The San Francisco Community Risk Reduction Plan: Technical Support Documentation

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Bay Area Air Quality Management District
San Francisco Department of Public Health
San Francisco Planning Department

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1. Introduction

This document describes technical work performed to support San Francisco's Community Risk Reduction Plan (CRRP). 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 three years: a base year (2010), a project development year (2014), and a future year (2025). The base year is used to establish baseline concentrations for which air pollution measurements are available. The project development year is the estimated earliest date that residents would occupy a new development project if an application is submitted this year (2012). The development and future year modeling show anticipated reductions in hotspot areas relative to the base year, but also identify areas where hotspots are anticipated to persist without additional emission reductions.

The development of the technical foundation that supports the CRRP, like the development of the CRRP itself, was a collaborative effort. Modeling systems and inputs developed by the San Francisco Department of Public Health (SFDPH) for on-road cars and trucks provided an initial blueprint for this effort, which built on analyses supporting San Francisco's Article 38, a City ordinance that recognizes the health and financial 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 significantly increasing the number of receptor points included for evaluation in the modeling analysis. Contractor Sonoma Technology, Inc., (STI) assisted the BAAQMD in developing portions of the CRRP emissions inventory (STI 2011; STI 2012a). The San Francisco Planning Department (SFPLAN) provided careful review of modeling inputs and results and helpful suggestions for improvements. Members of the Air District's Community Air Risk Evaluation (CARE) Task Force helped to guide early stages of the CRRP technical work, in addition to generating discussions that led to the concept of a community risk reduction planning tool.

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).

2. Emissions Inventory

This section presents a summary of the emissions inventory developed for the CRRP. 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 cruise ships, excursion boats, and tug boats (Section 2.4),
- The Transit Center bus depot, including diesel emissions from local transit buses (Section 2.5), and
- Major construction projects in 2010 and 2025 (Section 2.6).

Source categories of emissions not included in the CRRP analysis are

- Residential wood burning from fireplaces and wood stoves,
- Commercial and residential cooking,
- Ferry boats,
- Indirect sources that generate vehicle trips such as distribution centers, retail centers, and postal service stations.

These categories are potentially important sources of PM 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), or 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) and ferry boats (small contribution compared to ocean-going vessels).

Annual emissions estimates were developed for three years: a base year 2010, a project development year 2014, and a future year 2025. The project and future year modeling included the following changes from the base year:

- Reductions in emissions for on-road trucks based on the California Air Resources Board's (CARB) on-road diesel regulation and assuming San Francisco Transit Authority's growth projections for 2020,
- Phase out of perchloroethlyene from dry cleaners by 2023,
- Shutdown of the Potrero Generating Station in 2011,
- Assumed electrification of Caltrain in 2025,
- Reduction in hoteling emissions associated with docking of cruise ships in 2025 based on available shore power, as required by CARB's ocean going vessel regulation, and
- Phase-specific emissions based on construction schedule of large multi-year construction projects. Year specific emissions (2010 and 2025) were developed to evaluate the one-year impact of major construction projects relative to other sources.

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

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 environments 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 CRRP analysis applied dispersion modeling for all roadways with 1,000 annual average daily traffic (AADT) counts or more, including all motor vehicle types.

Activity Data:
For estimating emissions from on-road mobile sources, roadway activity data were generated using the San Francisco County Chained Activity Modeling Process (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, the official travel forecasting tool for San Francisco, is an activity-based model that predicts future travel patterns for the city. Traffic for year 2010 was used to model emissions for 2010, while predicted traffic volumes for year 2020 were used to estimate emissions for 2025. Between years 2010 and 2020,

traffic volumes were linearly interpolated. For years beyond 2020, traffic volumes were assumed to remain constant[1].

In addition to the total traffic volume, an estimate of heavy-duty truck volumes was also developed for each roadway link. Several sources were relied upon to estimate truck volumes. For California freeways (Highways 1, 35, 101, 280, and 80), the California Department of Transportation's (Caltrans) 2009 truck fractions were used and assigned by spatially joining the Caltrans GIS representation of State freeways with the SF-CHAMP network. Average truck fractions for surface streets were estimated using ortho-photo analysis, whereby truck counts were derived in neighborhoods and street segments based on aero-photographs taken at specific times of the day. 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) 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 AADT for total vehicles and for heavy-duty trucks were roadway link specific, the diurnal profile was constant across all roadways.

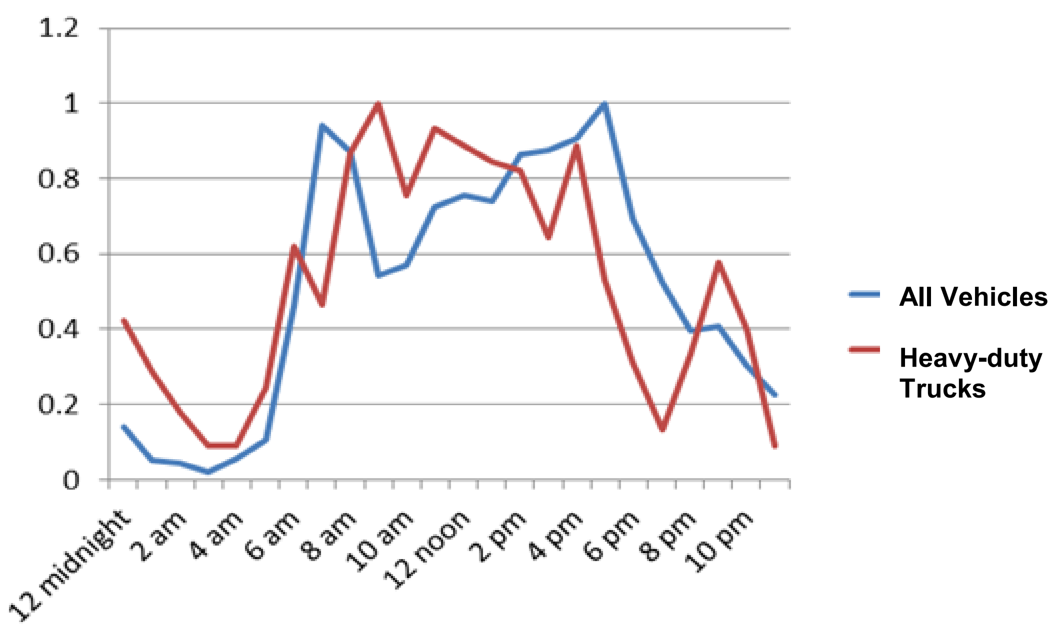


Figure 1. Normalized activity patterns of on-road traffic for all vehicles (blue line) and heavy-duty trucks (red line). Values are normalized to peak-hour traffic.

[1] Should extended activity forecasts become available for years beyond 2020, dispersion modeling and analyses could be updated.

Emission Factors and Emissions:
Activity-based emission factors were applied for $PM_{2.5}$, diesel PM, and total organic gases from non-diesel, on-road mobile sources. Emission factors were derived using the latest version of EMFAC (EMFAC2011, CARB 2011) for all vehicle classes at all speeds for EMFAC2007 vehicle categories. 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 $E_{PM2.5}$ represents the emissions (g/day) of $PM_{2.5}$ on a roadway,

$e_{PM2.5,\,k,\,i}$ is the 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 is the roadway link length (mi), and

N_k is the count for vehicle type *k.*

Diesel PM (DPM) was derived similarly by summing PM10 exhaust emissions including brake and tire wear for only the diesel fuel type:

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

where E_{DPM} represents the emissions (g/day) of diesel particulate matter,

$e_{PM10,\,k}$ is the emission factor (g/day per vehicle mile travelled) of PM10 (running exhaust only) for the average link speed for vehicle type *k* and diesel fuel only*,*

L is the roadway link length (mi), and

N_k is the 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 $E_{non\text{-}diesel\ TOG}$ represents the emissions (g/day) of non-diesel TOG,

$e_{TOG,\,exhaust,\,k}$ is the 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*,*

$e_{TOG,\ loss,\ k}$ is the emission factor (g/day per hr) of TOG (running loss) for the average link speed for vehicle type *k* and gasoline fuel only,

T is the roadway link length (mi) divided by the average speed (mi/hr), and

N_k is the count for vehicle type *k*.

Total traffic counts and heavy-duty truck traffic counts for roadway links 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 EMFAC2007 heavy-duty classifications, LHD1, LHD2, T6, T7, SBUS, OBUS, and UBUS were used to represent heavy-duty truck counts. Remaining categories were classified as light duty. Relative fractions of traffic volumes within each category were taken to match EMFAC2011 estimates.

Emission factors (per VMT) from running exhaust were derived from EMFAC2011 for years from 2010 to 2035 for all EMFAC2007 vehicle categories. Emission factors for years beyond 2035 were assumed to remain constant.

2.2 Permitted Stationary Sources

Stationary sources of air pollution—including larger facilities such as refineries, power plants, and chemical manufacturers as well as smaller facilities such as diesel generators, gasoline dispensing facilities (GDFs or gas stations), and drycleaners—are regulated and subject to permit conditions established by the BAAQMD. BAAQMD maintains a database of the permitted sources and their associated emissions. Emissions are determined by measurement (source testing) or engineering calculation based on process throughput. Emissions are reported annually to CARB via the California Emissions Inventory Development and Reporting System (CEIDARS, CARB 2008) and, subsequently, reported to EPA to supplement the National Emissions Inventory database (NEI, EPA 2012).

The starting point for the CRRP permitted source emissions inventory development was the 2008 and 2009 CEIDARS point source submittals to CARB. These data submittals were supplemented and improved to develop a stationary source modeling database for the CRRP. One important improvement was the addition of GDFs to the point-source dataset. Historically, emissions from GDFs have been reported as part of county-level area sources in CEIDARS. Adding GDFs as point sources instead provided information on emissions from individual GDFs. Gas station information included street addresses, geocoded coordinates, and emissions of total organic gases and toxic air contaminants.

Another key improvement to the database was correcting and reporting *release parameters*. Release parameters—such as stack locations, stack heights, and stack diameters, and exhaust gas flow rates and temperatures—are auxiliary data needed to determine plume rise and pollutant transport in dispersion models. The BAAQMD's CEIDARS submittals contain placeholders for release parameters; but, because these parameters are not required, much information is incomplete or inaccurate. Significant effort was directed toward collecting and manually entering data to replace missing or inaccurate data fields (STI 2012a).

Data Sources:
Data collection and data quality assurance efforts focused on the following types of sources within the Bay Area:

- Top 1,000 highest emitting prime and standby generators,
- Top 1,000 of the highest emitting gas stations,
- Dry cleaners that use perchloroethylene,
- Top 100 permitted stationary sources of toxic air contaminants (TAC), with rankings based on cancer risk weighted emissions (year 2008) and excluding generators, gas stations, dry cleaners, and refineries, and
- Top 100 permitted stationary sources of $PM_{2.5}$ (year 2009) emissions.

These sources were targeted because they emit compounds that have high toxicities and because they have relatively high intake potential, that is, the sources tend to be near receptors so their emissions have a high likelihood of leading to exposures. A variety of data sets were used to assemble emissions data, release parameters and risk information for permitted stationary sources:

- **California Emissions Inventory Development and Reporting System (CEIDARS) database** – The CEIDARS data include emissions inventory data for all point sources in BAAQMD's jurisdiction were incorporated as comma separated value (CSV) files that contain facility information, annual criteria and TAC emissions, stack parameters, and process-level activity data (e.g., throughput and operating cycles). Initially 2008 CEIDARS data were used; these data were later augmented with a 2009 inventory.
- **2008 GDF emissions inventory** – This inventory was incorporated from an Excel spreadsheet format that included facility information (e.g., address and location coordinates) and total organic gas (TOG) and air toxics emissions data for all GDFs in the BAAQMD, which are not included in the District's CEIDARS data.
- **2011 District survey** – Results of a survey of owners and operators of GDFs and stationary diesel engines provided some missing data for GDFs and diesel generators. For GDFs, survey results provided information on the number of dispensers and dispenser dimensions at each facility, as well as the facility's annual throughput (gallons of gasoline). For diesel engines, the survey results provided information on engine make and model, outlet location, and stack configuration.
- **District permit applications** – applications dating back to the year 2000 that include information on dispersion modeling conducted as part of a health risk assessment (HRA) or prevention of significant deterioration (PSD) analysis.[2] For permits that include such an analysis, information was available in one of three formats:
    1. Electronic model inputs files developed by the engineer assigned to conduct that analysis;

[2] PSD requirements apply to new point sources or existing point sources where major modifications have been made. The requirements include the use of air quality modeling to demonstrate that emissions from the facility will not cause or contribute to a violation of applicable air quality standards.

2. Permit applications scanned into the District's online document storage system (Peelle Tech.); or
3. Hard copies of permit applications that were scanned and converted into PDF format.

Contractor STI reviewed each of these data sets, extracted pertinent information, and assembled that information into a stationary source modeling database.

Database Design:

STI worked with the BAAQMD to identify the types of data that were to be included in the stationary source database and to develop a database structure that would incorporate these data. The final database design includes 5 tables with a total of 146 data fields (STI 2012a). The contents of each table are summarized below:

- **Plant Table** – contains facility-level data such as address, contact information, location coordinates, and industry type, e.g., Standard Industrial Classification (SIC) code.
- **Source Table** – contains data on individual emissions sources within a facility, including activity data (e.g., hours of operation per year), engine characteristics (e.g., make, model, horsepower), and controls information.
- **Emissions Table** – contains annual emissions by pollutant for each emissions source at a facility. Two different emissions fields are provided for each pollutant: one for emissions from the District's CEIDARS database, and one for an alternative data source (e.g., emissions recorded in a permit application).
- **Release Table** – contains information on emissions release points within a facility, including stack parameters and definitions for area and volume sources.[3] Note that multiple emission sources can be routed to a single stack, and the Source Table includes stack assignments for each emissions source.
- **Applications Table** – contains health risk information (e.g., modeled $PM_{2.5}$ concentrations and associated cancer risk) from permit applications for which HRAs were conducted. The risk information may be connected to individual or multiple emissions sources at a facility.

Because the data fields in the tables listed above were populated with data from the District's CEIDARS database where possible, additional data fields were included that cross-referenced data fields in the CEIDARS database with corresponding fields in the stationary source database. The CEIDARS data, in some cases, contained emissions for total PM or for PM10, and not $PM_{2.5}$ directly, $PM_{2.5}$ emissions were estimated outside the database using source-specific ratios ($PM_{2.5}$/PM or $PM_{2.5}$/PM10). Compound specific cancer toxicities were applied to TAC emissions estimates to calculate toxicity-weighted emissions.

Table 1 presents a summary of the permitted sources in the Bay Area identified for inclusion in the stationary source database, as well as the fraction of sources and emissions captured for each

[3] In dispersion modeling, an area source is a two-dimensional emissions source that is represented by polygon vertices, while a volume source is a three-dimensional emissions source that is represented by a location, release height, and initial lateral and vertical plume sizes.

source category. These results show that the selected diesel engines, GDFs and dry cleaners emit 78% to 100% of the total $PM_{2.5}$ and risk-weighted emissions associated with those source categories. While the "Other Sources" of $PM_{2.5}$ and TACs selected represent only a small number of the total remaining sources in the CEIDARS database, they emit 36% of the $PM_{2.5}$ and 45% of the cancer-risk-weighted emissions associated with such sources.

Table 1. Summary of sources and emissions included in the stationary source database.

Source Category	Number of Sources Selected	Total Number of Sources	Percentage of Total Emissions Captured for Each Source Category[a]	
			$PM_{2.5}$	Cancer Risk-Weighted
Stationary Diesel Engines	1,000	5,152	93%	84%
Gas Stations	1,001[b]	2,580	--	85%
Perchloroethylene Dry Cleaners	605	605	--	100%
Other $PM_{2.5}$ Sources	100	6,679	36%	--
Other TAC Sources	100	4,525	--	45%

[a] Percentage of emissions captured, based on emissions reported in the District's 2008 CEIDARS database.
[b] Gas station sources ranked 1,000 and 1,001 had the same emission levels.

CEIDARS contains data by individual sources that are associated with each facility. If at least one source was selected for inclusion in the database, then all of the associated sources within the facility were exported to the database. STI entered available emissions, health risk data, stack parameters, and other source characteristics for the sources of interest, augmenting or replacing existing CEIDARS data as appropriate. Survey responses were included for 423 gas stations of the 441 surveys sent out and 345 individual diesel engines out of 310 surveys (some of which had multiple engines). Much of the data was gathered from permit applications, including information from HRA and PSD analyses performed as part of the permitting process. Because detailed modeling data was available through the HRA, all facilities that had at least one HRA completed for a source was included in the database.

Quality Assurance:
Throughout the data entry process, STI performed regular quality assurance checks and also provided interim copies of the stationary source database to the District for review. Internal quality assurance checks performed by STI included:

- **Range checks** – sorting variables such as annual emissions, stack heights, and cancer risk values to check for outliers (i.e., values that fall outside the expected range for the parameter of interest).
- **Completeness checks** – pairing data fields to check for incomplete information. For example, if stack height information is entered for a given source, the stack diameter field

should also be filled. Similarly, if health risk information is entered, pollutant concentrations should also be available.

- **Spot checks** – periodically, staff members not directly involved in data entry were asked to review entries for random sources to check for accuracy and completeness of information.

