for each roadway link modeled and roadway lengths were also provided by SF-CHAMP. Average speed was used in the selection of emission factors, as described below. The product of roadway length and vehicle counts was used to calculate the total vehicle miles travelled (VMT).

Hourly traffic activity for San Francisco County was set to an hourly (weekday) profile for San Francisco County derived from CARB's Emission FACtors (EMFAC) 2014 model. The diurnal profile sets hourly fractions (relative to peak traffic) representing hourly changes in traffic over the course of a day. Diurnal profiles (Figure 1) were specified for all vehicles and for heavy-duty trucks. While annual average daily traffic (AADT) counts for total vehicles and for heavy-duty trucks were roadway link specific, the diurnal profile was constant across all roadways.



Note: Normalized activity patterns of on-road traffic for all vehicles (blue line) and heavy-duty trucks (red line). Values are normalized to peak-hour traffic.

Figure 1. Diurnal Traffic Profiles

Emission Factors and Emissions:

Activity-based emission factors were applied for $PM_{2.5}$, DPM, and total organic gases from non-diesel, on-road mobile sources. Emission factors were derived using EMFAC2014, CARB 2014 for heavy-duty and medium-duty trucks, cars, and buses at speeds listed for each roadway. Emissions of $PM_{2.5}$ on each roadway link were estimated by summing $PM_{2.5}$ exhaust and brake and tire wear emissions across all vehicle categories, using emission factors for the average roadway speed:

$$E_{PM2.5} = \sum_{i}^{\substack{all\ fuel\\types}} \sum_{k}^{\substack{all\ vehicle\\types}} e_{PM2.5,i,k}\ L\ N_k\ .$$

where $E_{PM2.5}$ = emissions (g/day) of $PM_{2.5}$ on a roadway,
$e_{PM2.5,\ k,\ i}$ = emission factor (g/day per vehicle mile travelled) of $PM_{2.5}$ (including running exhaust, brake wear, and tire wear) for the average link speed for vehicle type k and fuel type i,
L = roadway link length (mi), and
N_k = count for vehicle type k.

DPM was derived similarly by summing PM_{10} exhaust emissions for only the diesel fuel type:

$$E_{DPM} = \sum_{k}^{\substack{all\ vehicle\\types}} e_{PM10,k}\ L\ N_k\ .$$

where E_{DPM} = emissions (g/day) of diesel particulate matter,
$e_{PM10,\ k}$ = emission factor (g/day per vehicle mile travelled) of PM_{10} (running exhaust only) for the average link speed for vehicle type k and diesel fuel only,
L = roadway link length (mi), and
N_k = count for vehicle type k.

Emissions of total organic gases (TOG) from tailpipe and evaporative losses were summed for non-diesel (gasoline) fueled vehicles:

$$E_{non-diesel\ TOG} = \sum_{k}^{\substack{all\ vehicle\\types}} e_{TOG,exhaust}\ L\ N_k + \sum_{k}^{\substack{all\ vehicle\\types}} e_{TOG,loss}\ T\ N_k\ .$$

where $E_{non\text{-}diesel\ TOG}$ = emissions (g/day) of non-diesel TOG,
$e_{TOG,\ exhaust,\ k}$ = emission factor (g/day per vehicle mile travelled) of TOG (running exhaust) for the average link speed for vehicle type k and gasoline fuel only,
$e_{TOG,\ loss,\ k}$ = emission factor (g/day per hr) of TOG (running loss) for the average link speed for vehicle type k and gasoline fuel only,
T = roadway link length (mi) divided by the average speed (mi/hr), and
N_k = count for vehicle type k.

SF-CHAMP modeled traffic volumes split by car, medium-duty trucks, buses, and heavy-duty trucks for each roadway link were used to determine the number of vehicles for each vehicle category for which EMFAC provides emission factors, N_k in the equations above. Using EMFAC2014 classifications, the following vehicle categories were grouped to represent the vehicle classes that were modeled in the Citywide HRA:

- Cars include light duty auto (LDA), light duty autos less than 3750 lbs (LDA1), light duty autos weighing between 3751 lbs and 5750 lbs (LDA2), motorcycles (MCY), and motor homes (MH);
- Medium duty trucks include medium duty vehicles weighing between 5751 lbs and 8500 lbs (MDV), light heavy duty trucks weighing between 8501 lbs and 10,000 lbs (LHDT1), and light heavy duty trucks weighing between 10,001 lbs and 14,000 lbs (LHDT2);
- Heavy duty trucks include medium heavy duty trucks weighing between 14,001 lbs and 33,000 lbs (MHDT) and heavy duty trucks weighing between 33,001 lbs and 60,000 lbs (HHDT); and
- Buses included urban buses (UBUS), school buses (SBUS), and other buses such as touring buses (OBUS).

Emission factors (per VMT) from running exhaust, evaporative losses, and brake and tire wear were derived from EMFAC2014 for years 2020 through 2040 for all EMFAC2007 vehicle categories. Emission factors for years beyond 2040 were assumed to remain constant.

The final significant source of roadway-related fine particulate matter considered in the Citywide HRA is resuspended dust of entrained surface materials by vehicles traveling on roads. Entrained paved road dust or fugitive dust contributes to airborne particulate matter emissions throughout the Bay Area. Although it is not feasible to directly measure the quantity of dust on every roadway, CARB recommends estimating emissions from this source following an approach consistent with USEPA AP-42 document[3]. Following this methodology, airborne PM as defined as the total PM loading in a region annually is estimated based on vehicle weight, silt loading based on the road type, and number of precipitation days. To determine a roadway link specific dust factor, the BAAQMD ratioed the total emissions from all PM roadway sources (i.e., resuspended dust, running exhaust, and tire and brake wear) by the non-dust sources (i.e., running exhaust and brake and tire wear). A resulting ratio of 1.91 characterizing the additional PM due to resuspended dust was then multiplied against the summed $PM_{2.5}$ emissions from exhaust, brake wear, and tire wear. This factor was uniformly applied to all roadways modeled.

2.2 Permitted Stationary Sources

Stationary sources of air pollution—including complex sources such as wastewater treatment plants and power plants as well as smaller facilities such as diesel generators, gasoline dispensing facilities (GDFs or gas stations), and boilers—are regulated and subject to permit conditions established by the BAAQMD. The BAAQMD maintains a database of its permitted sources and their associated emissions. These emissions are determined either through direct measurements via source test or by engineering calculations based on process throughput and industry emission factors. Using either method, the emissions are updated annually or bi-annually depending on the facility's permit cycle. Emissions from all permitted facilities are reported annually to CARB under the California Emissions Inventory Development and Reporting System (CEIDARS, CARB 2013[4]) and, subsequently, reported to US Environmental Protection Agency (EPA) to supplement the National Emissions Inventory database (NEI, EPA 2014).[5]

The 2014 CEIDARS report was used as the starting point to identify permitted facilities and assemble the stationary source emission inventory for San Francisco. The inventory focused on fine particulate matter less than 2.5 microns in diameter ($PM_{2.5}$) and TACs including diesel particulate matter (DPM). Historically, GDF emissions are reported as part of county-level area totals in CEIDARS. The San Francisco inventory was expanded to include GDFs as individual point sources. The 2014 inventory included 123 geolocated GDFs with emissions based on actual or permitted throughputs. Certain permitted sources were excluded from the inventory such as portable engines and other portable equipment and registered restaurants since their operations are intermittent and emissions are not well characterized.

Another key enhancement that improves the accuracy of the modeling was updating and correcting the release parameters such as the stack height, stack diameter, flow rates, release temperatures, etc. for each source. Release parameters are necessary information needed to determine plume rise and pollutant transport in dispersion models. Although BAAQMD provides release parameters information as part of the CEIDARS report, the data are not routinely updated to include information submitted by permitted facilities when a facility health risk assessment is conducted as part of a permit application. Improvements to the accuracy of the release parameters results in higher confidence in the model performance and estimated downwind exposure concentrations to sensitive receptors. Significant effort was directed toward accurately collecting and manually entering the information for each source identified in San Francisco. Much of the data was gathered from permit applications, including information from health risk assessment and prevention of significant deterioration (PSD) analyses performed as part of the permitting process.

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[3] California Air Resources Board (CARB). 2016. Miscellaneous Process Methodology 7.9. Entrained Road Travel, Paved Road Dust. Revised and updated November 2016. Available at: https://ww3.arb.ca.gov/ei/areasrc/fullpdf/full7-9_2016.pdf.

[4] CEIDARS 2.5 Database Structure can be found at https://www.arb.ca.gov/ei/drei/maintain/dbstruct.htm

[5] EPA NEI web page can be found at: https://www.epa.gov/air-emissions-inventories

Figure 2 plots permitted sources in San Francisco by facility type. The majority of permitted stationary sources in San Francisco are located in the eastern side of the city. Dry cleaners and gas stations are the most evenly distributed. Back-up diesel generators are clustered in the downtown areas, reflecting the fact that many multi-story buildings, such as hotels or offices, have emergency generators. Other sources in Figure 2 are associated with industrial activities and tend to be located on the historically industrial parts of the city on the Bay side.

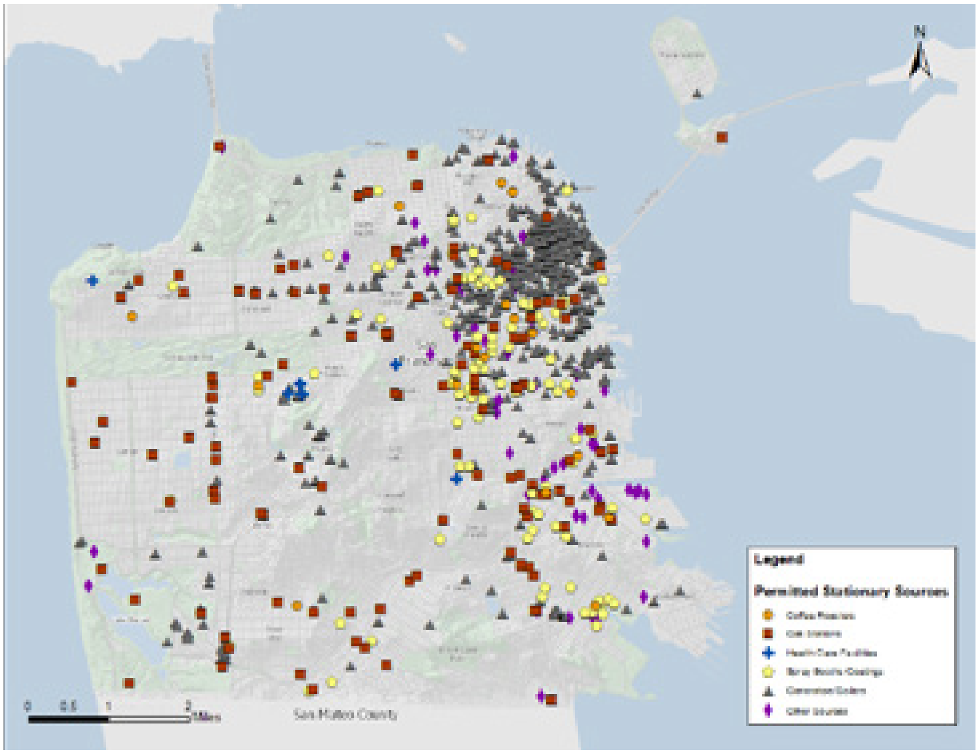

Figure 2. Permitted Stationary Emissions Sources in San Francisco

Table 1 summarizes the stationary source completeness data. The final permitted stationary source database contained 1,492 individual sources at 822 unique facilities. All 1,492 sources have associated emissions of $PM_{2.5}$ or TACs and thus were modeled in the Citywide HRA. More than half (58%) of these release points had known release heights and 34% had complete release information.[6]

Table 1. Summary of Data Completeness for Permitted Stationary Sources in San Francisco

Data Record	Number of Records
Permitted sources	1,492
Release points with emission of $PM_{2.5}$ or toxic air contaminants	1,492
Release points with release height	859
Release points with complete release information	510

2.3 Caltrain

Caltrain is a diesel-powered locomotive passenger rail service, owned and operated by the Peninsula Corridor Joint Powers Board. In San Francisco, Caltrain travels along the eastern portion of the city, with stations at Bayshore (Tunnel Avenue near Blanken Avenue), 22nd Street (at Pennsylvania Avenue), and Downtown San Francisco (4th & Townsend Streets). Trains travel daily between San Clara, San Mateo, and San Francisco counties with 92 weekday, 36 Saturday, and 32 Sunday runs.

Activity:
Caltrain operates three levels of service that vary by train speed and frequency of stops. The Baby Bullet express service travels at the fastest speed and has few station stops; the Limited service operates at a slower speed and has more stops; the Local service is slowest and stops at the most stations.

Locomotives operate under a series of load modes called “notches” that, combined with idling, determine operating mode. For each train service, the throttle notch was assumed based on the load expected at

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[6] Complete release information is defined as a full set of stack parameters (height, diameter, exit temperature, and exit flow rate or velocity)

each station as well as the average speed. The train service along with average speed and throttle notch is summarized in Table 2. Locomotives emissions depend on average speed, distance traveled, and throttle notches. The weighted average speed of a locomotive is estimated from the distance traveled over time. Distances from city boundaries to the stations were obtained from city maps and distances between the stations were obtained from mile posts between each station (Caltrain Table, July 2011). The time required to travel between stops were extrapolated from the Caltrain Table. Based on this information, the average speed of the Baby bullet train through San Francisco was estimated to be 54 miles per hour (mph). For the Limited, average speed was 38 mph; for the Local, average speed was 37 mph.

Table 2. Caltrain Locomotives Average Train Speed and Operating Notch in San Francisco

Train Service	Average Train Speed (mi/hr)	Average Throttle Notch
Baby Bullet	54	5
Limited	38	3
Local	36	3

Emissions calculations were based on average speed along the rail lines, but also on idling activity at the stations. The Caltrain schedule suggests that trains idle for about 90 seconds at each station. When trains stop at Downtown San Francisco terminus, idle time was extended to 20 minutes to account for locomotive power down.

Weighted hourly average emissions were calculated based on the number of trains travelling within each hour of the day, engine mode emission rates, and the average time in each mode profile. Weighted emissions vary for weekday versus weekend activities based on the number of commuter trains running per day. Figure 3 shows normalized hourly activity for Caltrain in San Francisco on weekdays, Saturday, and Sunday. Since activity patterns on Saturday and Sunday were similar, emissions for weekend days were merged for the purposes of modeling.

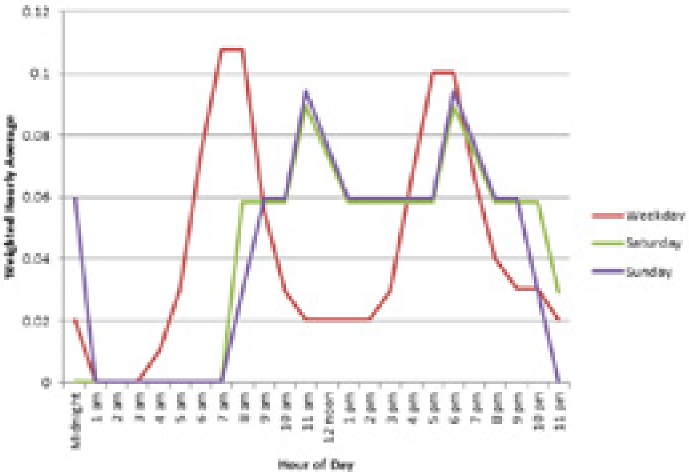

Figure 3. Caltrain Normalized Hourly Activity for Weekdays, Saturday, and Sunday in San Francisco

Emission Factors & Emissions:
Locomotive DPM emissions were estimated from the locomotives using emission factors for PM derived from the Port of Oakland 2005 Maritime Air Emissions Inventory (ENVIRON 2007), adjusted for fuel sulfur content of 15 ppm by weight in compliance with CARB's Marine and Locomotive Diesel Fuel regulation (adopted November 2004). Locomotives used by Caltrain were assumed to have a fleet mix similar to GP4x and Dash 9 with respective certification levels of pre-controlled and Tier 1. Table 3 presents the locomotive model group, certification tier, and emission factors for San Francisco.

