DIESEL PARTICULATE MATTER EXPOSURE ASSESSMENT STUDY FOR THE PORTS OF LOS ANGELES AND LONG BEACH

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Diesel Particulate Matter Exposure Assessment Study for the Ports of Los Angeles and Long Beach

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DIESEL PARTICULATE MATTER EXPOSURE ASSESSMENT STUDY FOR THE PORTS OF LOS ANGELES AND LONG BEACH

PART I: SUMMARY

The California Air Resources Board (ARB or Board) conducted an exposure assessment (study) to evaluate the impacts from airborne particulate matter emissions from diesel-fueled engines associated with port activities at the Ports of Los Angeles and Long Beach (ports) located in Southern California. The purpose of the study was to enhance our understanding of the port-related diesel particulate matter (PM) emission impacts by evaluating the relative contributions of the various diesel PM emission sources at the ports to the potential cancer risks to people living in communities near the ports. This information will assist in the efforts underway to reduce diesel PM emissions at the ports by helping to identify the sources that have the greatest impact on potential cancer risks to nearby residents and by providing a tool that will allow evaluation of the impacts of measures planned and under development that are designed to reduce diesel PM emissions.

The study focused on the on-port property emissions from locomotives, on-road heavy-duty trucks, and cargo handling equipment used to move containerized and bulk cargo such as yard trucks, side-picks, rubber tire gantry cranes, and forklifts. The study also evaluated the at-berth and over-water emissions impacts from ocean-going vessel main and auxiliary engine emissions as well as commercial harbor craft such as passenger ferries and tugboats. For the ocean-going vessel emissions, the study evaluated the hotelling emissions, i.e. those emissions from vessel auxiliary engines while at berth, separately from the maneuvering and transiting emissions. While there are locomotive and on-road heavy-duty truck emissions associated with the movement of goods through the ports that occur off the port boundaries, these were not evaluated in this study. Future analyses will consider the impact of these off-port emissions.

The results from the study are presented in this report which is comprised of two parts. Part I, "Summary," provides an overview and summary of the study in a less technical and more easily understood format. Part II, "Technical Support Document," provides a description of the supporting technical basis for the study and a more comprehensive summary of the results. For simplicity, the Summary is presented in question-and-answer format. The reader is directed to Part II for more detailed information.

1. What are the major elements of the study?

The major elements of the study were:

- developing a baseline (2002) inventory of diesel PM emissions at the two ports from ocean going vessels (transit, maneuvering, and hotelling), harbor craft, cargo handling equipment, in port trucks, and in port trains,
- estimating the ambient concentration of diesel PM downwind of the ports, and

- estimating the potential cancer risk levels and other non-cancer health effects associated with the diesel PM concentrations.

2. What are the key findings from the study?

The key findings from this study are:

- Diesel PM emissions from the ports are a major contributor to diesel PM in the South Coast Air Basin.

  The combined diesel PM emissions from the ports are estimated to be about 1,760 tons per year in 2002. This represents a significant component of the regional diesel PM emissions for the South Coast Air Basin (SCAB) at about 21 percent of the total SCAB diesel PM emissions in 2002. Focusing only on diesel PM emissions occurring on port property or within California Coastal Waters (CCW)[1], the emissions from ship activities (transiting, maneuvering, and hotelling) account for the largest percentage of emissions at about 73 percent, followed by commercial harbor craft vessels (14%), cargo handling equipment (10 %), in-port heavy duty trucks (2%), and in-port locomotives (1%).

- Diesel PM emissions from the ports impact a large area and the associated potential health risks are of significant concern.

  Diesel PM emissions from the ports result in elevated cancer risk levels over the entire 20-mile by 20-mile study area. In areas near the port boundaries, potential cancer risk levels exceed 500 in a million. As you move away from the ports, the potential cancer risk levels decrease but continue to exceed 50 in a million for more than 15 miles.

  Primary diesel PM emissions from the ports also result in potential non-cancer health impacts within the modeling receptor domain. The non-cancer health effects evaluated include premature death, asthma attacks, work loss days, and minor restricted activity days. Based on this study, average numbers of cases per year that would be expected in the modeling area have been estimated as follows:

  - 29 premature deaths (for ages 30 and older), 14 to 43 deaths as 95% confidence interval (CI);
  - 750 asthma attacks, 180 to 1300 as 95% CI;
  - 6,600 days of work loss (for ages 18-65), 5,600 to 7,600 as 95% CI;
  - 35,000 minor restricted activity days (for ages 18-65), 28,000 to 41,000 as 95% CI.

[1] In 1983, the ARB established the California Coastal Waters (CCW) boundary based on coastal meteorology within which pollutants released offshore would be transported onshore. The development of the boundary was based on over 500,000 island, shipboard, and coastal observations from a variety of records, including those from the U.S. Weather Bureau, Coast Guard, Navy, Air Force, Marine Corps, and Army Air Force (ARB, 1982). The CCW boundary ranges from about 25 miles off the coast at the narrowest to just over 100 miles at the widest.

- “Hotelling” emissions from ocean-going vessel auxiliary engines and emissions from cargo handling equipment are the primary contributors to the higher pollution related health risks near the ports.

  Hotelling emissions from ocean-going vessels account for about 20 percent of the total diesel PM emissions from the ports. These emissions are responsible for about 34 percent of the port emissions related risk in the modeling receptor domain based on the population-weighted average risk. These emissions resulted in the largest area (2,036 acres) where the potential cancer risk levels were greater than 200 in a million in the nearby communities. The second highest category contributing to cancer risk levels above 200 in a million was cargo handling equipment, which impacted a residential area of 410 acres and is responsible for about 20 percent of the total risk in the modeling receptor domain based on the population-weighted average risk. Reducing emissions from these two categories will have the most dramatic effect on reducing the port emissions related risks in nearby communities.

- Emissions from commercial harbor craft, in-port trucks, in-port rail, and ocean-going vessels (transit and maneuvering activities) account for about 46 percent of the port emissions related risk in the modeling receptor domain based on the population-weighted average risk. These emissions are an important contributor to elevated cancer risk levels over a very large area.

  Emissions from commercial harbor craft, on-port trucks, on-port rail, and ocean going vessels (maneuvering and transit activities) account for about 70 percent of the total diesel PM emissions for the ports. While emissions from these source categories do not have a major role in the near port risk levels, they are significant contributors to the overall elevated risk levels in the study area. Addressing the emissions from these sources is critical if we are to significantly reduce the exposure of a large population (over 2 million people) to cancer risk levels in the 50 in a million range.

3. Why is ARB concerned about Diesel PM?

Diesel engines emit a complex mixture of air pollutants, composed of gaseous and solid material. The visible emissions in diesel exhaust are known as particulate matter or PM, which includes carbon particles or "soot.” In 1998, ARB identified diesel PM as a toxic air contaminant based on its potential to cause cancer, premature deaths, and other health problems. Health risks from diesel PM are highest in areas of concentrated emissions, such as near ports, rail yards, freeways, or warehouse distribution centers. Exposure to diesel PM is a health hazard, particularly to children whose lungs are still developing and the elderly who may have other serious health problems.

The health impacts of particulate matter (PM10 and PM 2.5) have been studied in epidemiological studies conducted in many different cities. Diesel particulate matter is a major component of particulate matter in many cities. Diesel particulate matter is composed of carbonaceous particles (soot) and particles that can form from nitrogen oxides (NO_X) emitted by diesel engines. These studies have found an increase of one to two percent in daily mortality associated with each 10 $\mu g/m^3$ increase in PM10 exposure. The most vulnerable subpopulations are those with preexisting respiratory or cardiovascular disease, especially the elderly. In addition, increased hospital admissions and morbidity from respiratory disease have been associated with particulate matter exposure in adults and children. Particulate matter exposure is associated with an increased risk of lung cancer in epidemiological studies.

