TECHNICAL MEMORANDUM

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February 15, 2008 STI-906020.08-3288

TO: Dr. Phil Martien

FROM: Stephen B. Reid, Manager, Emissions Assessment Group

SUBJECT: Final documentation of the preparation of year-2005 emission inventories of toxic air contaminants for the San Francisco Bay Area (Contract No. 2006-019)

This memorandum is a deliverable for the "Bay Area Air Quality Management District Toxic Air Contaminant Emission Inventory" project. The work was performed as part of an ongoing effort by the Bay Area Air Quality Management District's (District) Community Air Risk Evaluation (CARE) program to characterize and reduce health risks from toxic air contaminants (TACs) emitted in the San Francisco Bay Area. In support of the CARE program's goals, Sonoma Technology, Inc. (STI) prepared year-2005 screening-level gridded emission inventories of TACs, updating the year-2000 TAC inventories that STI had previously prepared for the District under this same contract.

In general, the techniques used to develop the year-2005 TAC inventories are the same as those used to develop the year-2000 inventories (Reid et al., 2006). Chemical speciation profiles and unit risk factors/reference concentrations were applied to the District's existing total organic gas (TOG) and particulate matter less than 10 microns (PM_{10}) emission inventories to generate mass-based and risk-weighted TAC inventories. These inventories were then spatially distributed to the District's 2-km x 2-km modeling domain and to a new finer-resolution 1-km x 1-km modeling domain using gridded surrogate data developed by STI.[1] However, several new sources of data were utilized in the development of the year-2005 TAC inventories, and this memorandum serves to document those sources of data, as well as the differences in emission estimates between the 2000 and 2005 inventories.

The methods and data sets used to perform each task associated with the development of the 2005 TAC emission inventories are highlighted in the following sections:

- Task 1 – Acquire and review existing 2005 emission inventories
- Task 2 – Apply speciation profiles and toxicity weighting factors
- Task 3 – Spatially distribute TAC emissions

[1] The finer-resolution modeling grid was used to allow the District to more accurately assess the locations of TAC emission sources.

- Task 4 – Assign temporal profiles to individual source categories

ACQUISITION AND REVIEW OF EXISTING INVENTORIES

The District provided STI with a number of existing 2005 emission inventories for use in this project:

- A county-level area and non-road mobile source inventory of TOG and PM_{10} emissions.
- Gridded on-road mobile source inventories of TOG and PM_{10} emissions for summer and winter weekdays (gridded emissions were provided at both a 1-km and 2-km grid resolution).
- A point source inventory of TAC emissions.

STI reviewed these inventories by making spatial plots of on-road and point source emissions and by comparing the 2005 emissions data to the corresponding year-2000 emission inventories that STI previously used to generate the District's 2000 TAC inventory. **Figures 1 and 2** illustrate the distribution of total TOG and PM_{10} emissions by major source category (point, on-road mobile, and area/non-road) for 2005 and 2000. These figures show that the District's total TOG inventory decreased by about 11% between 2000 and 2005, primarily due to decreases in on-road mobile source and point source emissions.[2] The District's total PM_{10} inventory showed a modest decrease of about 4% between 2000 and 2005. The remainder of this section is a summary of the District's emission inventories for each major source category.

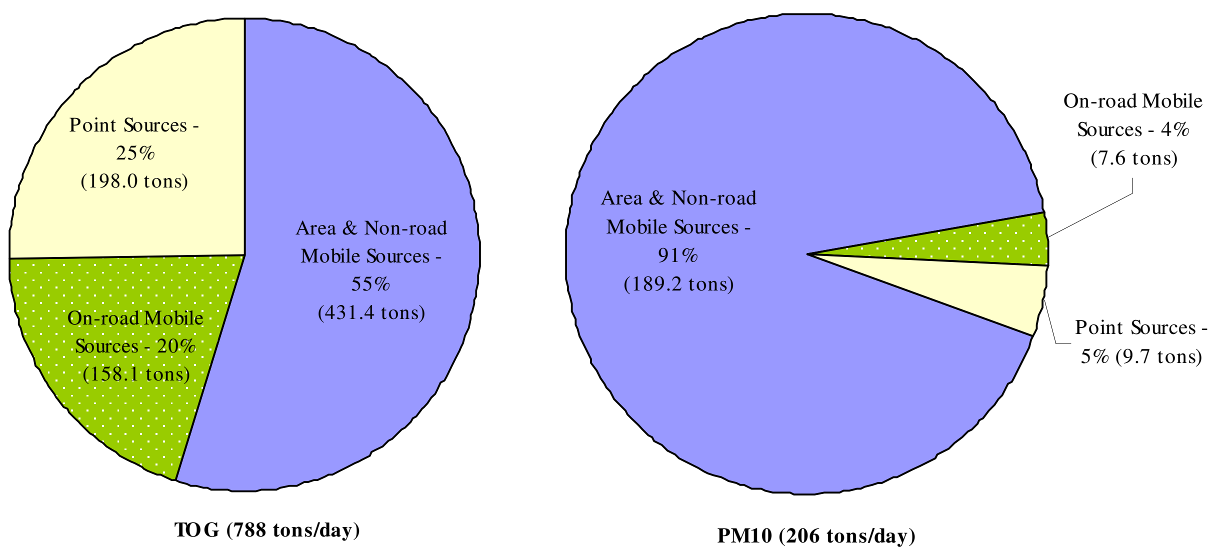

Figure 1. District 2005 TOG and PM_{10} emissions by major source type.

[2] The District provided STI with the latest estimates of total TOG emissions from point sources. The point source TOG emissions shown for 2000 differ from those reported in the year-2000 TAC inventory report (Reid et al., 2006) due to an updated methodology for estimating emissions from landfills. This change does not affect toxic emission estimates for 2000 because point source toxics are estimated independently of TOG, and TOG from landfills is primarily composed of methane, which is not toxic.

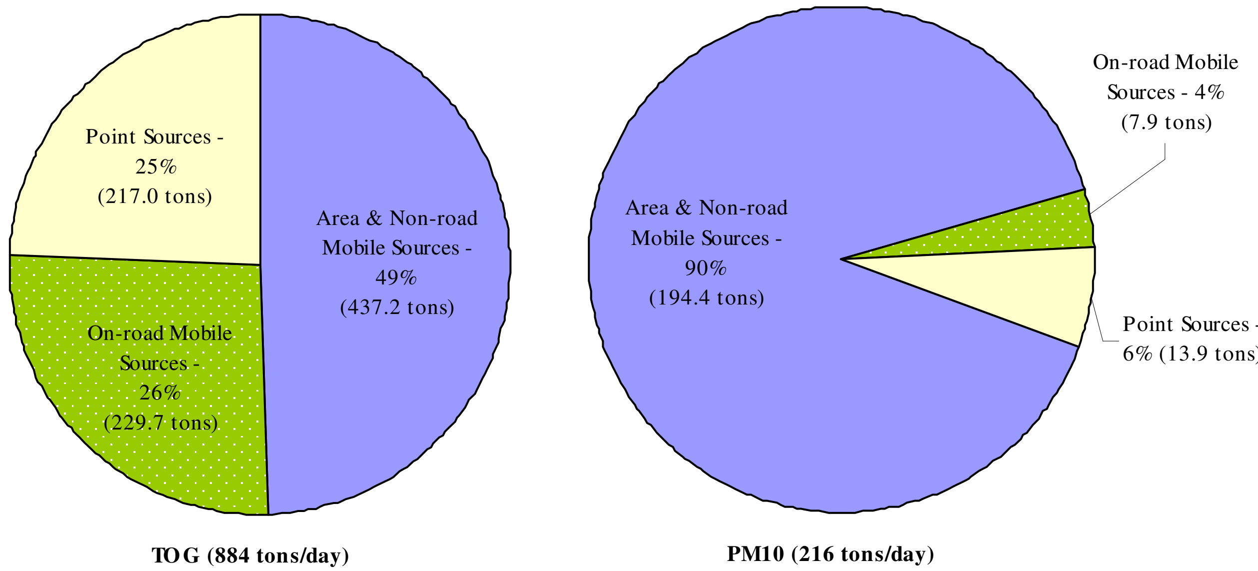

Figure 2. District 2000 TOG and PM_{10} emissions by major source type.

Area and Non-road Mobile Sources

The District provided STI with county-level area and non-road mobile source inventories of year-2005 TOG and PM_{10} emissions. These inventories reflected several changes since the year-2000 inventories:

- District-wide TOG emissions from area and non-road mobile sources decreased slightly from 437.2 tons per day in 2000 to 431.4 tons per day in 2005.
- District-wide PM_{10} emissions from area and non-road mobile sources decreased slightly from 194.4 tons per day in 2000 to 189.2 tons per day in 2005.
- The number of emission inventory codes (EICs) in the area and non-road mobile source inventories increased from 356 in 2000 to 417 in 2005. Most of the new codes reflected new evaporative emission modes for gas-powered, non-road mobile sources and new consumer product categories.

The District also provided STI with data on general aviation aircraft operations at all airports within District boundaries. These data were used to estimate lead emissions from general aviation aircraft, because available speciation profiles for this source type do not account for lead. In keeping with the U.S. Environmental Protection Agency's (EPA) National Emission Inventory (NEI) documentation, STI assumed a lead content of 2.0 grams per gallon for aviation gasoline, and a 75% retention value to reflect the lead that is retained in an aircraft's engine or exhaust system (U.S. Environmental Protection Agency, 2003). District land-and-takeoff (LTO) operations data for each airport were converted to fuel consumption estimates using fuel consumption data for civilian aircraft provided in an EPA guidance document (U.S. Environmental Protection Agency, 1992). EPA fuel consumption data for two representative engines (Continental O-200 and Lycoming O-320) were averaged to produce an estimate of 1.9 gallons per LTO. Lead emissions for each airport were then calculated as follows (general aviation LTO data from Sky Ranch Airport in Petaluma are used as an example calculation):

$$\text{Sky Ranch}_{Pb} = 26{,}645 \text{ LTOs/year} \times 1.9 \text{ gal/LTO} \times 2 \text{ grams}_{Pb}\text{/gal} \times 0.75$$
$$= 75{,}938 \text{ grams/year (167.4 lbs/year)}$$

Following this method, District-wide lead emissions from general aviation aircraft operations were estimated to be 5,775 lbs per year. These lead emissions were combined with other TAC emission estimates for area and non-road mobile sources produced by applying the speciation profiles described below (Speciation and Toxicity Weighting).

County-level area and non-road mobile source emissions were spatially distributed using geographic information system (GIS) databases that were acquired primarily from the Association of Bay Area Governments (ABAG). An emission density plot of area and non-road mobile source TOG emissions is shown in **Figure 3**, and the spatial distribution process is described in more detail below.