Table 3. PM Emission Factors for Caltrain Locomotive

Locomotive Model Group	Certification Tier	Emissions Factors (g/hr) by Throttle Notch		
		Idle	3	5
CP-4x[1]	Pre-control	47.9	210.9	286.2
Dash 9[2]	1	16.9	256.2	377.2

Sources:
1 USEPA, 1997.
2 Fritz, 1995.

Note: Caltrain locomotive emissions factors are adjusted for reduced fuel sulfur content (15 ppmw)

The emission rate by engine mode, multiplied by the hours operated, gives the estimated emissions. Table 4 summarizes the total daily emissions (weekdays and weekends) associated with Caltrain locomotive activities for the City of San Francisco. Running emissions were distributed equally along the rail line; idling emissions were focused near the Downtown San Francisco rail station, where most idling occurs.

Table 4. Estimated Caltrain PM Emissions for San Francisco from all Services.

Service	Weekday PM Emissions (tons/yr)	Saturday PM Emissions (tons/yr)	Sunday PM Emissions (tons/yr)
Baby Bullet, Limited, and Local services combined	1.24	0.50	0.43

The emissions in Table 4 were applied to years 2014 and 2022. Although Caltrain is expected to electrify by 2022 under a financing agreement between the Peninsula Corridor Joints Power Agency, the Metropolitan Transportation Commission and the California High Speed Rail Authority, the southern portion of the Caltrain line from Tamien station to Gilroy station will continue to operate diesel locomotives. Because Caltrain will continue to operate 25% of its existing diesel locomotive fleet to service non-electrified routes, diesel emissions were reduced by 75% after year 2022 to account for the continued operation of a limited diesel locomotive fleet.

2.4 Ocean Going Vessels and Harbor Craft

Maritime emissions used for the San Francisco Citywide HRA were based on the 2017 emissions inventory developed for the Port of San Francisco (Ramboll, 2019). The emission inventory includes emissions from the largest sources of air emissions from maritime operations, including emissions from ocean-going marine vessels (OGVs) and harbor craft. Emissions from tug boats were integrated with each maritime activity. Privately owned terminals and non-maritime activity on Port property were not quantified in the Port inventory report, consistent with prior inventories. Cargo handling equipment, heavy duty on road vehicles, and transportation refrigeration unit activities all still occur, but were not updated in the 2017 inventory as they account for a small fraction of total emissions (less than 3% of the total PM from all Port activities).

The Citywide HRA analysis focused solely on the emissions from two categories of ships: ocean-going vessels and harbor craft (which includes tug boats). While ferry boat activities were excluded from the Port inventory for consistency with prior inventories, they are included in this Citywide HRA, as discussed in Section 2.5.

Activity:

The Port of San Francisco manages about 7.5 miles of coastline, from the Hyde Street Pier in the north, across the Fisherman's Wharf area, the Ferry Building, the base of the Bay Bridge, the baseball stadium, and then south through the waterfront industrial areas up through the Islais Creek area ending at Berth 96. The Port has over 500 tenants, conducting a wide variety of businesses. Most of the Port's tenants, although located near the water, have no waterside activity and therefore are not considered maritime businesses.

In 2017, the Port received four types of ocean-going vessel traffic; cruise ships, vehicle carriers, tankers, and bulk cargo ships. The cruise ships docked primarily at Berth 27, equipped with shorepower connections, and Berth 35, while vehicle carriers and tankers docked primarily at Pier 80, and bulk carriers at Pier 94.

Several Port tenants operate vessels classified as harbor craft. Harbor craft consist of a variety of vessel types including assist tugs, tug and barge movements, excursion, and pilot boats either based at the Port or serving the vessels headed to and from the Port. Consistent with prior Port inventories, harbor craft based at Pier 50 or at private berths as well fishing boats, pleasure craft, and dredging activities were not included in the 2017 inventory. While ferry boats are excluded from the Port inventory, they are included in this Citywide HRA as discussed in Section 2.5.

OGVs produce emissions that depend on operating mode. Common modes include open ocean cruising, cruising at reduced speed inside the Bay (in the reduced speed zone or RSZ), maneuvering (lower speed operation near berths), and hoteling (at berth). For arriving ships, the RSZ mode occurs after the pilot takes command of the vessel at the Sea Buoy[7] until the vessel slows to a maneuvering speed directly in front of the Port. During hoteling, the main engines are off and the auxiliary engines are running (if not connected to shorepower). The sources of emissions include the vessels' main propulsion engines, auxiliary engines during hoteling, and boilers for heating.

Harbor craft emissions include emissions from tug boats, towboats, excursion boats, and pilot boats. Assist tugs are used to assist OGV inbound and outbound from the Port's piers. The assist tugs assigned to these operations come from the fleets based in the Bay Area. The assist tug fleets that served the ships calling to the Port were the tug operators AMNAV, BayDelta, Crowley, Foss, and Starlight. Piers 50 and 92 primarily received tugs (towboats) with barges during 2017. The towboats bring the barge in from the ocean or other points in the Bay. These towboats are similar to but were not the same types as those used to assist larger OGV. In most cases the freight on the barges are bulk sand and gravel from other points within the Bay or were tanker barges. The tug activity included in this inventory was the time for an inbound or outbound trip from the previous dock and to the next dock within the Bay. Excursion boats that have home berths in San Francisco travel to Alcatraz and/or around the Golden Gate Bridge and Fisherman's wharf. Some excursion boats transit to destinations in Marin, Napa, and/or Alameda Counties. Four fleets of Port-based excursion and pilot vessels operate: Hornblower, Blue and Gold, Red and White, and San Francisco Bar Pilots (SF Bar Pilots). Hornblower, Blue and Gold, and Red and White primarily operate excursions (including Bay cruises and Alcatraz route) based at the Port. The SF Bar Pilots are based at the Port but serve all ships that enter the Bay.

Emissions:
For this analysis, emissions from OGV and harbor craft were bounded at the San Francisco County line, consistent with other inventory elements. Total PM emissions within the County line comprised about 60% of the full Port inventory. For purposes of modeling, emissions were split into the following ship category and movement types: OGV (Bulk Carrier, Cruise Ship, Vehicle Carriers, Tanker) anchorage, hoteling, maneuvering, and transiting, and Harbor Craft (Excursion, Pilots, Assist Tugs, Towboats) at-berth and transiting. Figures 4a–4d show the locations of Port maritime operations used in the dispersion modeling.

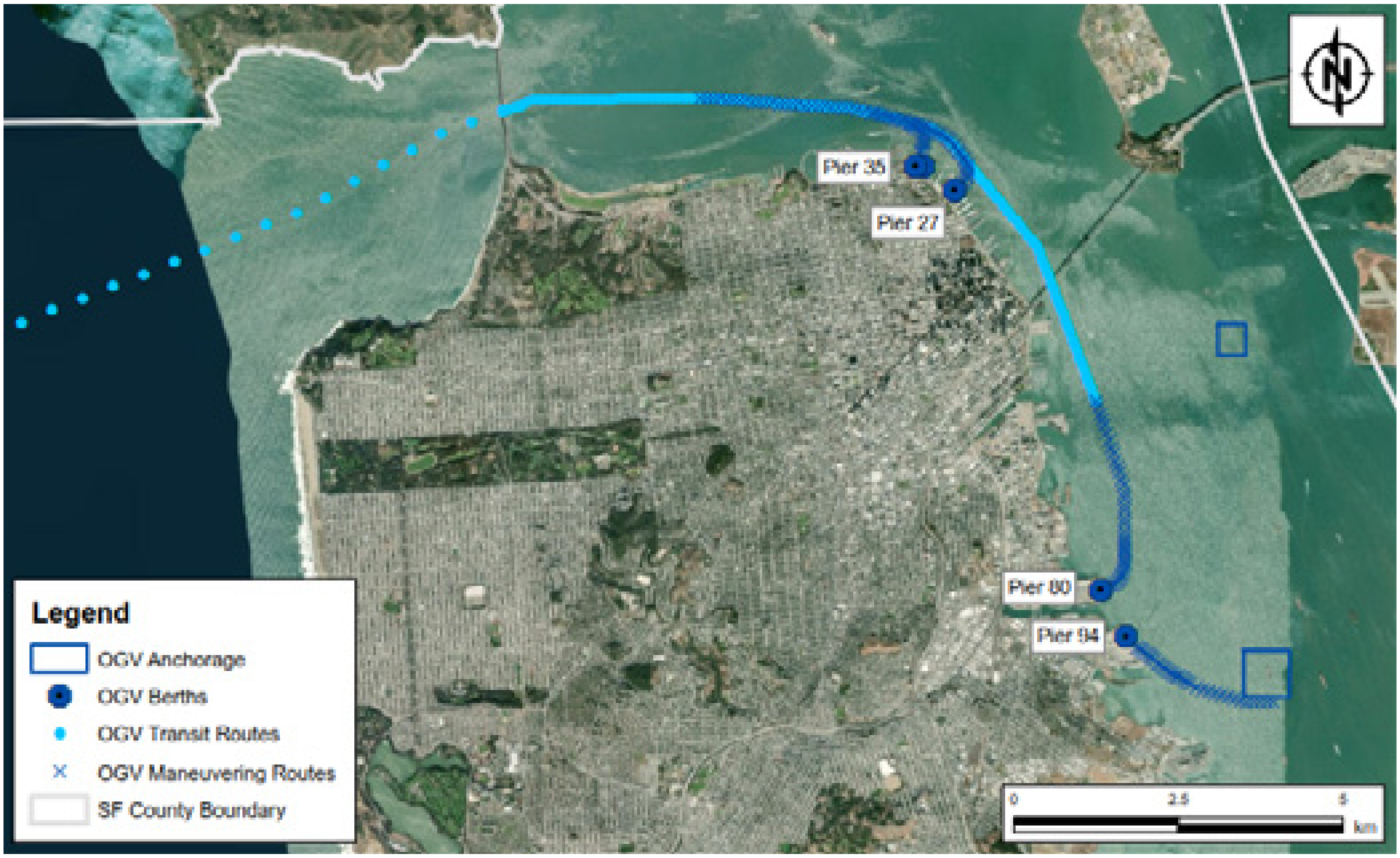

Figure 4a. Ocean Going Vessel Routes, Berths, and Anchorage

Figure 4b. Excursion Vessel Routes and Berths

Figure 4d. Tug and Towboat Routes and Berths

Figure 4c. Pilot Boat Routes and Berths

Table 5 presents a summary of the emission inventory (excluding ferries) for year 2017 that includes OGV and harbor craft emissions by ship and transit type. Estimates indicate that cruise ship, excursions, and pilot boats are the largest source of ship emissions in San Francisco (excluding ferries). It was assumed that all PM emissions, excluding those associated with boiler operation, are attributable to diesel exhaust. The 2017 POSF emissions inventory report (Ramboll 2019) can be referenced for further details of the emissions methodology and activity data assumptions used.

Table 5. OGV and Harbor Craft Emissions for Year 2017

Category	Ship Type	Movement Type	DPM (tons/yr)	$PM_{2.5}$ (tons/yr)
OGV	Bulk Carrier	Anchorage	0.01	0.01
		Hoteling (Pier 94)	0.10	0.09
		Maneuvering	0.01	0.01
		Transiting	0.03	0.03
	Cruise Ship	Hoteling (PIER 27)	0.93	0.96
		Hoteling (PIER 35)	0.16	0.17
		Maneuvering	1.26	1.23
		Transiting	1.28	1.18
	Vehicle Carriers	Anchorage	0.002	0.002
		Hoteling (PIER 80)	0.32	0.30
		Maneuvering	0.02	0.02
		Transiting	0.10	0.09
	Tanker	Hoteling (PIER 80)	0.01	0.02
		Maneuvering	0.0006	0.0007
		Transiting	0.0004	0.0004
Harbor Craft	Excursion	Transiting	1.96	1.80
		At Berth	0.92	0.85
	Pilot	Transiting	1.43	1.31
		At Berth	0.17	0.15
	Assist Tugs	Transiting	0.34	0.31
	Towboats	At Berth (Piers 50, 92)	0.17	0.16

2.5 Ferry Boats

Ferry emissions used for the San Francisco Citywide HRA were based on the 2017 San Francisco Commuter Ferry Emissions report developed by BAAQMD (BAAQMD 2018). The emissions inventory includes emissions from ferry routes to and from the main SF ferry terminals including the SF Ferry Building, Pier 41, and AT&T Park. These three terminals serve over 99% of ferry commuter's arrivals and departures to and from the city.

Activity:
The 2017 San Francisco Commuter Ferry Emissions report incorporates operations while ferries are at port ("at berth") and from engine operation along service routes ("transiting"). Ferry activity data was collected through a combination of field studies for berthing operational time and review of ferry schedules to determine at-berth and transiting times.

Emissions:
Table 6 presents a summary of the emission inventory for year 2017 that includes transiting and at-berth emissions. Similar to other maritime emissions, ferry emissions were bounded at the SF County line. Additionally, a 30% reduction due to renewable diesel and/or diesel control technologies (e.g. diesel particulate filters) was applied to the emissions presented in the 2017 SF Commuter Ferry Emissions report.[8] Emissions were split by ferry route and by ferry terminal for purposes of dispersion modeling. Figure 5 shows the locations of ferry routes and terminals (berths) used in the modeling. The 2017 San Francisco Commuter Ferry Emissions report (BAAQMD 2018) can be referenced for further details of the emissions methodology and activity data assumptions used.

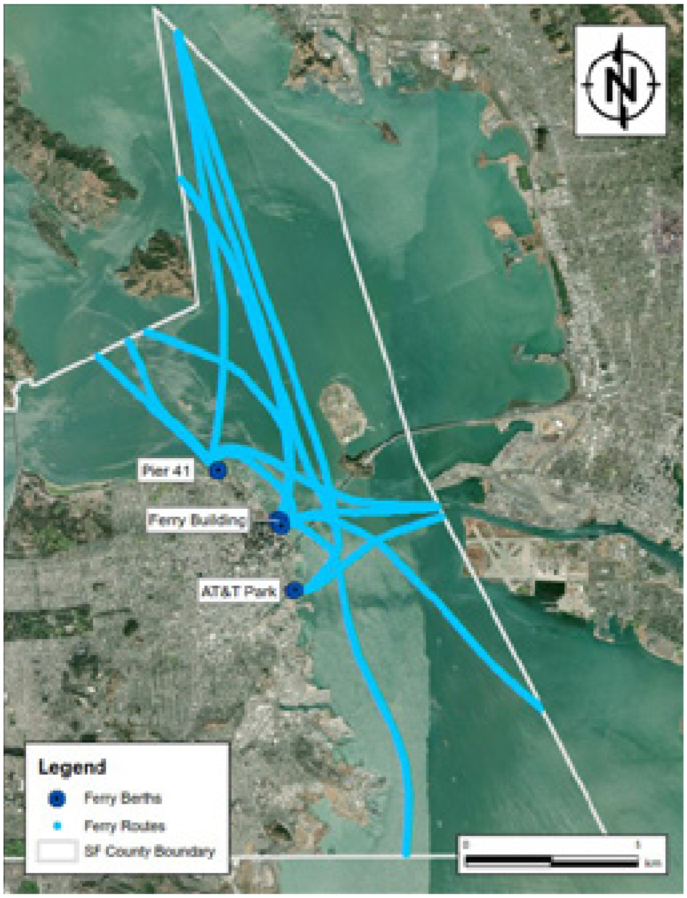

Figure 5. Ferry Routes and Berths

Table 6. Ferry Emissions for Year 2017

Category	Route/Location	Movement Type	DPM (tons/yr)	$PM_{2.5}$[1] (tons/yr)
Ferry Boats	SF Ferry Building to Pier 41	Transiting	0.23	0.23
	SF Ferry Building to South SF	Transiting	0.08	0.08
	SF Ferry Building to Oakland	Transiting	0.40	0.40
	SF Ferry Building to Alameda	Transiting	0.40	0.40
	SF Ferry Building to Harbor Bay	Transiting	0.29	0.29
	SF Ferry Building to Vallejo	Transiting	0.78	0.78
	SF Ferry Building to Sausalito	Transiting	0.55	0.55
	SF Ferry Building to Larkspur	Transiting	1.11	1.11
	Pier 41 to SF Ferry Building	Transiting	0.23	0.23
	Pier 41 to Oakland	Transiting	0.03	0.03
	Pier 41 to Alameda	Transiting	0.05	0.05
	Pier 41 to Vallejo	Transiting	0.11	0.11
	Pier 41 to Tiburon	Transiting	0.56	0.56
	Pier 41 to Sausalito	Transiting	0.33	0.33
	SF AT&T Park to Oakland	Transiting	0.01	0.01
	SF AT&T Park to Vallejo	Transiting	0.02	0.02
	SF AT&T Park to Larkspur	Transiting	0.02	0.02
	SF Ferry Building	At Berth	1.88	1.88
	SF Pier 41	At Berth	0.61	0.61
	SF AT&T Park	At Berth	0.01	0.01

[1] $PM_{2.5}$ conservatively set equal to PM_{10}.