The ARB staff has estimated that 2,000 premature deaths statewide are linked to direct diesel PM exposure and 900 premature deaths are associated with indirect diesel PM exposure in the year 2000 alone. Exposure to fine particulate matter, including diesel PM 2.5, can also be linked to a number of heart and lung diseases. For example, the ARB staff has estimated that 5,400 hospital admissions for chronic obstructive pulmonary disease, pneumonia, cardiovascular disease, and asthma were due to exposure to direct diesel PM 2.5 in California. An additional 2,400 admissions were linked to exposure to indirect diesel PM (Lloyd, 2001). There are uncertainties in these analyses, but the non-cancer public health impacts of diesel PM exposure may outweigh the considerable public health impacts of diesel PM as a carcinogenic substance.

4. What are exposure and risk assessments?

*A **risk assessment** is a tool used to evaluate the potential for a chemical or pollutant to cause cancer and other illnesses.*

Risk assessment is a yardstick useful for comparing the potential health impacts of various sources of air pollution. For this risk assessment, the amount of diesel PM emitted from each source (e.g. cruise ships) is estimated. An air modeling computer program uses local meteorological data (e. g. wind speed and direction) to estimate the annual average ground level concentrations of diesel PM in the communities around the facility. The increased risk of developing lung cancer from exposure to a particular level of diesel PM can be estimated using the Office of Environmental Health Assessment's (OEHHA) cancer potency factor for diesel PM. The non-cancer health impacts of diesel PM exposure are possible to quantify, but the cancer health impacts have more commonly been used as the yardstick with which to compare the impacts of various diesel sources. Risk assessment has various uncertainties in the methodology and is therefore deliberately designed so that risks are not under predicted. Risk assessment is thus best understood as a tool for comparing risks from various sources, usually for purposes of prioritizing risk reduction, and not as literal prediction of the community incidence of disease from exposure.

*For **cancer** health effects, the risk is expressed as the number of chances in a population of a million people who might be expected to get cancer over a 70-year lifetime. The number may be stated as "10 in a million" or "10 chances per million". Often times scientific notation is used and you may see it expressed as 1×10^{-5} or 10^{-5}. Therefore, if you have a potential cancer risk of 10 in a million, that means if one million people were exposed to a certain level of a pollutant or chemical there is a chance that 10 of them may develop cancer over their 70-year lifetime. This would be 10 new cases of cancer above the expected rate of cancer in the population. The expected rate of cancer for all causes, including smoking, is about 200,000 to 250,000 chances in a million (one in four to five people).*

In a risk assessment, risk is expressed as the number of chances in a population of a million people who might be expected to get cancer over a 70-year lifetime. However, for informational purposes only, the risk is sometimes reported for other exposure times, such as a 30-year or a 9-year risk. The longer the exposure to a given air concentration, the greater the cancer risk will be. In this report, only the 70-year lifetime risk is presented. The exposure assessment study for the Ports of Los Angeles and Long Beach focuses on potential cancer cases due to exposure to diesel PM emissions. However, there is a growing body of scientific data suggesting that exposure to fine PM results in premature death and morbidity (illness) due to respiratory and cardiovascular disease. The sensitive subpopulations include people with pre-existing cardiovascular disease and respiratory disease, including asthma, particularly those who are also elderly.

5. Where are the Port of Los Angeles and the Port of Long Beach located and what port activities occur there?

The Ports of Los Angeles (POLA) and Long Beach (POLB) are located adjacent to each other on San Pedro Bay, about 20 miles south of downtown Los Angeles. Together, they form the third-largest port complex in the world. The primary purpose of the ports is to move cargo on and off ocean-going ships and onto trucks or railcars. The majority of goods are transported in containers although the ports also handle non-containerized goods such as coke and motor vehicles. These activities involve a wide variety of sources that contribute to diesel PM and oxides of nitrogen (NOx) emissions such as the ocean-going ships that participate in international trade. Other sources include trucks, locomotives, cargo handling equipment, and harbor craft such as tug boats, crew boats, and fishing vessels.

6. What are the diesel PM emissions from port-related activities at POLA and POLB?

The emissions of diesel PM from port-related activities were estimated to be approximately 965 tons per year for the POLA and 795 tons per year for the POLB in the year 2002, or a total of 1,760 tons per year for both ports. As shown in Table 1, by source category, ocean-going vessels, ship auxiliary engines' hotelling, harbor craft, cargo handling equipment, in-port heavy-duty trucks, and in-port locomotives account for about 53, 20, 14, 10, 2, and 1 percent of the mass emissions, respectively.

Table1: Estimated 2002 Diesel PM Emissions Inventory for POLA and POLB

	OGV	HOTEL	CHC	CHE	IPT	IPL	COMBINED
Diesel PM Emissions T/Y	942	343	244	172	41	18	1760
Percent of Total	53%	20%	14%	10%	2%	1%	100%

Note: OGV – Oceangoing vessels; HOTEL – Ship's auxiliary engine hotelling; CHC – Commercial harbor crafts; CHE –Cargo handling equipment; IPT – In-Port heavy-duty trucks; IPL – In-Port locomotive.

By source area, about 43 percent of the emissions occur on land-based port property and over the water within the breakwater[2] and the remaining (57 percent) occur outside of the breakwater over water. These emissions estimates include only the emissions that are occurring on port property and the over-water emissions from ocean-going ships. It does not include the more regional land-based emissions from trucks and locomotives that occur outside of the port boundaries.

The diesel PM emissions resulting from port activities have been a significant and growing contributor to regional air pollution and community exposure to toxic air pollutants. For example, in the South Coast Air Basin (SCAB), the diesel PM emissions resulting from the ports activities accounted for about 21 percent of the total SCAB diesel PM emissions in 2002. Growth forecasts predict that trade at the POLA and POLB will triple by 2020, resulting in a 60 percent increase in diesel PM emissions from current levels unless further controls are enacted.

7. How were the diesel PM concentrations near the ports estimated?

ARB staff used the United States Environmental Protection Agency (U.S. EPA) approved computer model (ISCST3) to estimate the annual average offsite concentration of diesel PM resulting from the activity at the two ports. The key inputs to the computer model were the diesel PM emissions information (magnitude, timing, and location), the meteorological data (wind speed, direction, etc.), and the dispersion coefficients (rural or urban). Meteorological data, used as a direct input to the dispersion model, are obtained from an air quality monitoring study conducted in Wilmington in 2001. The meteorological observations were located about one mile from the north boundary of the Port of Los Angeles. These data are the most recent and most representative meteorological data for the dock areas of the Ports of Los Angeles and Long Beach. Because the area surrounding the ports has urban characteristics, the modeling was done using the urban dispersion coefficients.

8. How were the potential cancer risks from diesel PM estimated?

The potential cancer risks were estimated using standard risk assessment procedures based on the annual average concentration of diesel PM predicted by the model and a health risk factor (referred to as a cancer potency factor) that correlates cancer risk to the amount of diesel PM inhaled.

The methodology used to estimate the potential cancer risks is consistent with the Tier-1 analysis presented in OEHHA's Air Toxics Hot Spots Program Guidance Manual for Preparation of Health Risk Assessments (September 2003). A Tier-1 analysis assumes that an individual is exposed to an annual average concentration of a pollutant

[2] The breakwater protects POLA and POLB Harbor from rough seas and waves. The breakwater is about nine miles long (east-west) and was built in a pyramid shape with rocks from Catalina Island. The bottom on the ocean floor is 200 feet wide and the top is only 23 feet wide. Construction of the breakwater began in 1899 and took 50 years to complete. The breakwater is approximately 4.5 miles from the ports' north land boundary.

continuously for 70 years.[3] The cancer potency factor was developed by the OEHHA and approved by the State's Scientific Review Panel on Toxic Air Contaminants (SRP) as part of the process of identifying diesel PM emission as a toxic air contaminant (TAC).