Application to San Francisco:
To date, the stationary source database developed includes information on 17,593 individual sources at 5,079 unique facilities for many of the larger cities across the Bay Area. This database was the starting point for the San Francisco CRRP. Efforts to quality assure and to supplement the database initially targeted the large sources of PM and sources with relatively high risk associated with the emissions. However, to ensure the adequacy of the CRRP, all permitted sources in San Francisco were added to the modeling database regardless of whether release information was available. In San Francisco, 1,582 unique sets of permitted source processes with emissions (Table 2) of $PM_{2.5}$ or toxic air contaminants were identified. Often more than one process with emissions is vented to a single release point—such as a stack or vent—which is why there are more processes than release points. In San Francisco, 705 release points were identified and modeled. More than half (64%) of these release points had known release heights; however, only 32% had complete release information.[4]

Table 2. Summary of data completeness for permitted stationary sources in San Francisco.

Data Record	Number of Records	% of Release Points
Permitted processes with emissions of $PM_{2.5}$ or toxic air contaminants	1582	224%
Release points	705	100%
Release points with release height	458	64%
Release points with complete release information	223	32%

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.

[4] Complete release information is defined as (1) a full set of stack parameters (height, diameter, exit temperature, and exit flow rate or velocity); (2) complete volume source characteristics (release height and initial lateral and vertical plume sizes); or (3) complete area source characteristics (release height and polygon dimensions).

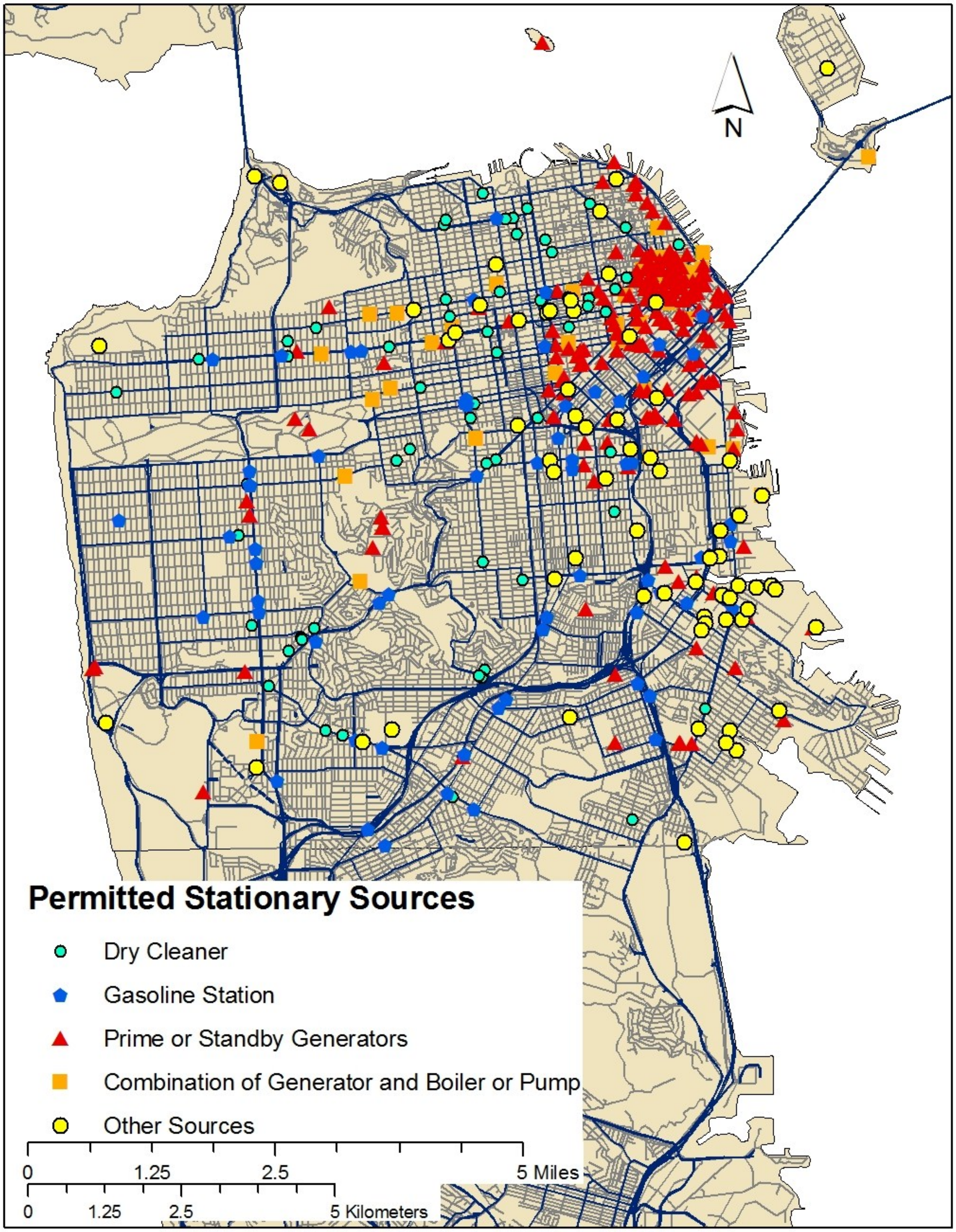


Figure 2. Permitted stationary sources in San Francisco are mapped by source category: dry cleaners (light blue circle), gas stations (blue pentagon), diesel engines or generators (red triangle), generators with a boiler or pump (orange square), and other sources (yellow circle).

Future year emission changes:
No changes in emissions were assumed from 2010 to 2025 except for dry cleaners and two stationary sources. CARB amended its Airborne Toxic Control Measure (ATCM) for emissions of perchloroethylene (PERC) from dry cleaning operations by requiring all PERC machines to be removed from service by January 1, 2023. The ATCM requires machines older than 15 years and co-residential machines to be phased out by July 1, 2010. Dry cleaners that operated PERC machines applicable to the July 1, 2010 deadline were removed from the inventory. The remaining facilities were included in the base year 2010 modeling and assumed to be operational until 2023. For the 2025 inventory, all of the facilities were assumed to comply with the ATCM and emissions from PERC dry cleaners were excluded from the modeling.

Adjustments were made to the emissions from two facilities, Potrero Power Plant and Bay View Management Company. Although Potrero Power Plant was one of the highest sources of emissions in 2010, by 2011, a new underground cable was installed to meet the electrical demand that was previously supplied by the power plant. The plant was closed in 2011 and contribution from the plant was not included in subsequent modeling.

Bay View composts San Francisco's green waste. The operations relied on multiple portable diesel engines to supply electrical power to process green waste collected from curbside recycling. However, they have agreed to replace these historic generators in favor of newer engines by 2012 that meets the District's permitting requirements. The emissions from this facility were adjusted in the model to account for the anticipated use of newer technology starting in 2012.

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 86 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 each station as well as the average speed. The train service along with average speed and throttle notch is summarized in Table 3. 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 estimated average speed of the Baby bullet train through San Francisco was estimated to be 54 mi/hr. For the Limited, average speed was 38 mi/hr; for the Local, average speed was 36 mi/hr.

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 second at each station. When trains stop at Downtown San Francisco terminus, idle time was extended to 20 minutes to account for locomotive power down.

Table 3. Average train speed and operating notch for Caltrain locomotives in San Francisco.

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

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.

Emission Factors & Emissions:
Locomotive diesel PM 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 4 presents the locomotive model group, certification tier, and emission factors for San Francisco.

Table 4. PM Emission Factors for Caltrain locomotives, adjusted for reduced fuel sulfur content (15 ppmw).

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

[1] USEPA, 1997.
[2] Fritz, 1995.

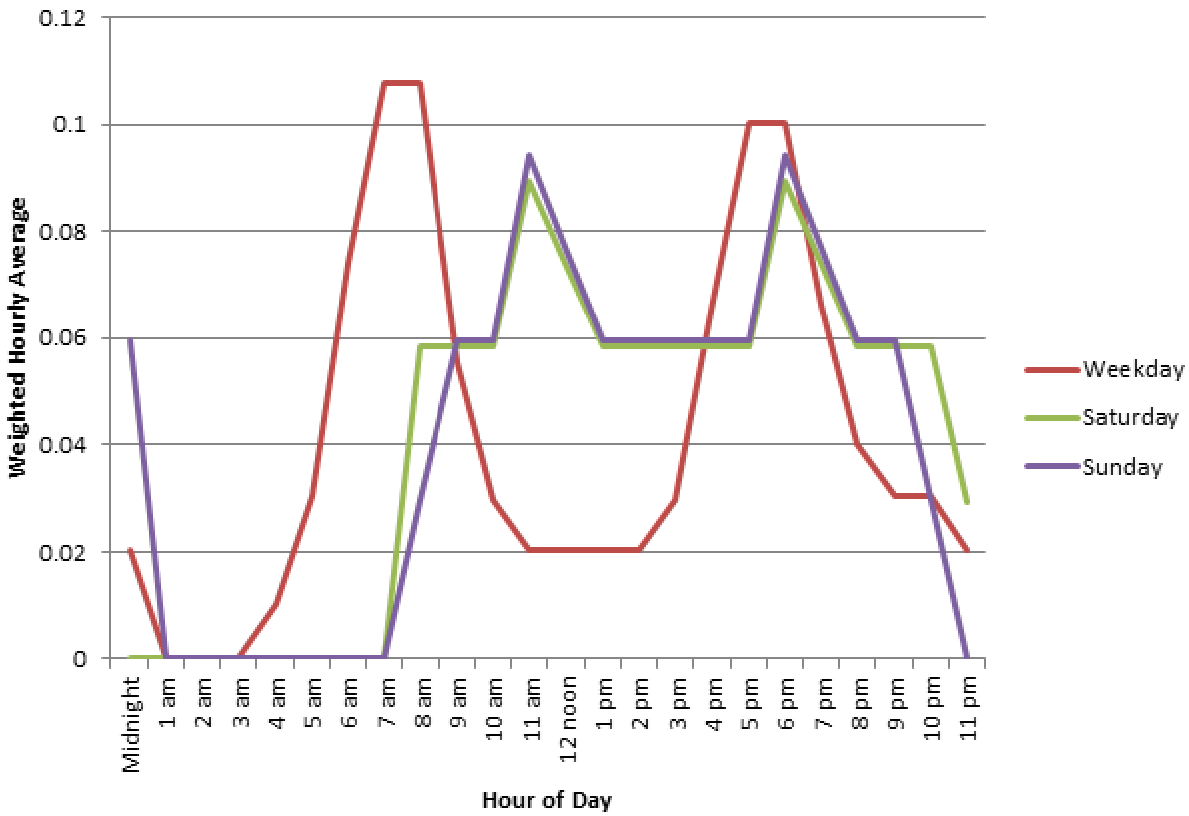


Figure 3. Normalized hourly activity for weekdays, Saturday, and Sunday for Caltrain in San Francisco.

The emission rate by engine mode, multiplied by the hours operated, gives the estimated emissions. Table 5 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.

The emissions in Table 5 were applied to years 2010 and 2014. Although Caltrain is expected to electrify by 2019 under a financing agreement between the Peninsula Corridor Joints Power Agency, the Metropolitan Transportation Commission and the California High Speed Rail Authority, Caltrains was assumed to operate diesel locomotives until 2025 to account for delays and other contingencies.

Table 5. Estimated weekday, Saturday, and Sunday Caltrain PM emissions (in tons per year) for San Francisco, from all services.

Service	Weekday PM Emissions (ton/yr)	Saturday PM Emissions (ton/yr)	Sunday PM Emissions (ton/yr)
Baby Bullet, Limited, and Local services combined	1.15	0.50	0.44

2.4 Ocean Going Vessels, Tug Boats, and Harbor Craft

Maritime emissions developed for the San Francisco CRRP were based largely on a report of 2005 emissions at publically operated ports in the Bay Area "SF Bay Area Seaports Air Emissions Inventory: Port of San Francisco 2005 Emissions Inventory" (Moffatt and Nichol and ENVIRON 2010). The report, a collaborative effort between BAAQMD and consultants Moffatt and Nichol and ENVIRON Corp., inventoried emissions from the largest sources of air emissions from maritime operations, including emissions from ocean-going marine vessels (OGVs), harbor craft, cargo handling equipment, heavy duty on-road vehicles, transportation refrigeration units, and rail locomotives. Emissions from tug boats were integrated with each maritime activity. Privately owned terminals, non-maritime activity on Port property, and ferry boat activities were not quantified in the Port inventory report. For the CRRP, emissions associated with cargo handling activity, heavy duty on-road vehicles, 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. The CRRP analysis focused solely on the emissions from two categories of ships: ocean-going vessels and harbor craft.

Activity:
The Port of San Francisco manages about 7.5 mi of coastline, from the Hyde Street Pier in the north to the Ferry Building, to the base of the Bay Bridge, then south through the waterfront industrial areas up through the Islais Creek area, and ending at Berth 96. The Port has over 500 tenants, though most are not engaged in maritime activities.

Emissions were estimated for 13 areas along the shoreline of San Francisco with either OGV or harbor craft activity. The Port currently operates an extensive cruise ship terminal at Berth 35; however, the Port intends to permanently relocate the terminal to Berth 27 in 2014 after the America's Cup event. The industrial area south of the ball park includes several cargo terminals, some lay berthing of large military supply vessels (US Maritime Administration – MARAD), and a large ship dry dock (BAE Systems) and repair yard. The types of activity are bulk and break bulk,[5] and mostly imports. One terminal exports tallow. The San Francisco Bar Pilots jointly lease a terminal with several excursion vessel companies. There is commercial fishing fleet and a charter boat fishing fleet and two tug companies berthed in San Francisco. In addition, there are some historic vessels (Jeremiah O'Brien at Pier 45) which have occasional outings in the Bay. Figures 4 and 5 outline areas with ship activity and list their affiliation based on the Port inventory report. Areas outlined in Figures 4 and 5 include areas where ships berth but do not include onshore property.

[5] Break bulk is loose material that must be loaded individually, and not in containers nor in bulk, as with oil or grain.

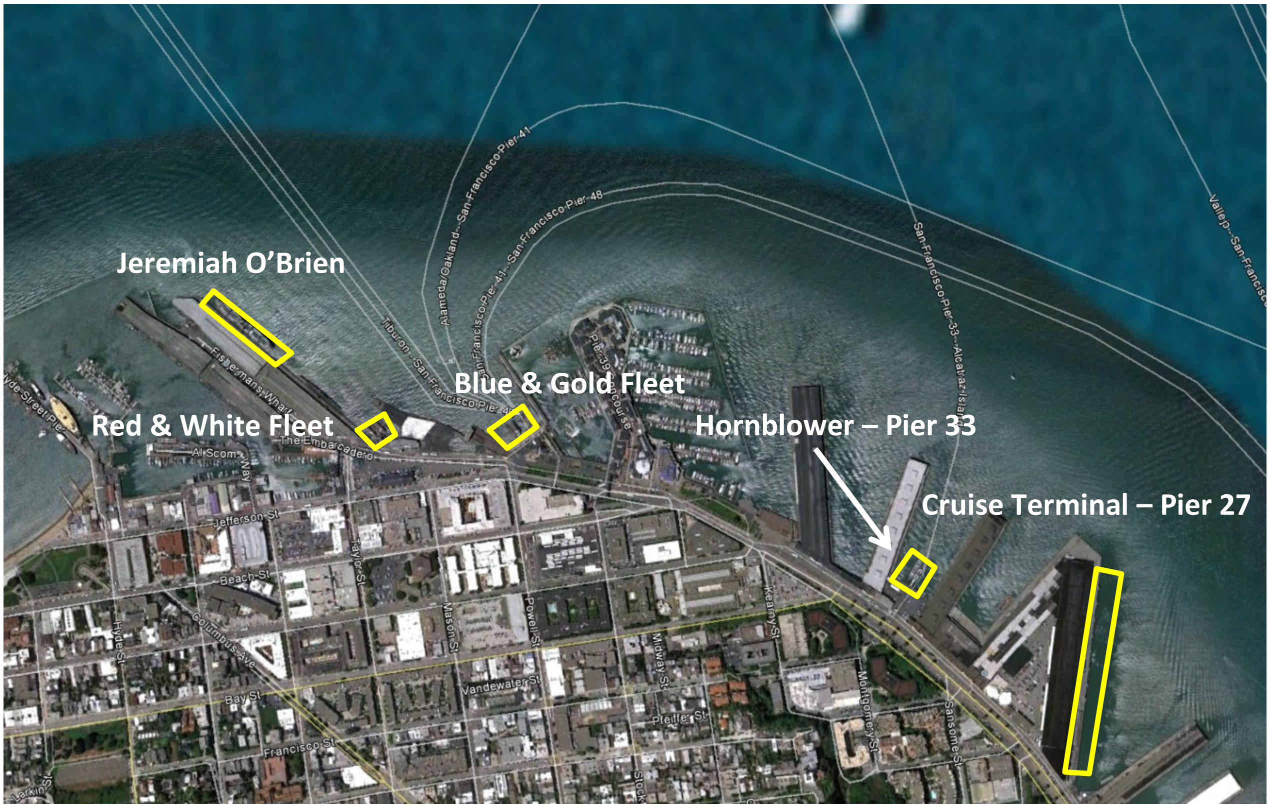


Figure 4. Sources of ship emissions in northern San Francisco.