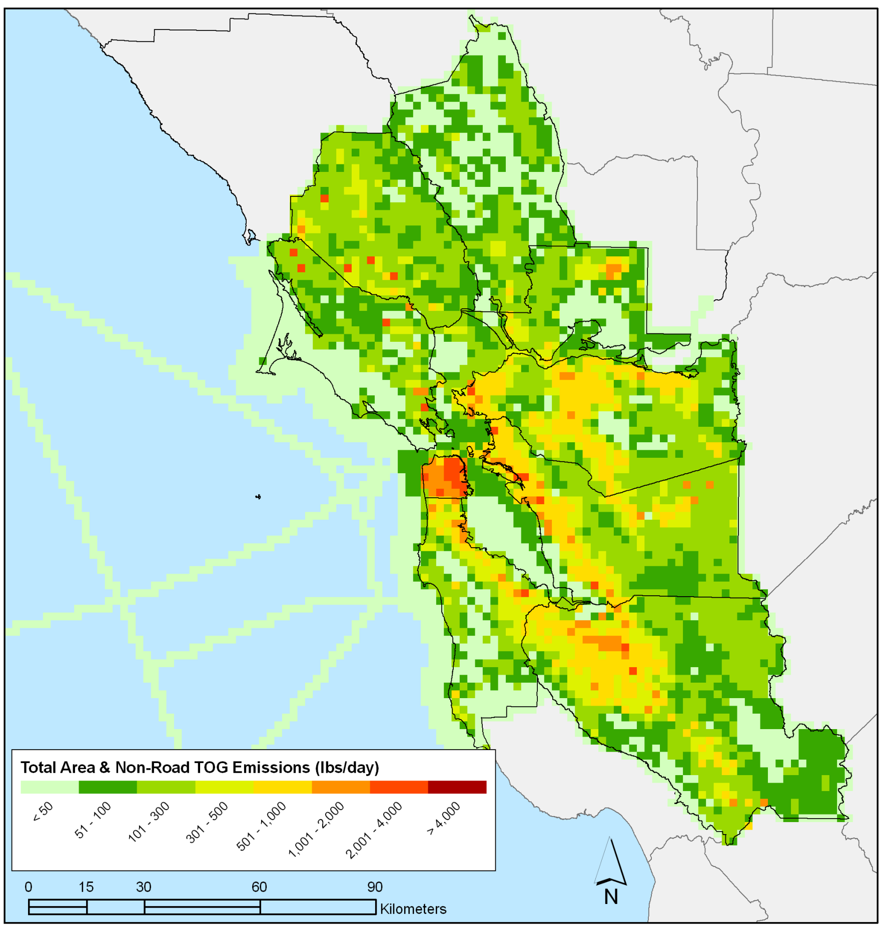

Figure 3. Emission density plot of area and non-road mobile source TOG emissions.

On-road Mobile Sources

The District provided STI with gridded on-road mobile source inventories of TOG and PM_{10} emissions in Modeling Emissions Data System (MEDS) format. District staff generated year-2005 on-road mobile source emission estimates using the California Air Resources Board's (ARB) EMFAC2007 model and gridded the emissions to the District's 2-km x 2-km and 1-km x 1-km modeling grids using Caltrans' DTIM4. The District provided summer and winter MEDS files for 2005, and these two inventories were averaged by grid cell to produce an annualized on-road emission inventory.

District-wide on-road mobile source TOG emissions for 2005 were about 30% lower than corresponding year-2000 emissions, decreasing from 229.7 tons per day to 158.1 tons per day. On-road mobile source PM_{10} emissions decreased slightly between 2000 and 2005, dropping from 7.9 to 7.6 tons per day. **Figures 4 and 5** show emission density plots of the gridded on-road mobile source inventories provided by the District.

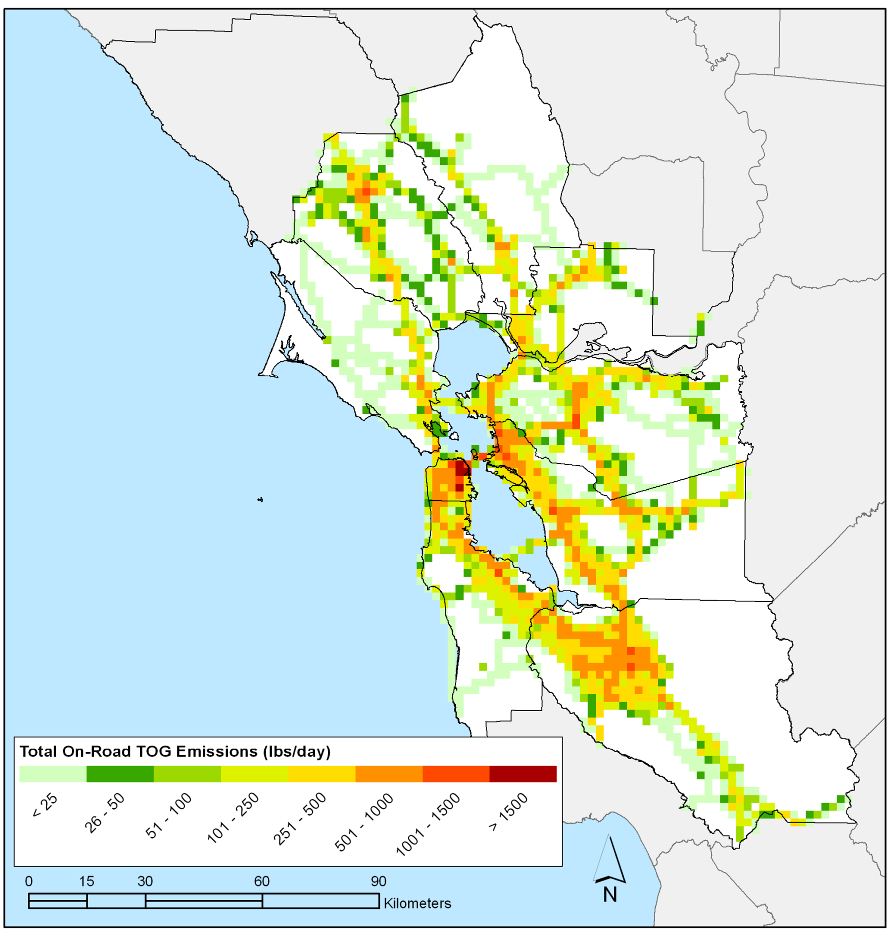

Figure 4. Emission density plot of on-road mobile source TOG emissions (2-km grid resolution).

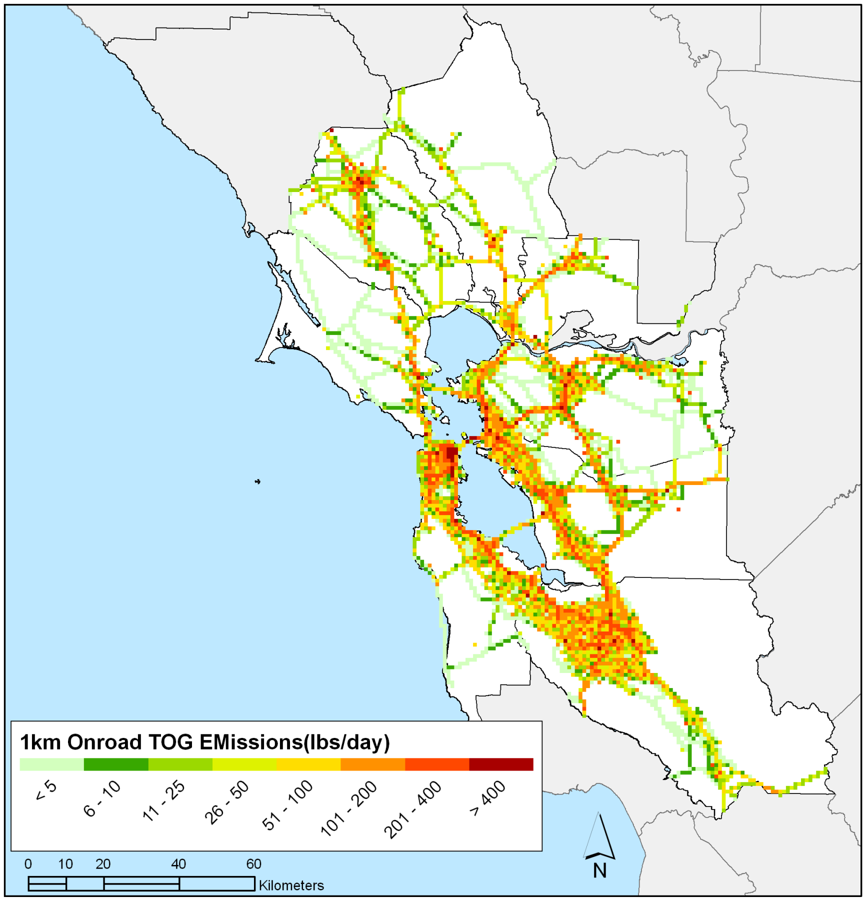

Figure 5. Emission density plot of on-road mobile source TOG emissions (1-km grid resolution).

<u>Point Sources</u>

The District provided STI with a year-2005 inventory of TAC emissions from point sources within the District, data that were compiled from emissions reported by almost 5,000 individual facilities. District-wide TAC emissions from point sources for 2005 were about 8% lower than corresponding year-2000 emissions, decreasing from 3,406 tons per day to 3,143 tons per day. STI produced plots of District point source locations based on Universal Transverse Mercator (UTM) coordinates provided in the District's point source inventory. The location coordinates of approximately 30 facilities appeared to be incorrect (i.e., outside District boundaries or over water), and new coordinates were developed for these facilities by geocoding their addresses. STI also "gridded" all point sources by using GIS software to determine the grid cell each source occupies in the District's 2-km x 2-km and 1-km x 1-km modeling domains. **Figure 6** illustrates the geographic distribution of benzene emissions (an example TAC) from point sources.