9. What is the estimated potential cancer risk from all sources at the ports?

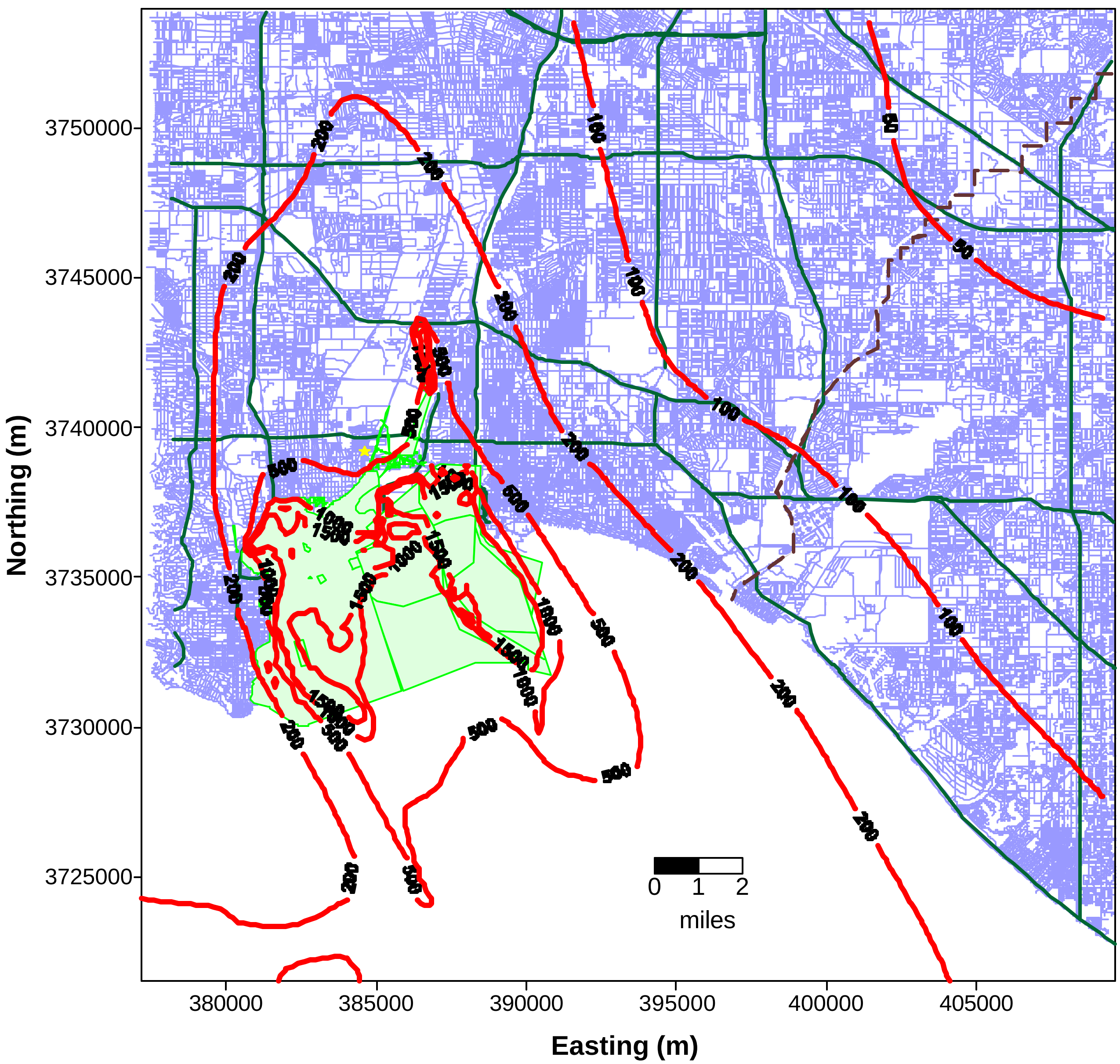
Figure 1 shows the potential cancer risk isopleths for all emission sources at the two ports superimposed on a map showing the ports and the nearby communities. The risk contour of 100 in a million extends beyond the modeling receptor domain to the north of the ports. The domain boundary is about 10 miles north of the port boundary. The area with predicted cancer risk levels in excess of 100 in a million is estimated to be about 94,000 acres, which is 57 percent of the effective land area (163,400 acres, excluding the port property and the water acreage) within the modeling receptor domain. The area in which the risks are predicted to exceed 200 in a million is also very large, covering an area of about 29,000 acres (18 percent of the effective land area within the modeling receptor domain). The areas with the greatest impact have an estimated potential cancer risk of over 500 in a million and cover about 2 percent of the effective land area within the domain. The risk isopleths of 1000 and 1500 in a million occur on the ports' property and the nearby ocean surfaces, and are not considered in this study as people do not reside in these areas.

Using the U.S. Census Bureau's year 2000 census data, we estimated the population within the isopleth boundaries. Nearly 60 percent of the 2 million people that live in the area around the ports have predicted risks of greater than 100 in a million. The affected population numbers for the cancer risk ranges of 100-200, 200-500, and over 500 have been estimated to be about 724,000 people, 360,000 people, and 53,000 people, respectively. The affected population numbers account for about 37, 18 and 3 percent of the total population within the modeling receptor domain, respectively. Note that the risk isopleth of 10 in a million is not shown in Figure 1 because it is outside of the modeling receptor domain. Also, note that if the modeling receptor domain expands, the impacted areas and affected population would be increased.

[3]According to the OEHHA Guidelines, the relatively health-protective assumptions incorporated into the Tier-1 risk assessment make it unlikely that the risks are underestimated for the general population.

Figure 1

Estimated Diesel PM Cancer Risk from POLA and POLB



Notes: Wilmington Meteorological Data, Urban Dispersion Coefficients, 80th Percentile Breathing Rate, Emission = 1,760 TPY, Modeling Receptor Domain = 20 mi x 20 mi, Resolution = 200 m x 200 m.

10. What are the relative contributions to the potential cancer risks from the various diesel PM emission sources at the ports?

The different emission sources are used at various locations on the ports property. Thus, contributions of these emission sources to exposures in the nearby neighborhoods are different. As shown in Tables 2 and 3, the emissions from cargo handling equipment and on-port heavy-duty trucks resulted in areas within the nearby communities having risk levels exceeding 500 in a million while the highest risk levels associated with the other categories were between 200 and 500 in a million. Within the modeling receptor domain, ship hotelling emissions and cargo handling equipment impacted the largest areas and affected more people than the other sources of emissions when considering the risk levels greater than 100 in a million. When considering risk levels greater than 10 in a million, all the port sources, other than in-port heavy-duty trucks and locomotives, had similar impacts, affecting at least 119,000 acres and at least 1.4 million people. By source location, the impacts resulting from the in-port emissions (within the breakwater) are much larger than those resulting from the out-of-port emissions (outside the breakwater), although the emission magnitude of the former is less than the latter (750 TPY vs 1010 TPY). Quantitatively, within the modeling domain, the population-weighted risk resulting from the in-port emissions is about 4.5 times greater than the risk resulting from the over water out-of-port emissions.