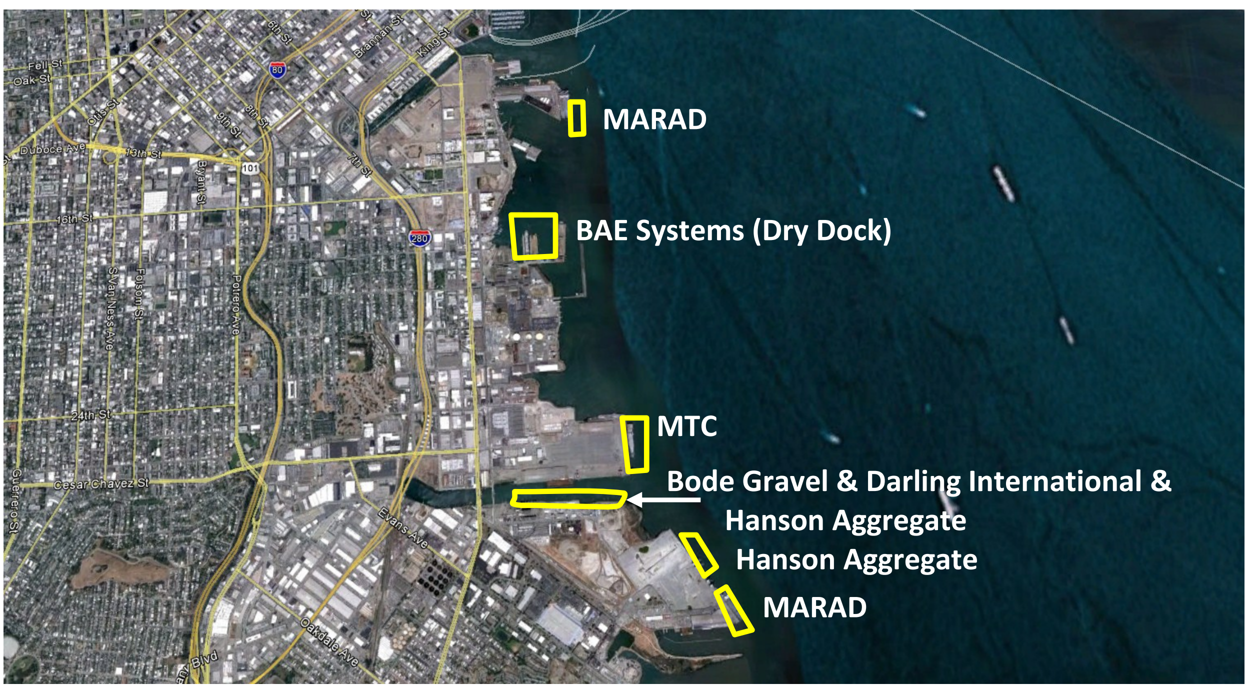


Figure 5. Sources of ship emissions in eastern San Francisco.

The two main types of OGVs are cruise ships and bulk carriers (or general cargo ships and small tanker ships). Cargo ships bring imports of aggregate, sand, steel, and newsprint and exports of tallow to and from the industrial terminals on the eastern piers in San Francisco. OGVs produce emissions at levels that depend on operating mode. Common modes include open ocean cruising, cruising at reduced speed (in the reduced speed zone or RSZ) inside the Bay, 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[6] 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. The sources of emissions include the vessels' main propulsion engines, auxiliary engines during hoteling, and boilers for heating. For this analysis, the District excluded emissions associated with cruising from the open ocean and 90% of the RSZ emissions since these emissions are released in the Bay away from the city. Emissions from the cruise terminal, including existing emissions from Berth 35 for years 2010 through 2014, were modeled from the proposed new location at Berth 27.

Harbor craft emissions include emissions from tug boats and excursion boats. Tug emissions are released from tug engines when the tugs assist OGVs (including barges) during arrivals and departures at the berths. 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. The emission estimates for harbor craft are based on two operating modes: vessel assist and transit to and from the vessel assist point using either the main propulsion engine or auxiliary diesel engines while berthed. Harbor craft emissions estimated in the SF Port inventory were incorporated when the craft was near berth, which constituted an estimated 20% of total emissions. The remaining 80% of emissions were assumed to be emitted during transit far from berth.

Tug boats are utilized in assisting ocean going vessel to dock and undock from the berths at the Port of San Francisco. Tug emissions during transit and assistance were attributed to each of the 13 source areas. Because most of the tug emissions occur in the Bay, the emissions were reduced by 80% to represent the fraction of emissions associated with maneuvering to and from the berths.

Emissions:
Table 6 presents a summary of the emission inventory for base year 2010 and project year 2014 that includes tug boat, OGV, and harbor craft emissions for each of the 13 source areas. Estimates indicate that cruise ships are the largest source of ship emissions in San Francisco. It was assumed that all PM emissions are attributable to diesel exhaust.

The emissions estimated from the 2010 report relied on emissions factors from 2005. Since then, CARB has adopted a marine main engine fuel regulation (2008) that requires all OGVs to use cleaner low sulfur fuels. Since January 2007, auxiliary engines in ocean going vessels were required to use low sulfur fuel when operating in California coastal waters (Marine Auxiliary Engine Clean Fuel Requirement). Harbor craft are likewise required to use the low sulfur fuel since January 2007. BAAQMD estimated that by using the low sulfur fuel, $PM_{2.5}$ emissions would be reduced by 54% for all ocean going vessels for base year 2010, relative to 2005 Port inventory report. Requirements for low sulfur fuel were already accounted for in the emissions factors for

[6] The Sea Buoy is located 17 miles west of the Golden Gate Bridge.

harbor craft and consequently additional reductions were not incorporated. It was conservatively assumed that emissions in project year 2014 would be consistent with base year 2010 even though continued reductions are expected in future years based on increased use of low sulfur fuel.

Table 6. Ship emissions for base year 2010 and project year 2014.

Location	$PM_{2.5}$ Emissions (tons/year) from		
	Main Engine	Auxiliary Engine	Boilers
MTC	0.077	0.303	0.040
Darling	0.010	0.043	0.002
Hanson Pier 92	0.131	0.125	0.005
Hanson Mission Valley	0.065	0.096	0.004
Bode	0.124	0.118	0.005
Cruise Terminal	5.994	---	0.017
MARAD Area 1	0.004	0.002	---
MARAD Area 2	0.004	0.002	---
BAE Systems (Dry Dock)	0.059	---	---
Jeremiah O'Brien	0.008	---	---
Red/White Fleet	0.799	0.083	---
Blue/Gold	0.799	0.083	---
Hornblower	0.137	0.015	---

For the 2025 emissions estimates, cruise terminal emissions were further reduced based on CARB's Shore Power Regulation (adopted December 6, 2007) which requires ocean going vessels to plug into electrical infrastructure (shore power), rather than idling main engines during the loading and unloading of cargo and at dock. The Port of San Francisco has plug-in capabilities and the regulation requires cruise ships that make five or more calls or any ocean going vessels equipped to receive shore power to utilize shore power. No hoteling emissions were used in 2025 for ships that came to port in San Francisco at least five times. There are occasions when more than one ship is at port with shore power capabilities and only one ship will be allowed to plug in. However these occurrences are infrequent, the District projects that there will be 14 days in 2012 in which two or more ships will be in port on the same day. The cruise temporarily disabled the shore power facilities during America's Cup activities and associated remodeling of the terminal. Consequently, emissions reductions associated with the plug in capabilities were not incorporated in the base year 2010 and project year 2014 inventories. Emissions for 2025 from ocean going vessels were reduced by 31% from 2010 inventory based on availability and wide use of low sulfur fuels. Table 7 presents the emission inventory for 2025.

BAE Systems has installed one shore power terminal in response to recently awarded contract to use the dry dock to repair T-AKE vessels. It is too early to assess the number of ships that will use the dock as well as the frequency in which the shore power will be used and consequently was not incorporated into the modeling analysis. Emissions for BAE was held constant except for reductions associated with low sulfur fuel. Future modeling of the site may incorporate these changes.

Table 7. Ship emissions for future year 2025.

Location	$PM_{2.5}$ Emissions (tons/year) from		
	Main Engine	Auxiliary Engine	Boilers
MTC	0.057	0.206	0.040
Darling	0.008	0.029	0.002
Hanson Pier 92	0.131	0.125	0.005
Hanson Mission Valley	0.065	0.096	0.004
Bode	0.124	0.118	0.005
Cruise Terminal	1.639	---	0.003
MARAD Area 1	0.003	0.002	---
MARAD Area 2	0.003	0.002	---
BAE Systems (Dry Dock)	0.043	---	---
Jeremiah O'Brien	0.008	---	---
Red/White Fleet	0.799	0.083	---
Blue/Gold	0.799	0.083	---
Hornblower	0.137	0.015	---

2.5 Transit Center Operations

The Transit Center is a transportation and housing project that will create a new major transit hub in downtown San Francisco. The project will replace the former Transbay Terminal at First and Mission Streets in San Francisco with a regional transit hub connecting eight Bay Area counties and the State of California through 11 transit systems: Alameda-Contra Costa Transit (AC Transit), Bay Area Rapid Transit (BART), Caltrain, Golden Gate Transit, Greyhound, Muni, SamTrans, Western Contra Costa Transit Authority (WestCAT) Lynx, Amtrak, Paratransit and future High Speed Rail from San Francisco to Los Angeles/Anaheim. Once completed in 2017, the Transit Center will be a five-story building with one above-grade bus level, ground floor, concourse, and two below-grade rail levels. New bus ramps will be created to connect the Transit Center to a new offsite bus storage facility and the Bay Bridge. Existing transit operations will continue until 2017, but at a temporary terminal. Many of the transit carriers have been rerouted to the temporary terminal located 500 feet east of the proposed Transit Center. Emissions from the transit operations including emissions from the temporary terminal for years 2010 through 2017 were modeled from the proposed new Transit Center.

Activity information for the transit center operations was derived from a report on prepared for the San Francisco Planning Department in compliance with the requirements for environmental review of the Transit Center (ENVIRON 2011). However, emissions from that report were based on EMFAC2007 and have been recalculated for the SF CRRP modeling using EMFAC2011.

Activity:

The Transit Center will generate emissions from bus operations at the following areas (ENVIRON 2011):

- Transit Center Bus Deck Level – this level is located two levels above the ground level of the Transit Center. Buses will load and off-load passengers from the level's central island. The bus level will be the primary bus transit facility for AC Transit to operate service from the East Bay. Muni route to Treasure Island, Amtrak and Greyhound will also use this level;
- Ground Level Bus Plaza – an outdoor bus plaza is located at the eastern end of the Transit Center building between Fremont and Beale Streets, serving Muni, Golden Gate Transit and SamTrans buses;
- Bus Ramps – as mentioned above, the new elevated bus ramps will connect the Transit Center to a new offsite bus storage facility and the Bay Bridge. The bus ramps enter the Transit Center from the west; and
- Bus Storage Facility – two bus storage facilities under the I-80 Freeway, bounded by Second, Perry, Fourth and Stillman Streets will be built to house buses for AC Transit and Golden Gate Transit during weekday off-peak hours. The portion dedicated to AC Transit is between Second and Third Streets, and the portion dedicated to Golden Gate Transit is between Third and Fourth Streets.

Emissions:

Emissions from bus operations were calculated using total number of bus trips (ENVIRON 2011) at each of the above four areas, emission factors from EMFAC2011, measured trip lengths, and an average length of idling time per trip. Average emission factors for PM10 (diesel PM exhaust—running and idling) and $PM_{2.5}$ (running, idling, brake and tire wear) for buses were obtained for 2017 when Transit Center operations are scheduled to start and for future year 2025. Table 8 presents the summary of the Transit Center bus operational emissions. Details of the emissions calculations follow that of the operations emissions calculations reported in the ENVIRON report, but use EMAC2011 emission factors. Year 2017 Transit Center emissions were used for planning year 2014, even though the project will not have been completed by 2014. In effect, the 2017 emissions were used as a proxy for emissions at the temporary terminal.

Table 8. Emissions from Transit Center operations in years 2014 and 2025, by source group.

Source Group	Diesel PM Emissions 2017 (t/yr)	$PM_{2.5}$ Emissions 2017 (t/yr)	Diesel PM Emissions 2025 (t/yr)	$PM_{2.5}$ Emissions 2025 (t/yr)
Transit Center Bus Deck Level – 24 hour	4.36E-04	6.81E-04	2.76E-04	5.33E-04
Transit Center Bus Deck Level – 6 a.m. to 12 p.m. operation	3.15E-02	6.29E-02	2.80E-02	5.97E-02
Transit Center Bus Deck Level - Commute Hour Operation	1.36E-03	2.69E-03	1.21E-03	2.55E-03
Ground Level Bus Plaza – 24 hour	4.55E-03	7.67E-03	3.98E-03	7.14E-03
Ground Level Bus Plaza – 6 a.m. to 12 p.m. operation	2.22E-03	4.06E-03	1.96E-03	3.82E-03
Ground Level Bus Plaza – Commute Hour Operation	1.20E-04	2.03E-04	1.05E-04	1.89E-04
Bus Storage Facility – AC Transit Area	1.15E-02	2.34E-02	1.02E-02	2.22E-02
Bus Storage Facility – Golden Gate Transit Area	4.07E-03	8.26E-03	3.62E-03	7.85E-03
Bus Ramps – to I-80	4.45E-02	9.03E-02	3.97E-02	8.59E-02
Bus Ramps – to Bus Storage Facility	2.51E-02	5.09E-02	2.23E-02	4.83E-02

2.6 Construction Projects

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. While recognizing these challenges, BAAQMD developed an emissions inventory for major multi-year projects. Minor projects are evaluated individually by the San Francisco Planning Department and are not included in this analysis. This section describes the methodology used to estimate emissions from construction activity in base year 2010 and projected to occur in 2025. No emission estimates were made for project year 2014. Emissions were estimated to represent the phase of construction expected to occur over the course of the modeling year and are not meant to encompass the entire project construction. Only exhaust emissions from construction equipment were included in the inventory; the analysis did not quantify emissions from fugitive dust or road dust. Health risk estimated from the emissions of construction projects are for informational purposes only and were not included in the city-wide assessment.

Major multi-year projects included residential projects, commercial/office/retail mixed use projects, and major transportation projects. The San Francisco Planning Department (SFPLAN) and review of Environmental Impact Reports (San Francisco County Transportation Authority

2007, SFPLAN 2008, San Francisco Redevelopment Agency 2010, San Francisco County Transportation Authority 2011, San Francisco Metropolitan Transportation Agency 2012, Transbay Center Joint Powers Agency 2012) provided a list of major projects that were constructed partially or fully during 2010 including:

- Transbay Terminal Demolition,
- Central Subway utility work,
- Presidio Parkway (Doyle Drive) construction,
- Mission Bay,
- Bayview Hunters Point, and
- Exploratorium at Pier 15/17.

The District developed a construction equipment list and construction periods for each of the major projects based on environmental clearance reports and photographs. Emissions were then estimated for each piece of equipment using emission factors and load factors taken from CARB's OFFROAD model (CARB 2010), which includes revisions to activity levels, load factors, and populations of construction equipment in California. Only equipment that is expected to be used during the modeling year was included in the emissions estimates. Table 9 presents the estimated diesel PM for major projects in units of tons per year.

Table 9. 2010 Major Construction Project Emissions

Project Name	Activity in 2010	DPM (t/yr)
Transbay Terminal	Demolition of East Loop ramps, Utility relocations, Geotechnical drilling	0.091
Central Subway	Utility relocation along 4th Street between Townsend and Market, and Clemintina Street	0.068
Presidio Parkway	Phase 1 work adjacent to existing roadway: Utility work, excavation of SB tunnel, building demolition.	0.348
Mission Bay	Construction of medical offices	0.19
Hunter's Point	Development of housing units, Blocks 53 & 54	0.001
Exploratorium	Demolition work and refurbishment of Pier 15 & 17	0.138

The future year emissions for 2025 were more difficult to quantify in comparison to 2010 due to less concrete data sources, such as construction reports and photographs. To estimate potential emissions for construction activities in 2025, the District focused on large, multi-phase projects that are already approved for construction by San Francisco Planning. Emissions were estimated for the following multi-phase projects in 2025 (SFPLAN 2009b, SFPLAN 2010b, SFPLAN 2010d):

- Park Merced
- Mission Bay
- Treasure Island
- Candlestick Point - Hunters Point

Emission estimates were determined by reviewing the published Environmental Impact Report for each project (see Table 11). Since each of these project emissions were estimated prior to the 2010 release of CARB's updated off-road emissions model, the District reduced the emissions by 33%, the average correction determined by CARB based on reduction in load factors.

Table 11. 2025 Large, Multi-Year Project Construction Estimates

Project Name	Activity in 2025	DPM (t/yr)
Park Merced	Final year of Phase 3 of reconstruction of Park Merced	0.6
Treasure Island	Phase 4 - Building Construction	0.3
Candlestick HPII-1	Residential development, Lot CP-12	0.1
Candlestick HPII-2	Residential development, Lot CP-13	0.1
Mission Bay 2025-1	Below Market Rate Housing, Lot 9	0.1
Mission Bay 2025-2	Below Market Rate Housing, Lots 3/4 East	0.07
Mission Bay 2025-3	Below Market Rate Housing, Lots 6 & 7	0.16
Mission Bay 2025-4	Below Market Rate Housing, Lot 12	0.04

3. Air Dispersion Modeling

From each of the air pollution sources inventoried in Section 2, the CRRP aims to quantify the contribution to annual concentrations of $PM_{2.5}$ and cancer risk, assuming a 70 year exposure. 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 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 CRRP: 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, buses at the Transit Center, and construction projects. Rcaline was applied 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). 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[7] (1 g/s). Model output was a *dispersion factor* with units of concentration per unit emissions ([μg/m3]/[g/s]). Following this approach, annual average concentrations resulted from multiplying the dispersion factor by an annual average emission rate.
For example, emissions were estimated on more than 9,200 roadway segments in San Francisco (Section 2.1). For each roadway segment, a modeling run was made, simulating a period of one year and assuming a unit emission rate. For each roadway, 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: annual concentrations for 2010 from multiplying by 2010 emissions and annual concentrations for 2025 from multiplying by 2025 emissions.