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[8] Office of the Mayor, 2018. "Mayor Mark Farrell, City Agencies Announce the Bay Area Ferry Fleet Will Make Historic Transition to Renewable Diesel." Available: https://sfmayor.org/article/mayor-mark-farrell-city-agencies-annouce-bay-area-ferry-fleet-will-make-historic-transition

3. Air Dispersion Modeling

From each of the air pollution sources inventoried in Section 2, the Citywide HRA aims to quantify the contribution to annual concentrations of $PM_{2.5}$ and cancer risk, assuming a 30 year residential exposure period. Concentrations and risk calculations relied on air dispersion modeling to track the pollutant releases and dispersal. The technical approach adopted tracked thousands of individual sources and identified individual contributions to annual average $PM_{2.5}$ concentrations and lifetime cancer risk (Section 3.1).

A finely spaced receptor grid (20 meters by 20 meters) established locations where source contributions were evaluated over the entire city (Section 3.2). The receptors established around an individual source covered a subset (sub-grid) of the total array of receptors (master grid) but overlapped the master grid so that source contributions could readily be summed over all receptors.

Two dispersion models were applied in developing the Citywide HRA: the American Meteorological Society/EPA Regulatory Model Improvement Committee Regulatory Mode (AERMOD; USEPA 2004) and Rcaline (Holstius 2011), a version of the CALINE3 model (Benson 1979, Benson 1992), developed by Caltrans. AERMOD was used to disperse unit emissions from on-road mobile sources, permitted sources, ships and harbor craft, and ferries. Rcaline was used to disperse unit emissions from Caltrain. Critical inputs for determining the character and extent of pollutant dispersion for both models are meteorological variables, such as winds and mixing parameters (Section 3.3), and source release parameters (Sections 3.4 and 3.5). The method of application and the development of inputs for AERMOD are outlined in Section 3.4. A similar discussion for Rcaline follows in Section 3.5.

3.1 Modeling Approach

Each source inventoried was modeled separately so that individual source contributions could be identified and assessed. To reduce the number of modeling runs required, each source was modeled with a unit emission rate[9] (1 g/s). The model output was a *dispersion factor* with units of concentration per unit emissions ($[\mu g/m^3]/[g/s]$) at each receptor location. Following this approach, annual average pollutant concentrations resulted from multiplying the dispersion factor by an annual average emission rate. For example, emissions were estimated on more than 26,500 roadway segments in San Francisco (Section 2.1). Each roadway segment was then split into adjacent volume sources, totaling over 170,000 individual volume sources. For each roadway segment, a modeling run was made, simulating a period of one year and assuming a unit emission rate. For each roadway segment, the simulation produced an annual average dispersion factor at each receptor point. Annual average concentrations for each roadway segment resulted when dispersion factors were multiplied by the annual average emission rate for the roadway.

In this roadway example, two modeling runs were conducted (and two dispersion factors generated) for each roadway segment: one using an activity profile and release parameters representing cars and medium-duty vehicle traffic and one using an activity profile and release parameters representing heavy-duty truck and bus traffic. Annual average $PM_{2.5}$ and DPM concentrations for total traffic resulted from multiplying segment specific on-road car and medium-duty vehicle emissions by the corresponding dispersion factor and segment specific heavy-duty truck and bus vehicle emissions by the corresponding dispersion factor and summing together.

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[9] The method of using unit emissions is sometimes referred to as the χ/Q ("chi over q") method. The origin of this reference stems from the conventional use of χ to represent average concentration at a receptor location and "q" or "Q" to represent an emission rate.

An advantage for modeling each source individually, instead of as part of a group of sources, was that it facilitated making changes in the emission rate of a single source without having to re-run the dispersion model. A disadvantage of this approach is that it requires tracking and storing many modeling input and output files.

Modeling a large number of sources, either individually or as part of a source group, requires a large amount of computing processor time, especially when there are many receptors. To reduce the elapsed time required to complete the analysis, a large number of computer processors were used in parallel. The computer platform used for dispersion modeling was a 4 node Linux cluster, with a total of 112 processors. Model runs for each source were submitted in batch using the Linux qsub command that automatically submits jobs in queue to processors as they become available. Modeling a single source on a single processor was determined to be a simple but efficient method of speeding throughput.

3.2 Receptor Grid

A master receptor grid was constructed to cover the entire city (Figure 6) with receptors spaced every 20 meters on a regular grid. The geographic coordinate system used throughout the modeling was a Universal Transverse Mercator (UTM) projection for zone 10 with the North American Datum of 1983 (NAD83). Geocoding the permitted facility locations was made within Google Earth™, for which the geographic datum is the World Geodetic System of 1984 (WGS84). NAD83 and WGS84 were assumed to be similar enough to each other that coordinates generated using one datum were interchangeable with the other. Each receptor modeling impacts from permitted stationary sources, ship and harbor crafts, ferries, and Caltrain, a height of 1.8 meters from terrain height (commonly referred to as flagpole receptors) representing the breathing zone of an average adult was used. For roadway modeling, receptors were placed at a height of 0 meters from terrain height, for consistency with year 2040 roadway modeling performed over the city.[10] Ramboll performed a sensitivity analysis and confirmed there was no significant change in results from modeling at a lower breathing height and, in fact, modeling at a lower breathing height results in equivalent or more conservative (i.e., higher) results.

For AERMOD modeling, individual sources, such as volume sources representing a roadway segment or a point source representing a smoke stack, were modeled with receptors defined on a sub-grid aligned to the master grid. The subgrid was defined using receptors in the master grid—identical grid spacing, origin, projection and datum parameters as the master grid—but covering a smaller area.

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[10] ENVIRON International Corporation, 2014, Air Quality Technical Report San Francisco Citywide Traffic Modeling, prepared for ESA Associates, Inc.

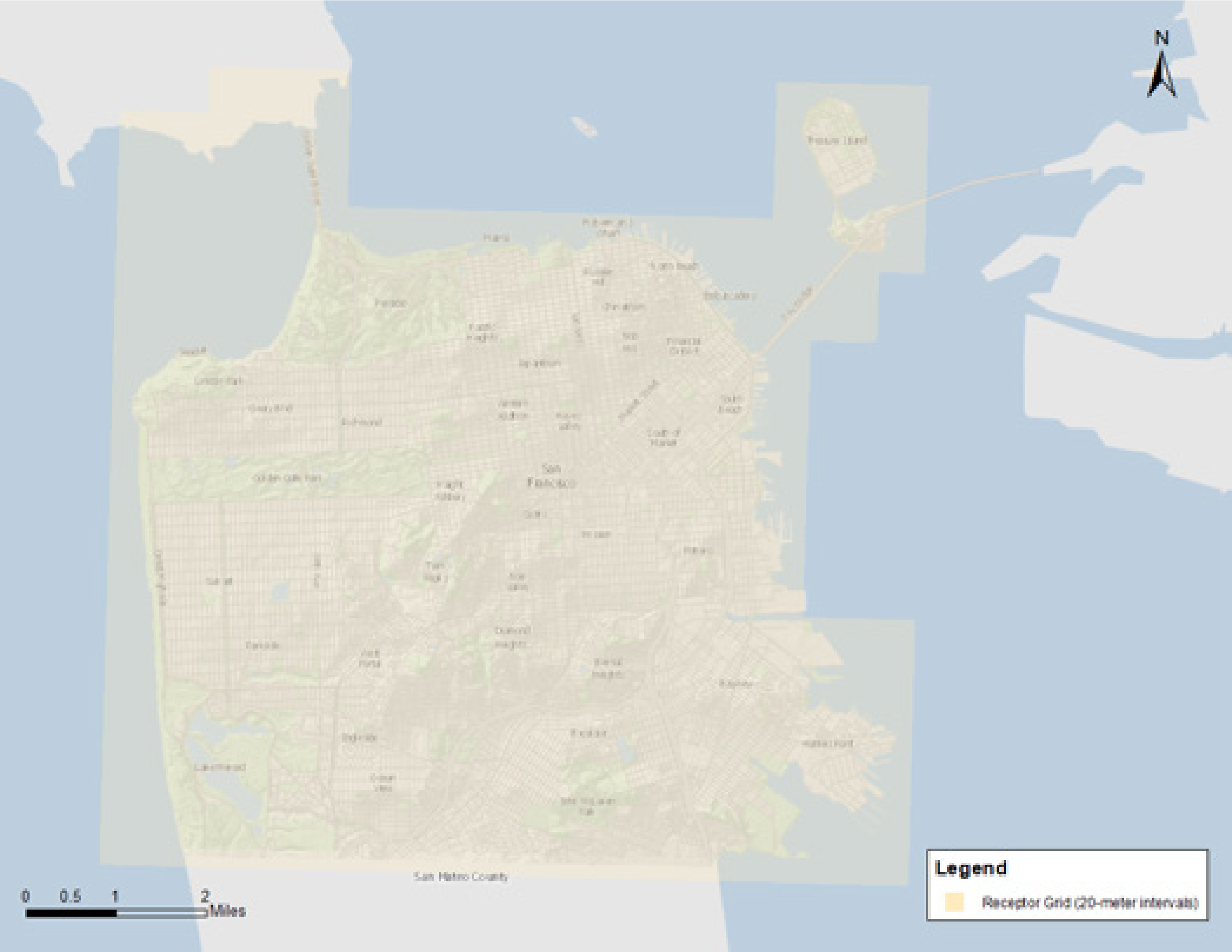


Figure 6. Master Receptor Grid with 20-meter Spacing

Each receptor subgrid was configured to be an array centered over the modeled source (Figure 6) with boundaries set at one to four kilometers from the source, depending on the source type. Individual roadway segments were modeled with a receptor array extending one kilometer in radius from the modeled sources. For air pollution emitted from permitted sources, a rectangular array was defined at least two kilometers from the modeled sources. Modeling of all maritime emissions (including ferry emissions) included a receptor grid with a four kilometer radius from any maritime source. Receptor arrays that extended beyond the master grid were clipped at the master grid boundary.

For Rcaline modeling, receptor grids were defined at regularly increasing distances from the line sources modeled. Receptors were set at regular distances along buffer rings defined at 10, 20, 50, 100, 250, 500, 750, and 1000 meters from each line source. This configuration of receptors resulted in significantly more realistic representation of concentration contours near line-source emissions than did receptors defined on a regular array (Holstius 2011). In a post processing step, concentrations were remapped to the master grid shown in Figure 6 using the R package aikma for bivariate interpolation of irregularly spaced data (Comprehensive R Archive Network 2012).

3.3 Meteorological Data

BAAQMD operates a meteorological monitoring network of stations throughout the nine Bay Area counties that provide accurate measurements of ambient meteorological parameters to support many air quality related programs, including those requiring air dispersion modeling. The current network has 19 stations with no BAAQMD-sponsored station in San Francisco, and collects information on:

- Hourly averaged wind speed and direction (cup and vane);
- Temperature;
- Relative humidity;
- Solar radiation; and
- Rainfall.

The Mission Bay monitoring station is a temporary station operated by the University of California San Francisco campus during construction of its Mission Bay campus. The station was determined to be most widely representative of conditions in San Francisco and to be located near many of the emission sources in the City. Meteorological data has been collected from this site since 2004 and is situated near Channel Street (latitude: 37.7722N, longitude: 122.3947W). Mission Bay data for year 2008 were processed through AERMET, meteorological preprocessor to AERMOD, to create meteorological inputs to AERMOD. A wind rose generated using the 2008 Mission Bay data (Figure 7) shows frequency bins of wind speed (color levels) and wind direction (compass sector winds are blowing from). Winds most frequently blow from the west at about 5 m/s (or about 10 mi/hr). A wind rose covering the 2008-2012 data period was also generated to confirm the 2008 processed meteorological set was still representative of long-term annual conditions, shown in Figure 8. The Mission Bay station closed in 2013.

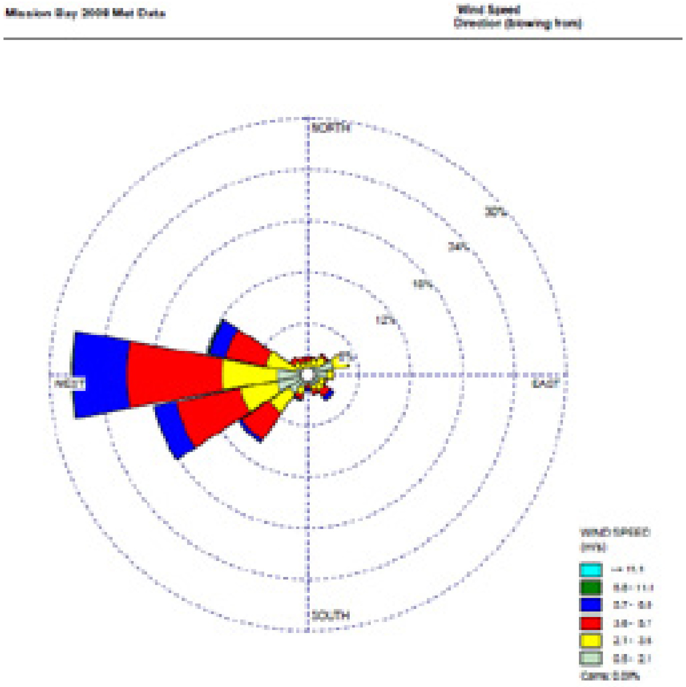
For Caltrain, the Rcaline model uses a compatible format to US EPA's Industrial Source Complex (ISC) model. The BAAQMD no longer processes the hourly meteorological data collected from the monitoring network into ISC format. Fortunately, Mission Bay 2008 data was previously processed in ISC format. To ensure consistency between all sources that were modeled, the BAAQMD used Mission Bay 2008 data (in ISC format) to model emissions from Caltrain.

3.4 AERMOD Model Configuration

AERMOD is a steady-state plume model that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated sources, and both simple and complex terrain. The AERMOD program is comprised of three programs: (1) AERMET – preprocessor for making compatible meteorological data sets, (2) AERMAP – preprocessor for digital terrain data, and (3) AERMOD – air dispersion model. Files generated from AERMET and AERMAP are then read by AERMOD to estimate downwind concentrations.