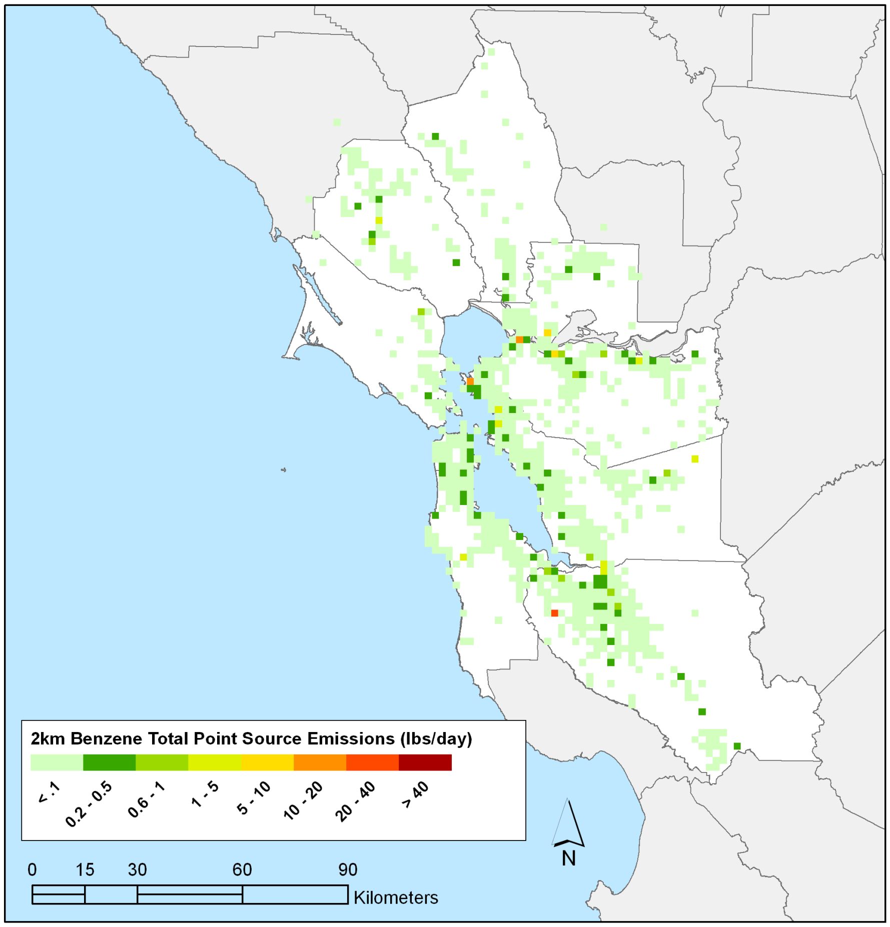

Figure 6. Emission density plot of benzene emissions from point sources (2-km grid).

SPECIATION AND TOXICITY WEIGHTING

Chemical Speciation

STI used speciation profiles to transform TOG and PM_{10} emissions into individual chemical species so that TAC emissions from area, on-road mobile, and non-road mobile sources could be estimated. STI assigned an appropriate speciation profile to each EIC or source classification code (SCC) in the inventories, primarily based on ARB-recommended profile-to-source code assignments. The ARB has developed a cross-reference file that indicates which TOG or PM_{10} speciation profile should be assigned to a given source type, and many of these assignments are specific to the emission inventory year (to account for changes to fuel compositions, etc.). In developing the 2000 TAC inventories, we used the speciation profiles recommended by ARB for most source categories. However, in some cases, ARB did not provide a recommended profile, or did not recommend a default composite profile. For these cases, we identified appropriate speciation profiles available from the Desert Research Institute (DRI) or listed in EPA's Speciate database.

Prior to the development of the 2005 TAC inventories, STI reviewed and updated the speciation profile assignments made to the 2000 emission inventories based on a new ARB speciation cross-reference file and discussions with District staff. A significant change was the application of the organic gas profile (818) to diesel exhaust emissions. During the development of the 2000 TAC inventories, ARB speciation profile 818 was applied to both on-road and non-road diesel exhaust emissions. This profile was based on a 1991 study conducted at California Polytechnic State University, San Luis Obispo, in which engine exhaust emissions were collected from heavy-duty diesel farm equipment (Censullo, 1991). However, unlike more recent diesel exhaust profiles, profile 818 does not include acrolein, an important TAC in the District. Therefore, after consultation with District and ARB staff, this profile was replaced with a profile from EPA's Speciate 4.0 database (U.S. Environmental Protection Agency, 2006). The EPA profile (4674) is based on dynamometer testing of medium-duty diesel trucks conducted in 1999 (Schauer et al., 1999).

Table 1 shows a complete list of all the speciation profile assignments that were revised for the 2005 TAC inventory development. Virtually all the profile changes resulted from the phase-out of methyl tertiary-butyl ether (MTBE) from California gasoline that was completed in 2003.

Once TAC emissions from area, non-road mobile, and on-road mobile sources were estimated by applying speciation profiles, these emissions were combined with the inventory of year-2005 TAC emissions from point sources provided by the District to form a complete inventory of TACs. TAC emissions by pollutant and source category can be seen in **Figures 7 and 8**[3]**.** Overall, TAC emissions from all sources in the District were estimated to be 115 tons per day for 2005, down about 20% from the 145 tons per day of TAC emissions estimated for year-2000.

[3] Ship and commercial boat emissions occurring more than 3 miles off-shore have been excluded from Figure 7 and Figure 8.

Table 1. Differences in the TOG and PM speciation profiles used to develop the Distict's 2000 and 2005 TAC inventories.

Pollutant	2000 Profile	Profile Source	Profile Description	2005 Profile	Profile Source	Profile Description	Associated Source Categories
TOG	401	ARB	Non-catalyst stabilized exhaust (summer 1996)	665	ARB	Non-catalyst stabilized exhaust (MTBE phaseout)	On-road non-catalyst running exhaust; gasoline-powered off-road equipment exhaust
TOG	402	ARB	Non-catalyst – FTP bag1-3 starts (summer 1996)	666	ARB	Non-catalyst start exhaust (MTBE phaseout)	On-road non-catalyst start emissions
TOG	422	ARB	Light-duty vehicle – hot soak – ARB 1999-2000	660	ARB	Liquid gasoline (MTBE phaseout)	On-road gasoline hot soak emissions
TOG	438	ARB	Catalyst - stabilized exhaust (summer 1999)	2105	ARB	Catalyst – stabilized exhaust 2005 (MTBE phaseout)	On-road catalyst running exhaust
TOG	818	ARB	Diesel exhaust – farm equipment	4674	EPA	Diesel exhaust – medium duty trucks	On-road and off-road diesel exhaust emissions
TOG	877	ARB	Catalyst – FTP Bag 1-3 STARTS (summer 1996)	664	ARB	Catalyst start exhaust (MTBE phaseout)	On-road catalyst start emissions
TOG	906	ARB	Gasoline headspace vapors (UC Berkeley)	661	ARB	Gasoline headspace vapors (MTBE phaseout)	Evaporative emissions from on-road gasoline vehicles (running and resting) and gasoline storage and transport
TOG	1204	EPA	Light-duty gasoline vehicles – evaporative	661	ARB	Gasoline headspace vapors (MTBE phaseout)	Evaporative emissions from gasoline-powered recreational boats
TOG	1305	EPA	Gasoline Composite (Hot Soak + Diurnal) Evaporative (circa 1990)	661	ARB	Gasoline headspace vapors (MTBE phaseout)	Evaporative emissions from gasoline-powered off-road equipment
TOG	1765	ARB	Consumer products – hair mousses (ARB draft)	2765	ARB	Consumer products – hair mousses (2001 survey)	Consumer Products – Hair Mousses
TOG	1766	ARB	Consumer Products – hair shines (ARB draft)	2766	ARB	Consumer Products – hair shines (2001 survey)	Consumer Products – Hair Shines
TOG	1782	ARB	Consumer Products – shaving gels (ARB draft)	2782	ARB	Consumer Products – shaving gels (2001 survey)	Consumer Products – Shaving Gels
TOG	1901	ARB	Architectural coatings – solvent borne (1998 Survey)	2901	ARB	Architectural coatings – solvent-based (2000 survey)	Various architectural coating products
TOG	1902	ARB	Architectural Coatings – water borne (1998 Survey)	2902	ARB	Architectural coatings – water-based (2000 survey)	Various architectural coating products
PM	–	–	–	16000	EPA	Meat Cooking – Charbroiling	Commercial charbroiling and deep-fat frying

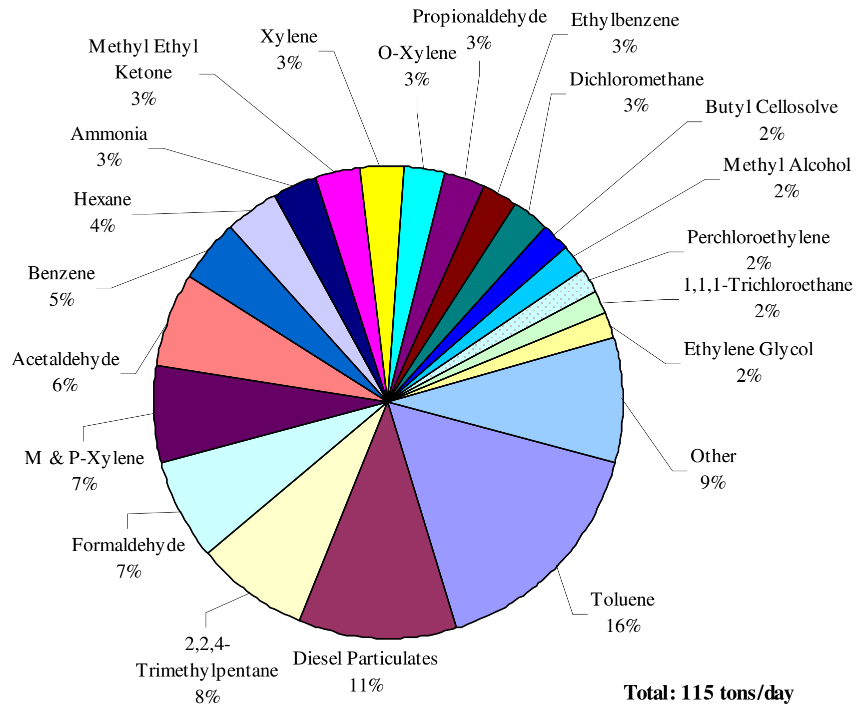

Figure 7. Average daily TAC emissions by species.

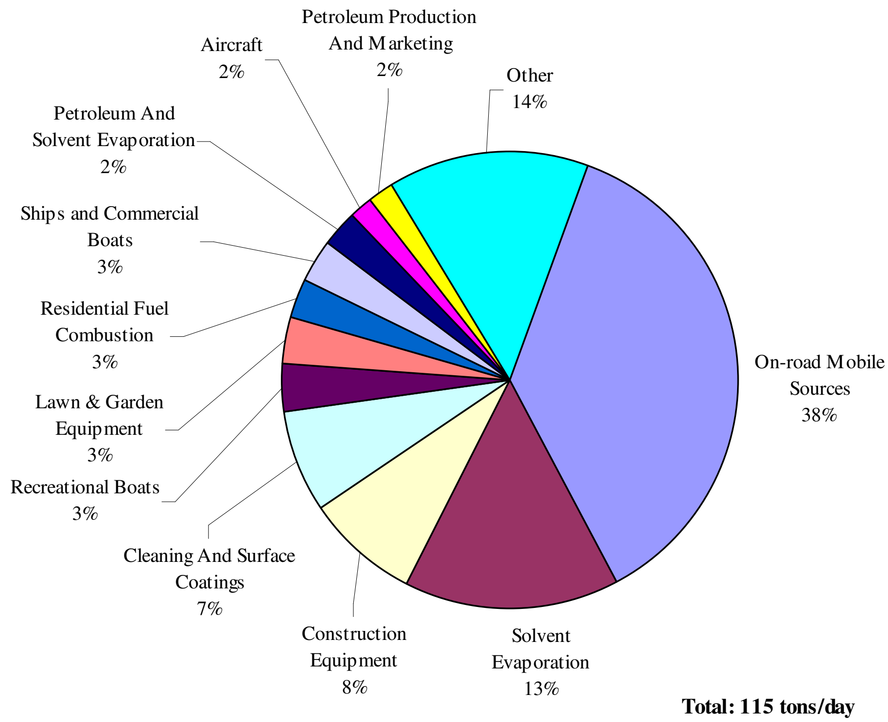

Figure 8. Average daily TAC emissions by source category[4].