In this roadway example, two modeling runs were actually made (and two dispersion factors generated) for each roadway segment: one using a profile of activity representing total vehicle traffic and one using an activity profile representing heavy-duty truck traffic. Annual average $PM_{2.5}$ concentrations for total traffic resulted from multiplying total on-road $PM_{2.5}$ emissions by the dispersion factor for total traffic. Since a large fraction of diesel PM was from heavy-duty traffic, to estimate annual diesel PM concentrations (used for estimating cancer risk) the dispersion factor for heavy-duty truck traffic was used.

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 14 node Linux cluster, each with eight Intel® Xeon® E5335 2 GHz 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.

[7] 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 and "q" or "Q" to represent an emission rate.

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). Some mapping of emissions sources 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 was placed at a height of 1.8 meters from terrain height (commonly referred to as flagpole receptors) representing the breathing zone of an average adult.

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 mastor grid—identical grid spacing, origin, projection and datum parameters as the master grid—but covering a smaller area.

Each receptor subgrid was configured to be a rectangular array centered over the modeled source (Figure 6) with boundaries set at one or two kilometers from the source, depending on the source type. Individual roadway segments and segments of roads and parking near the Transit Center were modeled with a rectangular receptor array extending at least one kilometer from modeled sources[8]. For air pollution emitted from permitted sources, ships and harbor craft, and construction projects, a rectangular array was defined at least two kilometers from the modeled sources.

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 intepolation of irregulary spaced data (Comprehensive R Archive Network 2012).

8 Or to the boundary of the master grid.

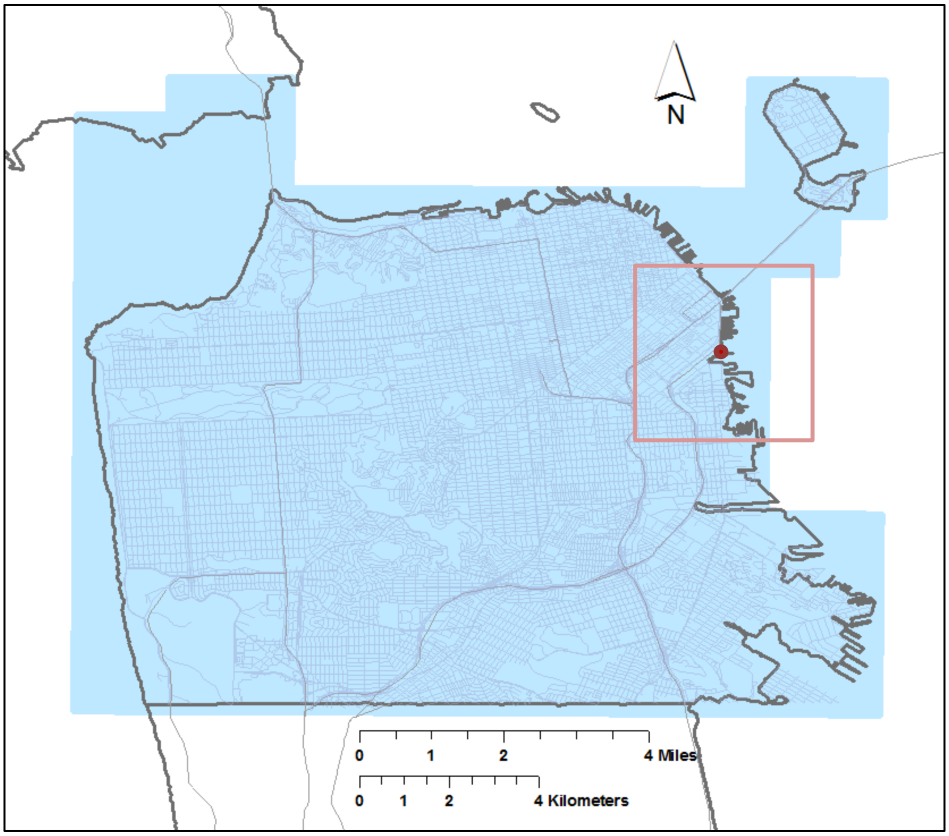


Figure 6. Master recetor grid (blue shaded area) with 20 meter spacing for the San Francisco CRRP. A receptor subgrid (such as the red rectangle) was defined around individual sources (such as the red dot representing the location of a permitted source) using receptors defined in the master grid with the same spacing.

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 23 stations, three in San Francisco (Figure 7), and collects information on:

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

Of the three meteorological stations located in San Francisco, the Mission Bay 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). A wind rose generated using the 2008 Mission Bay data (Figure 8) 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).

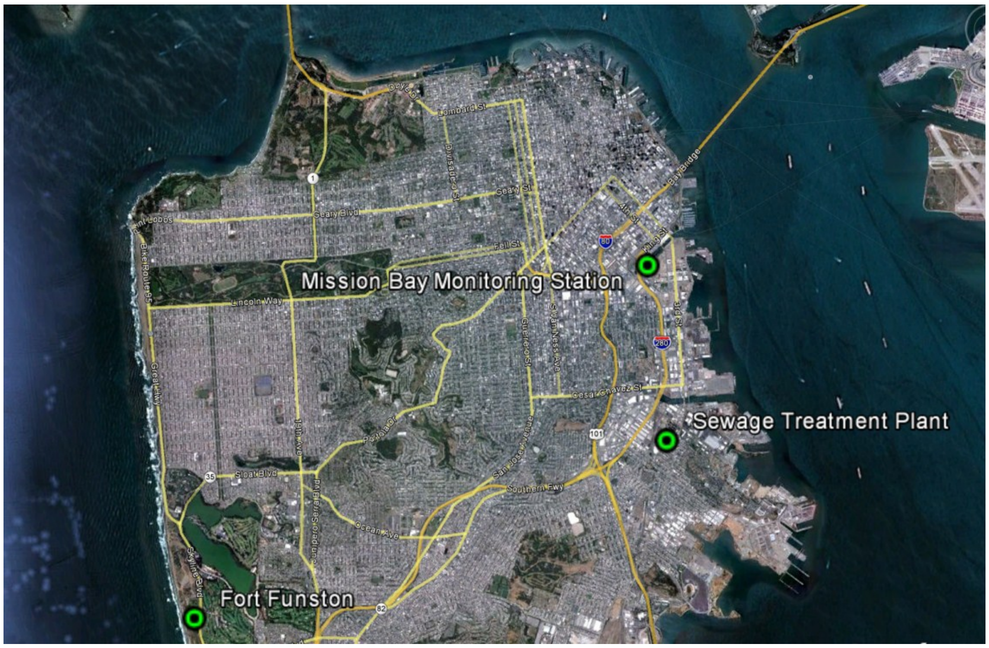


Figure 7. Meteorological monitoring stations in San Francisco

Mission Bay data for year 2008 were processed through AERMET, meteorological preprocessor to AERMOD, to create meteorological inputs to AERMOD. For Caltrain, the Rcaline model uses a compatible format to US EPA's Industrial Source Complex (ISC) model. The District routinely processes the hourly meteorological data collected from the monitoring network into ISC format and makes it available to the public. To ensure consistency between all sources that were modeled, the District used Mission Bay 2008 data (in ISC format) to model emissions from Caltrain.

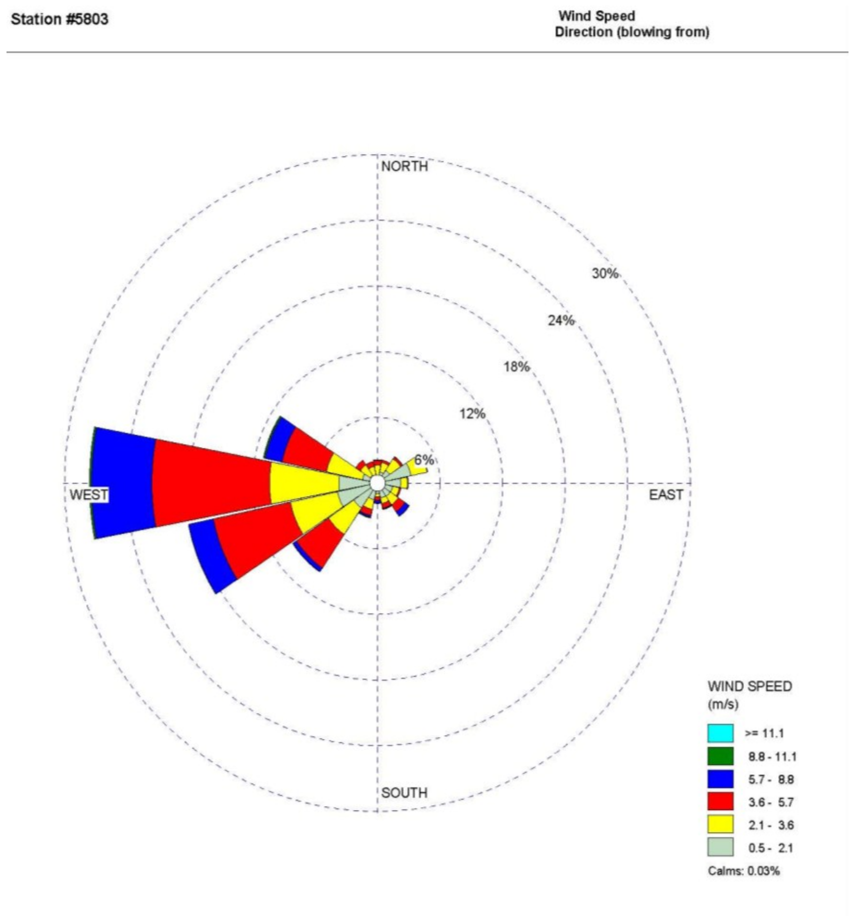


Figure 8. Mission Bay 2008 wind rose. Histogram colors indicate wind speed; compass sector indicates direction wind is blowing from.

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.

AERMOD FORTRAN source code (version dated 11103—April 13, 2011) was downloaded from the US EPA Support Center for Regulatory Air Models (SCRAM) web site (http://www.epa.gov/scram001/dispersion_prefrec.htm). Source code was compiled on the District's Linux cluster using the Portland Group, Inc., `pgf95` (v8.0-6 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.

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. A rural land use category was consistently selected to be representative of land cover in San Francisco. 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 and harbor craft, buses at the Transit Center, and construction projects, 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 were used for the CRRP are described below.

On-Road Mobile Sources:

On-road 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, an Esri™-formatted shapefile of San Francisco streets segments was subdivided into evenly spaced elements. 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. A new shapefile, produced from elements in all street segments, was overlaid on the SRTM raster map of San Francisco. The pixel values of the SRTM map represented the height above terrain of all streets and buildings in the city. The SRTM pixel value beneath each element determined the element height. These heights were then used to specify the vertical location of each roadway volume source. The release height, above roadway height, was set to 2 m; the initial lateral dimension was variable, dependent on roadway width; and the initial vertical dimension was 2.3 m.

The diurnal activity patterns—one for total traffic and one for heavy-duty trucks—coupled with corresponding release parameters were input to the model. Simulations were run both for total traffic and for heavy-duty truck activity patterns.

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 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. 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 13 were applied.

Table 13. Default modeling parameters for stationary sources.

Source Description	Source Type Assumed	Default Parameters
Prime or Standby Generator	Stack	Stack Height = 3.66 m (12 ft) Stack Diameter = 1.83 m (0.6 ft) Stack Temperature = 739.8 C (872 F) 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 m (3.4 ft) Initial lateral dimension = 1.98 m (6.49 ft, for assumed 4 dispensers, otherwise the equation below was applied (STI 2010): Lateral dimension (ft) = -0.0129 x n^2 + 1.08 x 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 defaults were applied: Stack Height = 6.1 m (20 ft) Stack Diameter = 3.05 m (1 ft) Stack Temperature = 644 C(700 F) Stack Velocity = 17.8 m/s (3,500 ft/min)
No information available	Volume	For sources that have no information, the District used the following defaults: Release Height = 1.8 m Initial Lateral Dimension = 10 m Initial Vertical Dimension = 1 m

Ships and Harbor Craft:

Ocean going vessels, tug boats, and harbor craft were modeled as two-dimensional area sources. For each of the source areas, the release height, length, and width of the source were entered. The dimensions of the release area encompassed the docking areas and piers but did not include land areas (see Figures 4 and 5). For each of these areas, an assumed release height of 6 m was used for tugs and harbor craft. An initial release height of 50 m was used for OGVs.

Transfer Station Operations:

For modeling bus emissions from the Transit Center deck, a series of adjacent 10 m by 10 m volume sources that cover the approximate dimension of the deck exhaust system were used as described in an earlier report (ENVIRON 2011). A release height of 29 m was used, with an initial vertical dimension of 0.5 m and an initial lateral dimension calculated by dividing the width of the volume sources by 4.3.

For the ground level bus plaza, a similar series of adjacent 10 m by 10 m volume sources that cover the area of the bus plaza were used. A release height of 0.6 m was used, with an initial vertical dimension of 0.14 m and an initial lateral dimension calculated by dividing the width of the volume sources by 4.3.

For the bus ramps, a series of adjacent 8.62 m by 8.62 m volume sources that cover the area of the ramps were used. A varying release height was used to reflect the height at different locations of the ramps, with an initial vertical dimension of 0.14 m and an initial lateral dimension calculated by dividing the width of the volume sources by 4.3.

For the bus storage facility, a series of adjacent 10 m by 10 m volume sources that cover the two bus storage facilities were used. A release height of 0.6 meters was used, with an initial vertical dimension of 0.14 m and an initial lateral dimension calculated by dividing the width of the volume sources by 4.3. For each of the different locations (deck exhaust, plaza, ramps and storage facility) emissions were distributed uniformly amongst all volume sources. Details of the source parameters used are presented elsewhere (ENVIRON 2011).

Construction Projects:
All construction projects were modeled as area sources. For all major projects, the dimensions of the active construction sites in 2010 and 2025 were applied if available through the environmental documents. Where exact information on the major construction site was not available, the District used the entire area of the proposed construction as the emission area. Because the emissions are produced from construction equipment exhaust, there is already some turbulent mixing that occurs at the release. To account for this mixing, an initial vertical dimension of 1.4 meters was used. In addition, construction emissions were modeled assuming eight hours of activity per day from 8 am to 4 pm.

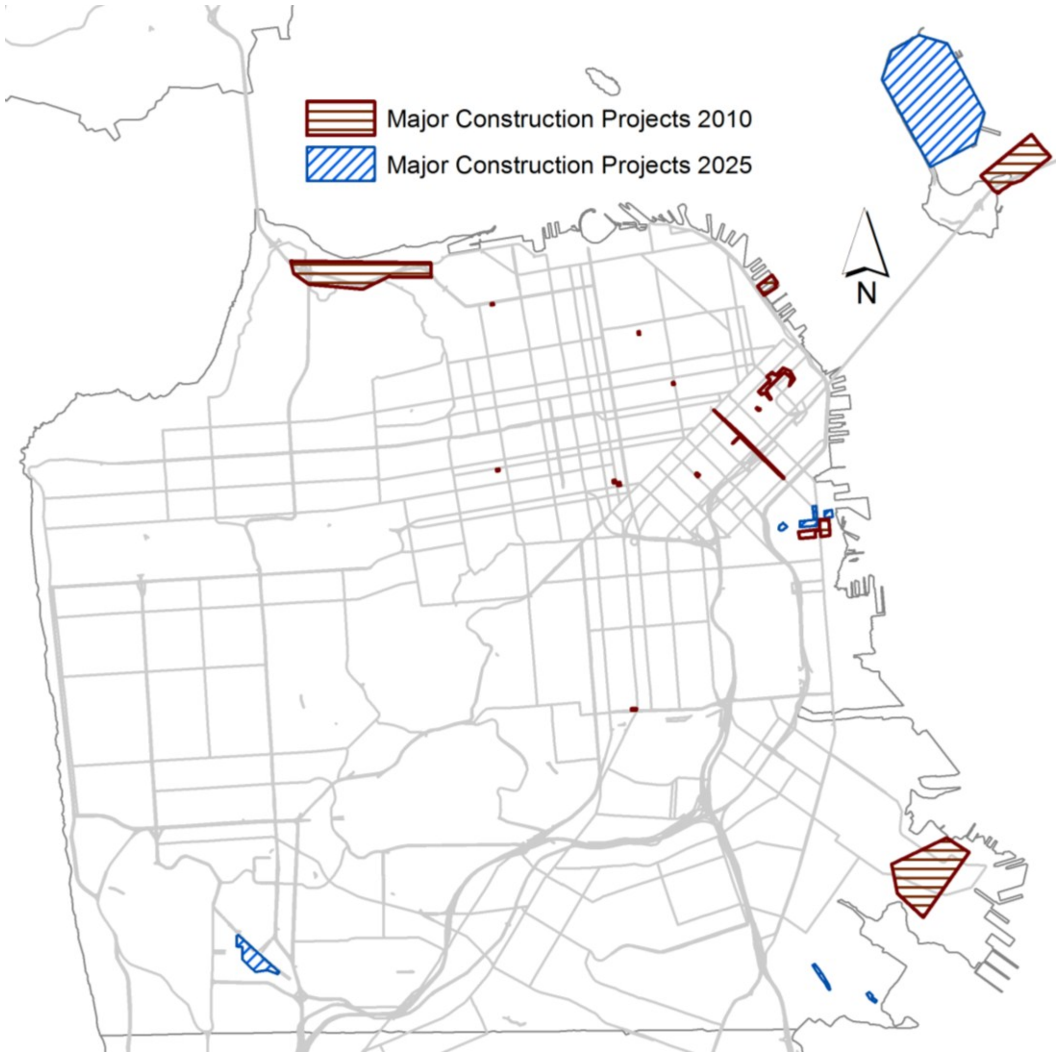


Figure 9. San Francisco major construction projects for 2010 (red horizontal shading) and 2025 (blue diagonal shading). Gray lines represent coastal boundaries and major roadways.