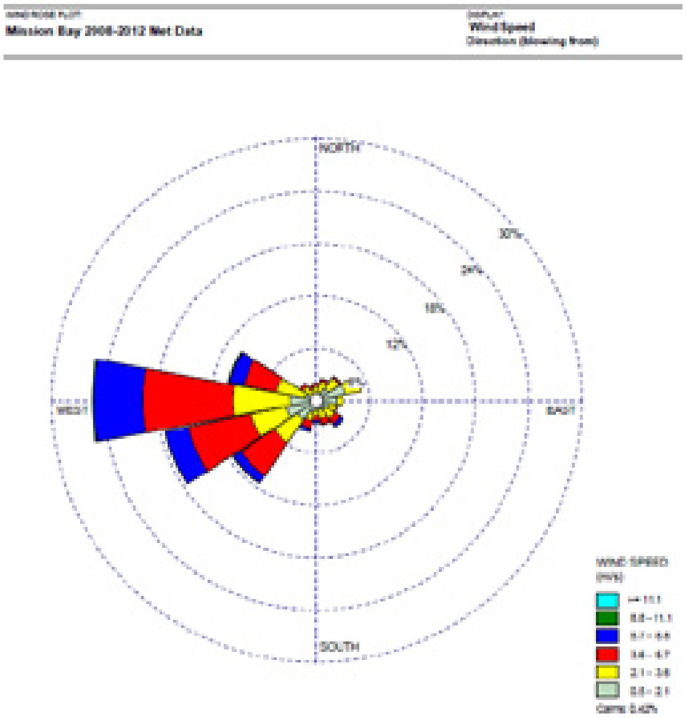
For the roadway, ships, harbor crafts, and ferry modeling, AERMOD FORTRAN source code (version dated 18081—March 22, 2018) was downloaded from the US EPA Support Center for Regulatory Air Models (SCRAM) web site (https://www3.epa.gov/ttn/scram/models/aermod/aermod_source.zip). Source code was compiled on Ramboll's Linux cluster using the Portland Group, Inc., pgfortran (v12.9-0 64 bit) FORTRAN compiler. Running on the cluster allowed simulations to proceed in parallel on multiple processors available on the cluster to reduce elapsed time required for the modeling and analysis.

The permitted stationary source inventory was modeled by the BAAQMD using a consistent version of AERMOD (version dated 111103 – April 13, 2011) to the prior citywide health risk assessment modeling conducted in 2012. Source code was compiled on BAAQMD's Linux cluster using the Portland Group, Inc., pgf95 (v8.0-6 64 bit) FORTRAN compiler.



Note: Histogram colors indicate wind speed; compass sector indicates direction wind is blowing from.Data Period:1/1/2008 (00:00)-12/31/2008(23:00). Total Count: 8780 hours. Calm Winds: 0.09%

Figure 7. Mission Bay 2008 Wind Rose



Note: Histogram colors indicate wind speed; compass sector indicates direction wind is blowing from. Data Period:1/1/2008 (00:00)-12/31/2012(23:00). Total Count: 43835 hours. Calm Winds: 0.42%

Figure 8. Mission Bay 2008-2012 Wind Rose

For each source, a Cartesian receptor grid (see Section 3.2) surrounding the source was used, with a receptor height of 1.8 meters (about 6 ft) above terrain height (or 0 meters for roadway modeling). A rural land use category was consistently selected to be a conservative representation of land cover in San Francisco, as discussed further in Section 6.2. Building downwash effects were not incorporated since individual building heights were not generally available.

Digital terrain data from the Shuttle Radar Topography Mission (SRTM) were used to assigned terrain heights every 20 meters, consistent with the receptor grid spacing that was used in the air dispersion modeling. The SRTM data provides full coverage of the US in 1 by 1 degree blocks with an approximate resolution of 30 by 30 meters. AERMAP software was used to process the digital terrain data into a format compatible with AERMOD.

For on-road mobile sources, permitted sources, ship, ferries, and harbor craft, the release parameters were developed for inputs to AERMOD. AERMOD requires that for each source, the user identify how the source will be modeled (i.e., point, area, and volume), the location of the source, and all associated modeling parameters such as emission rates, sources heights, temperature, etc. Source specific modeling parameters used for the Citywide HRA are described below.

On-Road Mobile Sources:

On-road mobile source emissions were modeled in AERMOD as adjacent volume sources, with the number of sources dependent on the length and width of the roadway segment. To locate the volume sources, San Francisco street segments was subdivided into individual elements, adjusted from the SF-CHAMP model to align with actual roadway locations. The number of elements per roadway segment was determined by dividing the segment length by the street width. Each element represented the location of a volume source. The release height, above roadway height, was set to 2.55 m for heavy-duty trucks and buses and 1.70 m for cars and medium-duty vehicles,[11] the initial lateral dimension was variable, dependent on roadway width; and the initial vertical dimension was 2.37 m for heavy-duty trucks and buses and 1.58 m for cars and medium-duty vehicles[12]. The modeled parameters for elevated roadways are the same as surface streets, but Ramboll incorporated Lidar data to apply elevation above ground level to freeway release heights.[13]

The diurnal activity patterns—one for total traffic and one for heavy-duty trucks—coupled with corresponding release parameters were input to the model. The diurnal activity pattern for all vehicles was assumed representative of car and medium-duty truck activity and the diurnal activity pattern for heavy-duty trucks was assumed representative of heavy-duty trucks and buses. Model simulations were run for both car/medium-duty truck and for heavy-duty truck/bus activity patterns.

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[11] Release height = (1.7 x vehicle height) / 2. Heavy-duty truck and bus vehicle height was set to 3 m; car and medium-duty vehicle height was set to 2 m.

[12] Initial Vertical Dimension = (1.7 x vehicle height) / 2.15. Heavy-duty truck and bus vehicle height was set to 3 m; car and medium-duty vehicle height was set to 2 m.

[13] USGS, Earth Explorer. Available online: http://earthexplorer.usgs.gov/.

Permitted Sources:
Most types of permitted sources were modeled as point releases when stack release parameters or default parameters were available. Gas stations were an exception, where vapor releases were modeled as volume sources, using the number of gasoline dispensers to determine the initial dimensions of the volume source. Stack releases required information on the stack height and diameter and information on the release gas flow rate and temperature. For sources for which a permit application with modeling was completed, the modeling information was obtained from the application. For the remaining sources that were missing all or partial information, the defaults listed in Table 7 were applied.

Ships, Harbor Craft, and Ferries:
Ocean going vessels, harbor craft (including tug boats), and ferries were modeled as adjacent volume sources (for maneuvering and transiting routes), area sources (for anchorage), or point sources (for hoteling and at-berth locations). Near-field maneuvering and transiting routes used volume source spacing of 50 meters, mid-field routes utilized volume source spacing of 100 meters, and far-field routes utilized volume source spacing of 500 meters. Source parameters for each source type are summarized in Table 8.

Table 7. Default Modeling Parameters for Stationary Sources

Source Description	Source Type Assumed	Default Parameters
Prime or Standby Generator	Stack (point)	Stack Height = 3.66 meters (12 feet) Stack Diameter = 0.183 meters (0.6 feet) Stack Temperature = 739.8 Kelvin (872 Fahrenheit) Stack Velocity = 45.3 m/sec (8,923 ft/min)
Gasoline Dispensing Facility (Gas Station)	Volume	Number of Dispensers = 4, if not known Height = 1.03 meters (3.4 feet) Initial lateral dimension = 6.49 feet (for assumed 4 dispensers, otherwise, used the equation (STI, 2010): Lateral dimension (ft) = $-0.0129 \times n^2 + 1.08 \times n + 2.39$ Where n = number of dispensers
Sources that have incomplete modeling information	Stack	In cases, where modeling information was not available, the following default parameters were applied: Stack Height = 6.1 meters (20 feet) Stack Diameter = 3.05 meters (1 feet) Stack Temperature = 644 Kelvin (700 Fahrenheit) Stack Velocity = 17.8 m/sec (3,500 ft/min)
No information available	Volume	For sources that have no information, the District used the following defaults: Release Height = 1.8 meters Initial Lateral Dimension = 10 meters Initial Vertical Dimension = 1 meter

Table 8. Model Source Parameters for OGVs, Harbor Craft, and Ferries.

Vessel Group	Vessel Type	Mode	Source Type	Spacing	Release Height (m)	Point Source Parameters			Volume Source Parameters		Area Source Parameters			Time of Day
						Temp (K)	Rel. Vel. (m/s)	Diam (m)	Sigma-y (m)	Sigma-z (m)	X-init (m)	Y-init (m)	Sigma-z (m)	
OGV	All	Anchorage	Area	--	43						420.69	480.22	10	
				--	43						693.31	834.85	10	
		Hoteling	Point	--	43	618	16.0	0.5						
		Maneuvering (near)	Volume	50	50				23.26	11.63				
		Maneuvering (mid)	Volume	100	50				46.51	11.63				
		Transiting (mid)	Volume	100	50				46.51	11.63				
		Transiting (far)	Volume	500	50				232.56	11.63				
Harbor Craft	Excursion	Routes (near)	Volume	50	10				23.26	2.33				6am-9pm
		Routes (mid)	Volume	100	10				46.51	2.33				6am-9pm
		At-Berth	Point	--	10	550	23.0	0.07						6am-9pm
	Pilots	Routes (near)	Volume	50	15.2				23.26	3.53				
		Routes (mid)	Volume	100	15.2				46.51	3.53				
		Routes (far)	Volume	500	15.2				232.56	3.53				
		At-Berth	Point	--	15.2	573.15	20.00	0.30						
	Assist Tugs	Routes (near)	Volume	50	15.2				23.26	3.53				
		Routes (mid)	Volume	100	15.2				46.51	3.53				
	Towboats	At-Berth	Point	--	15.2	573.15	20.00	0.30						
Ferry	All	Routes	Volume	50	10				23.26	2.33				6am-9pm
		At-Berth	Point	--	10	550	23.0	0.07						6am-9pm

3.5 Rcaline Model Configuration

Caltrain:

Caltrain emissions were modeled using Rcaline (v0.95, Holstius 2011). The Rcaline model was run under the statistical programming language R (v2.12.1) as an interface for the CALINE3 model. The updated Rcaline model removes some of the limitations present in the Caltrans version of CALINE3 by allowing a large number of roadway links and receptor combinations that are only restricted by the computer's available memory and CPU capacity. Rcaline is able to receive and process Esri™ shapefiles as input.

A representation of the Caltrain rail network in San Francisco was available as an Esri™ shapefile from the 2008 Topographically Integrated Geographic Encoding and Referencing (TIGER) Line spatial database. Emissions estimated in Section 2.3 were then assigned to each link.

Effective release widths and railway height (assumed release height) were both set to 5 m. Rings enclosing each rail link were defined at buffer distances of 10, 20, 50, 100, 250, 500, 750, and 1,000 m from the link. Receptors were spaced evenly along the rings at intervals approximately corresponding to the ring buffer distances: 20, 50, 100, 150, 250, 500, 750, and 1000 m. Concentrations calculated at these receptor locations were remapped to the Cartesian master receptor grid (Section 3.2). As was the case for AERMOD simulations, a receptor height of 1.8 m was specified for use in Rcaline.

4. Fine Particle Concentrations and Cancer Risk

This section outlines methods applied to determine pollutant concentrations and cancer risk from emission sources identified, quantified, and provided as inputs to dispersion models. The results of this analysis are used to identify the *air pollutant exposure zone* as required by San Francisco Health Code Article 38. To update the air pollutant exposure zone, health vulnerable locations are identified. Section 4.4 describes the methodology for identifying health vulnerable locations.

4.1 Concentration Estimates

Concentration of a pollutant at each receptor location was calculated for a modeled source by multiplying annual average emissions of the pollutant from the source by the dispersion factor for the source. Dispersion factors are calculated using dispersion modeling with unit emissions from each source, as described in Section 3.1.

$$C_i = E_i \times F ,$$

where C_i = Annual average concentration for pollutant i ($\mu g/m^3$)
E_i = Annual average emission rate for pollutant i (g/s)
F= Dispersion factor, concentration per unit emission rate ($\mu g/m^3$)/(g/s)

Concentration of $PM_{2.5}$ was calculated for all source categories: on-road motor vehicles, permitted stationary sources, Caltrain, ships and harbor craft, and ferries. Concentrations of DPM and other pollutants were also calculated from these sources to estimate their contribution to potential cancer risk.

4.2 Risk Characterization Methods

Excess lifetime cancer risks are estimated as the incremental probability that an individual will develop cancer over a lifetime as a direct result of exposure to potential carcinogens. The estimated risk is a unitless probability, often expressed as the number of people who might get cancer per million people similarly exposed. The cancer risk attributed to a chemical was calculated over an assumed 30-year lifetime exposure by multiplying the chemical intake or dose through the lungs by the chemical-specific cancer potency factor (CPF). A year-specific age sensitivity factor (ASF) increases the risk in early years of exposure to account for increased sensitivities during fetal development and early childhood. Additionally, year-specific daily breathing rates (DBR) are applied to account for the increased level of breathing that occurs during childhood. During adult years of 16-30, a factor of 0.73 is applied to account for the fraction of time a resident spends at home. ASF, DBR, and fraction of time at home adjustments are consistent with exposure assumptions recommended by California Office of Environmental Health Hazard Assessment (OEHHA 2015).

The equations used to calculate the potential excess lifetime cancer risk for the inhalation pathway is as follows:

$$\text{Cancer Risk}_i = \sum C_i \text{ x } CF \text{ x } IFinh \text{ x } CPF_i \text{ (over 30 years) / } AT$$

Where Risk_i = Cancer risk; the incremental probability of an individual developing cancer as a result of inhalation exposure to a particular potential chemical_i
C_i = Annual Average Air Concentration for chemical_i ($\mu g/m^3$)
CF = Conversion Factor (0.001 mg/µg)
IFinh = Intake Factor for Inhalation (m^3/kg-day)
CPF_i = Cancer Potency Factor for chemical_i ([mg chemical/kg body weight-day]$^{-1}$)
AT = Averaging Time (30 years)

$$IFinh \text{ (each year)} = \sum DBR * FAH * EF * ED * CF * ASF \text{ (for each age group)}$$

Where DBR=Daily Breathing Rate (L/kg-day)
FAH = Fraction of time at home (unitless)
EF = Exposure Frequency (days/year)
ED = Exposure Duration (years)
CF = Conversion Factor (0.001 m3/L)
ASF = Age Sensitivity Factor (unitless)

Concentrations vary by year in response to annual average emissions for the year. Risk values were calculated for DPM from all the source categories. Organic gases from on-road gasoline-powered vehicles and other pollutants, such as PAHs and benzene from permitted stationary sources also contributed to the cancer risk estimates. CPF and exposure assumptions used were those recommended by California Office of Environmental Health Hazard Assessment (OEHHA 2015).

4.3 Citywide Mapping

Modeling and the calculations described above produced average annual $PM_{2.5}$ concentrations and cancer risk for each source within each source category on a grid of receptors with 20 m spacing extending one to four kilometers (depending on source type) in each direction from the source. The next processing step created citywide maps for each source category by summing individual source contributions to $PM_{2.5}$ concentration and cancer risk across the subgrids to the master grid (see Section 3.2). The $PM_{2.5}$ concentrations and cancer risk per year results for all source categories were totaled to produce a set of maps with all sources combined. Maps were produced for year 2020 and are provided in Section 5, Results and Findings.