Table 2: Summary of Area Impacted by Risk Levels and Activity Categories (Acres)

Risk Level	OGV	HOTEL	CHC	CHE	IPT	IPL	COMBINED
Risk > 500	0	0	0	50	50	0	2,500
Risk > 200	110	2,036	20	410	160	40	29,000
Risk > 100	227	12,700	750	4,100	376	160	94,000
Risk > 10	163,435	160,470	125,250	119,000	29,750	11,240	163,435

Table 3: Summary of Population Affected by Risk Levels and Activity Categories (Number of People)

Risk Level	OGV	HOTEL	CHC	CHE	IPT	IPL	COMBINED
Risk > 500	0	0	0	3,200	205	0	53,000
Risk > 200	18	46,020	5,000	11,100	1,780	680	411,200
Risk > 100	1,810	221,567	22,960	82,000	8,270	4,330	1,135,000
Risk > 10	1,977,760	1,949,850	1,516,515	1,444,000	422,910	213,430	1,977,770

Notes:

1. OGV – Oceangoing vessels; HOTEL – Ship's auxiliary engine hotelling; CHC – Commercial harbor crafts; CHE – Cargo handling equipment; IPT – In-Port heavy-duty trucks; IPL – In-Port locomotive.
2. The model receptor domain of 20-mile x 20- mile with urban dispersion coefficients with a receptor resolution of 200m x 200m was used. The effective receptor modeling domain (excluding the port properties and the ocean water) is estimated to be about 255 square miles; The calculations here are ONLY based on the effective modeling receptor domain.
3. The 80th percentile breathing rate for adults over 70-year lifetime was assumed,
4. Meteorological data from Wilmington (2001) was used for POLA and POLB.
5. The risks within both ports and over the ocean water were excluded for calculations of average risks and affected areas.
6. The estimated population in this Table is ONLY based on the modeling receptor domain using the U.S. Census Bureau's year 2000 census data.
7. If the modeling receptor domain expands, the population and area affected would be increased.
8. The combined column provides the population affected and area impacted for the cumulative impacts from all the emission sources. The individual impacts are not additive since the combined impacts are greater than the sum of the individual sources. For example, cargo handling equipment and commercial harbor craft emissions may impact the same location and population. While individually the impacts may result in cancer risk levels between 100 and 200 in a million, when you combine the impacts, the resulting risks could be greater than 200 in a million.

11. How do the results compare to the monitoring programs and the SCAQMD MATES-II study

For comparison purposes, the ARB staff compared the study results to two monitoring programs conducted by the POLA (POLA, 2005) and ARB (ARB, 2002) and to the South Coast Air Quality Management District (SCAQMD)'s second Multiple Air Toxic Exposure Study (MATES-II (SCAQMD, 2000).

The POLA is currently conducting an air quality monitoring program within the Port and in the nearby communities to estimate the ambient levels of diesel PM in proximity to the Port that are due to Port operational activities. For the comparison, the measured elemental carbon (EC) is used as the surrogate of diesel PM and it is assumed that the ratio of EC with diesel PM is 0.5. Table 4 shows the potential cancer risks based on the modeling results compared to those derived from the half year's monitoring results conducted during the period February 1 through August 5, 2005 at Wilmington community and San Pedro monitoring stations. The computer modeling performs adequately in simulating the measured diesel PM risks at the two locations.

The ARB conducted an air monitoring program in Wilmington from May 2001 to July 2002 as part of the Children's Environmental Health Program. The derived potential diesel PM cancer risks at two sites - Wilmington Park Elementary School and Hawaiian Elementary School are also listed in Table 4 and compared with the predicted risks. It is shown that the predicted results are favorably comparable with the monitored results at the two sites.

Table 4. Comparisons of predicted potential cancer risks with measurements (unit in cases per million)

Location	Port of L. A. monitoring results	ARB SB 25 monitoring results	Model prediction
Wilmington Community	585	N/A	600
San Pedro	533	N/A	500
Wilmington School	N/A	450	470
Hawaiian School	N/A	710	650

Note:

1. The ratio of elemental carbon (EC) with diesel PM has been reported to be 0.375 to 0.75 by literature. A ratio of 0.5 is used in this calculation;
2. For POLA's monitoring program, the measured EC 24-hr average concentrations over the half year from February 9 to August 5, 2005 are reported;
3. For ARB SB 25 Wilmington monitoring study, about 71% of the samples collected were below the detection limit of 1 ug EC/m^3. It is assumed that all measurements below the limit are arbitrarily assumed to be 0.5 ugEC/m^3;
4. For the detailed monitoring programs and results, please check POLA and ARB's web sites.

The ARB staff also compared the study results to the SCAQMD's MATES-II. The MATES-II study indicated that the modeled potential risk in the grid cell containing the Wilmington air quality monitoring station was 1,187 potential cancer cases per million due to diesel PM emissions from port activities, freeways, and other sources of diesel PM. This Wilmington grid cell is approximately 2 miles north of the Ports. Our study shows a risk level of about 450 cases in a million in the same general vicinity. In the nearby residential areas within one mile from port boundaries, risk levels (from diesel PM emissions as well as other toxics) ranged from 1000 to 1500 cases in a million based on the MATES-II study. Our study shows a risk range of 500 to 1000 cases in a million from the Ports' diesel PM emissions. The differences can be attributed to different modeling configurations. For example, MATES-II used the Urban Airshed Model (UAM) model, a grid based model with 2 km grid cells, while our study used the ISCST3 model, a Gaussian plume model. In addition, MATES-II simulated diesel PM from all sources (e.g., port activities and freeway emissions) for the 1998 base year while our study was limited to diesel PM from port activities for the year 2002. Also the MATES-II study released ocean-going emissions near ground level (within the first horizontal layer of the UAM). Our study released ocean going emissions at 50 meters above "ground" (sea level) which will result in greater dispersion of emissions. [4]

12. What are the uncertainties associated with risk assessments?

The estimated diesel PM concentrations and risk levels produced by a risk assessment are based on a number of assumptions. Many of the assumptions are designed to be health protective so that potential risks to individuals are not underestimated. Therefore, the actual risk calculated by a risk assessment is intentionally designed to avoid underprediction. There are also many uncertainties in the health values used in the risk assessment. Some of the factors that affect the uncertainty are discussed below.

When available, as is the case with diesel PM, scientists use studies of people exposed at work to estimate risk from environmental exposures. There can be a wider range of responses in the general public than in the workers in the epidemiology study used to determine the cancer potency factor. Also, the actual worker exposures to diesel PM were based on limited monitoring data and were mostly derived based on estimates of emissions and duration of exposure. Different epidemiological studies suggest somewhat different levels of risk. When the State's Scientific Review Panel (SRP)[5] identified diesel PM as a toxic air contaminant, they endorsed a range of inhalation cancer potency factors (1.3×10^{-4} to 2.4×10^{-3} $(\mu g/m^3)^{-1}$) and a risk factor of 3×10^{-4} $(\mu g/m3)^{-1}$, as a reasonable point estimate of the unit risk. From the unit risk factor an inhalation cancer potency factor of 1.1 $(mg/kg\text{-}day)^{-1}$ may be calculated.

As mentioned above, there is no direct measurement technique for diesel PM. This analysis used an air dispersion modeling to estimate the concentrations to which the public is exposed. The air dispersion models are based on the state-of-the-science

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[4] The higher release point was used because the average ship stack height is about 43 m tall. When the emissions are released from the top of a ship's exhaust stack, there is a plume rise that occurs which was estimated to average to be about 7 meters. This results in an average release height of 50 meters.

[5] The Scientific Review Panel (SRP/Panel) is charged with evaluating the risk assessments of substances proposed for identification as toxic air contaminants by the Air Resources Board (ARB) and the Department of Pesticide Regulation (DPR). In carrying out this responsibility, the SRP reviews the exposure and health assessment reports and underlying scientific data upon which the reports are based, which are prepared by the ARB, DPR, and the Office of Environmental Health Hazard Assessment (OEHHA) pursuant to the sections 39660-39661 of the Health and safety Code and sections 14022.

formulations which have uncertainties. Three air dispersion models – ISC, AERMOD, and CALPUFF, could be used in this study. As stated above, the primary propose of this study was to prioritize emission sources/categories from the Ports operation which are to be regulated. ISC was used in this study because of its fewer requirements for the model inputs. Although AERMOD or CALPUFF may predict somewhat different impacts in the nearby communities, we believe that the conclusions drawn from this study, especially the ranking of the emission sources/categories, may not be altered. This is because that each model assumes that the concentration is linearly proportional to emission rate, thus, the relative contributions or prioritization scheme of each emission source/category to the total impacts in the nearby communities would not be affected.

The model inputs included emission rates, release parameters, meteorological conditions, and dispersion coefficients. Each of the model inputs has an uncertainty of their own. In addition, a relative small model domain of 20 mi x 20 mi was used in this study because of the ISC model's limitation. In reality, the impacts of diesel PM from the Ports in the nearby communities could exceed the domain. Fully impacts of diesel PM from the Ports could be addressed using the long range transport model – CALPUFF in future time.