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 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 form emission sources identified, quantified, and provided as inputs to dispersion models.

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 (µg/m^3)
E_i	=	Annual average emission rate for pollutant i (g/s)
F	=	Dispersion factor, concentration per unit emission rate (µg/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, Transit Center operations, and construction projects. Concentrations of diesel PM and other pollutants were also calculated for 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 70-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.

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

$$Risk_i = 0.001 \times IF \times CPF_i \times \sum_j^{70\,years} C_{i,j} \times ASF_j,$$

where

$Risk_i$	=	Cancer risk; the incremental probability of an individual developing cancer as a result of inhalation exposure to a particular potential carcinogen i (unitless)
0.001	=	conversion factor (mg/µg)
IF	=	Intake Factor for inhalation (m^3/kg-day)
CPF_i	=	Cancer Potency Factor for pollutant i (mg chemical/kg body weight-day)$^{-1}$
$C_{i,j}$	=	Annual average concentration for pollutant i during year j (µg/m^3)
ASF_j	=	Age Sensitivity Factor for year j; the value of the factor is higher in early years of exposure (unitless)

Concentrations vary by year in response to annual average emissions for the year. Risk values were calculated for diesel PM from all the source categories. Organic gases from on-road gasoline-powered vehicles and other pollutants, such as PAHs and PERC, from permitted stationary sources also contributed to the cancer risk estimates. CPF and ASF values used were those recommended by CalEPA (CalEPA 2009, CalEPA 2011).

4.3 City-wide 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 two kilometers (depending on source type) in each direction from the source. The next processing step created city-wide 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 results for all source categories (excluding major construction projects) of $PM_{2.5}$ concentrations and cancer risk per year were totaled to produce a set of maps with all sources combined. Maps were produced for base year 2010, project year 2014, and future year 2025.

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), ships and harbor craft (Section 5.4), Transit Center (Section 5.5), and major construction projects (Section 5.6). 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 TAC 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, in particular maps of impacts of all sources combined, 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. Impacted areas were identified by comparing modeled results of local contributions to CRRP standards. For cancer risk, this local contribution was used directly for comparison to a CRRP standard. For $PM_{2.5}$, the local contribution was added to a background concentration for comparison to a CRRP standard.

To estimate the background concentration of $PM_{2.5}$, monitored levels from six locations (Figure 10) were compared to the value predicted from dispersion modeling for the base year (2010) at those locations. Monitoring data from a special study conducted in 2008 were used along with routinely collected data from the BAAQMD routine monitoring site at the Arkansas Street site for the same year.

Table 14. Measured and modeled $PM_{2.5}$ concentrations (μg/m3) and their differences at San Francisco monitoring sites.

Monitoring Location	Measured Value (μg/m^3)	Modeled Value (μg/m^3)	Difference (μg/m^3)
BAAQMD Arkansas St	9.10	0.88	8.22
SFDPH Arkansas St	8.90	0.88	8.02
Southeast Community Center	9.30	0.84	8.46
Muni Maintenance Yard	8.90	0.44	8.46
Potrero Recreation Center	7.60	0.21	7.39
Malcolm X Academy	7.90	0.06	7.84
Average Difference			**8.06**

The average difference between the monitored and modeled values (8.06 μg/m^3; Table 14) was used as the citywide ambient level for $PM_{2.5}$. This difference was added to the predicted value at each receptor site for comparison to the CRRP standard for $PM_{2.5}$.

Modeling results were generally developed for three years: a base year 2010, a project development year 2014, and a future year 2025. Where project emissions were assumed to be unchanged, only a single year is presented. When emissions from a source are eliminated (such as for Caltrain in 2025), no modeling results were developed.

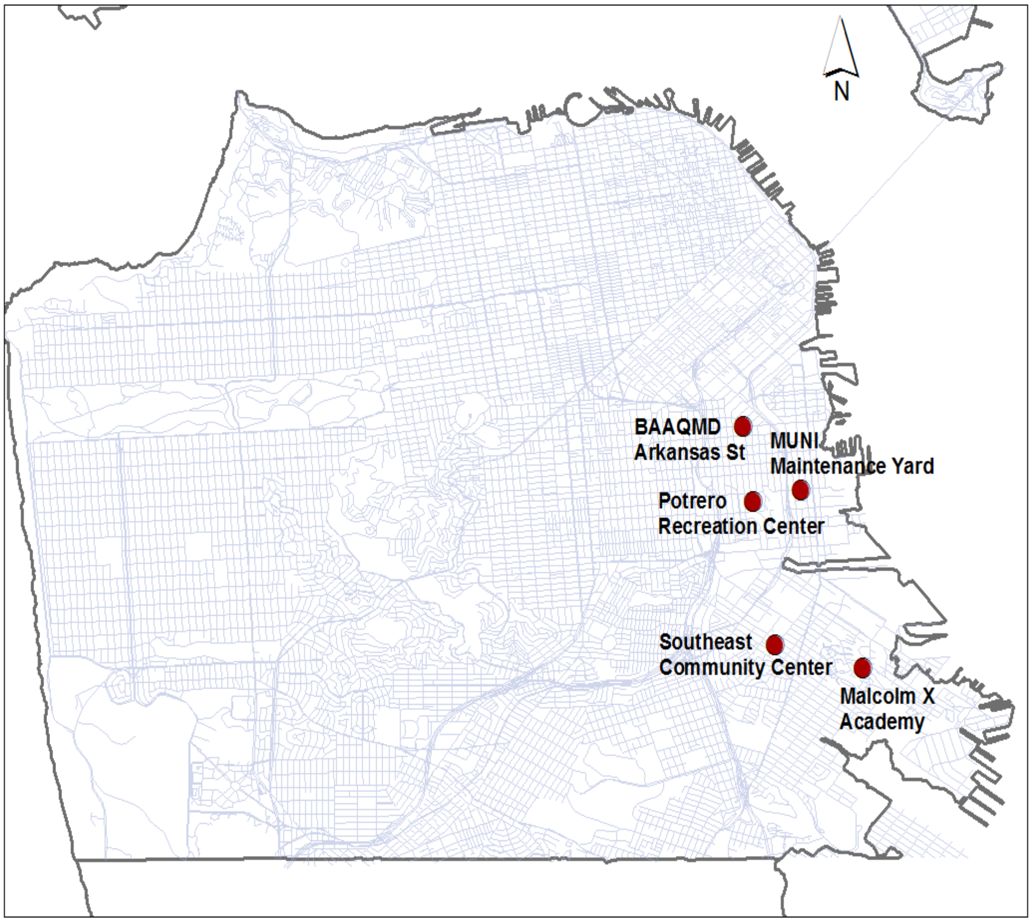


Figure 10. $PM_{2.5}$ monitoring locations in San Francisco, including 2008 special study sites.

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 11. Concentrations were mapped to the master receptor grid with color shading indicating the level of $PM_{2.5}$. In Figure 11, mapped concentration levels range from 0-0.1 μg/m3 (no shading) to more than 3 μg/m3 (darkest shading); darker shades indicate higher $PM_{2.5}$ concentrations. Emissions contributing to these mapped concentration increments include those from running exhaust but also from tire and brake wear. The spatial pattern of concentrations shown in Figure 11 closely follows the traffic activity: concentrations are highest near busy roadways, especially near the intersection of major freeways (such as 280 and 101) and where the roadway density is greatest (near downtown). All roadways in San Francisco with annual average daily traffic levels greater than 1,000 contribute to the roadway maps.

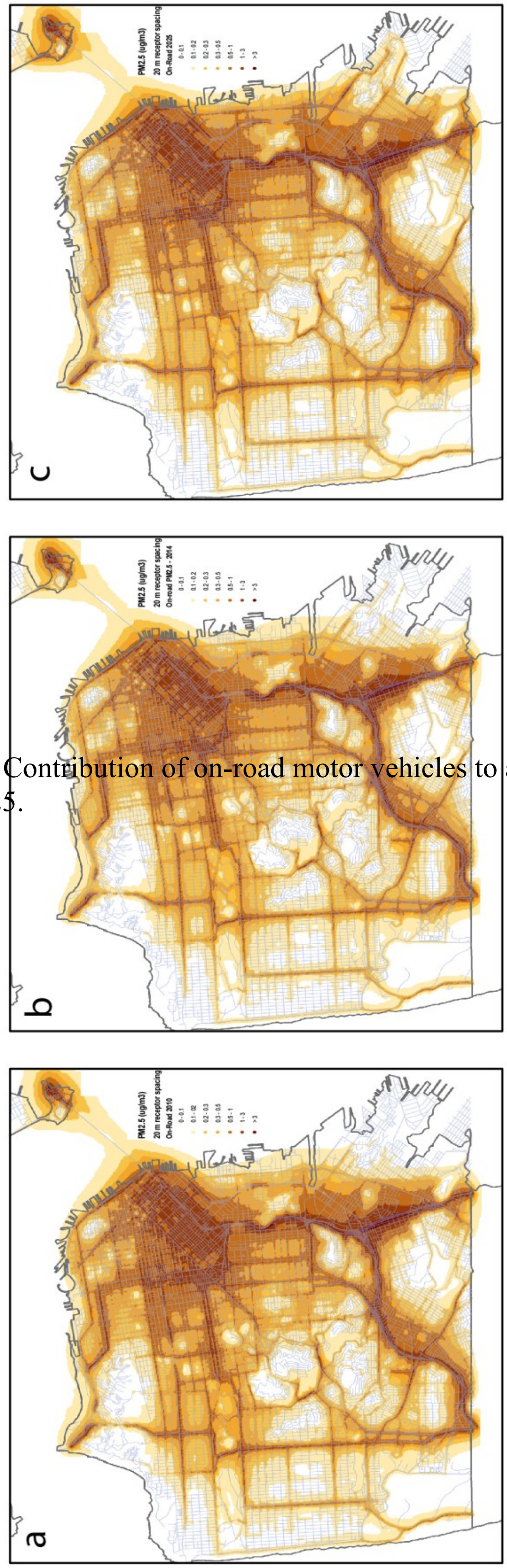


Figure 11. Contribution of on-road motor vehicles to annual average fine particulate matter (PM
and (c) 2025.

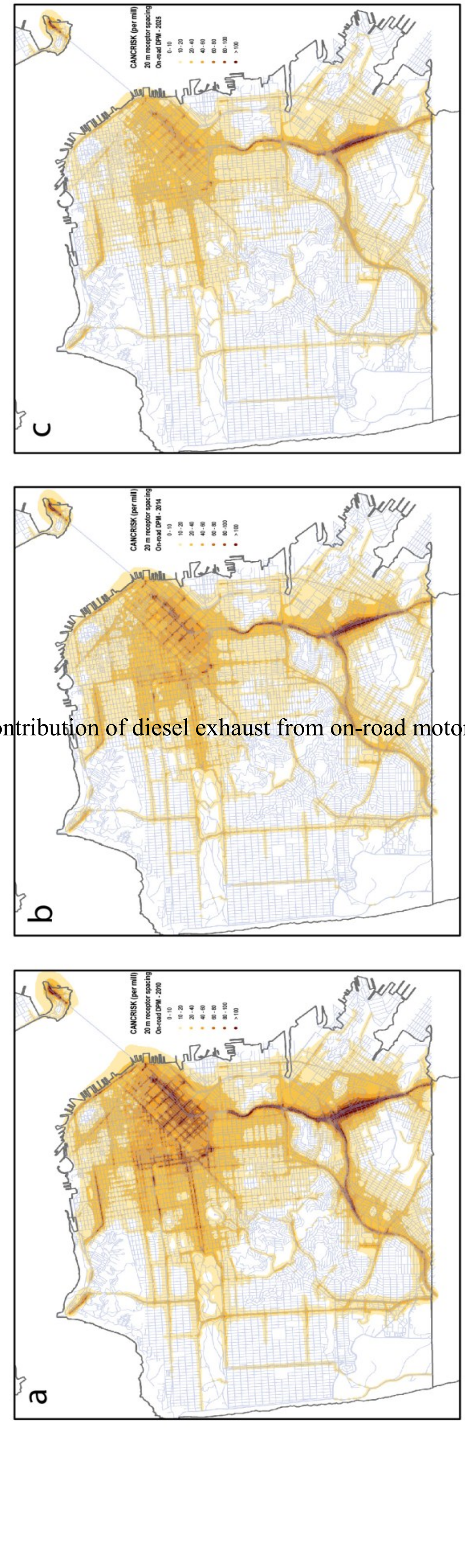


Figure 12. Contribution of diesel exhaust from on-road motor vehicles to cancer risk in (a) 2010, (b) 2014,

The incremental contribution of directly emitted $PM_{2.5}$ from on-road motor vehicles to $PM_{2.5}$ concentrations changes between years 2010 (Figure 11a), 2014 (Figure 11b), and 2025 (Figure 11c), but only by a small amount. Only small changes in $PM_{2.5}$ concentrations are indicated from one figure to the next. EMAC2011, used to generate emission factors, does report small reductions in PM exhaust emission factors between 2010 and 2025. These reductions in exhaust emission factors contribute to small emission reductions overall between these years. However, tire and brake wear emission factors hold constant, and there are projected increases in traffic in San Francisco, particularly evident in 2025 (Figure 11c) in the South Bayshore planning district (see Figure 9) where new development projects and more traffic emissions are expected. Increases in traffic tend to offset reductions in exhaust emission factors.

Cancer risk from diesel exhaust:

Figure 12 maps the contribution of diesel exhaust 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. Incremental cancer risk was mapped to the master receptor grid with color shading indicating the level of risk (per million) assuming a 70-year exposure, and accounting for changes in emissions. In Figure 12, mapped risk levels range from 0-10 per million (no shading) to more than 100 per million (darkest shading); darker shades indicate higher potential cancer risk. The spatial pattern of risk shown in Figure 12 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.

Recognizing the relatively high contribution of heavy-duty trucks to diesel particulate matter, in relation to their numbers, CARB has introduced important regulation of PM from on-road trucks and buses. The regulation requires diesel trucks and buses that operate in California to be upgraded to reduce emissions. Heavier trucks must be retrofitted with PM filters beginning January 1, 2012, and older trucks must be replaced starting January 1, 2015. By January 1, 2023, nearly all trucks and buses will need to have 2010 model year engines or equivalent. These diesel PM emission reductions emissions lowered cancer risk values shown in for all maps in Figure 12 (risks assume a 70-year exposure). However, risk reductions are greater for later years.

Cancer risk from non-diesel organic gases:

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. Maps in Figure 13 show the spatial distribution of cancer risk from gasoline-powered vehicles and the reductions in risk over time. Color shadings mark the same concentration levels in Figure 13 as in Figure 13. Cancer risk estimates from gasoline-powered vehicles included contributions from total organic gases (TOG) present in the exhaust emissions but included those from running evaporative losses, from un-combusted fuel escaping vehicle fuel lines and engines. As gasoline fleets become cleaner (lower emission factors for TOG) cancer risks are reduced for project year 2014 (Figure 13b) and future year 2025 (Figure 13c) relative to base year 2010 (Figure 13a).

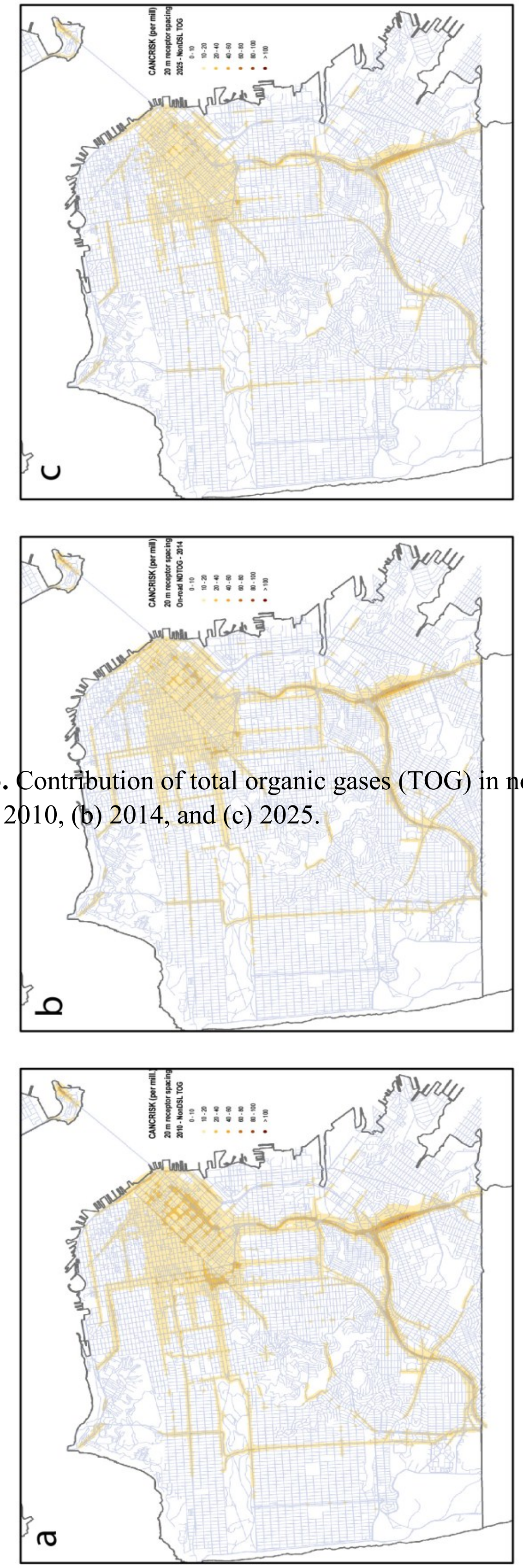


Figure 13. Contribution of total organic gases (TOG) in non-diesel exhaust from gasoline-powered on-
risk in (a) 2010, (b) 2014, and (c) 2025.