4.4 Health Vulnerable Zip Codes

This Citywide HRA was conducted in part to update the *air pollutant exposure zone* map referenced in San Francisco Health Code article 38. In accordance with section 3806 of the health code, the *air pollutant exposure zone* map is based on the following standards:

- Locations where cumulative $PM_{2.5}$ concentrations meet or exceed 10μg/m^3 or 9μg/m^3 in health vulnerable locations (cumulative $PM_{2.5}$ concentrations is the sum from all modeled sources discussed herein in addition to background concentrations, discussed in Section 5); or
- Locations where excess cancer risk from all modeled sources meet or exceed 100 in one million or 90 in one million in health vulnerable locations; or
- Locations within 500 feet of freeways

The methodology for identifying health vulnerable locations is provided below. The most current available mortality and morbidity data (2012-2016) was obtained from the Community Health Needs Assessment (CHNA). The following categories of data records were used for analysis:

- Mortality (multi-year aggregated age-adjusted rates per 100,000)
  - Lung Trachea-Bronchial Cancer
  - Hypertensive Diseases
  - Ischemic Heart Disease
  - Cerebrovascular Disease
  - Other Heart Diseases
  - COPD
  - Influenza and Pneumonia
  - Asthma
  - Diseases of Arteries, Arterioles, and Capillaries
- Morbidity (multi-year aggregated age-adjusted rates per 10,000)
  - Asthma ER Visits
  - COPD ER Visits
  - Cerebrovascular Disease ER Visits
  - Hypertensive Disease ER Visits
  - Influenza and Pneumonia ER Visits
  - Ischemic Heart Disease ER Visits
  - Other Heart Diseases ER Visits
  - Asthma Hospital Admissions
  - COPD Hospital Admissions

Data records were aggregated by zip code as the spatial identifier. Mortality data records from long-term care facilities and data categories with too few cases to be stratified by zip code were excluded from the analysis. All San Francisco zip codes were ranked according to the case frequency and assigned value based on that ranking for each data category. For example, if zip code 94102 had the highest number of cases for hypertensive disease hospital admissions among 27 zip codes with available data, it would be assigned a value of 27 for that data category; likewise, if 94102 had the lowest number of ischemic heart disease deaths, a value of 1 would be assigned to 94102 for that data category. A vulnerability index (VI) was calculated for each zip code by using the following equation:

$$VI = \frac{\sum_{i=1}^{n} RV_i}{nt}$$

where VI = vulnerability index
n = number of data categories
RV_i *= rank value of* i^{th} *data category*
t = total number of zip codes

For example, if zip code 94102 ranked the highest in relation to other zip codes in terms of numbers of cases for all data categories, the vulnerability index would be calculated to be 1.0. The five San Francisco zip codes with highest vulnerability indexes are considered to be the health vulnerable locations as defined by San Francisco Health Code article 38. Using this methodology, the following zip codes were identified as the health vulnerable locations: 94102, 94103, 94110, 94124, and 94134.

5. Results and Findings

Annual average $PM_{2.5}$ and cancer risk results derived from dispersion modeling are presented in this section in the form of a series of maps. A set of maps is included for each of the major source categories described in previous sections: roadways (Section 5.1); permitted stationary sources (Section 5.2); Caltrain (Section 5.3); and ships, harbor craft, and ferries (Section 5.4). The final section (Section 5.7) presents the combined results for all of these sources together.

When discussing the maps and drawing conclusions from them, it is important to consider what they portray and how they were produced. Specifically, the dispersion modeling, from which the maps are derived, produced concentrations and risk estimates from direct emissions. The maps themselves therefore portray concentrations of directly emitted $PM_{2.5}$ and cancer risk associated with directly emitted TACs at locations near the sources of these emissions. The results do not reflect regional or long-range transport of air pollutants. Nor do they include the effects of the chemical transformation (formation or loss) of pollutants. The modeling results are intended to aid local planning efforts by identifying areas where emission reductions or other efforts may be implemented to help protect current and future residents from major local sources of air pollution. The local contributions to cancer risk are presented in the sections below. For $PM_{2.5}$, the local contribution was added to a background concentration for comparison to the air pollutant exposure zone $PM_{2.5}$ standard. To estimate the background concentration of $PM_{2.5}$, monitored levels from six locations (Figure 9) were compared to the value predicted from dispersion modeling for 2020 at those locations. Monitoring data was collected from a special study conducted in 2008 for five of the six locations. In addition, three years of data from 2014–2016 were collected from the BAAQMD's Arkansas Street monitoring station.[14] The average difference between the monitored and modeled values (7.8 μg/m³; Table 9) was used as the citywide ambient $PM_{2.5}$ concentration. This difference was added to the modeled value at each receptor site to identify areas for inclusion in the Article 38 air pollutant exposure zone map.

Table 9. Measured and Modeled $PM_{2.5}$ Concentrations (μg/m³) and their Differences at San Francisco Monitoring Sites

Monitoring Location	Measured Value μg/m³)	Modeled Value (μg/m³)	Difference (μg/m³)
BAAQMD Arkansas St	7.5	0.88	6.62
SFDPH Arkansas St	8.9	0.88	8.02
Southeast Community Center	9.3	0.84	8.46
Muni Maintenance Yard	8.9	0.44	8.46
Potrero Recreation Center	7.6	0.21	7.39
Malcolm X Academy	7.9	0.06	7.84
		Average Difference	7.8

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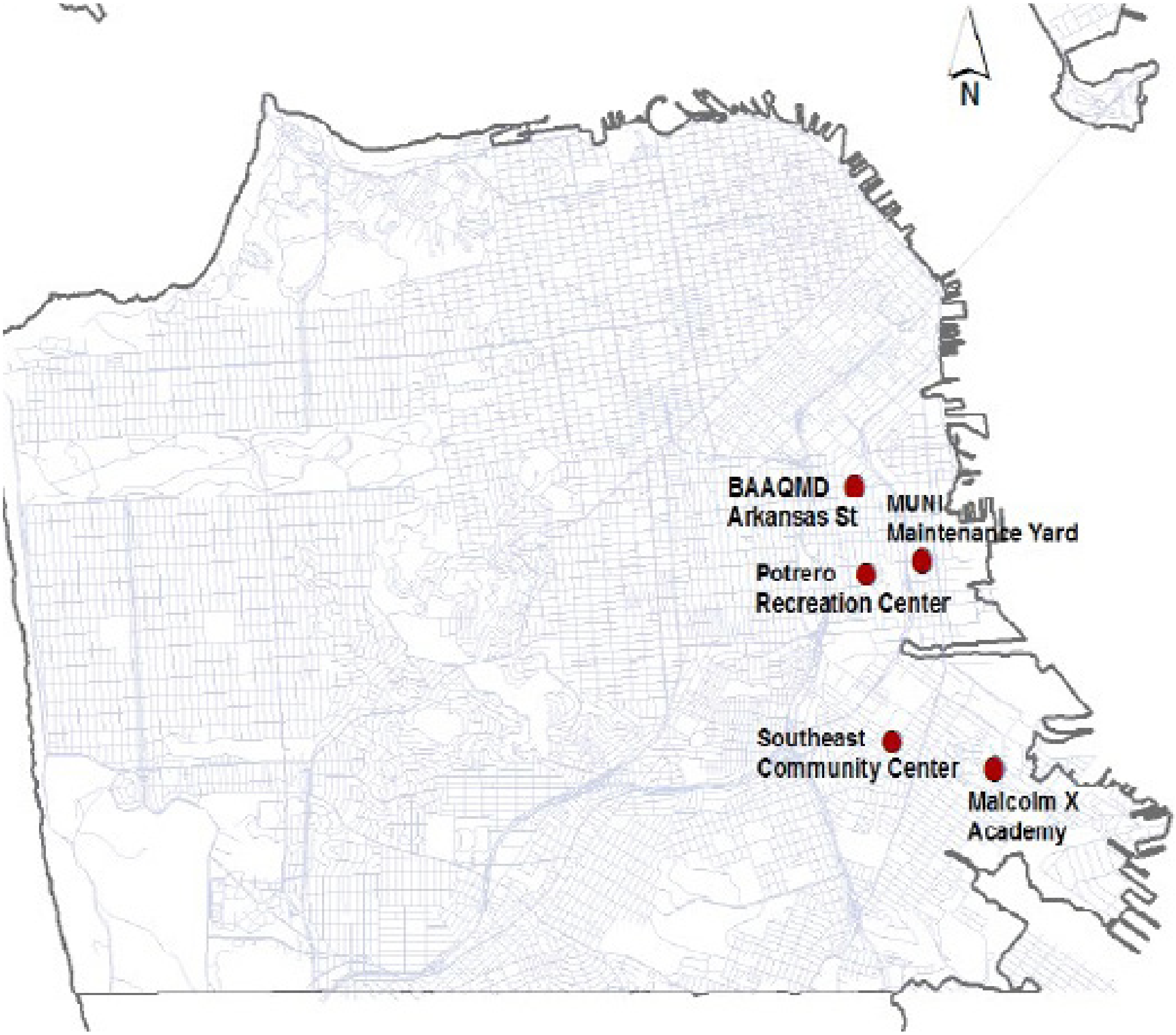
[14] The Arkansas Street measured value reflects a 36-month average over years 2014-2016.



Note: There are 5 monitoring locations shown in this figure, but there are two monitors at the Arkansas Street location (one is operated by BAAQMD and one is operated by DPH) for a total of 6 monitors in San Francisco.

Figure 9. $PM_{2.5}$ Monitoring Locations in San Francisco

5.1 Roadways

Annual $PM_{2.5}$:

The estimated contribution of directly emitted $PM_{2.5}$ from on-road motor vehicles to annual average $PM_{2.5}$ concentrations in San Francisco is mapped in Figure 10. Concentrations were mapped to the master receptor grid with color shading indicating the level of $PM_{2.5}$. In Figure 10, mapped concentration levels range from 0-0.5 $\mu g/m^3$ (no shading) to more than 2.2 $\mu g/m^3$ (darkest shading); darker shades indicate higher $PM_{2.5}$ concentrations. The maximum modeled $PM_{2.5}$ contribution from on-road mobile sources is approximately 14.1 $\mu g/m^3$. Emissions contributing to these mapped concentration increments include those from running exhaust, tire and brake wear, and resuspended roadway dust. The spatial pattern of concentrations shown in Figure 10 closely follows the traffic activity: concentrations are highest near busy roadways, especially near the intersection of major freeways (such as I-280 and US 101) and where the roadway density is greatest (near downtown).

Cancer risk from diesel exhaust and from non-diesel organic gases:

Figure 11 maps the combined contribution of diesel exhaust and non-diesel organic gases from on-road motor vehicles to the incremental potential cancer risk in San Francisco. Diesel particles from all sources have been recognized by OEHHA and CARB as having a high cancer potency factor. On-road, non-diesel cars and trucks emit toxic organic gases, such as benzene and 1,3-butadiene, that add to the incremental potential cancer risk in San Francisco. Cancer risk estimates from gasoline-powered vehicles included contributions from total organic gases (TOG) present in the exhaust emissions and those from running evaporative losses. Incremental cancer risk was mapped to the master receptor grid with color shading indicating the level of risk (per one million persons exposed) assuming a 30-year residential exposure, and accounting for changes in emissions on an annual basis. In Figure 11, mapped risk levels range from 0–29.9 per million (no shading) to more than 100 per million (darkest shading); darker shades indicate higher potential cancer risk. The maximum modeled cancer risk from on-road mobile sources is approximately 687 in one million. The spatial pattern of cancer risk shown in Figure 11 is greatly influenced by the distribution of heavy-duty diesel truck traffic activity because heavy-duty trucks have high emission factors for diesel particulate matter. In general, cancer risk from on-road mobile sources also follows the pattern seen for $PM_{2.5}$ as overall traffic volumes drive locations of elevated risk.

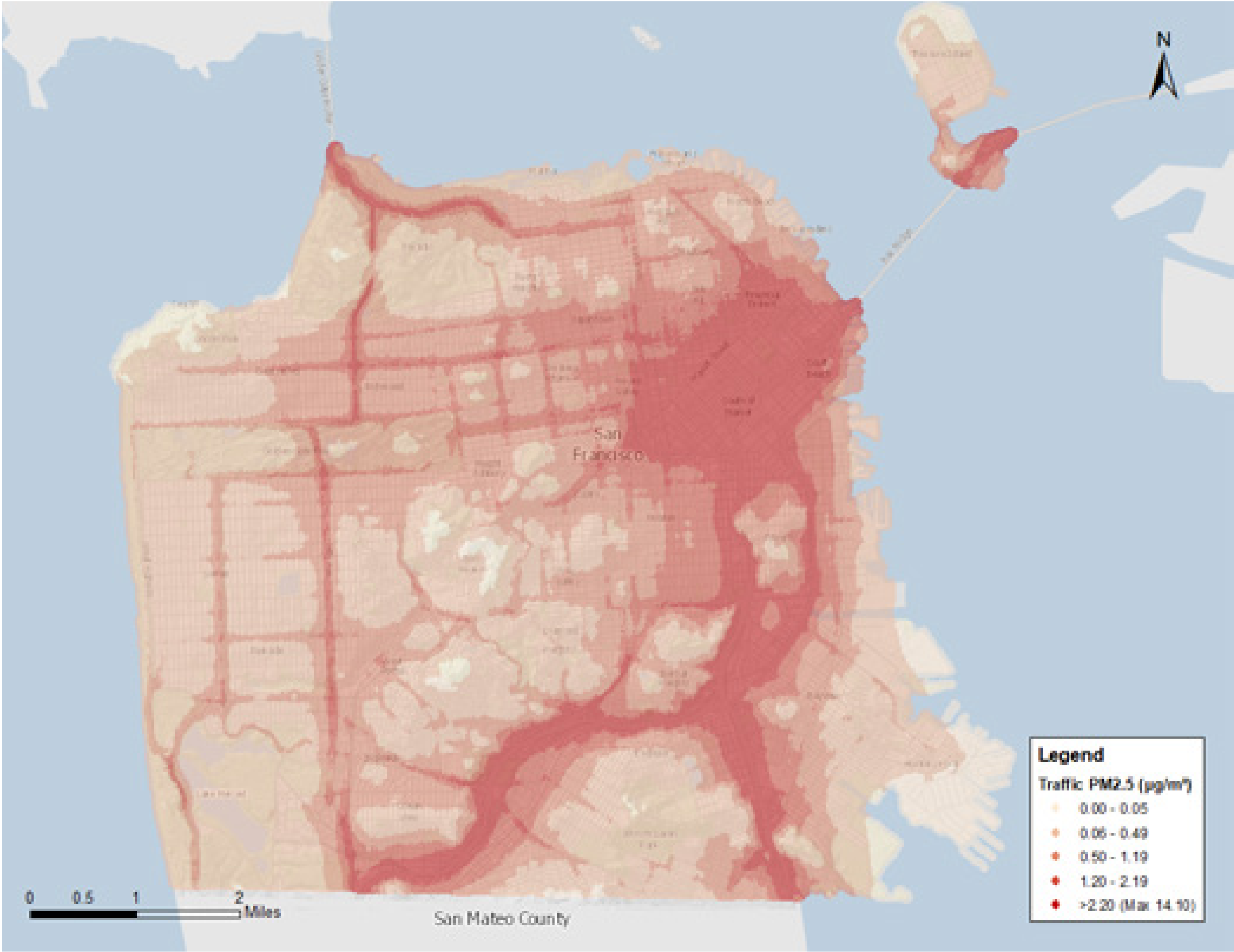


Figure 10. 2020 Annual Average $PM_{2.5}$ Contributions from Mobile Sources in San Francisco