13. What are the non-cancer health endpoints associated with exposures to Diesel PM from port operations?

A substantial number of epidemiologic studies have found a strong association between exposure to ambient particulate matter (PM) and adverse health effects (CARB, 2002). As part of this study, ARB staff conducted an analysis of the potential non-cancer health impacts associated with exposures to the model-predicted ambient levels of directly emitted diesel PM (primary diesel PM) within the modeling domain. The non-cancer health effects evaluated include premature death, asthma attacks, work loss days, and minor restricted activity days.

ARB staff assessed the potential non-cancer health impacts associated with exposures to the model-predicted ambient levels of directly emitted diesel PM (primary diesel PM) within each 200 meter by 200 meter grid cell within the modeling domain. The populations within each grid cell were determined from U.S. Census Bureau year 2000 census data. Using the methodology peer-reviewed and published in the Staff Report: Public Hearing to Consider Amendments to the Ambient Air Quality Standards for Particulate Matter and Sulfates, (PM Staff Report) (CARB, 2002), we calculated the number of annual cases of death and other health effects associated with exposure to the PM concentration modeled for each of the grid cells and then calculated the totals over the entire modeling area. Based on our analysis, it is estimated that the exposures to the directly emitted diesel PM from on-port operations within the modeling domain result in approximately 29 premature deaths for the 2 million people exposed per year. In addition, these exposures are predicted to result in 750 asthma attacks, 6,600 work loss days, and approximately 35,000 minor restricted activity days. In each case, the values presented represent the mean value in cases per year for the health end point listed.

These estimates are based on a well-established methodology for calculating changes in health endpoints due to changes in air pollution levels. However, since the estimates apply to a limited modeling domain (20 miles by 20 miles), the affected population is small, and hence the overall estimated health impacts are smaller than estimates made on a statewide basis. In addition, to the extent that only a subset of health outcomes is considered here, the estimates should be considered an underestimate of the total public health impact.

In this study, we also did not consider the diesel PM emissions of on-road heavy-duty trucks and locomotives related to port activities that occur off-port boundary within the SCAB (regional emissions). We estimate the off-port regional diesel PM emissions to be about 206 TPY for the both ports, or 10 percent of the total port-related emissions (206 TPY vs 1,970 TPY). These regional emissions are distributed throughout the SCAB and may result in localized health impacts to people who are live near freeways and railroad corridors within the SCAB. These health impacts will be evaluated in future studies.

14. Are there other studies planned that will evaluate the impacts of port-related diesel PM emissions?

As mentioned above, during 1998 -1999, the South Coast Air Quality Management District (SCAQMD) conducted the second Multiple Air Toxics Exposure Study (MATES-II) to determine the Basin-wide risks associated with major airborne carcinogens, including diesel PM. Currently, SCAQMD is conducting MATES-III to assess current air toxics levels within the Air Basin using updated emission inventories, refined modeling methodologies, and improved assumptions. MATES-III will incorporate all air toxic emission sources, e.g., stationary, on-road, and off-road mobile sources, and all air toxics, e.g., diesel PM, 1,3-butadiene, benzene, chromium, etc. In addition, ARB is conducting a neighborhood assessment study for Wilmington, which is nearby the ports. This study is a part of ARB's Neighborhood Assessment Program. The objective is to estimate health risks in Wilmington and surrounding areas. Like MATES-III, this project will consider all emission sources and all air toxic contaminants.

15. What activities are underway to reduce risks?

There are many efforts currently underway to reduce exposures to diesel PM. POLA and POLB have instituted voluntary programs to reduce diesel PM emissions from port operations including installation of diesel oxidation catalysts on yard equipment, funding the incremental costs of cleaner fuels, cold-ironing of ocean-going ships and providing monetary support to the Gateway Cities truck fleet modernization program. In addition, efforts at the State and local level to implement the Diesel Risk Reduction Plan and to fulfill commitments in the State Implementation Plan will also reduce emissions. For example, the new off-road engine standards adopted by ARB and the U.S. EPA will reduce emissions from new off-road engines by over 95% compared to uncontrolled levels. In the fall of 2005, ARB has considered two measures to reduce emissions from sources of diesel emissions at ports. One measure will require reductions from cargo handling equipment and the other from ship auxiliary engines. To ensure continued emission declines in the face of the expected growth, ARB is leading an effort to develop a Port and Intermodal Goods Movement Comprehensive Emission Reduction Plan that will build upon current efforts and define the additional strategies needed to reduce public health impacts from port and related activities. This effort is part of Governor Schwarzenegger's *Goods Movement Action Plan*, a plan that reflects the Governor's desire to improve the movement of goods in California at the same time we work to improve air quality and protect public health.

PART II: TECHNICAL SUPPORT DOCUMENT

I. INTRODUCTION

Emissions from port-related goods movement are a significant and growing contributor to community air pollution. In communities with significant goods movement activity, such as communities located adjacent to California maritime ports, a particular concern is exposure to diesel particulate matter (diesel PM). This pollutant poses a lung cancer hazard for humans and causes non-cancer respiratory and cardiovascular effects that increase the risk of premature death (ARB, 1998a). The particles are readily inhaled because of their small size and can effectively reach the lowest airways of the lung. Many of the adsorbed compounds are known or suspected mutagens and carcinogens. (ARB, 2002)

To better understand the impacts from port activities, Air Resources Board (ARB) staff conducted an exposure assessment study of diesel PM emissions from port-related activities at the Ports of Los Angeles and Long Beach (ports) located in Southern California. This part provides the technical details on the exposure assessment. The reader is directed to Part I, Summary, for a less technical discussion of the study.

A. Overview

Risk assessment is a complex process that requires the analysis of many variables to model real-world situations. Three steps were taken to perform the exposure assessment for the ports:

- developing a diesel PM emissions inventory that reflects the amount of diesel PM released annually from port-related activities;
- conducting air dispersion modeling to estimate the ambient concentration of diesel PM that results from these emissions; and
- estimating the potential cancer risk from the modeled exposures.

The following chapters provide a description of each element of the exposure assessment. Specifically, the following information is provided:

- the methodology used to develop the port-related diesel PM emissions;
- a summary of the estimated diesel PM emissions inventory for the ports;
- a discussion on the air dispersion modeling conducted to estimate ambient concentrations of diesel PM;
- the results of the air dispersion modeling;
- an estimate of the potential impacts (potential cancer risks) to nearby residences due to exposure to ambient concentrations of diesel PM from port-related activities at the ports; and
- a comparison between the risk impacts from the various emission sources at the ports.

B. Purpose

In the South Coast Air Basin (SCAB), diesel PM emissions from port-related activities are a significant and growing contributor to regional air pollution and community exposures to toxic air pollutants. For example, in the SCAB, the diesel PM emissions resulting from the movement of goods through the Ports of Los Angeles (POLA) and the Port of Long Beach (POLB) accounted for about 21 percent of the total SCAB diesel PM emissions in 2002. Growth forecasts predict that trade at POLA and POLB will triple by 2020, resulting in a 60 percent increase in diesel PM emissions from current levels unless further controls are enacted. POLA and POLB operate in close proximity to several communities including San Pedro, Long Beach, and Wilmington. These nearby communities face potentially higher health risks from the port-generated diesel PM emissions.