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[4] The “Other” source category in Figure 8 consists mostly of non-road mobile sources such as transportation refrigeration units, industrial equipment, and commercial equipment.

Toxicity Weighting

To develop toxicity-weighted emission inventories, STI applied available cancer unit risk (UR) factors and non-cancer reference concentrations (RfC) for the inhalation exposure pathway. UR factors estimate the expected change in the rate of observed adverse effects per unit change in dose (or air concentration). An RfC is a regulatory definition that indicates the dose at which no adverse effects are expected plus a safety margin allowing for measurement uncertainty plus another safety margin based on professional toxicologists' judgment. UR factors and RfCs were compiled from the following information sources in declining order of preference: ARB in conjunction with EPA's Office of Environmental Health Hazard Assessment (OEHHA), the EPA's Integrated Risk Information System (IRIS), and the EPA's Technology Transfer Network. Secondary sources were used to estimate factors for important TACs not available in the preferred references. No change was made to the methods or data sources used to develop toxicity-weighted emissions for the District's 2000 TAC inventories, and details about the selection and application are provided in the final report for that project (Reid et al., 2006).

Figures 9 through 14[5] show toxicity-weighted emissions by pollutant and source category for cancer-related, chronic, and acute effects caused by inhalation exposure. Diesel particulate matter (DPM) constitutes about 86% of cancer toxicity-weighted emissions. On-road mobile source, construction-related activities, and commercial marine vessels contribute about three-fourths of the cancer toxicity-weighted emissions. Acrolein, formaldehyde, and DPM appear significant when considering toxicity-weighted emissions for chronic effects. Acrolein appears in the new speciation profile used for diesel exhaust emissions (EPA 4674) but was not a part of the ARB speciation profile (818) used during the development of the year-2000 TAC inventories[6]. Use of the new speciation profile for diesel sources resulted in an increase of toxicity-weighted emissions for chronic effects from 16.8 equivalent tons per day in 2000 to 20.9 equivalent tons per day in 2005. On-road mobile sources, construction equipment, and aircraft contribute about 60% of the chronic toxicity-weighted emissions.

Toxicity-weighted emissions for chronic and acute effects increased from 2.7 equivalent tons per day in 2000 to 4.2 equivalent tons per day in 2005, primarily due to increased acrolein emissions associated with the new diesel exhaust profile. On-road mobile sources, construction equipment, and aircraft are the most important source categories for acute risks, comprising about three-fourths of acute toxicity-weighted emissions.

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[5] Ship and commercial boat emissions occurring more than 3 miles off-shore have been excluded from Figures 9 through 14.

[6] Acetophenone, like acrolein, is a component of the new speciation profile for diesel exhaust emissions that was not part of the ARB speciation profile for diesel exhaust used to develop the District's 2000 TAC inventories. EPA and ARB have not released toxicity values for this compound as yet, but acetophenone may need to be considered during future TAC inventory efforts.

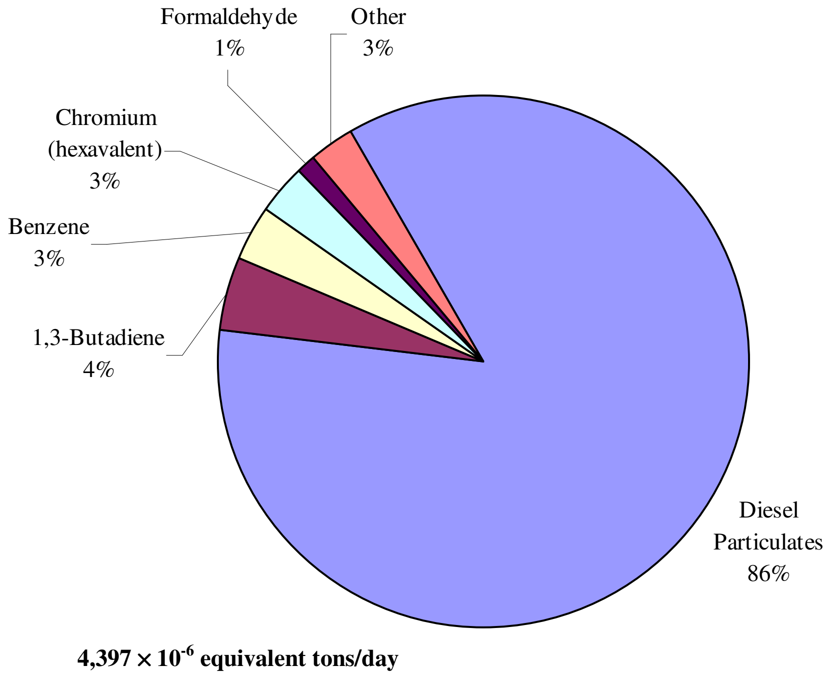

Figure 9. Cancer toxicity-weighted emissions by pollutant.

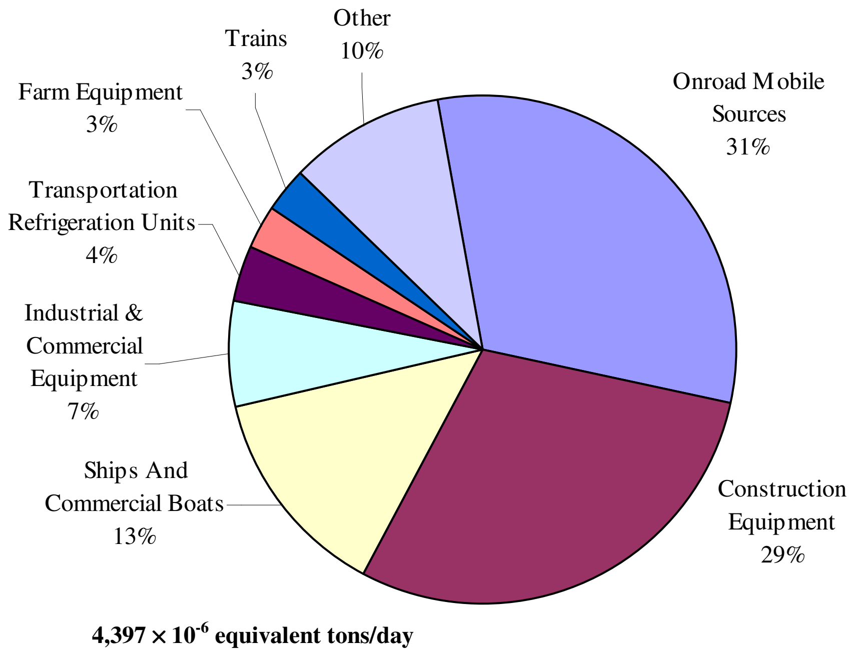

Figure 10. Cancer toxicity-weighted emissions by source category[7].

[7] The "Other" source category in Figure 10 consists mostly of non-road mobile sources such as aircraft, recreational boats, and lawn and garden equipment.

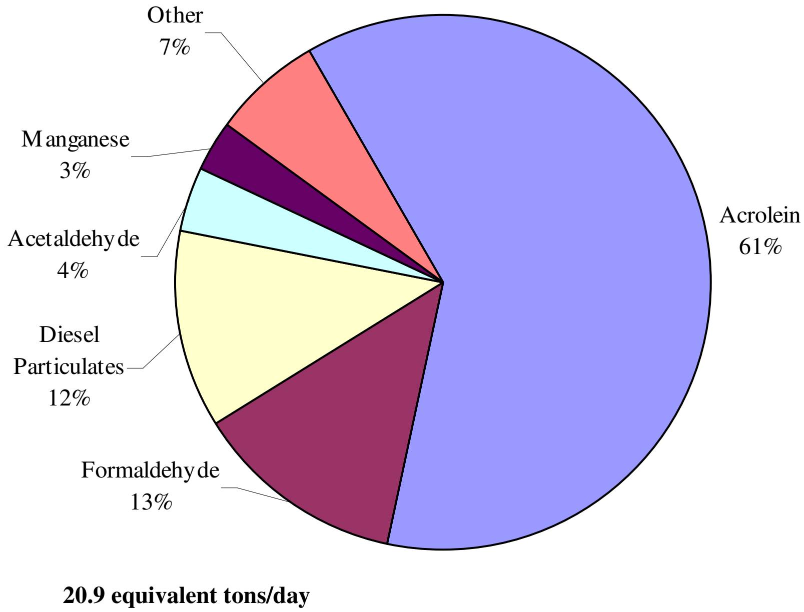

Figure 11. Chronic toxicity-weighted emissions by pollutant.

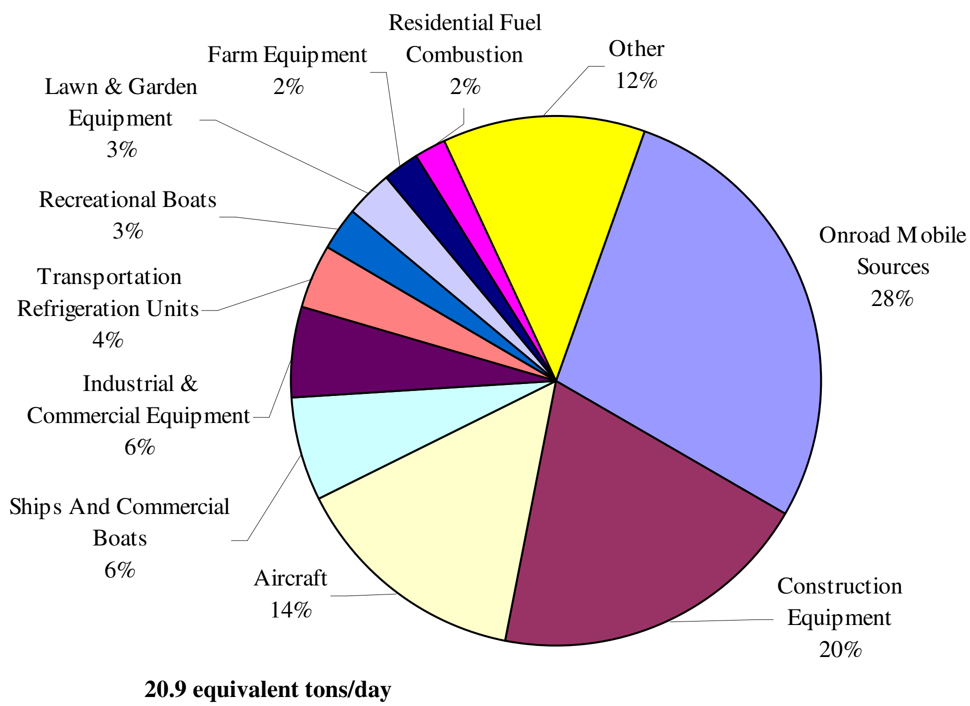

Figure 12. Chronic toxicity-weighted emissions by source category[8].