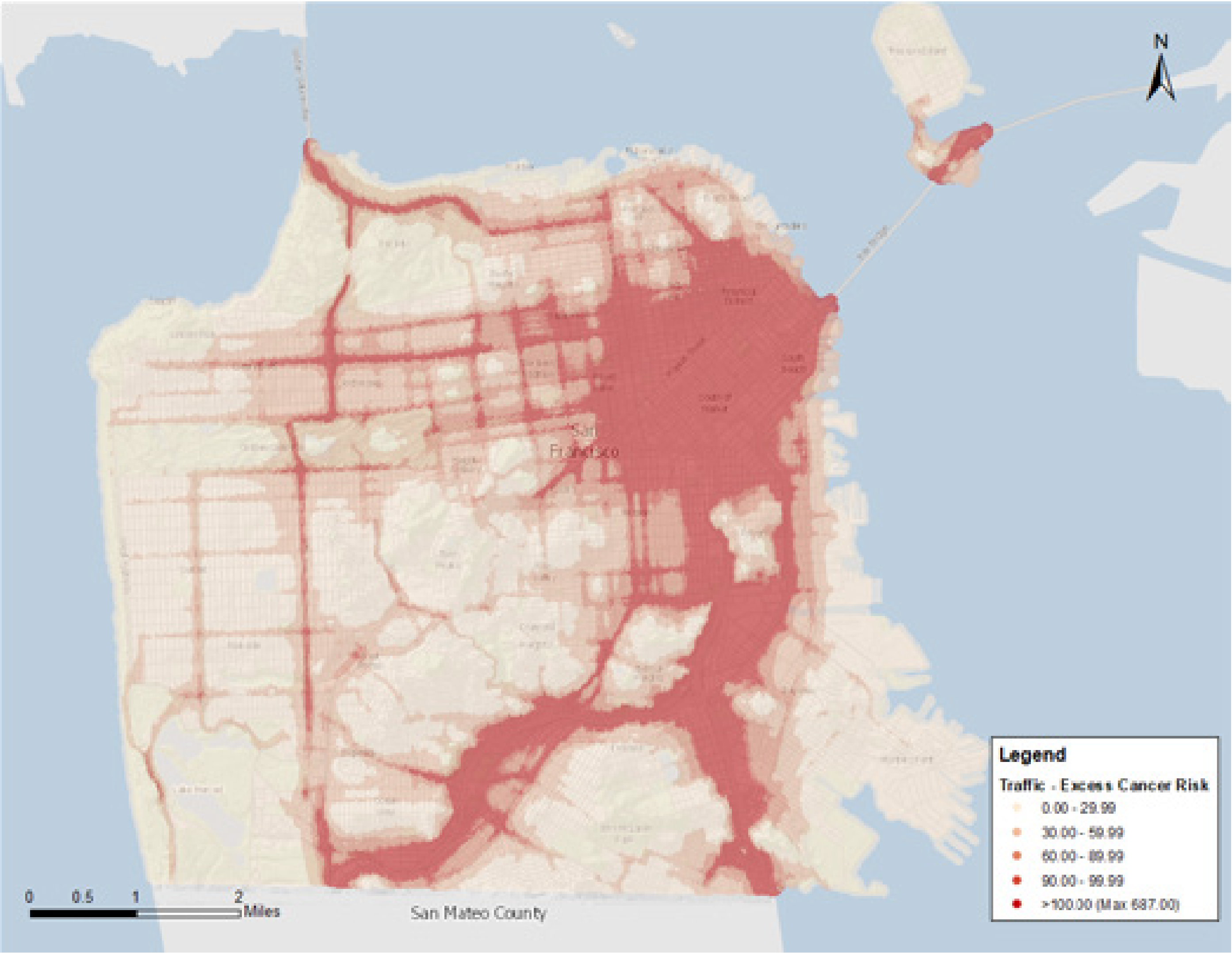


Figure 11. 2020 Cancer Risk Contributions from Mobile Sources in San Francisco

5.2 Permitted Stationary Sources

Annual $PM_{2.5}$:

The estimated contribution of directly emitted particles from permitted stationary sources to annual average $PM_{2.5}$ concentration in San Francisco is shown in Figure 12. In Figure 12, mapped concentration levels range from 0-0.5 $\mu g/m^3$ (no shading) to more than 2.2 $\mu g/m^3$ (darkest shading); darker shades indicate higher $PM_{2.5}$ concentrations. The maximum modeled $PM_{2.5}$ contribution from permitted stationary sources is approximately 188 $\mu g/m^3$. Many of the sources contributing to local peaks in $PM_{2.5}$ concentration in Figure 12 are combustion-related sources, such as engines and backup generators. Other non-combustion sources release PM from activities such as sand blasting (e.g., near the Golden Gate Bridge), aggregate handling (near Islais Creek), or recycling (near the south east corner of the city). Both combustion and non-combustion sources of $PM_{2.5}$ emissions are included in the dispersion modeling.

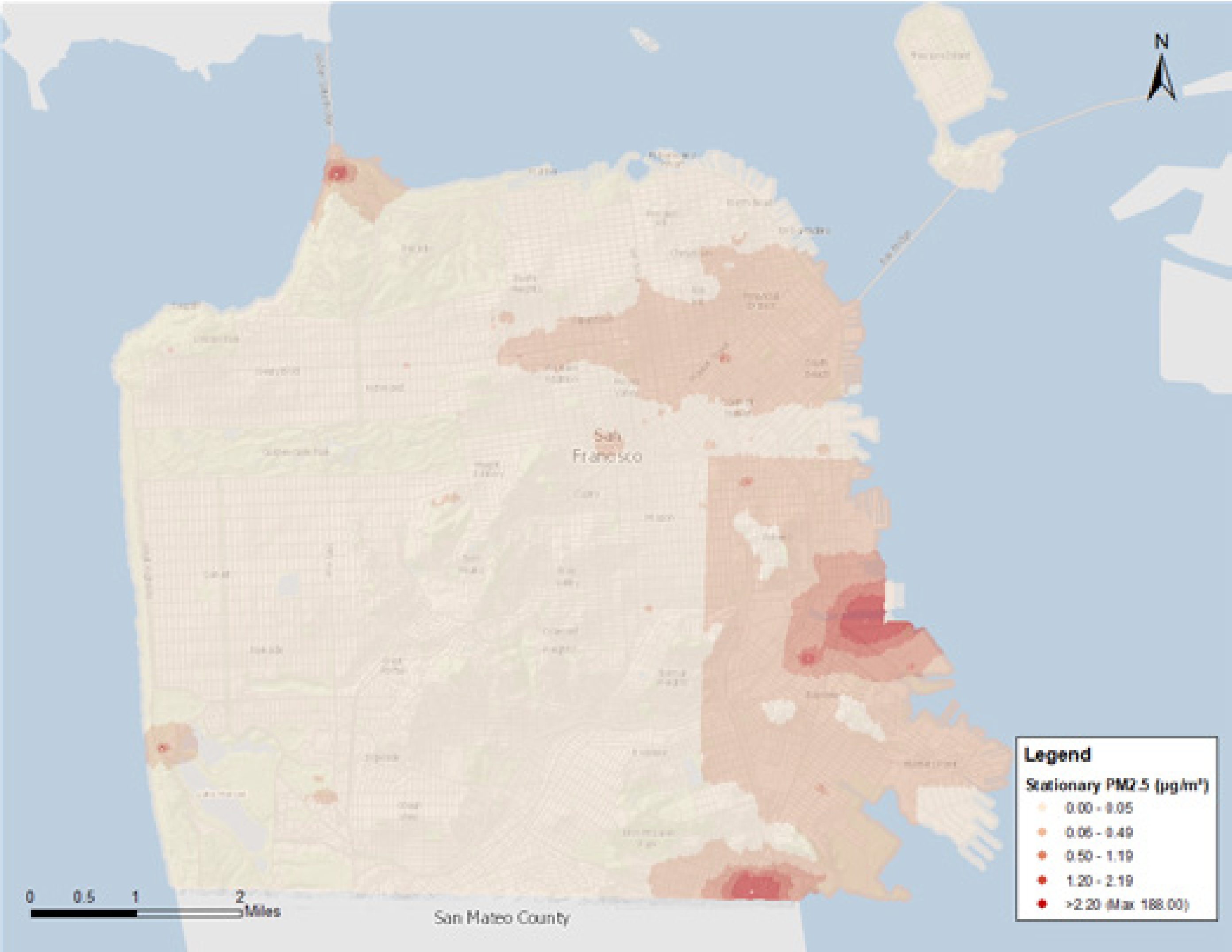


Figure 12. 2020 Annual Average $PM_{2.5}$ Contributions from Permitted Stationary Sources in San Francisco

Emission rates of pollutants from stationary sources are regulated and monitored by the BAAQMD. Over time, emissions rates of $PM_{2.5}$ have dropped significantly due to ongoing rule adoptions by the BAAQMD.

Cancer Risk:

Combustion of diesel fuel is a major contributor to potential cancer risk from permitted stationary sources in San Francisco (Figure 13). For example, a large contributor to the area of high potential cancer risk in downtown San Francisco is backup diesel generators. Gas stations contribute many localized peaks in cancer risk at scattered locations throughout the city. In Figure 13, mapped risk levels in the vicinity of the sewage treatment plant range from 0–29.9 per million (no shading) to more than 100 per million (darkest shading); darker shades indicate higher potential cancer risk. The maximum modeled cancer risk from permitted stationary sources is approximately 678 in one million; however, the bulk of that impact is associated with sources from the former Central Shops facility at 1800 Jerrold Avenue, which has been decommissioned. While activities at the Central Shops have been relocated to either 555 Selby Street or 450 Toland Street, virtually all of the large emissions sources have been permanently decommissioned and are no longer in operation at either of the new locations resulting in the reduced estimation of cancer risk in the area of approximately 30 in a million.

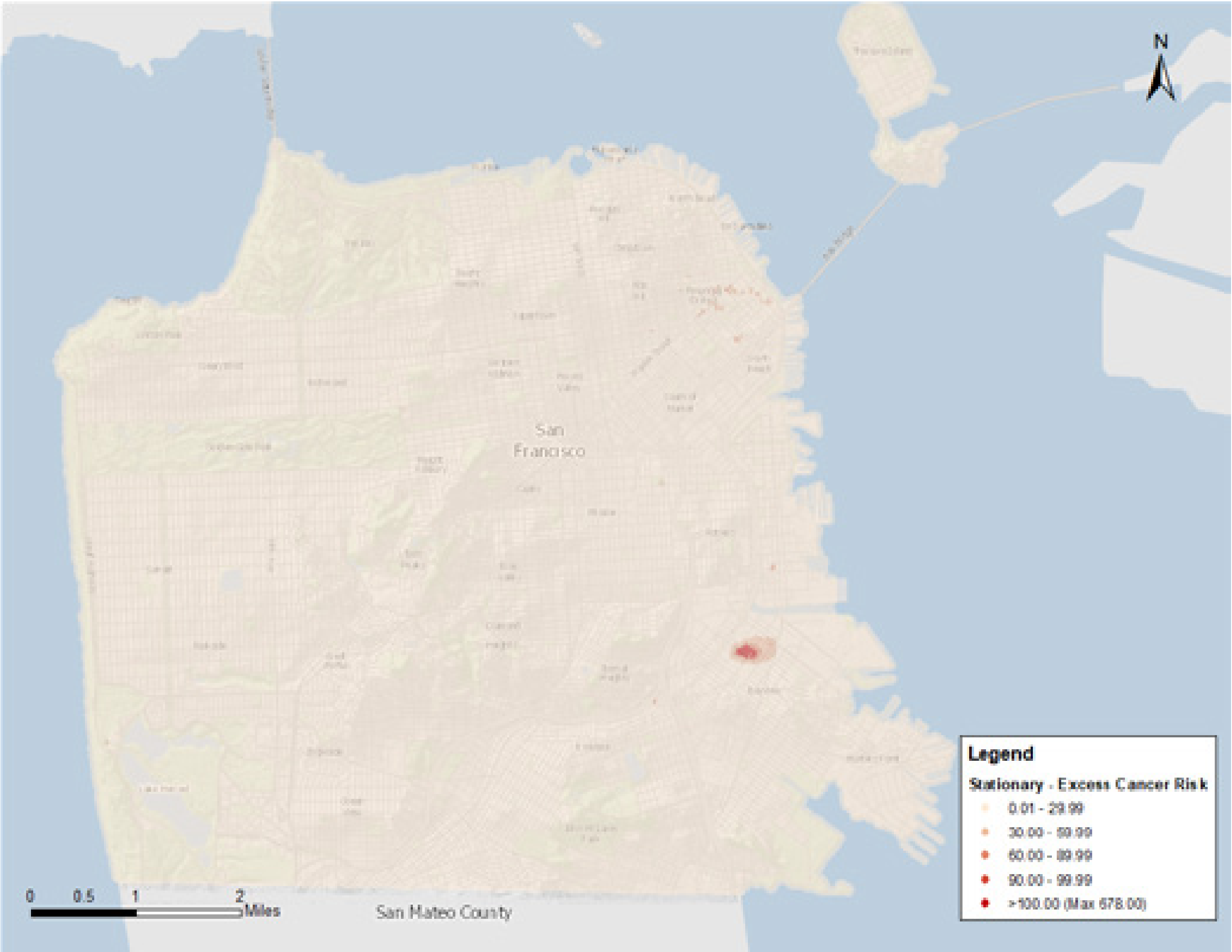


Figure 13. 2020 Cancer Risk Contributions from Permitted Stationary Sources in San Francisco

5.3 Caltrain

Annual $PM_{2.5}$:

The estimated contribution of Caltrain emissions to annual average $PM_{2.5}$ concentration in San Francisco is shown in Figure 14. In Figure 14, mapped concentration levels range from 0–0.5 $\mu g/m^3$ (no shading) up to 0.27 $\mu g/m^3$ darker shades indicate higher $PM_{2.5}$ concentrations. The modeled $PM_{2.5}$ contribution from Caltrain emissions did not exceed 0.27 $\mu g/m^3$ at any receptor point. The highest concentrations of $PM_{2.5}$ were predicted near the Caltrain terminal at 4th and King streets where extended periods of idling occur (20 min per train). Here, annual average $PM_{2.5}$ concentrations above 0.2 $\mu g/m^3$ from Caltrain locomotives' diesel exhaust do not extend beyond the Caltrain terminal or beyond the Caltrain tracks.

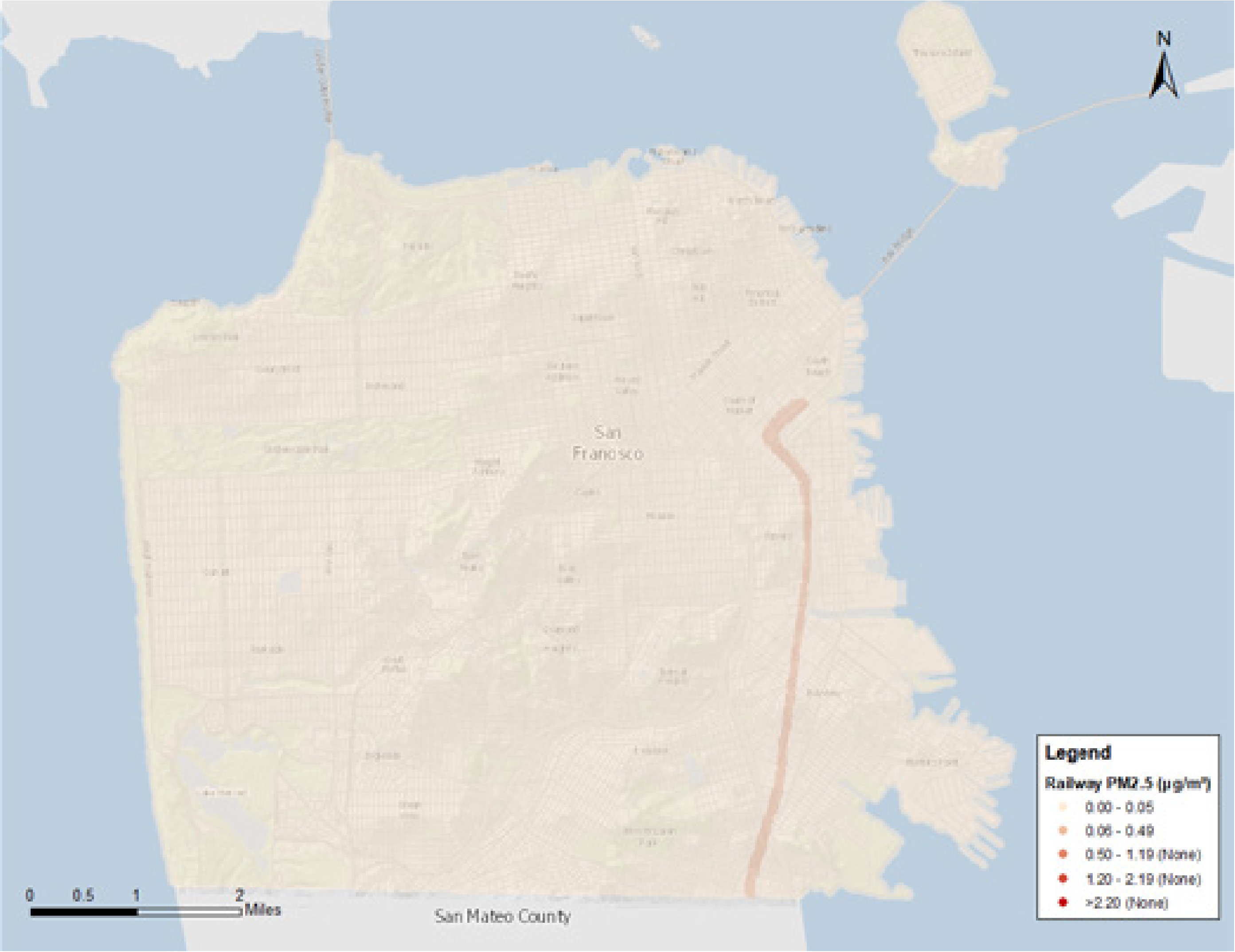


Figure 14. 2020 Annual Average $PM_{2.5}$ Contributions from Caltrain in San Francisco

Cancer Risk:

Exposure concentrations from DPM emissions were estimated assuming electrification of the Caltrain routes from San Francisco to San Jose by 2022. Because routes south of San Jose to Gilroy will continue to operate diesel locomotives, diesel emissions were reduced by 75% beyond 2022. Figure 15 shows the cancer risk contribution from Caltrain operations. In Figure 15, mapped risk levels range from 0–29.9 per million (no shading) to more than 100 per million (darkest shading); darker shades indicate higher potential cancer risk. The maximum modeled cancer risk from Caltrain emissions is approximately 139 in one million. The highest concentrations of $PM_{2.5}$ were predicted near the Caltrain terminal at 4th and King streets where extended periods of idling occur (20 min per train). Here, cancer risk above 100 in one million from Caltrain locomotive's diesel exhaust do not extend beyond the Caltrain terminal or beyond the Caltrain tracks. These calculated risks would need to be reevaluated if the projected date for Caltrain electrification changes.