There are many efforts currently underway to reduce exposures to diesel PM. POLA and POLB have instituted voluntary programs to reduce diesel PM emissions from port operations including installation of diesel oxidation catalysts on yard equipment, funding the incremental costs of cleaner fuels, cold-ironing of ocean-going ships, and providing monetary support to the Gateway Cities truck fleet modernization program. In addition, efforts at the State and local level to implement the ARB Diesel Risk Reduction Plan and to fulfill commitments in the State Implementation Plan will also reduce emissions. New off-road engine standards adopted by ARB and the United States Environmental Protection Agency (U.S. EPA) will reduce emissions from new off-road engines by over 95% compared to uncontrolled levels. In the fall of 2005, ARB has considered two measures to reduce emissions from port sources. One measure will require reductions from cargo handling equipment and the other from ship auxiliary engines. To ensure continued emission declines in the face of the expected growth, ARB is leading an effort to develop a Port and Intermodal Goods Movement Comprehensive Emission Reduction Plan that will build upon current efforts and define the additional strategies needed to reduce public health impacts from port and related activities.

The purpose of this exposure assessment study is to enhance our understanding of the port-related diesel PM emission impacts on communities near POLA and POLB and to assist in the evaluation of control measures under development or planned. Because the emission sources are located at various locations on the port property, the contributions of these emission sources to nearby neighborhoods will be different. Both the location of the emissions and the magnitude need to be taken into consideration when determining the degree of health risks to people who are living around the ports. To summarize, the purpose of the exposure assessment is to:

- investigate the impacts of the various port emission sources on nearby neighborhoods;
- identify the most significant emission source(s);
- prioritize possible mitigation measures to control diesel PM emissions based on the relative magnitude of health risks; and
- assist in evaluating the impacts of measures developed to reduce emissions.

C. Description of the Ports

POLA and POLB are located adjacent to each other on the San Pedro Bay, about 20 miles south of downtown Los Angeles. The ports are directly adjacent to the communities of Long Beach, San Pedro, and Wilmington. The ports are primarily container ports, moving goods into and out of California in containers. However, they also handle non-containerized goods such as coke and automobiles. While the majority of the goods movement occurs during the day, the ports do operate 24 hours a day, 7 days a week, and 365 days a year. The ports are the first and second busiest seaports in the Western United States. POLA encompasses 7500 acres, 43 miles of waterfront and features 26 cargo terminals. These terminals handle nearly 150 million metric revenue tons of cargo annually. In 2004, the POLA moved in 7.4 million TEUs[1], which was a new national container record. POLB covers about 3000 acres of land. In 2004, tonnage through POLB was 73.6 million metric tons, and about 5.8 million TEUs moved through the Port. Combined, POLA and POLB are the world's third-busiest port complex, after Hong Kong and Singapore.

[1] The TEU is the international standard measure used to describe containers. A 20-foot container = 1 TEU.

2a. Port of Los Angeles (Courtesy of POLA, http://www.portoflosangeles.org)

2b. Port of Long Beach (Courtesy of POLB, http://www.polb.com)

Figure 2: Aerial Photos of POLA and POLB

II. EMISSION INVENTORY DEVELOPMENT

Air dispersion models require emission inputs that properly characterize source-specific emissions for diesel PM from various activities in the ports. The port-related activities are categorized as: ocean-going vessels, auxiliary engine hotelling, commercial harbor craft, cargo handling equipment, railroad locomotives, and heavy-duty trucks. POLA and POLB recently hired Starcrest Consulting Group, LLC (Starcrest) to develop detailed emission inventories for all emission sources for POLA and three sources (cargo handling equipment, in-port locomotives, and in-port heavy-duty trucks) for the POLB. At the request of the ports, Starcrest used 2001 as the base year for POLA and 2002 as the base year for POLB. For this exposure assessment study, 2002 was chosen as the baseline year for both ports. In this chapter, we briefly describe how we projected the 2001 POLA emission inventory to 2002 and how we developed the 2002 emissions inventory for ocean-going ships, auxiliary engine hotelling and commercial harbor craft for POLB. The basic methodologies used in the emission inventory development are briefly described in Appendix A.

A. Port of Los Angeles

As stated above, Starcrest prepared an emission inventory for all emission sources at the POLA using 2001 as the baseline year. (Starcrest, 2004a) The inventory utilizes an activity-based approach and focuses on emissions of diesel PM for all significant sources operating in the Port. In addition to in-port activities, emissions from railroad locomotives and on-road trucks transporting port cargo were also estimated based on the activity that occurs outside the Port, but within the South Coast Air Basin boundaries. Only in-port emissions and over water emissions from ocean-going ships and harbor craft were evaluated in this exposure assessment. Our methodology for projecting the 2001 POLA inventory to 2002 is presented below.

<u>Ocean-going Vessels</u>

For 2001, Starcrest estimated emissions from ship cruising (includes transiting and maneuvering) and hotelling activities. To estimate the 2002 POLA emissions, ARB staff assumed that the emissions per vessel call would be the same in 2001 and 2002. Emissions per vessel call were calculated from the emissions per vessel call (expressed in emissions/call number) for each ocean-going vessel (OGV) type (i.e. auto carrier, bulk, container, cruise, general cargo, reefer, RoRo, tanker) reported in the 2001 POLA emission inventory data. Emissions per vessel call were estimated for each activity (transiting, maneuvering, hotelling). ARB staff then estimated the emissions for each OGV type in 2002 by multiplying the emissions per call in 2001 by the number of vessel calls for each of the corresponding OGV types in 2002, that is:

$$E_{POLA,2002,i} = \frac{E_{POLA,2001,i}}{CN_{POLA,2001,i}} x CN_{POLA,2002,i} \quad (1)$$

where $E_{POLA,2002,i}$ is the estimated emissions of OGV type i (i = 1, 10) in 2002, $E_{POLA,2001,i}$ is the emission of OGV type i at POLA for 2001 (known), $CN_{POLA,2001,i}$ and $CN_{POLA,2002,i}$ are the vessel call numbers from POLA in 2001 and 2002 for OGV type i, respectively. Table 5 provides a summary of the estimated emissions per vessel call and the actual vessel call numbers for each port in 2002.

Table 5: Estimated Diesel PM Emissions per Vessel Call and 2002 Port Calls

Vessel Type	POLA 2001 Diesel PM Emissions Per Vessel Call (T/Y-CALL)			POLA 2002 Vessel Calls	POLB 2002 Vessel Calls
	Transit*	Auxiliary – Transit	Auxiliary – Hotelling		
Auto	0.0904	0.0055	0.011	154	109
Bulk	0.0887	0.0039	0.0374	86	453
Container	0.2019	0.0109	0.0581	1,673	1,304
Cruise	0.2675	0.065	0.0975	257	36
General Cargo	0.0807	0.0047	0.0234	158	126
Miscellaneous	0.0875	0	0.1143	3	207
Other Tug	0.0353	0	0	70	51
Tanker	0.0942	0.0058	0.0986	341	546

*Transit includes both transiting and maneuvering emissions. Vessel call estimates provided by POLA and POLB.

Adjustments to the hotelling emissions were also made based on additional data obtained subsequent to release of the Starcrest inventories. Specifically, corrections were made to the emission factor for auxiliary engines running on heavy fuel oil (HFO). In addition, the assumption on the percentage of engines running on HFO and marine distillate was modified to reflect new data obtained in an ARB survey conducted in 2004. (ARB, 2004) With respect to the emission factor, for ship auxiliary engines, Starcrest utilized a single diesel PM emission factor of 0.3 g/kW-hr in calculating auxiliary engine emissions, regardless of diesel fuel type. Based on a review of published emissions data, the emission factor for HFO should be much higher. In U.S. EPA's 2002 "Commercial Marine Emission Inventory Development" report prepared by ENVIRON International Corporation, an emission factor of 1.74 g/kW-hr is reported for engines running on HFO with a 3% sulfur content. (Environ, 2002) ARB staff adjusted this emission factor to 1.5 g/kW-hr based on the average sulfur content of HFO reported as being used in the 2004 ARB survey and retained the 0.3 g/KW-hr factor for auxiliary engines operating on marine distillate.[2] (See Appendix B.) Starcrest also assumed that 50% of the auxiliary engines were operating on HFO and 50% on marine distillate. ARB's survey results established that 75 percent of the auxiliary engines use HFO and 25 percent use marine distillate. These two modifications resulted in increasing the hotelling emissions by a factor of 4 over the estimates that would have resulted from growing the Starcrest values to 2002 based on the number of ship calls.