[8] The "Other" source category in Figure 12 consists mostly of fugitive dust sources such as paved road dust and construction/demolition dust, as well as non-road mobile sources such as trains.

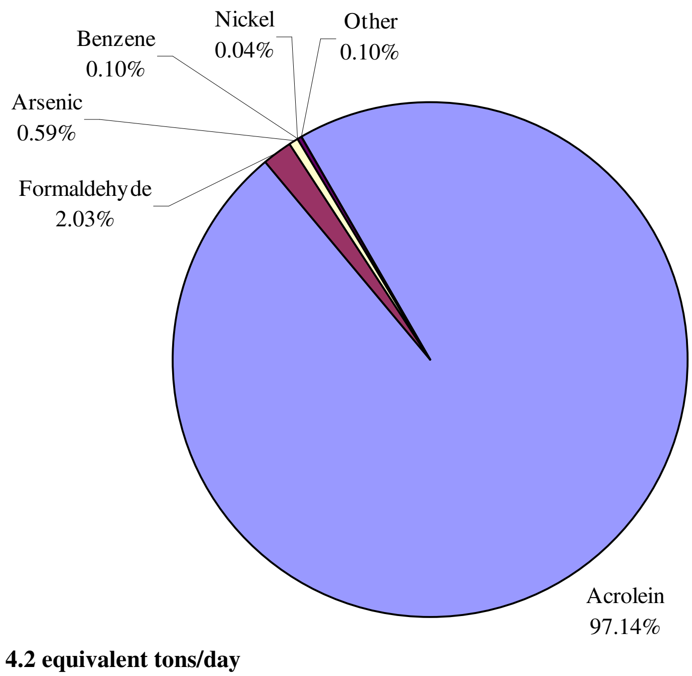

Figure 13. Acute toxicity-weighted emissions by pollutant.

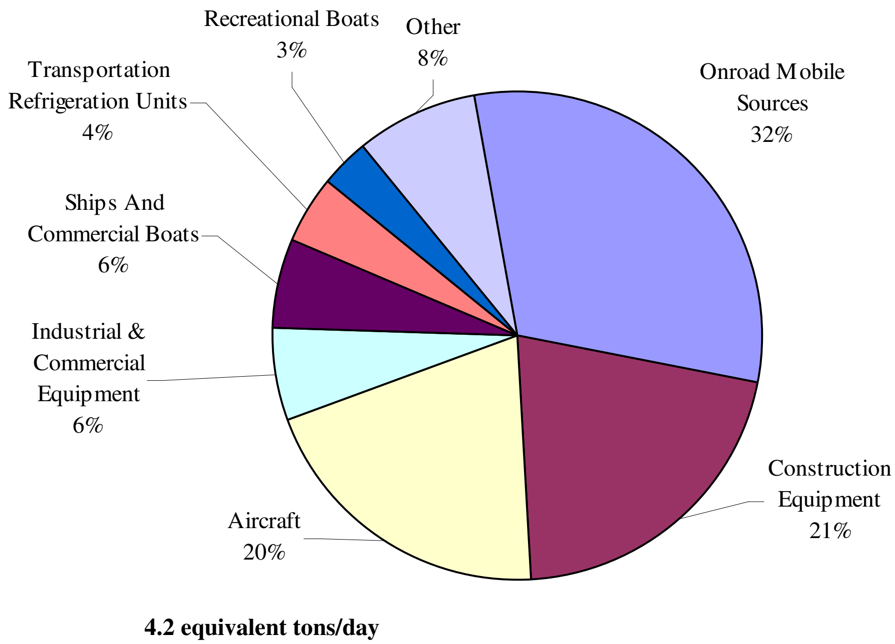

Figure 14. Acute toxicity-weighted emissions by source category[9].

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[9] The "Other" source category in Figure 14 consists mostly of non-road mobile sources such as farm equipment, lawn and garden equipment, and trains.

SPATIAL DISTRIBUTION OF EMISSIONS

County-level area and non-road mobile source emissions were geographically distributed to the spatial resolution of the District modeling domain (2-km x 2-km) and to a new finer-resolution domain (1-km x 1-km). Because the exact locations of emissions sources are unknown at this spatial scale, GIS databases with suitable spatial resolutions were used as surrogates to represent the locations of related emissions sources. County-level emissions were allocated to individual grid cells proportionally according to the spatial patterns of the surrogate GIS data. Spatial allocation factors for individual grid cells were developed by processing the surrogate GIS data within a customized ArcGIS Visual Basic (VBA) program that outputs allocation factors by grid cell to Microsoft Access database tables.

As was the case during the development of the year-2000 TAC inventories, STI relied primarily on ABAG land use databases for the development of spatial allocation factors. However, some changes were made to the data sets and methods used:

- Updated 2000 ABAG land use databases to 2005 versions.
- Acquired new GIS data sets that were not available in 2000, including the locations of dairies and fuel-specific data for residential fuel combustion sources.
- Developed new computed surrogates for non-residential construction activities by performing a difference calculation in each grid cell for retail, non-retail, and other non-residential land use types between 2000 and 2005 to determine where construction activity was likely to have occurred.
- Developed a new computed surrogate for residential construction activities based on the spatial distribution of residential building permits for 2005.
- Adjusted spatial allocation factors for shipping lanes in Alameda County to shift ship and commercial boat emissions from shipping lanes going to San Leandro and Alviso to shipping lanes in the northern part of the county[10].
- Gridded emissions to a new 1-km x 1-km grid resolution to enable the District to more accurately assess the locations of TAC emission sources.

Spatial distributions of emissions of several prominent TACs are illustrated in **Figures 15 through 20**, including 1,3-butadiene, DPM, acrolein, benzene, formaldehyde, and toluene. In addition, spatial distributions of cancer toxicity-weighted, chronic toxicity-weighted, and acute toxicity-weighted emissions are shown in **Figures 21 through 23**.

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[10] For future inventory development efforts, it may be desirable to conduct a more thorough evaluation of shipping lanes and ferry travel patterns to generate more refined spatial allocation factors for ship and commercial boat emissions.

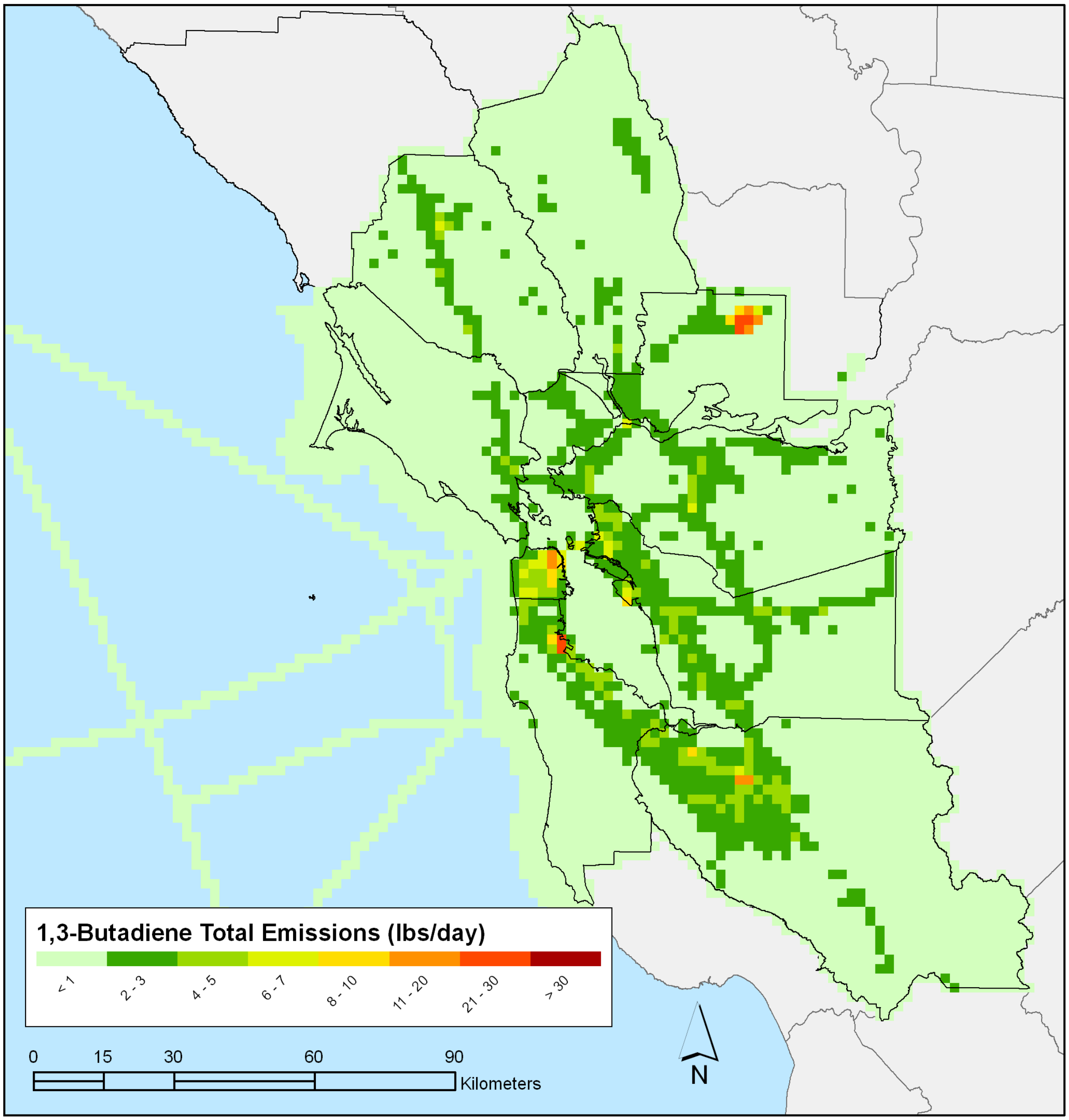

Figure 15. Emission density plot of 1,3-butadiene emissions.