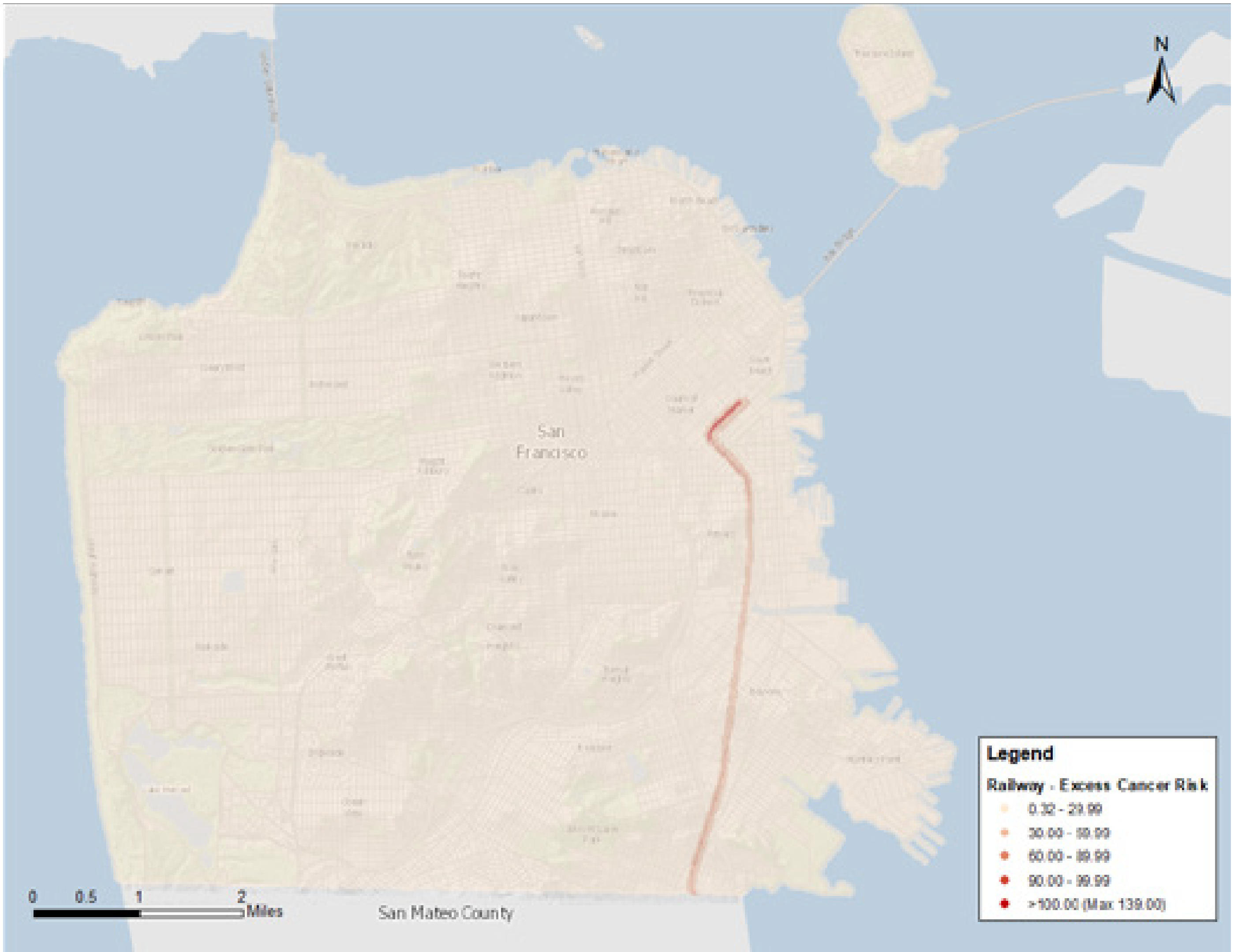


Figure 15. 2020 Cancer Risk Contributions from Caltrain in San Francisco

5.4 Ocean Going Vessels, Harbor Craft, and Ferries

Annual $PM_{2.5}$:

The highest increment in annual average $PM_{2.5}$ estimated from OGVs, harbor craft, and ferries was predicted near the Ferry Building, followed by Pier 41/ Pier 35 (Figure 16), due to the primary contribution from ferry boats operating at those terminals, as well as cruise ship and excursion vessels at the northern piers. Ferries and excursions operating near AT&T park also contributed to elevated $PM_{2.5}$ concentrations in that area. Maritime impacts extend inland due to the elevated release from point sources such as ferry and OGV berthing, with release points at heights from 10 to 50 meters. The estimated $PM_{2.5}$ contribution from maritime sources in San Francisco is shown in Figure 16. In Figure 16, mapped concentration levels range from 0–0.5 $\mu g/m^3$ (no shading) up to 1.94 $\mu g/m^3$ (darkest shading); darker shades indicate higher $PM_{2.5}$ concentrations. The modeled $PM_{2.5}$ contribution from maritime emissions did not exceed 1.94 $\mu g/m^3$ at any receptor point.

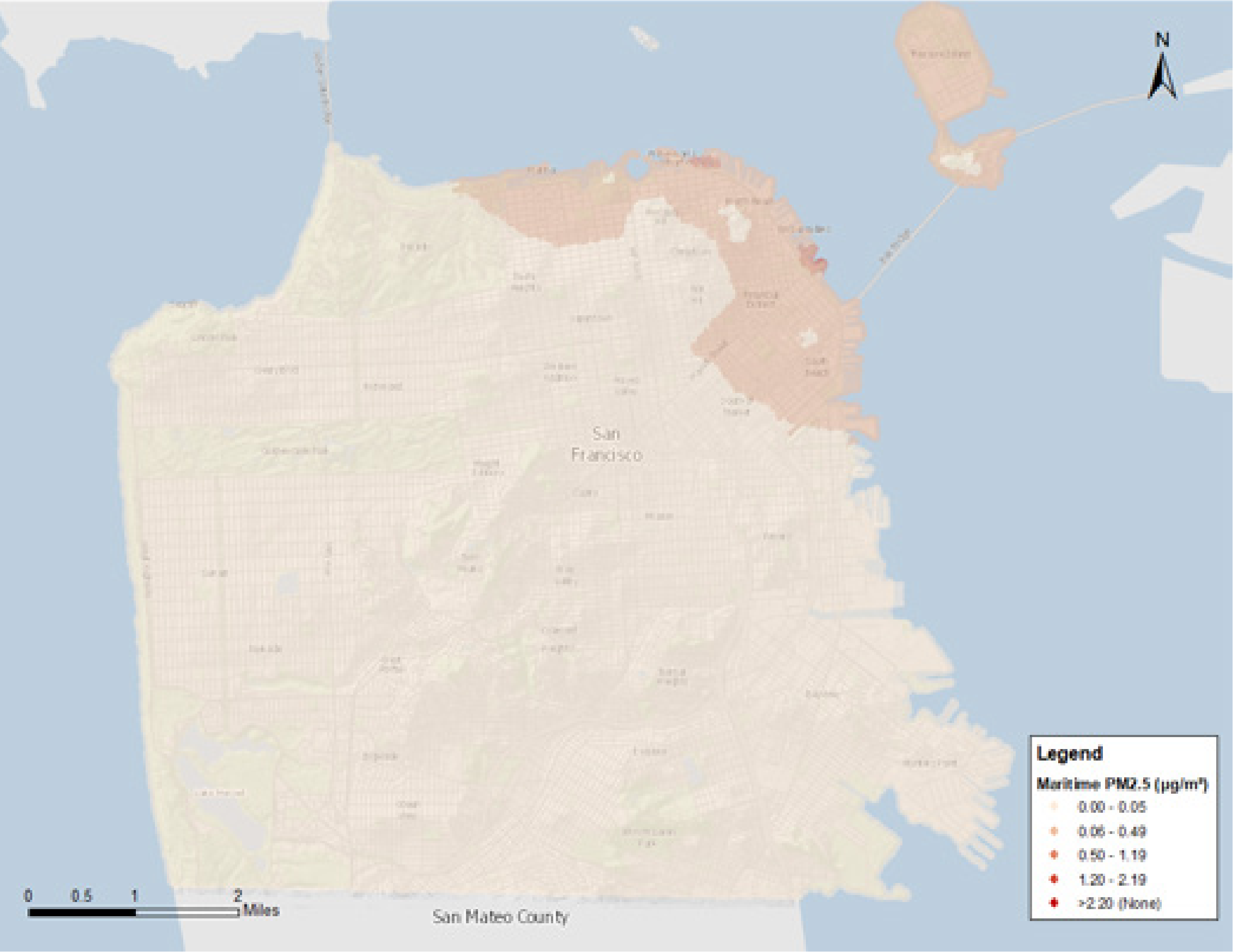


Figure 16. 2020 Annual Average $PM_{2.5}$ Contributions from Maritime Sources in San Francisco

Cancer Risk:

Cancer risk calculations treated all PM_{10} emitted by OGVs, harbor craft, and ferries as DPM, with the exception of PM_{10} from OGV boiler operation, so the cancer risk maps in Figure 17 essentially mirror the $PM_{2.5}$ maps in Figure 16. The highest increment in potential cancer risk was predicted near the Ferry Building and Pier 41/Pier 35, due to the primary contribution from ferry boats operating at those terminals, as well as cruise ship and excursion vessels at the northern piers. Similar to $PM_{2.5}$ concentrations, cancer risk contributions extend inland due to the elevated release from point sources such as ferry and OGV berthing. In Figure 17, mapped risk levels range from 0–29.9 per million (no shading) to more than 100 per million (darkest shading); darker shades indicate higher potential cancer risk. Estimated cancer risks near the Ferry Building and along the north shoreline are at levels over 100 in a million. The maximum modeled cancer risk from maritime emissions is approximately 1,091 in one million.

Additional improvements expected in shore power facilities, the continued/expanded use of renewable diesel fuel, and further retrofits of ferry and excursion boats will lead to reductions in estimated $PM_{2.5}$ concentrations and cancer risk in future years.

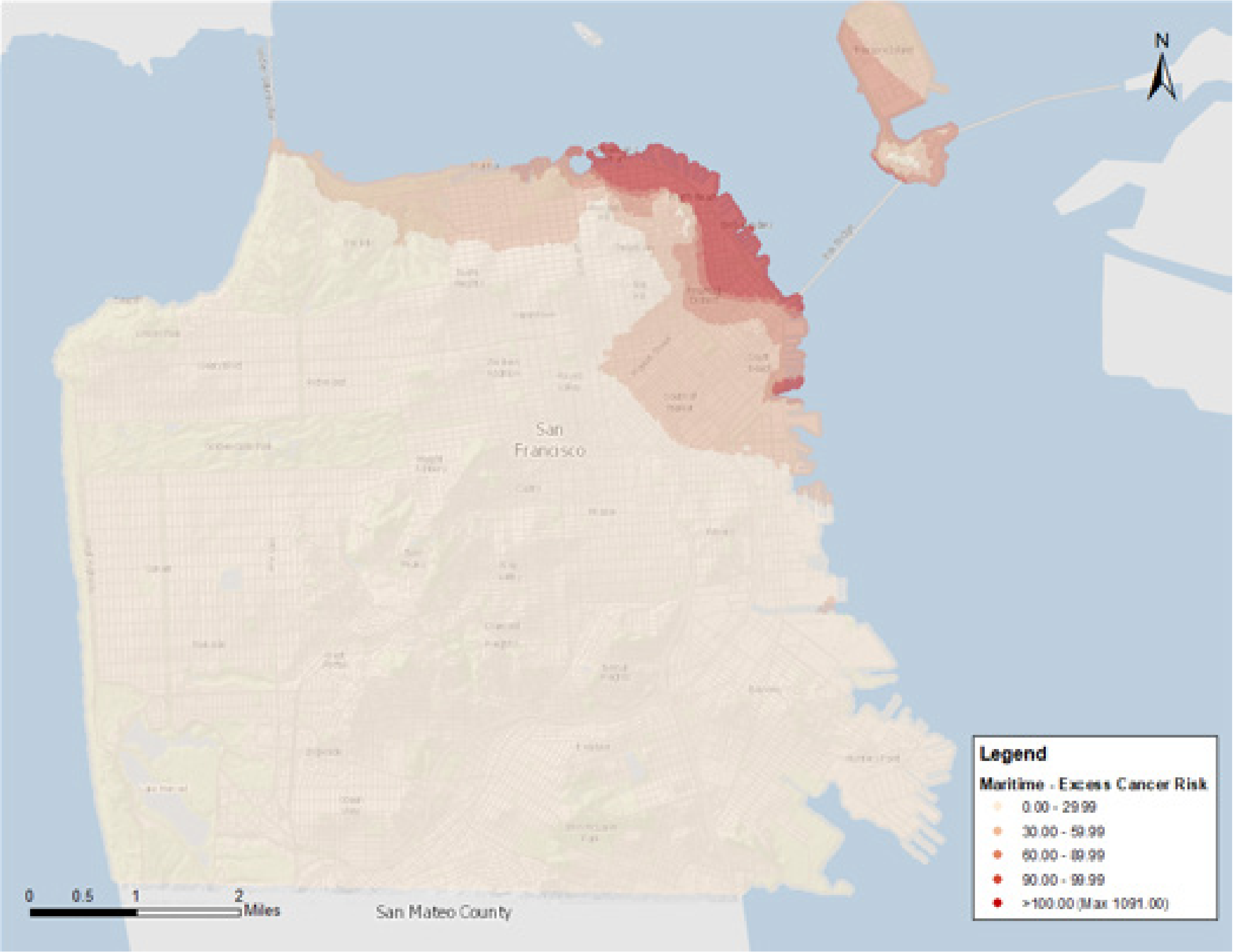


Figure 17. 2020 Cancer Risk Contributions from Maritime Sources in San Francisco

5.5 Combined Impacts

Annual $PM_{2.5}$:

Summing the incremental contributions of annual average $PM_{2.5}$ from all modeled sources produces an estimate of the combined impact of these local sources. Adding background $PM_{2.5}$ concentrations (7.8 $\mu g/m^3$ as estimated in Section 4.1) gives an estimate of total annual average $PM_{2.5}$, including secondarily formed PM and PM transported from distant sources.