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 14. In Figure 14, mapped concentration levels range from 0-0.1 μg/m3 (no shading) to more than 3 $\mu g/m^3$ (darkest shading); darker shades indicate higher $PM_{2.5}$ concentrations. Many of the sources contributing to local peaks in $PM_{2.5}$ concentration in Figure 14 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). The contribution a stationary sources to $PM_{2.5}$ concentrations is determined by its emission rate and also by the type of release. For example, stack releases are influenced by stack height and by plume rise of the exhaust stream.

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 existing rules adopted by the BAAQMD. However, no specific new regulations for fine particulate matter have been assumed for future years, so planning (2014) and future year (2025) year emission rates and concentrations are largely similar to 2010. Adjustments for year 2014 (and beyond), relative to 2010, were made to the emissions from two facilities: Potrero Power Plant and Bay View Management Company. The Potrero Power Plant closed in 2011 and contribution from the plant was not included in subsequent modeling. Bay View has committed to replacing historic generators in favor of newer engines which meet the District's permitting requirements by 2012. The emissions from this facility were adjusted to account for the use of newer technology.

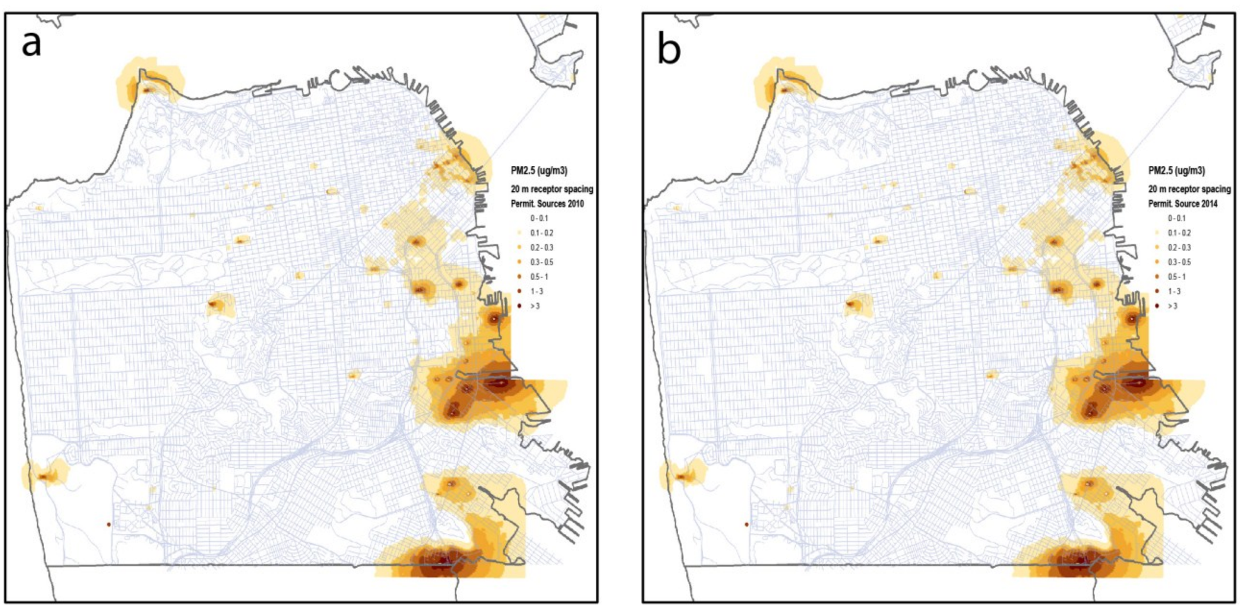


Figure 14. Contribution of permitted stationary sources to annual average fine particulate matter ($PM_{2.5}$) in (a) 2010 and (b) 2014. $PM_{2.5}$ levels in year 2025 from these sources were estimated to be the same as in 2014.

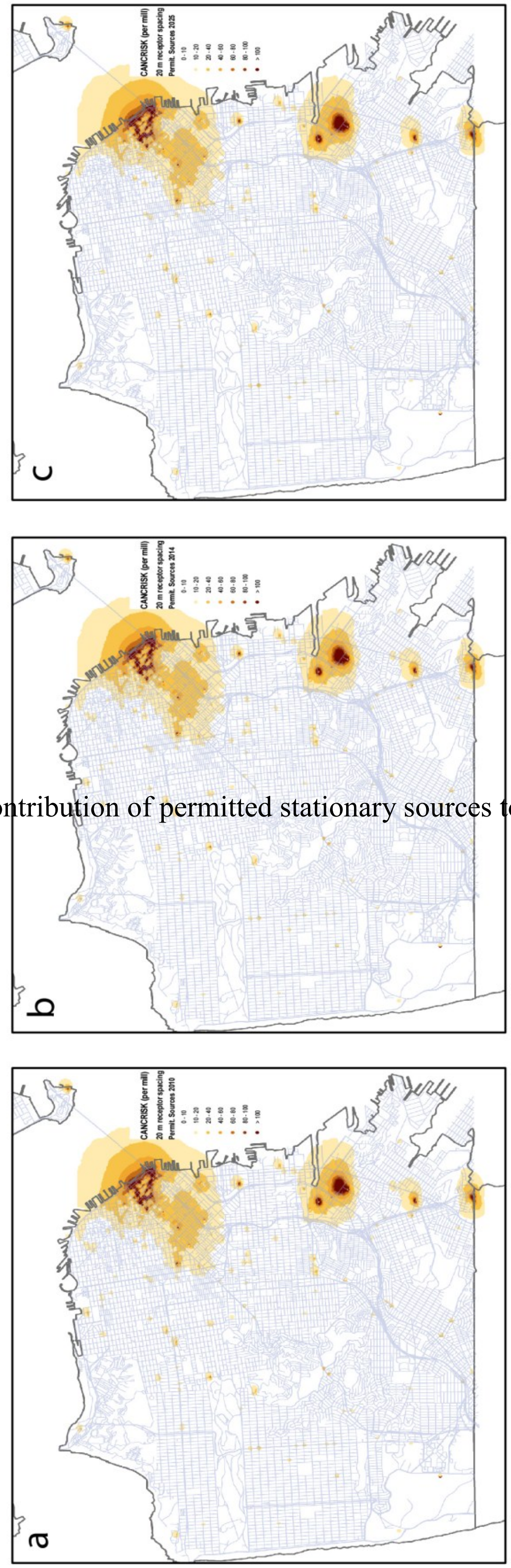


Figure 15. Contribution of permitted stationary sources to potential cancer risk in (a) 2010, (b) 201

Cancer Risk:

Combustion of diesel fuel is a major contributor to potential cancer risk from permitted stationary sources in San Francisco (Figure 15). For example, a large contributor to the area of high potential cancer risk in downtown San Francisco was backup diesel generators. Other sources, such as PERC drycleaners and gas stations, contribute many localized peaks in risk at scattered locations throughout the city. The sewage treatment plant produces a large peak from volatilized ages emitted from wastewater. Localized changes in risk were predicted from the elimination of PERC drycleaners by 2023.

5.3 Caltrain

Annual $PM_{2.5}$:

Annual average $PM_{2.5}$ concentrations in 2010 from Caltrain locomotive's diesel exhaust were estimated at between 0.1 and 0.2 μg/m^3 immediately adjacent to the rail line running through San Francisco (Figure 16a). Dominant westerly winds push higher concentrations to the east side of the rail line: the annual average $PM_{2.5}$ concentration contributed from Caltrain is roughly 0.1 μg/m^3 to a distance of about 50 m (about 150 ft) east of the tracks and drops quickly at greater distances. Highest concentrations of $PM_{2.5}$ were predicted near the downtown train station where extended periods of idling occur (20 min per train). Near the downtown station, $PM_{2.5}$ concentration levels of 0.1 μg/m^3 or greater extend to about 200 m (about 650 ft) east of the rail lines; values of 0.2 μg/m^3 or greater extend to about 50 m east of the lines.

$PM_{2.5}$ emissions and concentrations in project year 2014 were estimated to be the same as in base year 2010. However, in future year 2025, when the Caltrain service is projected to be electrified, locomotives will no longer emit diesel $PM_{2.5}$ and the concentration increment from Caltrain will be zero.

Cancer Risk:

The emitted diesel PM from Caltrain locomotives creates an increment in potential cancer risk along the rail line. In 2010, an increment in potential risk of 10 per million extends about 200 m (about 650 ft) east and 50 m (150 ft) west of the rail line (Figure 16b). A similar increment in potential risk from Caltrain extends about 500 m (about 1/3 mi) east and about 200 m west of the downtown station, where the incremental potential risk is highest. The calculated incremental potential risk for base year 2010 assumes that the Caltrain service will be electrified in 2025: diesel PM concentrations were assumed to remain constant from 2010 to 2025, but to drop to zero after 2025. The increment in potential risk in project year 2014 is closer to the projected date of Caltrain electrification, so risks were projected to be lower for 2014 (Figure 16c). These calculated risks would need to be reevaluated if the projected date for Caltrain electrification changes.

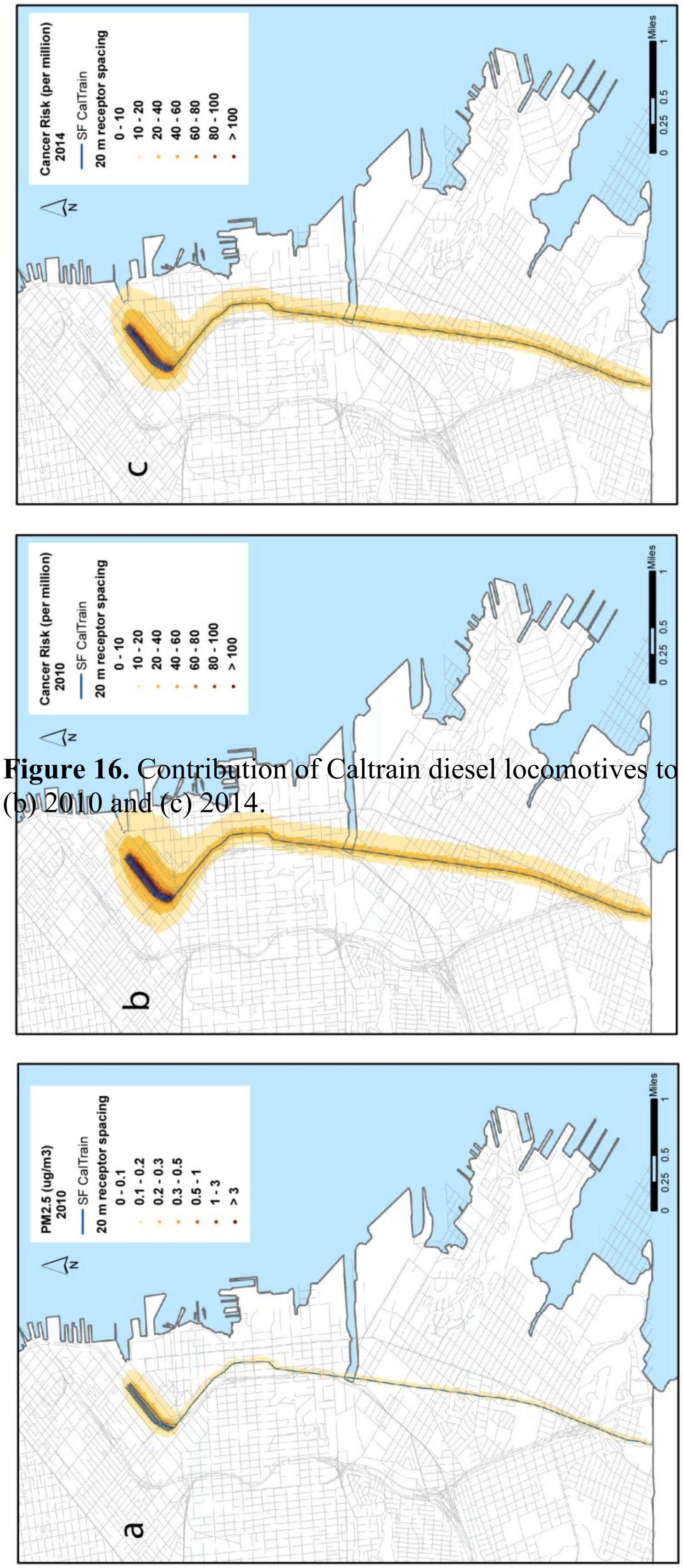


Figure 16. Contribution of Caltrain diesel locomotives to (a) annual average fine particu
(b) 2010 and (c) 2014.

5.4 Ocean Going Vessels, Tug Boats, and Harbor Craft

Annual $PM_{2.5}$:

The highest increment in annual average $PM_{2.5}$ estimated from OGVs, tugs, and harbor craft was predicted near Pier 41 in the northeast edge of the city (Figure 17). $PM_{2.5}$ concentrations, especially from the elevated releases of particles from tall OGV stacks, come onshore and intersect with terrain at Russian Hill and Telegraph Hill. From Pier 41, $PM_{2.5}$ concentrations ranging from 0.1 to 1 $\mu g/m^3$ extend southward onshore to about 600 m (about 1/3 mi). Smaller $PM_{2.5}$ peak concentrations were predicted in the south near Pier 94. On-shore concentrations of 0.1-0.2 $\mu g/m^3$ were predicted in the industrial area near Amador Street.

Because of shore power projects, which reduce near-shore exhaust from ship main engines near the northern piers, the contribution of $PM_{2.5}$ from OGVs is reduced for project and future years (Figures 17b and 17c, respectively) relative to the base year (Figure 17a).

Cancer Risk:

Cancer risk calculations treated all PM emitted by OGVs, tugs boats, and harbor craft as diesel PM, so the cancer risk maps in Figure 18 mirror the $PM_{2.5}$ maps in Figure 17. The highest increment in potential cancer risk was predicted near Pier 41. Cancer risk contributions, especially from the elevated OGV stacks, come onshore and intersect with terrain at Russian Hill and Telegraph Hill. From Pier 45 to Pier 29, potential cancer risk exceeds 100 per million. A much smaller area to the south, near Islais Creek, extending to Amador Street, also has potential risk concentrations of over 100 per million.

Small reductions over time in potential cancer risk from OGVs, due to improvements in shore power facilities, are shown in Figure 18. The extent of areas over 10 per million and the magnitude of the peak risk are reduced between base year 2010 (Figure 18a) and future year 2025 (Figure 18c).

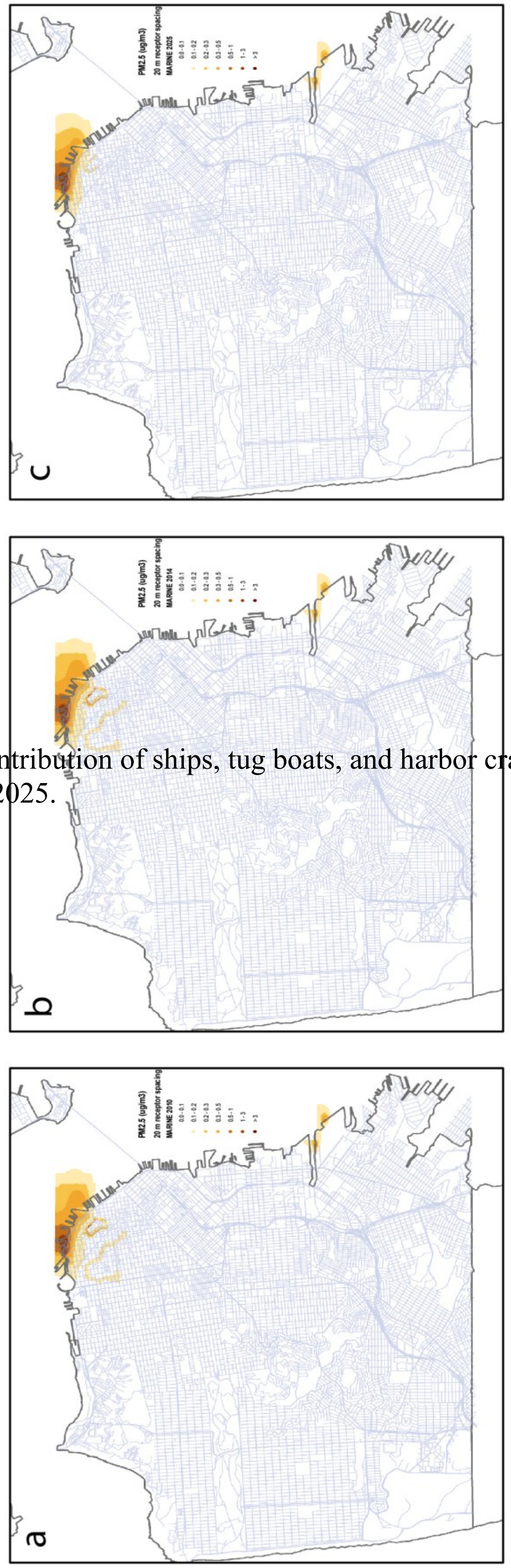
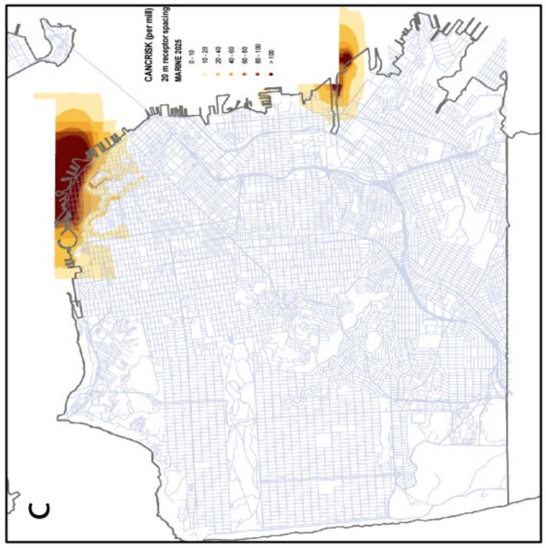
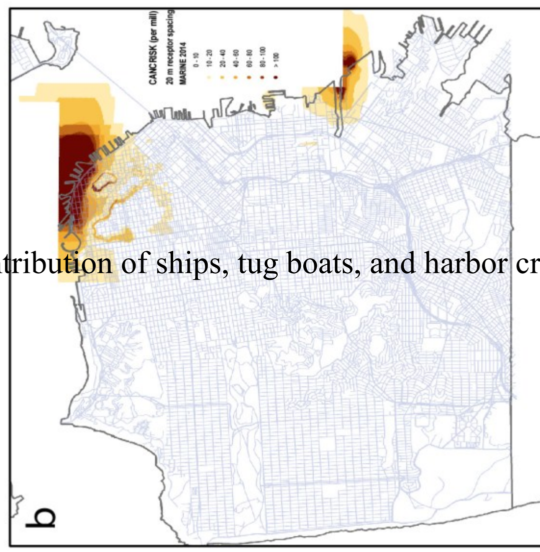


Figure 17. Contribution of ships, tug boats, and harbor craft to annual average fine particulate matt
2014, and (c) 2025.