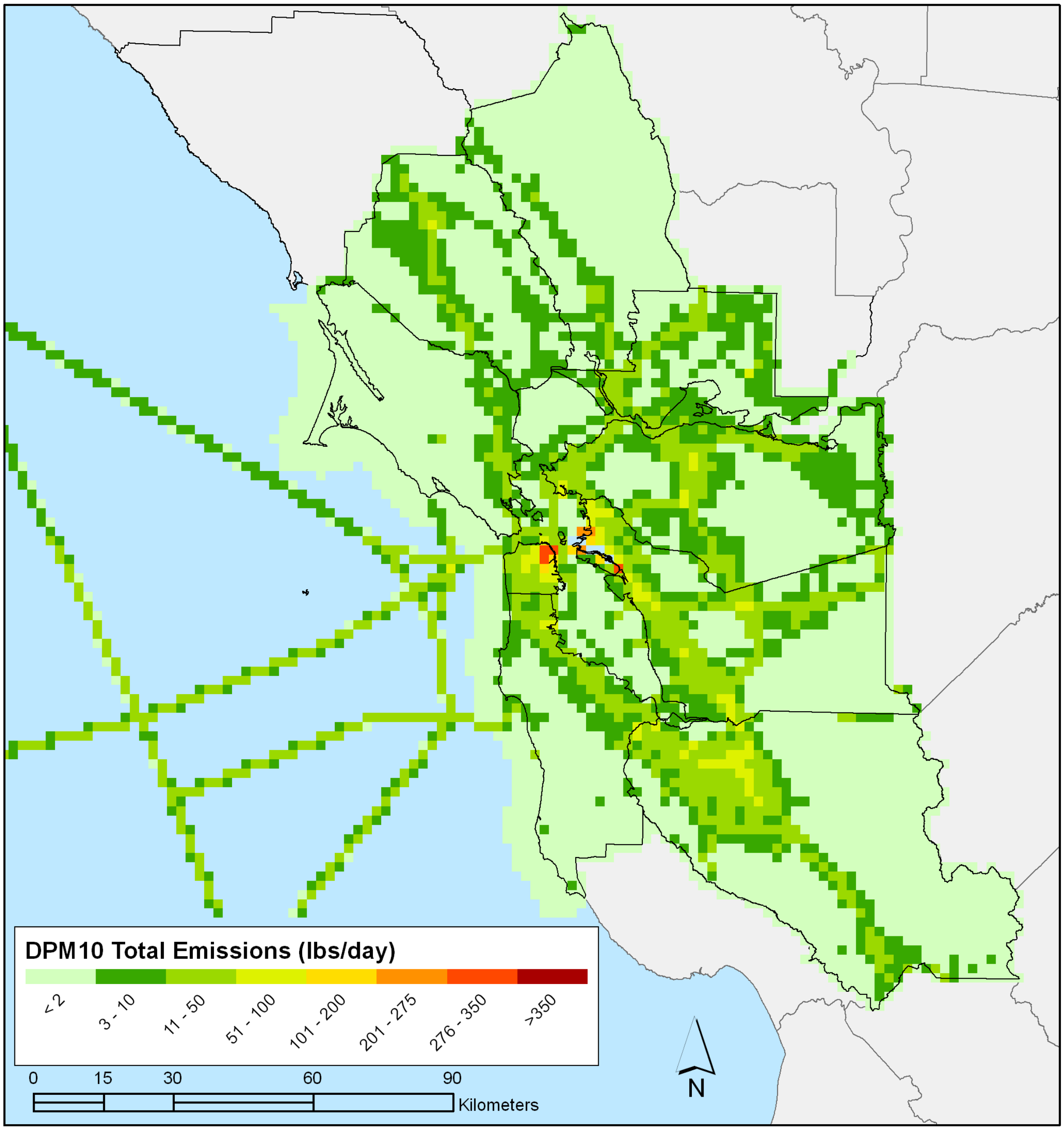

Figure 16. Emission density plot of diesel particulate matter emissions.

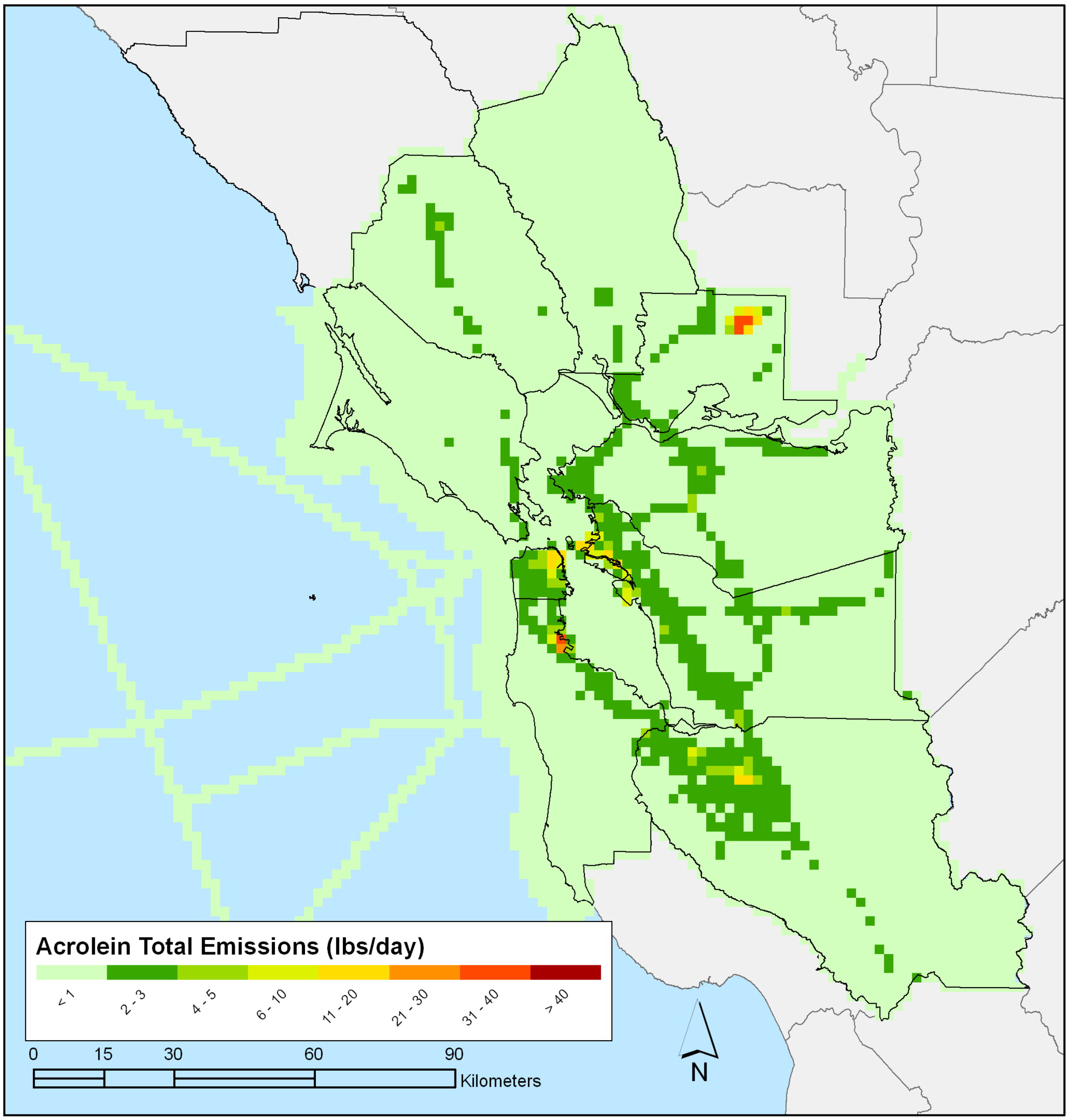

Figure 17. Emission density plot of acrolein emissions.

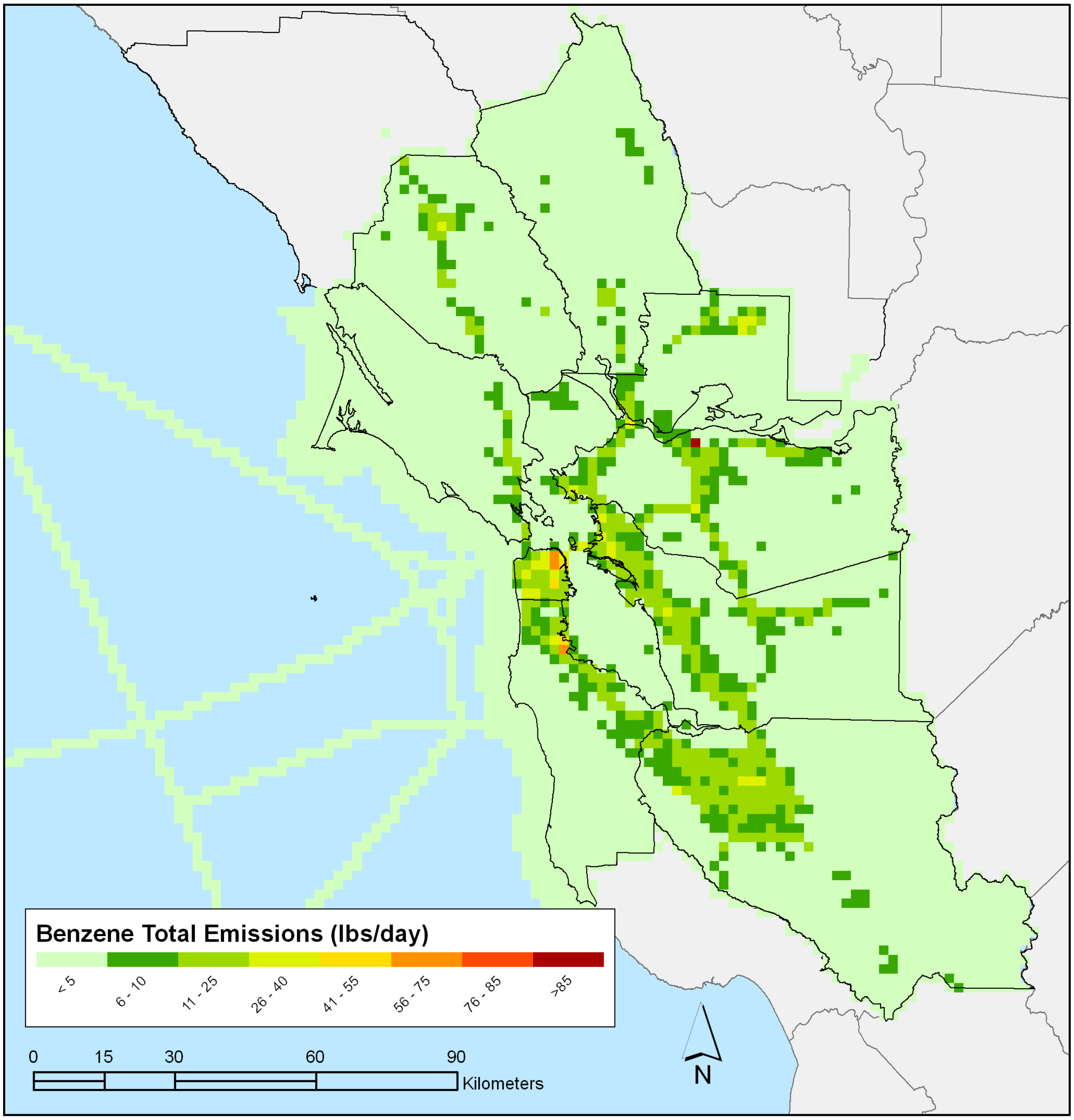

Figure 18. Emission density plot of benzene emissions.