Cargo Handling Equipment

To project the emissions inventory for cargo handling equipment from 2001 to 2002, we estimated the annual growth factors by interpolating between the 2001 baseline year and the reported 2005 emissions developed for the No Net Increase (NNI) Task Force Project. We assumed linear growth between 2001 and 2005. The emissions for cargo handling equipment developed for the NNI project for 2005 reflect both the impacts from adopted control measures and any growth that has occurred in activity. This resulted in a net annual average growth rate of about 4.5%.

In addition, the emissions for cargo handling equipment were further modified to reflect emission inventory adjustments that ARB staff have developed to support a 2005 rule-making for cargo handling equipment. These adjustments result in about a 34% decrease in the emissions from cargo handling equipment for the year 2002. The main inventory changes to the OFFROAD model methodology used to estimate emissions from cargo handling equipment include: (1) revising zero hour emission factors, and (2) revising equipment useful life, based on the data provided in a 2004 ARB Cargo Handling Equipment Survey (ARB, 2004). The zero hour emission factors are revised by calculating composite emission factors based on the percentages of off-road, on-road, and retrofitted equipment. Because on-road and retrofitted engines generally have lower emission factors than off-road engines, these revisions resulted in lower zero hour emission factors. The useful life of the equipment is used to calculate the rate that the emissions increase over the life of the equipment. The 2004 ARB CHE Survey results showed that CHE equipment useful lives are significantly longer than the useful lives used in the OFFROAD Model. Since the deterioration rate is calculated as a percentage of the zero hour emissions divided by the useful life, the revised deterioration rates are lower than the original deterioration rates used in the OFFROAD Model. Because both the zero hour emission factor and the deterioration rate are lower than those used in OFFROAD Model, the resultant emissions for cargo handling equipment are lower than those previously predicted by the OFFROAD Model for use in the 2001 POLA emission inventory.

[2] In July 2002, the European Commission published, "Quantification of Emission from Ships Associated with Ship Movements between Ports in the European Community" (Entec Report). The Entec report recommended an emission factor of 0.8 g/kW-hr for auxiliary engines operating on HFO. ARB staff believes this emission factor would result in an underestimation of diesel PM emissions. Applying U.S. EPA's methodology to estimate emissions of sulfate PM from diesel-fueled engines to an auxiliary engine operating on 2.5% sulfur HFO would generate 0.8g/kW-hr of sulfate PM alone. Because there are many other components of PM such as ash and semi-volatile compounds, the 0.8 g/kW-hr emission factor appears to only account for the sulfate PM that is generated.

Harbor Craft, In-Port Heavy-duty Trucks, and In-Port Locomotives

To project the emissions inventory for commercial harbor craft, in-port trucks, and in-port locomotives from 2001 to 2002, we estimated the annual growth factors by interpolating between the 2001 baseline year and the reported 2005 emissions developed for the No Net Increase (NNI) Task Force Project. We assumed linear growth between 2001 and 2005 for each source category. The emissions of each category developed for the NNI project for 2005 reflect both the impacts from adopted control measures and any growth that has occurred in activity. The resulted net annual average growth rates are 0.0, -6.0, and 11.0 percent for commercial harbor craft, in-port heavy-duty trucks, and in-port locomotives, respectively.

B. Port of Long Beach

For POLB, Starcrest developed emission inventories for three categories: cargo handling equipment, in-port locomotives, and in-port heavy-duty vehicles using 2002 as the base year. The methodologies used in estimating emissions for these categories are similar to those used in estimating corresponding emission inventories for the POLA. To complete the emission inventories for POLB, ARB staff used the methodologies described below to estimate the emissions for ocean-going vessels (transiting, maneuvering, and hotelling) and commercial harbor craft vessels.

Ocean-going Vessels

To estimate emissions from ocean-going vessels for POLB, ARB staff assumed that the emissions per vessel call for each OGV type in POLB in 2002 is the same as that for the corresponding OGV type from POLA in 2001 (see Table 5). The emissions for each OGV type calling on POLB in 2002 are estimated by multiplying the emissions per call by the number of vessel calls for the corresponding OGV type at POLB in 2002, that is:

$$E_{POLB,2002,i} = \frac{E_{POLA,2001,i}}{CN_{POLA,2001,i}} x\, CN_{POLB,2002,i} \qquad (5)$$

where $E_{POLB,2002,i}$ is the estimated emission of OGV type i at POLB for 2002, $E_{POLA,2001,I}$ is the emission of OGV type i at POLA for 2001 (known), $CN_{POLA,2001,i}$ and $CN_{POLB,2002,i}$ are the call numbers from POLA in 2001 and from POLB in 2002 for OGV type i, respectively.

Cargo Handling Equipment

Consistent with the approach used to adjust the POLA cargo handling equipment emissions inventory, POLB 2002 cargo handling equipment inventory was decreased by 34 percent to reflect the inventory updates to the methodology used to estimate emissions from cargo handling equipment. (See discussion provided under A. Port of Los Angeles.)

Harbor Craft

To estimate emissions from harbor craft vessels operating at POLB, ARB staff used the estimates of emissions from harbor craft vessels from ARB's 2004 commercial harbor craft emission inventory. These emission estimates were based on information on vessels registered (California Department of Fish and Game), permitted (California Public Utilities Commission), or documented (U.S. Coast Guard) with a "home port" listed as "Long Beach." These vessels registered as "Long Beach" were then allocated to the nine categories (commercial fishing, charter fishing, ferries/excursion, crew and supply, pilot, tugs, tows, work boats, and others) using the harbor craft vessel composition developed in ARB's 2003 Commercial Harbor Craft Survey (released in 2004). The emissions of each category for POLB in 2004 were estimated using the emission density (emission/per vehicle per category) multiplied by the corresponding vessel number in each category, that is:

$$E_{POLB,2004} = \sum_{i=1}^{2}\sum_{j=1}^{9} \left(\frac{E_{statewide,2004}(i,j)}{N_{statewide,2004}(i,j)} \right) x\, N_{POLB,2004}(i,j) \qquad (6)$$

where $E_{POLB,\,2004}$ is the estimated emissions for all harbor craft vessels at POLB for 2004, $E_{statewide,\,2004}(i, j)$ is the estimated emission for engine type i and harbor craft vessel type j in the statewide for 2004, $N_{statewide,\,2004}$ (i, j) and $N_{POLB,\,2004}$ (i, j) are the numbers of harbor craft type j for engine type i in the statewide and in POLB for 2004 respectively, i is the index for engine type (propulsion and auxiliary), and j is the index for harbor vessel type (j = 1 to 9, defined above).

Consistent with the growth projections developed for the NNI project, it was assumed no growth in harbor craft emissions between 2001 and 2005. Based on this assumption, we assumed that for POLB, the total emissions of harbor craft vessels in the 2002 baseline year are equal to that in 2004 as calculated above.

C. In-Port and Out-of-Port Emissions Allocation

The emissions of different source categories are distributed at various locations in the ports and over the offshore ocean water surfaces. To investigate spatial effects of emission sources on the nearby neighborhoods, the total emissions of the two ports are spatially allocated into two broad areas: in-port and out-of-port. In-port refers to the area inside the breakwater of the ports, which is approximately 5 miles from the shoreline; the out-of-port refers to the ocean water surface beyond the breakwater, extending up to 50 miles from the ports. The land-based emissions resulting from heavy-duty truck and locomotive activities outside of the Port boundaries are not included in the "out-port" for this modeling analysis.