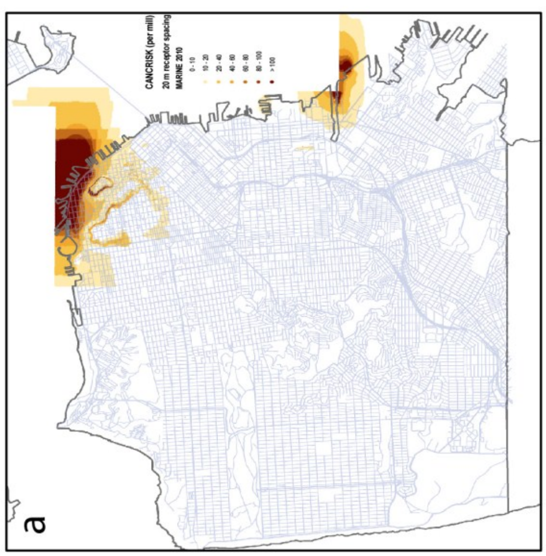


Figure 18. Contribution of ships, tug boats, and harbor craft to potential cancer risk in (a) 2010, (b)

5.5 Transit Center Operations

Annual $PM_{2.5}$:

Compared to other sources identified and modeled, Transit Center operations contribute a relatively small amount to the local annual average $PM_{2.5}$ concentrations (Figure 19). Elevated annual average $PM_{2.5}$, in the range of 0.1 to 0.2 mg/m3, occurs near the bus storage facility, the ground level bus plaza, and the transit center deck. Operations are scheduled to begin at the new Transit Center in 2017 and this was the first year modeled and presented (Figure 19a). Small reductions in $PM_{2.5}$ between 2017 and 2025 were predicted due to fleet turnover and cleaner buses in the future year (Figure 19b).

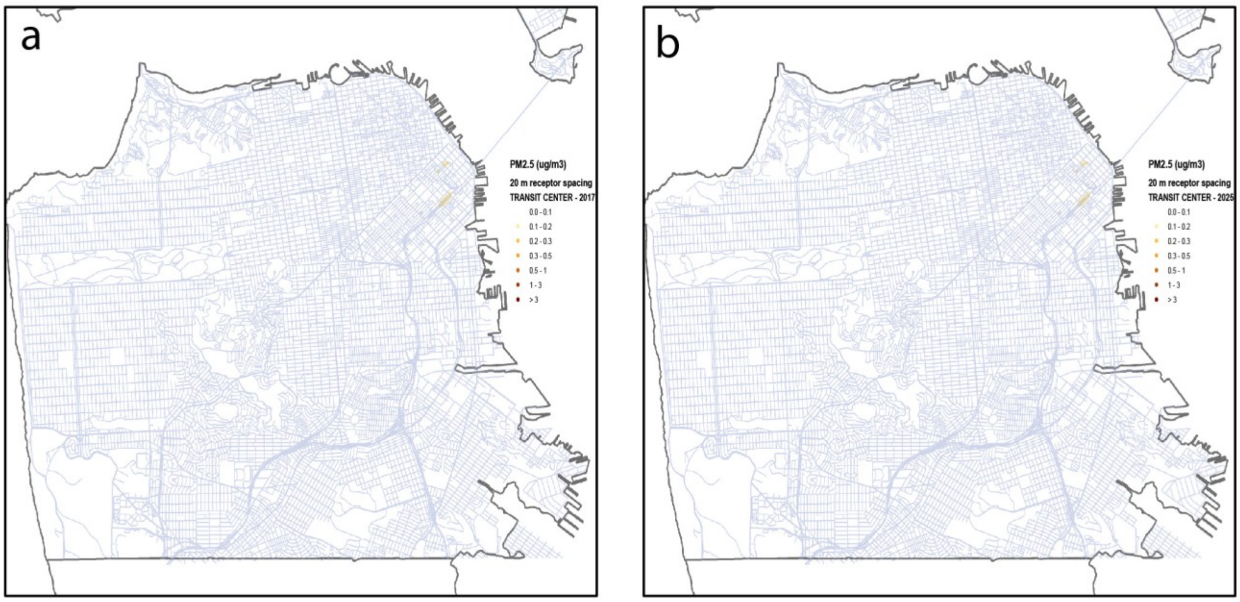


Figure 19. Contribution of Transit Center bus operations to annual average fine particulate matter ($PM_{2.5}$) in (a) 2017 and (b) 2025.

Cancer Risk:

Exhaust emissions of diesel PM from buses produced an estimated 20 to 40 per million increased potential cancer risk near the bus storage facility, the ground level bus plaza, and the transit center deck (Figure 20). A larger area with between 10 to 20 per million increased risk encompassed these areas and the bus ramps connecting the Transit Center to Interstate 80. Small reductions in risk were predicted in the future year 2025 (Figure 20b) compared to 2017 (Figure 20a).

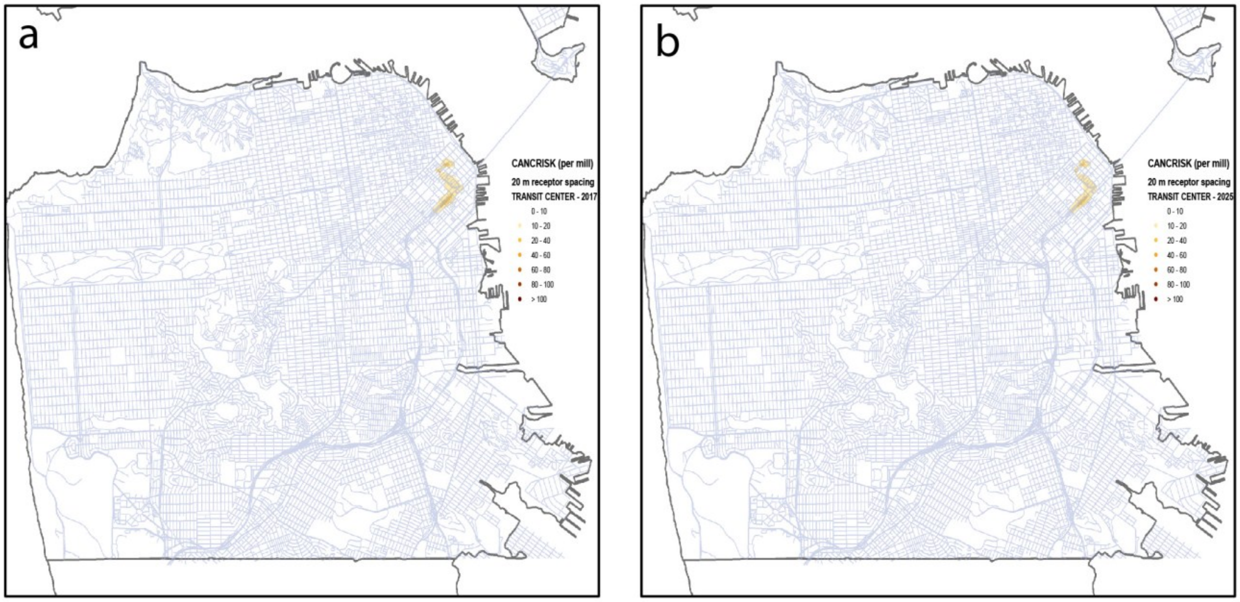


Figure 20. Contribution of Transit Center bus operations to potential cancer risk in (a) 2017 and (b) 2025.

5.6 Construction Projects

Annual $PM_{2.5}$:

The locations of the highest incremental contribution to annual average $PM_{2.5}$ from construction projects' diesel exhaust in 2010 (Figure 21a) and in 2025 (Figure 21b) correspond to the locations of major projects (Figure 9) that occurred in 2010 and those projected for 2025.

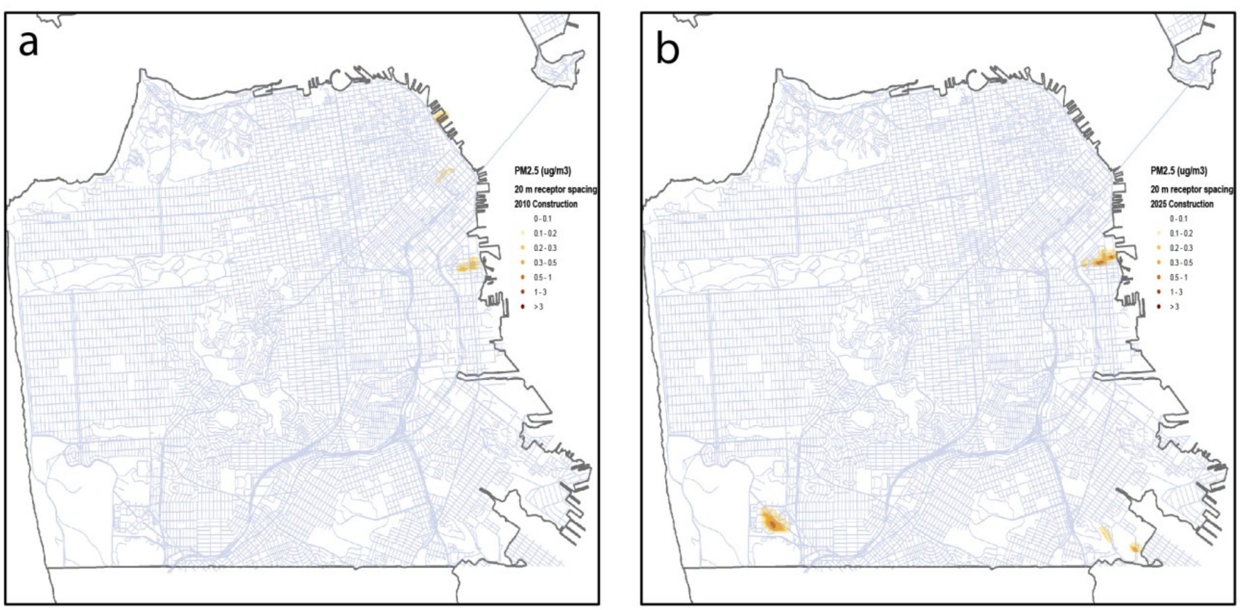


Figure 21. Contribution of construction projects to $PM_{2.5}$ in (a) 2010 and (b) 2025.

Cancer Risk:

Because construction emissions are variable in magnitude and location from year to year and because they were estimated only for the base year 2010 and future year 2025, the incremental contributions to potential cancer risk from construction projects in each case was based on a single year of exposure only. Figure 22 shows that peak incremental potential cancer risk from a single year of exposure in both base and future years peaks near the major construction projects, coinciding with the peak of incremental diesel exhaust PM.

The major construction analysis represents a snapshot of emissions expected to occur during the specific year of activity. The purpose of the analysis was to provide a general level of understanding regarding the likely impacts associated with large construction projects. However, the cancer risk and average $PM_{2.5}$ concentrations associated with major construction projects were not incorporated into the city-wide assessment because of the uncertainties associated with the emission estimates and future construction activities.

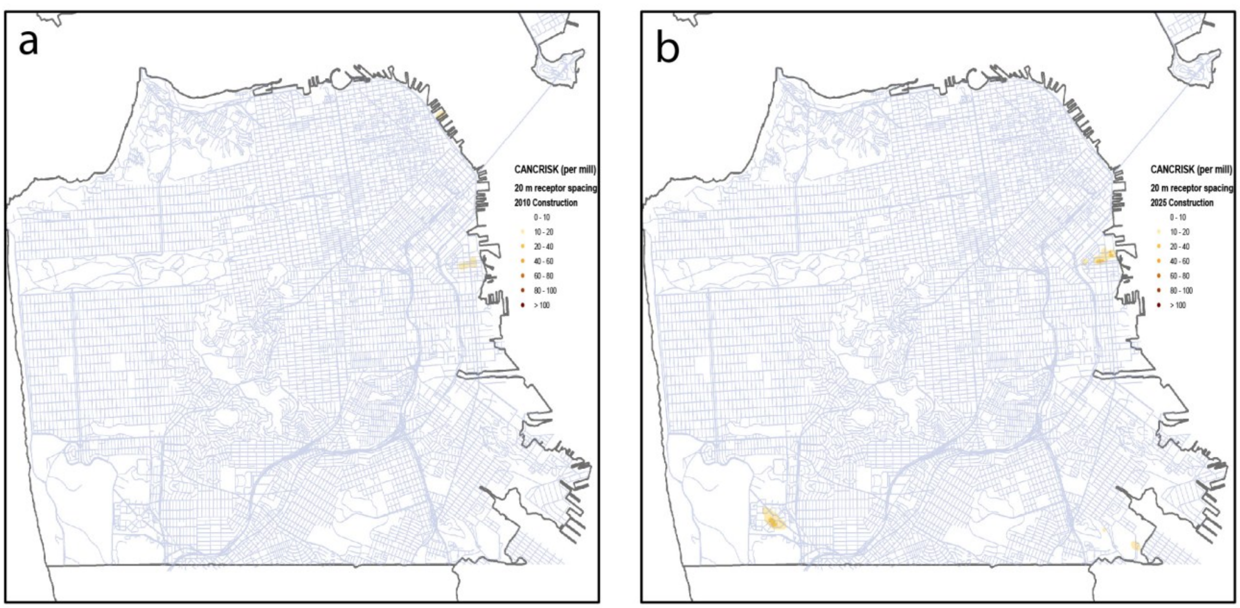


Figure 22. Contribution of construction projects to potential cancer risk in (a) 2010 and (b) 2025. For each year, cancer risk was calculated for a single year of construction only.

5.7 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. Figure 23 shows the combined incremental impacts of $PM_{2.5}$ directly emitted from local sources. Adding background concentrations of $PM_{2.5}$ value (about 8 μg/m^3 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 21, 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 $PM_{2.5}$, with peak incremental concentrations reaching about 2 μg/m^3 in 2010 (Figure 21a; without the background added[9]). Projected changes in $PM_{2.5}$ concentrations in project year 2014 (Figure 21b) and 2025 (Figure 21c) are relatively small and mostly due to reductions in exhaust emissions from on-road motor vehicles due to fleet turnover and cleaner cars and trucks in the future. However these reductions are at least partially offset by increased traffic in many areas, which results in more PM emissions from tire and brake wear in future years. Increased traffic from new development projects in the Hunter's Point area in the result in higher $PM_{2.5}$ along local roadways.

Some specific sources of local $PM_{2.5}$, other than on-road sources, are indicated in Figure 24. Ship emissions and a few permitted stationary sources are highlighted as significant contributors.

Cancer Risk:

Combined source maps show that on-road mobile sources are also major contributors to incremental potential cancer risk (Figure 25). 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 and harbor craft 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 26 identifies additional contributions from a number of industrial facilities.

Relative to potential cancer risk in 2010 (Figure 25a) in future years (Figure 25b-c) significant reductions were projected. These anticipated reductions result mainly from State regulation of diesel exhaust emissions from on-road heavy-duty trucks. In 2025, cancer risk near Caltrain is expected to be eliminated with the electrification of the service. Shore power reduces the impact of OGVs in future years. Smaller, but locally important, reductions in potential cancer risk are due to the phase out of PERC from drycleaners.

As risk from others sources is reduced or eliminated in future years, the potential is clear for additional risk reductions from stationary sources, particularly for older diesel engines and back-up generators, many of which are in densely populated areas downtown.

[9] Or about 10 μg/m^3 with the background added.