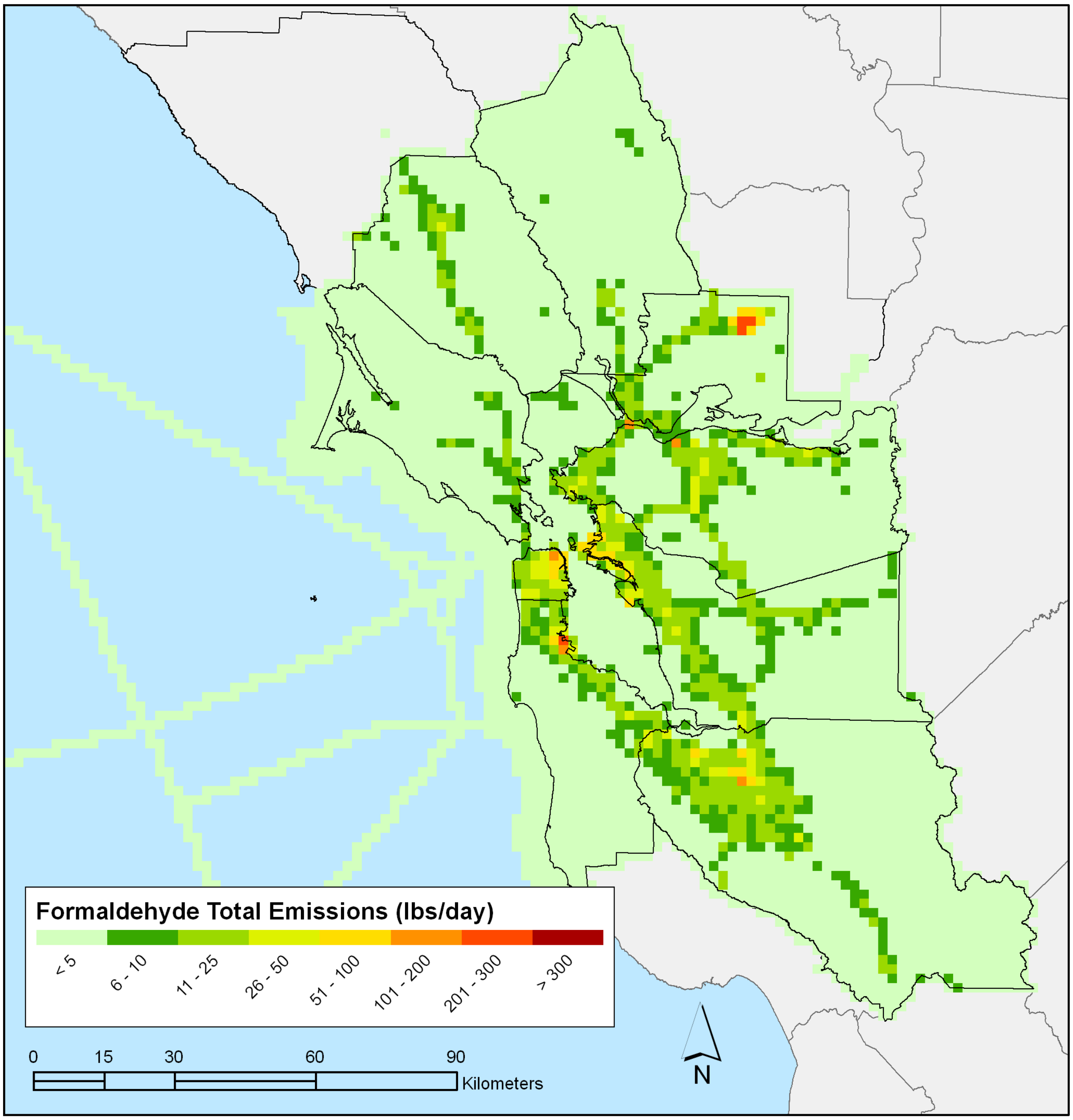

Figure 19. Emission density plot of formaldehyde emissions.

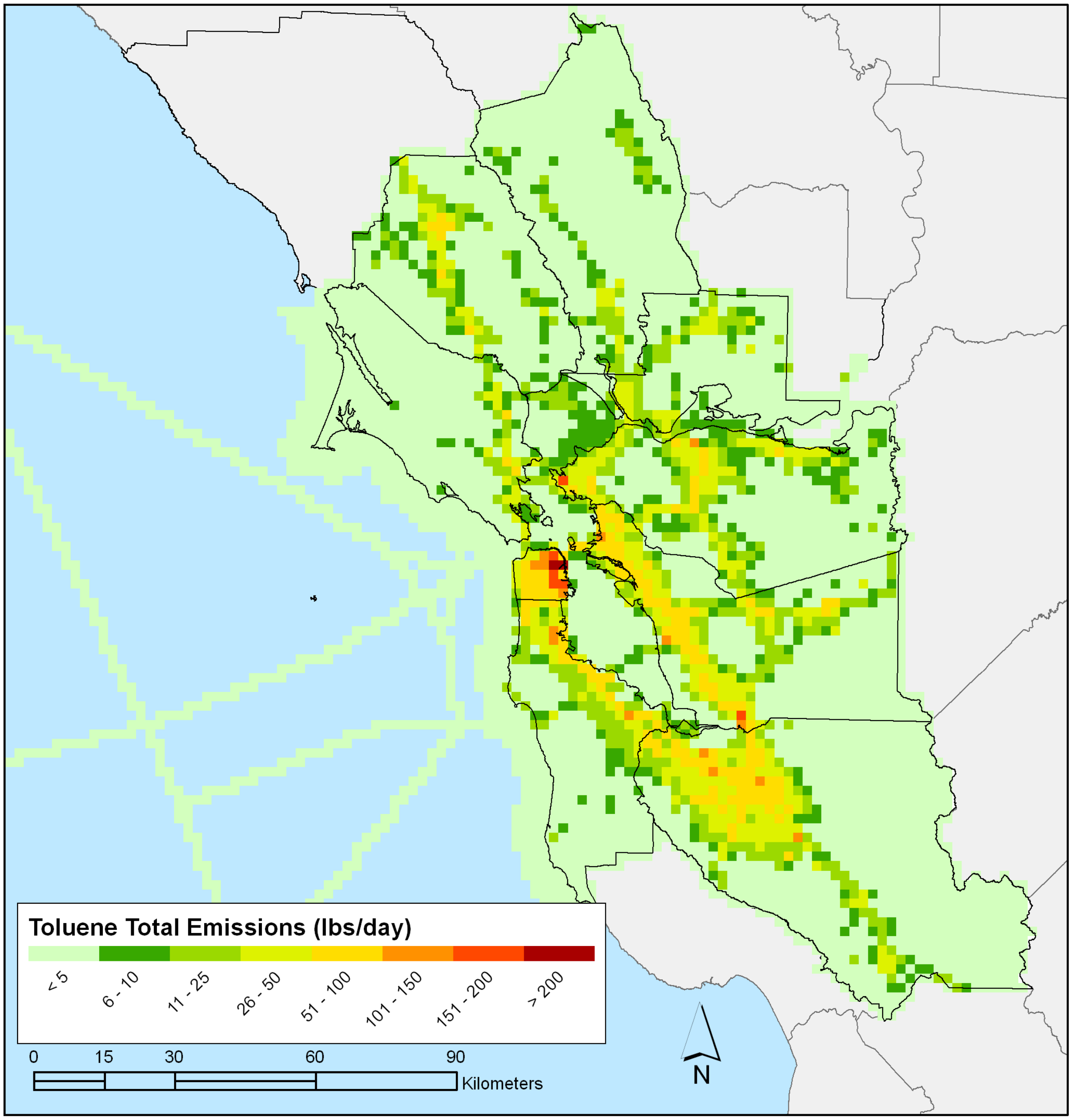

Figure 20. Emission density plot of toluene emissions.

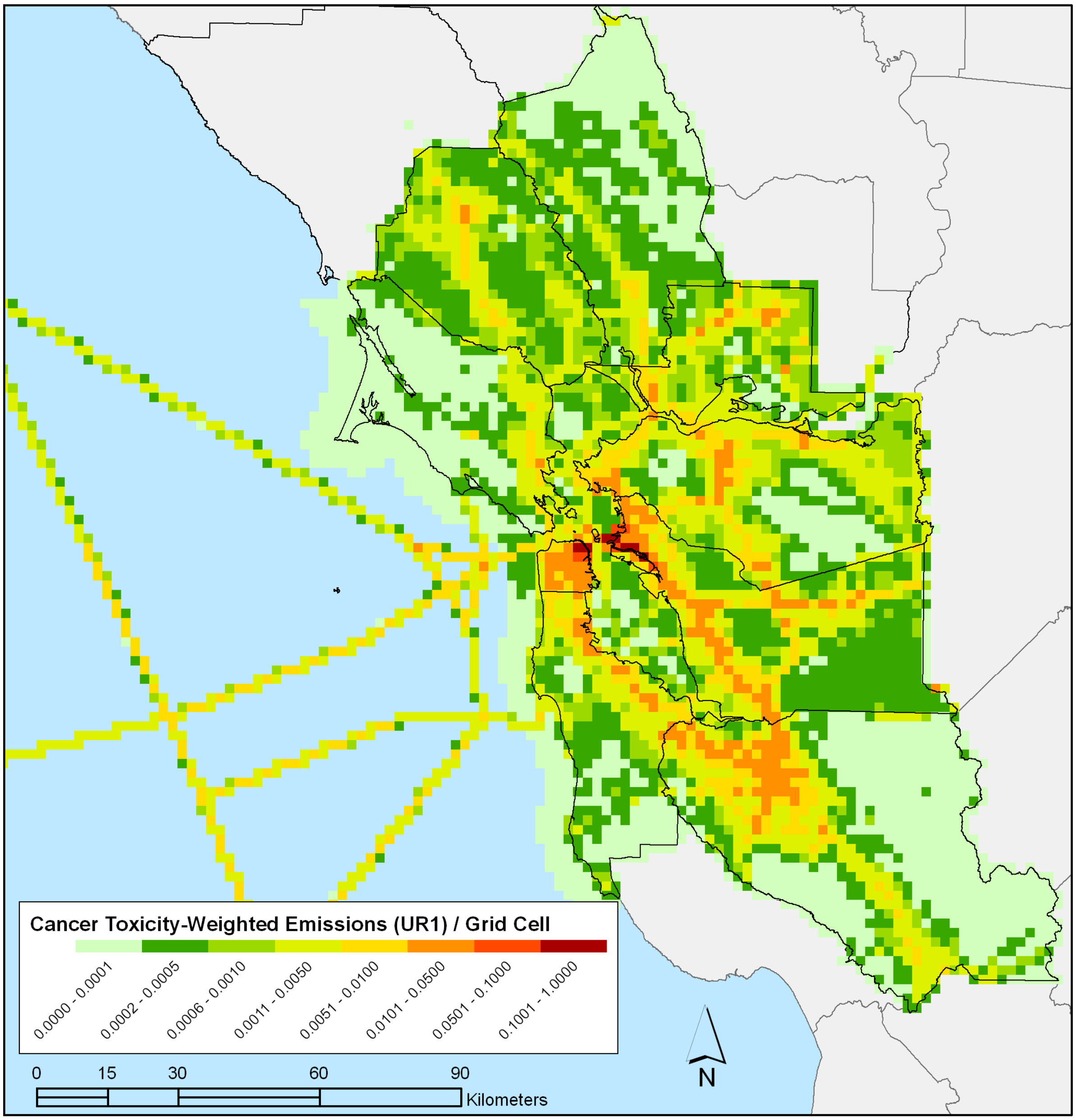

Figure 21. Emission density plot of cancer toxicity-weighted emissions.