On-road mobile sources—cars and trucks—are major contributors to local $PM_{2.5}$ in San Francisco. In Figure 18, major roadways are clearly discernible and some of the highest PM areas are near the freeways where total traffic and truck traffic are highest. Areas along US 101, near the intersection with Interstate 280, stand out as those with some of the highest estimated annual average $PM_{2.5}$ concentrations. Areas of the city where $PM_{2.5}$ concentrations exceed 10 $\mu g/m^3$ include the entire south of market area, portions of the Mission and Bayview neighborhoods, locations adjacent to US 101, including portions of 101 that run through the city (Van Ness Avenue) and the Presidio, Interstate 280, 19th Avenue, portions of Geary Boulevard and Park Presidio Boulevard, and similar areas with a high volume of vehicle traffic. In Figure 18, mapped $PM_{2.5}$ concentrations range from 7.8 $\mu g/m^3$ (lightest shading) to more than 10 $\mu g/m^3$ (darkest shading); darker shades indicate higher $PM_{2.5}$ concentrations. The maximum annual average $PM_{2.5}$ contribution is 196 $\mu g/m^3$. $PM_{2.5}$ concentrations above 100 $\mu g/m^3$ occur in two locations: industrial activities occurring near Pier 94 and Recology's operations near the city and county border with Daly City. The primary contributor to these high $PM_{2.5}$ concentrations are permitted stationary sources at these locations.

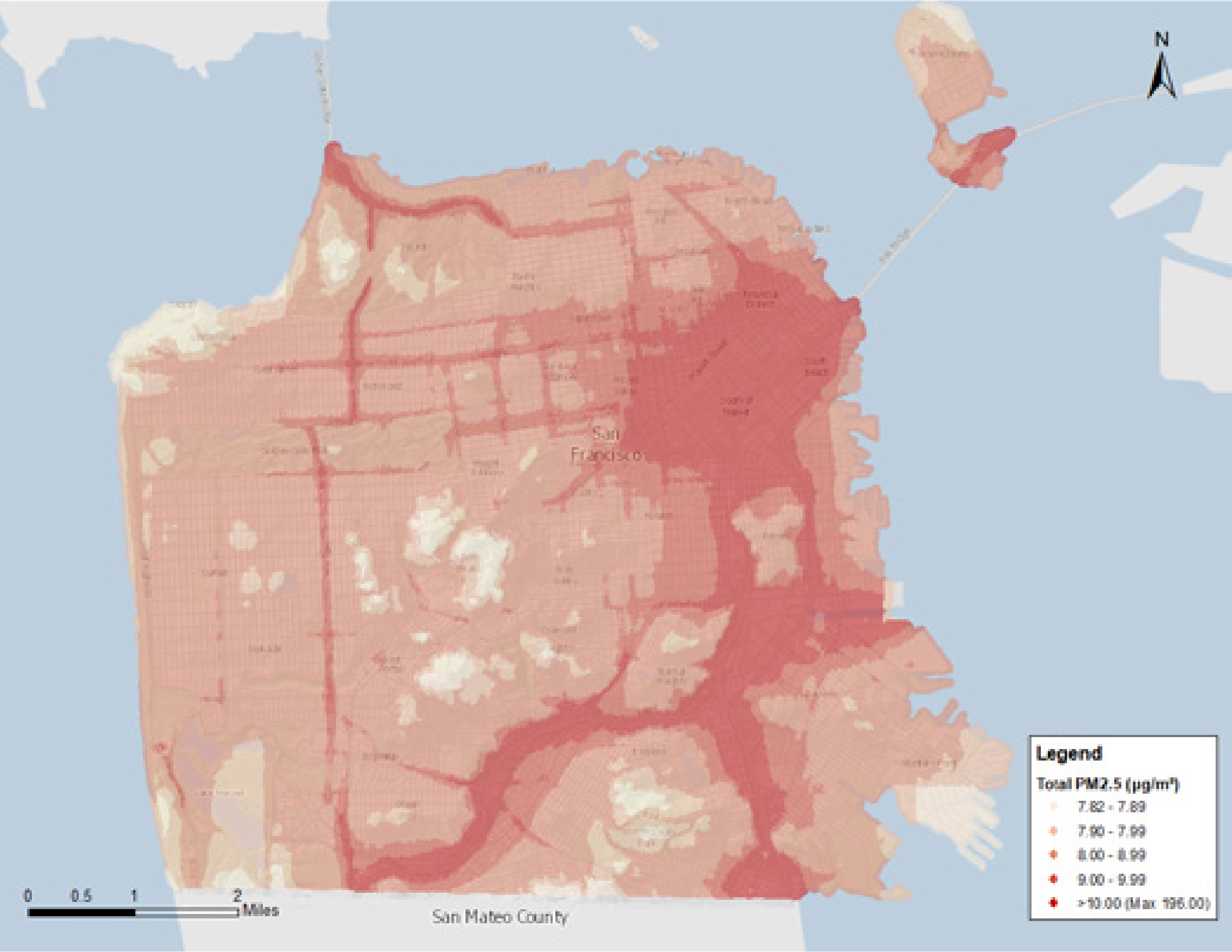


Figure 18. Annual Average PM$_{2.5}$ from all Modeled Sources and Background Concentrations in San Francisco in 2020

Cancer Risk:
Combined source maps show that on-road mobile sources are also major contributors to incremental potential cancer risk (Figure 19). Diesel truck traffic on freeways and the downtown roadway network is largely responsible for the areas near these roadways with incremental potential cancer risk over 100 per million. The Caltrain station and ships, harbor craft, and ferries are also major contributors to cancer risk near these areas. A large number of backup diesel generators associated with high rise buildings also add to potential cancer risk, particularly in the downtown areas. Figure 19 shows cancer risk from the combination of all modeled source with a range from 2.5 to 29 per one million persons exposed (lightest shading) to more than 100 per one million persons exposed; darker shades indicate higher excess cancer risk. The maximum cancer risk from modeled sources is approximately 1,155 per one million persons exposed. Combined cancer risks above 1,000 per one million persons exposed occur near maritime operations at the ferry building and Pier 41.

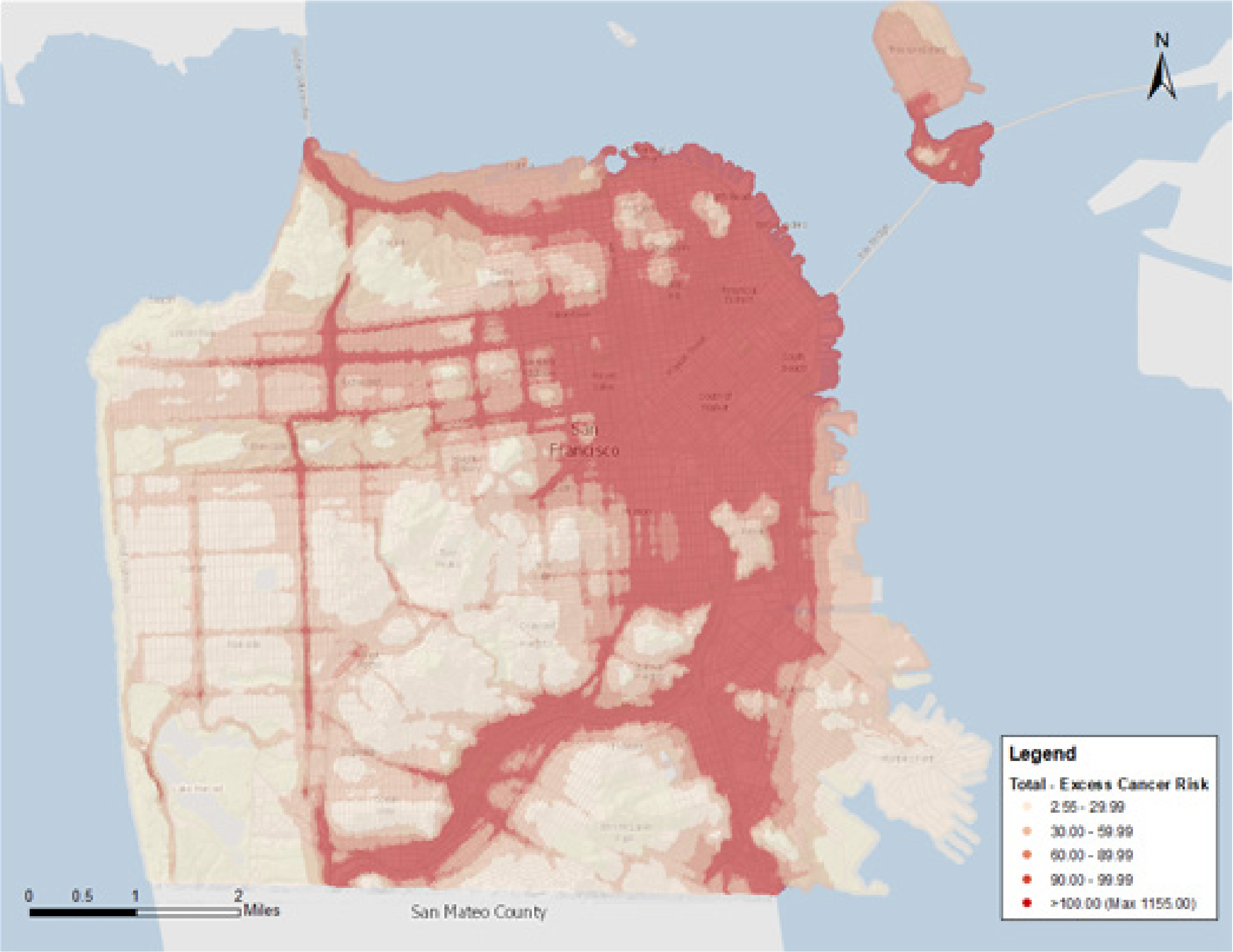


Figure 19. Cancer Risk from all Modeled Sources in San Francisco in 2020

6. Uncertainties

In accordance with risk assessment guidance, the Citywide HRA has qualitatively evaluated the uncertainties associated with the HRA, including emissions estimation, the modeling approach, and risk estimation. A quantitative uncertainty analysis was beyond the scope of this evaluation since necessary uncertainty inputs were not available and the models applied did not include methods for propagating uncertainties. The following sections summarize common sources of uncertainty associated with the emissions estimation, air dispersion modeling, and risk estimation components of the risk assessment.

6.1 Emissions Estimates

There are a number of uncertainties associated with the estimation of emissions from each of the source categories considered that may affect the subsequent estimation of exposure concentrations and risk characterization. For example, uncertainties associated with the estimation of emissions from on-road motor vehicles may affect the subsequent estimation of exposure concentrations and risk characterization. Estimates of traffic volumes and truck fractions on specific roadways vary daily and these daily variations are not captured in the modeling. Traffic volumes are based on the SF-CHAMP model, which has its own uncertainties and limitations. EMFAC2014 was used to estimate on-road emission factors for cars, trucks and buses in San Francisco and as with any emissions model, there were also uncertainties associated with these.

At the commencement of this modeling effort, emissions estimates for 2014 were the most recent available for permitted stationary sources. Emissions from some sources may have changed between these dates and will likely continue to change in the future.

In addition, some source categories were excluded from the modeling analysis. For example, emissions associated with Port-related cargo handling activity, drayage trucks, transportation refrigeration units, and rail locomotives were excluded since these sources combined contributed less than 3% of the total PM emissions from all port activities.

6.2 Modeling Approach

In addition to uncertainty associated with emission estimates, there is also uncertainty associated with the estimated exposure concentrations. The limitations of the air dispersion model provide a source of uncertainty in the estimation of exposure concentrations. According to USEPA, errors due to the limitation of the algorithms implemented in the air dispersion model in the highest estimated concentrations of +/-10 percent to 40 percent are typical (USEPA 2005).

In San Francisco, with its many multi-story and high-rise buildings, urban flow patterns are likely influenced by recirculation and channeling in urban canyons. The dispersion modeling does not account for such patterns. The urban heat island effect which results from surface heating of paved and built-up environment leads to longer periods of mixing and generally lower predicted air concentrations. AERMOD allows the user to model urban heat island impacts by selecting urban land use option. Although San Francisco fits the definition of an urban area, AERMOD was run using rural land use option in order to estimate conservative (i.e., higher) air pollutant concentrations.

In addition, building height information for including building downwash was not available. The building downwash option in AERMOD accounts for the buildup of air pollution in the building cavity due to recirculating winds created by nearby buildings. The effects are governed by the building geometry and the wind direction. To take advantage of this option in the model, information on all building heights and stacks within the City is required. Typically, building downwash effects often lead to higher concentrations downwind of the stack release. Not capturing these effects and using meteorological data from single monitoring site to represent transport throughout the city add to errors and uncertainties in the modeling approach.

Throughout the city, receptors were placed at a height of 1.8 meters (commonly called flagpole receptor height) above the surface terrain, with the exception of roadway modeling where a receptor height of 0 meters was used. This option is used to conservatively model exposures within an individual's breathing zone at ground level. Using flagpole receptors may not always capture the highest predicted concentration in cases where both the source and the residential receptors are elevated above the surface terrain.

Uncertainties in input parameters used to represent and model emission releases add uncertainty to the modeling approach. For all emission sources, where parameters such as stack height and diameter were unknown, source parameters were used that were either recommended as defaults or expected to produce more conservative (i.e., higher) results. In particular, many of the stack parameters for standby diesel generators were unknown and default release parameters were used. However, in cases where the actual stack height is greater than the default used in the model, the exposure concentrations may be underpredicted at downwind receptor locations, or overpredicted at nearby receptor locations. Since there can be discrepancies in actual emissions characteristics of a source and its representation in the model, exposure concentrations used in this assessment represent approximate exposure concentrations. For example errors and uncertainties persist in the specification of locations of stacks at facilities, in spite of significant effort expended to improve the permitted source database.

6.3 Risk Characterization Methods

Numerous assumptions must be made in order to estimate human exposure to chemicals. These assumptions include parameters such as breathing rates, exposure time and frequency, exposure duration, and human activity patterns. While a mean value derived from scientifically defensible studies is a reasonable estimate of central tendency, the exposure variables used in this assessment are only estimates.

CalEPA/OEHHA cancer potency factors (CPFs) for toxic air contaminants were used to estimate cancer risks associated with pollutant exposures for the emission sources modeled. However, the CPF values derived by Cal/EPA for many pollutants, including that for DPM, are uncertain in both the estimation of response and dose. Public health and regulatory organizations such as the International Agency for Research on Cancer, World Health Organization, and USEPA agree that diesel exhaust may cause cancer in humans. However, there is significant uncertainty in the value applied for the CPF.

The USEPA notes that the conservative assumptions used in a risk assessment are intended to assure that the estimated risks do not underestimate the actual risks posed by a site and that the estimated risks do not necessarily represent actual risks experienced by populations at or near a site (USEPA 1989). Furthermore, this evaluation quantifies risk at all receptor locations assuming residential exposure parameters, while some receptor locations may be workplaces or recreational areas where the overall exposure would be less.

The method applied to estimate cancer risk includes the age-specific exposure factors recommended by CalEPA/OEHHA which increases the effective CPF to account for increased sensitivity of the young to cancer-causing pollutants. However, there may be pollutants in the urban environment whose cancer toxicity is magnified in ways that are not accounted for because of the presence of other pollutants (synergic effects) or because of pre-existing conditions or sensitivities. Furthermore, there may be pollutants whose toxicity is not yet recognized or quantified and, as such, is unaccounted for in this risk assessment.

7. References

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