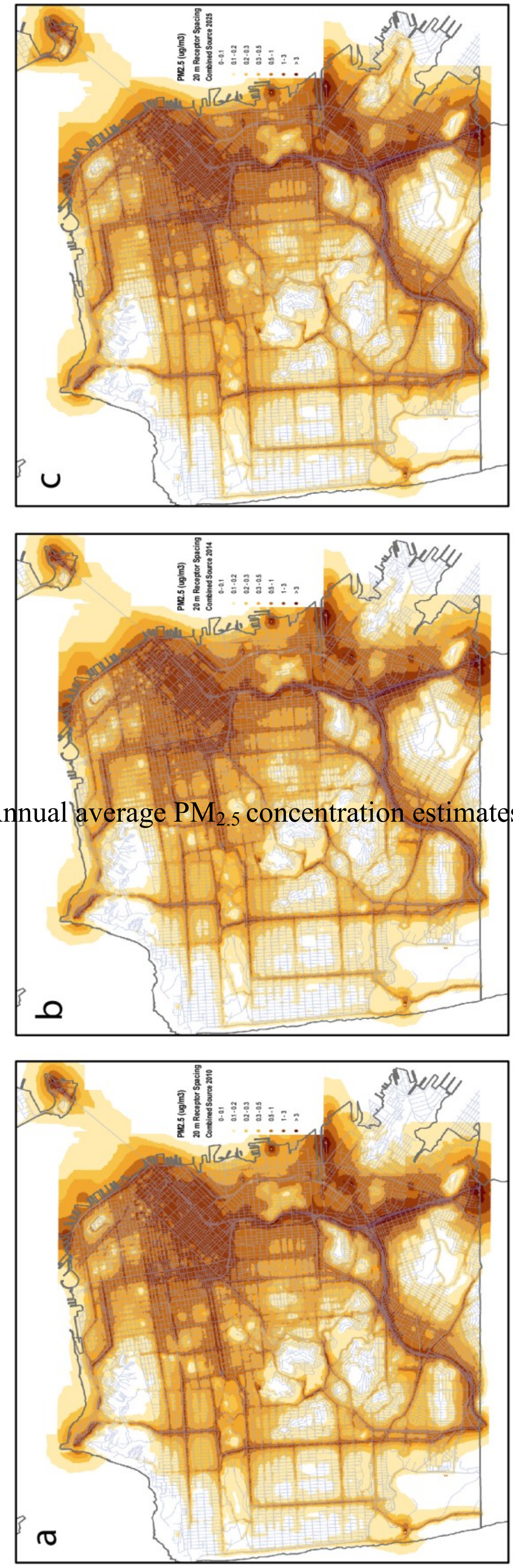


Figure 23. Annual average $PM_{2.5}$ concentration estimates from all modeled sources in (a) 2010, (b

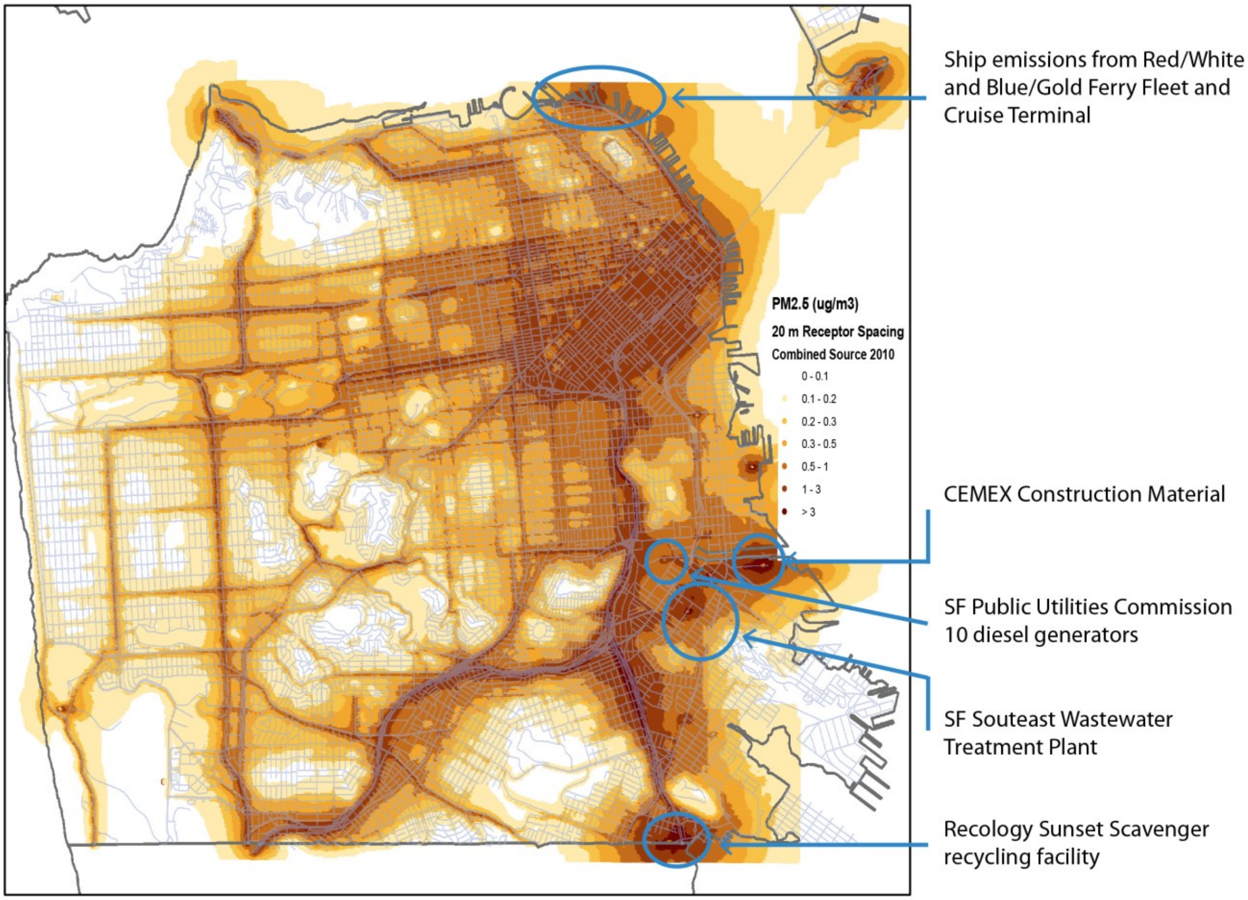


Figure 24. Identification of sources associated with high incremental contributions of $PM_{2.5}$.

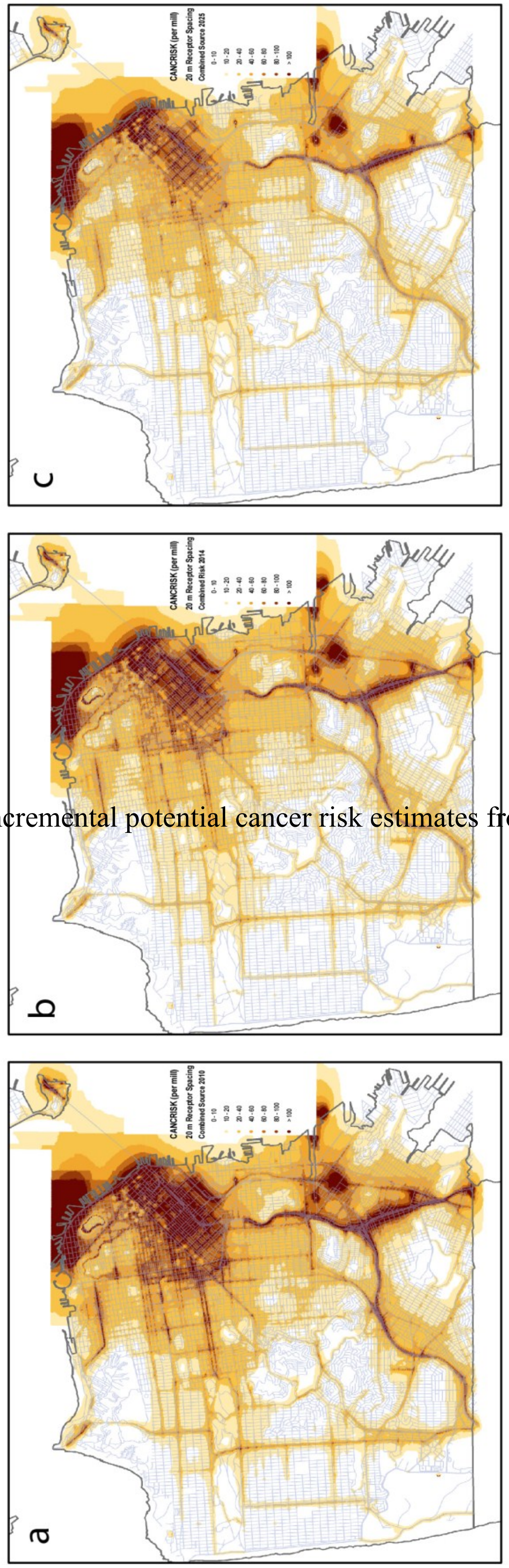


Figure 25. Incremental potential cancer risk estimates from all modeled sources for (a) 2010, (b) 2

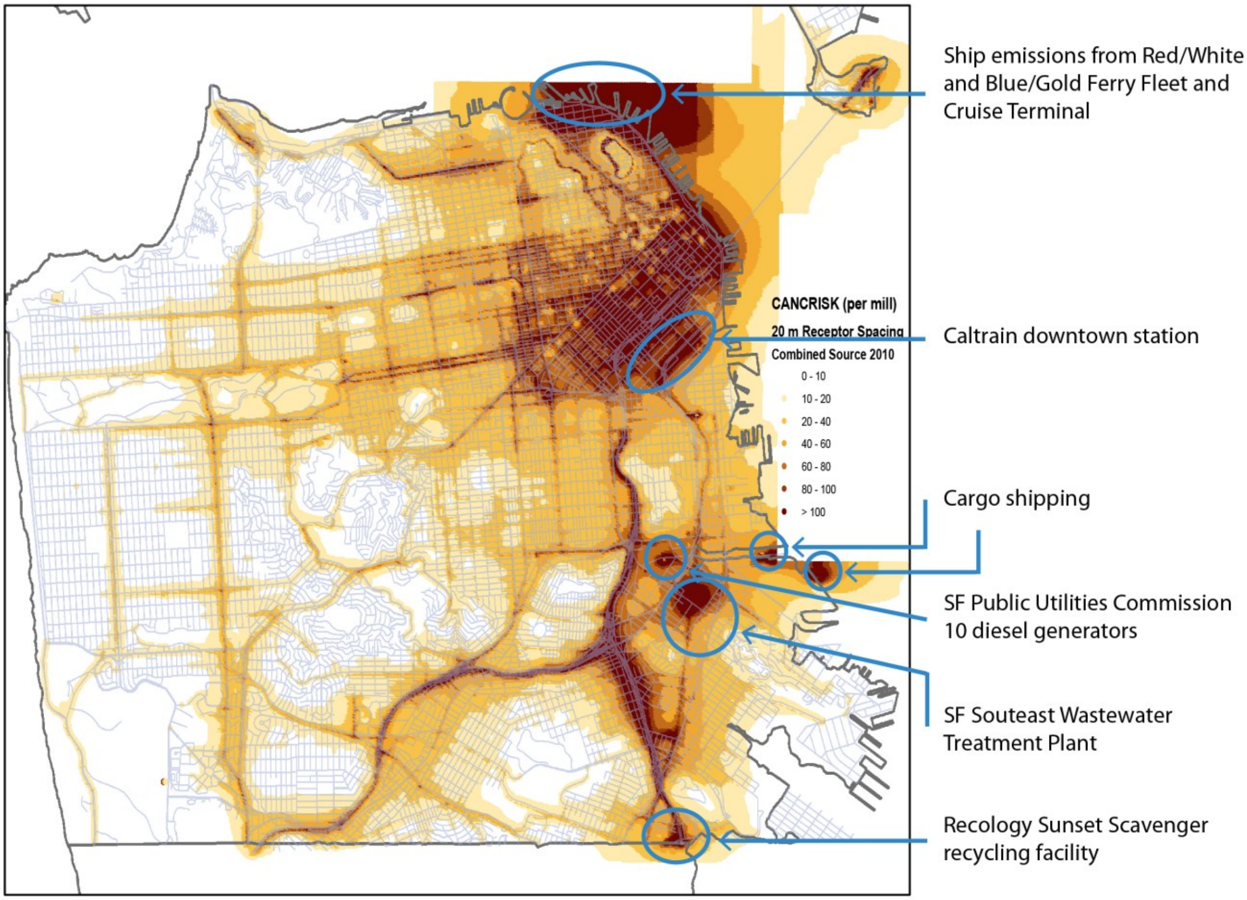


Figure 26. Identification of sources associated with high incremental contributions of potential cancer risk.

6. Uncertainties

In accordance with risk assessment guidance, the CRRP has qualitatively evaluated the uncertainties associated with the HRAs, 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 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 have significant uncertainties associated with them, especially in future years. Average truck fractions for surface streets were estimated by counting trucks seen in aero-photographs taken at specific times of the day. In most cases, the truck counts using the ortho-photo analysis yielded higher truck percentage and estimated higher emissions attributed to trucks than if default truck percentages from Caltrans California state highways studies were used. EMFAC2011 was used to estimate on-road emission factors for cars, trucks and buses in San Francisco and there were also uncertainties associated with these.

At the commencement of the CRRP development for San Francisco, emissions estimates for 2008 were the most recent available for permitted stationary sources. Since then, some sources were supplemented with 2009 data, but emissions from some sources may have changed between these dates and base year 2010. Where specific information was available about changes in future year emissions from permitted sources, this information was used; but uncertainty exists in forecasts for many stationary source categories.

In addition, some source categories were excluded from the modeling analysis. The emissions associated with commuter ferries to San Francisco Ferry Building were not included in the CRRP since they were not originally quantified in the Port of San Francisco reference report. The ferry building is used by six commuter ferry services including Golden Gate Ferry, Vallejo Baylink Ferry, Blue and Gold Ferry, Alameda/Oakland Ferry, Harbor Bay Ferry, and Water Emergency Transportation Authority (WETA) Ferry. In a report completed by Environ for a residential development at 8 Washington Street dated April 1, 2011, they estimated that commuter ferries produce 1.24 tons per year of diesel particulate matter from idling and maneuvering. Based on this emission estimates, commuter ferry contribute approximately 12% of the base year emissions in 2010 and 21% of the future year emissions for marine vessels. Marine emissions may be underestimated based on the exclusion of commuter ferries.

The modeling did incorporate PM emission changes due to the Potrero Power Plant closure and from updates at the Bay View facility based on review of District files and discussions with San Francisco Planning. PM emissions for the remaining facilities were held constant to base year 2010. It is likely that many of these facilities will have permit condition changes that will impact their future emissions. However at this time, the District cannot forecast what the future emissions maybe. For example, BAE Systems (dry dock) at Pier 70 was recently awarded a contract to repair Navy T-AKE vessels starting in 2011. To reduce some of the emissions, the dry dock also installed shore power at the pier this year. Because of the unknown number of T-AKE vessels that will be repaired at the dry dock and the expected emissions reductions associated with the shore power, the emissions for BAE Systems based on the District's 2009 inventory was used. Future CRRP analysis may include updates to the emission inventories that include, but are not limited to, adding commuter ferries emissions and updating the Pier 70 inventory.

Default emission factors were used to estimate emissions of all off-road equipment. This assumes that emissions from all equipment will be equal to the default emissions when some emissions may vary from this rate. Furthermore, a load factor is included in the calculation of emissions. This load factor was obtained from CARB's OFFROAD model and is a fleet wide average. This load factor may not be representative of the exact piece of equipment in use, but was the most reasonable estimate. In addition, the analysis only included evaluation of impacts associated with multi-year construction project, but does not forecast future emissions associated with new construction of both major and minor projects due to the lack of information regarding the location, duration, and type of equipment that will be used on the project. The construction analysis conducted in this evaluation was for information purposes only and was not incorporated into the city-wide analysis. San Francisco plans to reduce emissions from construction equipment by adopting a local ordinance that requires equipment to meet low emissions standards for sites within the city limits. Because construction emissions are intermittent, the local ordinance may be the most effective mitigation for ensuring long term reductions from construction 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 air pollutant concentrations.

In addition, we did not have building height information for including building downwash, the effects of which the modeling does estimate. 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, we would require information on all the building heights and stacks within the City. 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. 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, we used source parameters which were either recommended as defaults or expected to produce more conservative 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. 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 the emission sources modeled. However, the CPF values derived by Cal/EPA for many pollutants, including that for diesel PM, 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).

The method applied to estimate cancer risk includes the age sensitivity factor (ASF) 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 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.

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8. Appendix A: 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
BART	Bay Area Rapid Transit
CALINE3	third generation of the California Department of Transportation Roadway Model
Caltrans	California Department of Transportation
CARB	California Air Resources Board
CARE	Community Air Risk Evaluation Program
CEIDARS	California Emissions Inventory Development and Reporting System
CPF	cancer potency factor
CPU	central processing unit
CRRP	Community Risk Reduction Plan
CSV	comma separated value
DPM	diesel particulate matter
EMFAC	California State emissions factor model for on-road mobile sources
GDF	gas dispensing facility
GIS	Geographic Information System
HRA	health risk assessment
ISC	Industrial Source Complex
NAD83	North American Datum of 1983
NEI	National Emissions Inventory
OGV	ocean going vessel
PAH	polycyclic aromatic hydrocarbons
PDF	Portable Document Format, developed by Adobe Systems Incorporated
PERC	perchloroethylene
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
SamTrans	San Mateo County Transit
SCRAM	US EPA Support Center for Regulatory Air Models
SF-CHAMP	San Francisco County Chained Activity Modeling Process
SFDPH	San Francisco Department of Public Health
SFPLAN	San Francisco Planning Department
SIC	Standard Industrial Classification
STI	Sonoma Technology, Incorporated
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
VMT	vehicle miles traveled
WestCAT	Western Contra Costa Transit Authority
WGS84	World Geodetic System of 1984