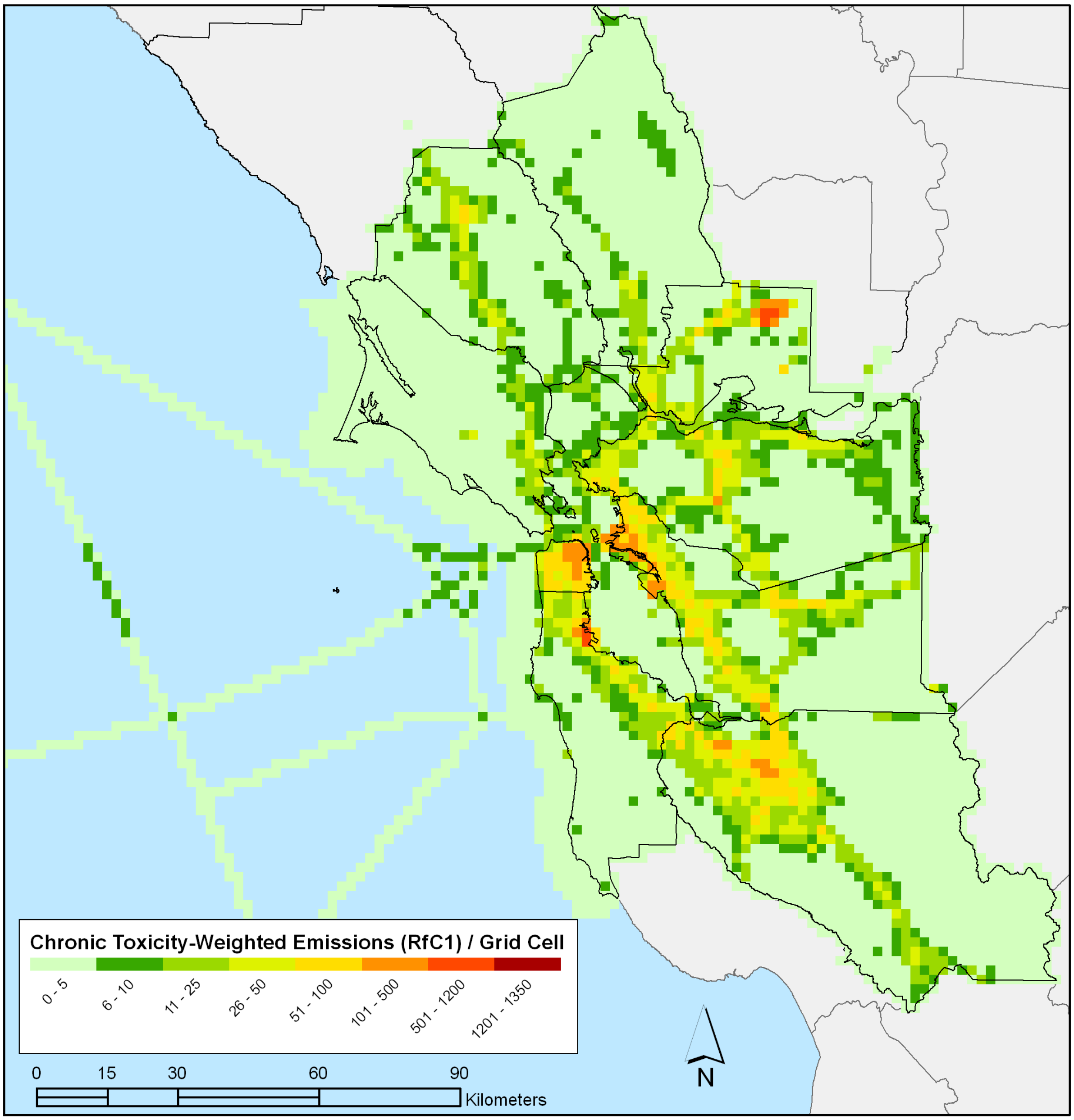

Figure 22. Emission density plot of chronic toxicity-weighted emissions.

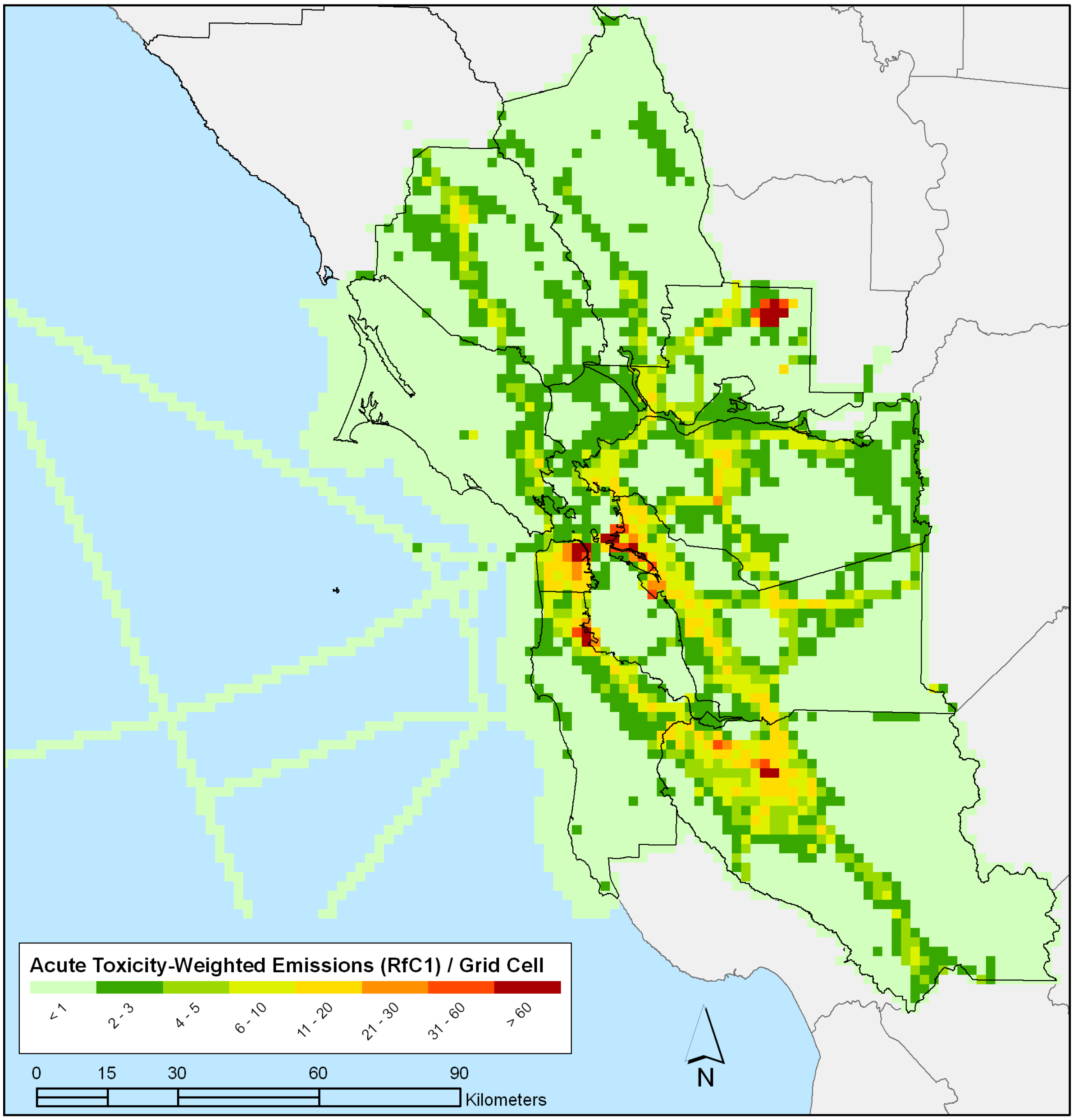

Figure 23. Emission density plot of acute toxicity-weighted emissions.

TEMPORAL PROFILE ASSIGNMENTS

The 2005 TAC inventories developed by STI contain annualized emissions (average lbs/day). However, it is desirable to resolve emissions on an hourly basis for modeling purposes. Therefore, STI assigned a diurnal profile to each area, non-road mobile, and point source (MEDS-formatted on-road mobile source emissions provided by the District were already resolved hourly).

ARB maintains a database of hourly temporal profiles, as well as a cross-reference file that assigns an appropriate hourly profile to all EIC codes and point source processes. STI based temporal profile assignments on the ARB cross-reference file, though some updates were made to sources in the District that were assigned an inappropriate profile. Specifically, several sources in the District were assigned diurnal profile 24—which distributes activity evenly across all hours of the day—even though these same sources in other California counties were assigned other, more reasonable diurnal profiles. STI updated diurnal profile assignments for these District sources:

- Emissions from residential natural gas combustion were assigned diurnal profile 33, which shows activity peaks during morning and evening hours and reduced activity levels during midday hours and at night.
- Emissions from commercial aircraft were assigned profile 35, which allocates emissions primarily to the hours between 7 a.m. and 1 a.m.
- Emissions from civil aircraft were assigned profile 33, which allocates emissions primarily to daylight hours.
- Emissions from vehicle refueling activities were assigned profile 31, which assumes that refueling activities peak between 5 p.m. and 9 p.m.

STI incorporated tables with ARB diurnal profiles and updated profile assignments in the point source and area and non-road mobile source databases that contain TAC emission estimates.

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