D. Emission Inventory Summary

Emission estimates by source category for POLA and POLB in 2002 are summarized in Figure 3 and Table 6. As can be seen, for both ports, OGVs (transit and maneuvering) are the biggest contributor to the combined total emissions. The next highest emission source is the hotelling of ship's auxiliary engines at berth, followed by commercial harbor craft. Cargo handling equipment is the fourth largest, in-port trucks fifth, and in-port locomotives are last. Based on the total combined emissions for the two ports, OGV accounts for about 53 percent, hotelling accounts for 20 percent, harbor craft accounts for 14 percent, cargo handling equipment accounts for 10 percent, in-port truck accounts for 2 percent, and in-port locomotive accounts for 1 percent. The emissions from POLA comprise about 55 percent of the total emissions from the two ports. The in-port and out-of-port emissions for both ports are presented in Figure 4. The in-port emissions comprise about 43 percent of the total emissions in the ports, and the remaining 57 percent occurs in over water area outside the breakwater. By source category, only OGVs and commercial harbor craft have emissions generated outside the breakwater. OGV comprises about 90 percent of the total out-of-port emissions, while commercial harbor craft accounts for the remaining 10 percent.

Table 6: 2002 Estimated Diesel PM Emissions for the POLA and POLB

	Diesel PM Emissions Tons per Year					
	Source Category					
	OGV	HOTEL	CHC	CHE	IPT	IPL
POLA	515	165	178	78	18	11
POLB	427	178	66	94	23	7
Combined	942	343	244	172	41	18

Note: OGV – Oceangoing vessels; HOTEL – Ship's auxiliary engine hotelling; CHC – Commercial harbor crafts; CHE –Cargo handling equipment; IPT – In-Port heavy-duty trucks; IPL – In-Port locomotive.

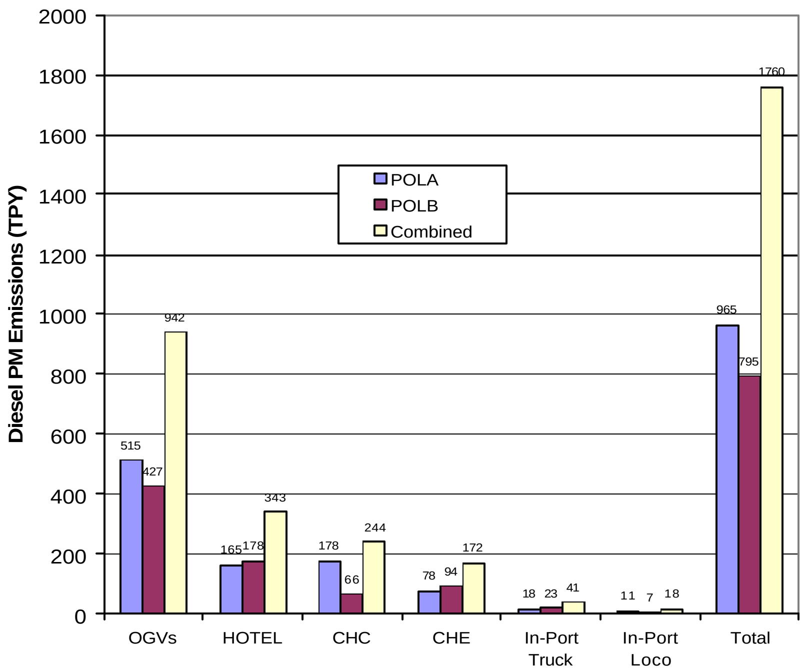

Figure 3: Estimated 2002 Diesel PM Emissions for POLA and POLB

Notes: OGV = Ocean-going Vessels; Hotel = Ship Auxiliary Engine Hotelling; CHC = Commercial Harbor Craft; CHE = Cargo Handling Equipment; In-Port Loco = In-Port Locomotives

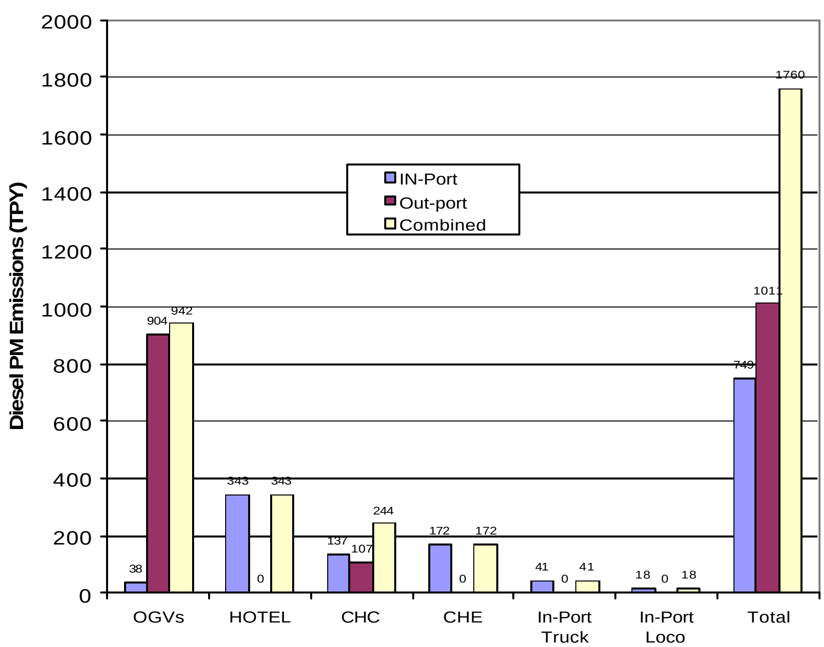

Figure 4: In-Port and Out-of-Port Distribution of POLA and POLB Diesel PM Emissions

Notes: OGV = Ocean-going Vessels; Hotel = Ship Auxiliary Engine Hotelling; CHC = Commercial Harbor Craft; CHE = Cargo Handling Equipment; In-Port Loco = In-Port Locomotives

III. AIR DISPERSION MODELING

In this chapter, we describe the air dispersion modeling performed to estimate the downwind dispersion of diesel PM exhaust emissions resulting from the activities at POLA and POLB. A description of the air quality modeling parameters, including air dispersion model selection, modeling domain, emission source distribution/allocation, model parameters, meteorological data selection, and model receptor network, is provided.

A. Air Dispersion Model Selection

Air quality models are often used to simulate atmospheric processes for applications where the spatial scale is in the tens of meters to the tens of kilometers. Selection of air dispersion models depends on many factors, such as, characteristics of emission sources (point, area, volume, or line), the type of terrain (flat or complex) at the emission source locations, and source receptor relationships. For this study, ARB staff selected the U.S. EPA Industrial Source Complex Model Short Term Version 3 (ISCST3, Version 02035) to simulate impacts at nearby receptors due to diesel PM emissions. The ISCST3 model is a micro-scale, steady-state Gaussian plume dispersion model applicable for estimating impacts from a wide variety of emission release patterns (point, area, line, and volume) such as those found at the ports for distances up to about 50 kilometers. The model may be used to predict annual average concentrations. ISCST3 is also able to simulate the dispersion of emissions generated from multiple sources and accommodate both continuous and intermittent sources in flat and complex terrain. ARB staff has successfully used ISCST3 model to assess public heath risk impacts of diesel PM emitted from the Roseville Railyard on nearby residential areas.

B. Model Domain and Receptor Network

The modeling receptor domain (study area) spans a 20 x 20 mile area as shown in Figure 5a. The domain includes both the ports, the ocean surrounding the ports, and nearby residential areas which have a population of about 2 million residents. Diesel PM emissions are released within the modeling receptor domain as well as beyond the receptor network for ocean-going vessels (see Figure 5b). The land-based portion of the modeling receptor domain, excluding the property of the ports, comprises about 65 percent of the modeling domain. A Cartesian grid receptor network (160 x 160 grids) with 200 m x 200 m resolution is used in this study. This network is convenient to identify the emission sources within the ports with respect to the receptors in the nearby residential areas. Since the exposure assessment was not designed to identify hot spots, a finer grid receptor network was not used. While receptors within the ports were included in the network, the risks from these on-site receptors were excluded from the final risk analyses. The elevation of each receptor within the modeling domain was determined from the United States Geological Service topographic data.

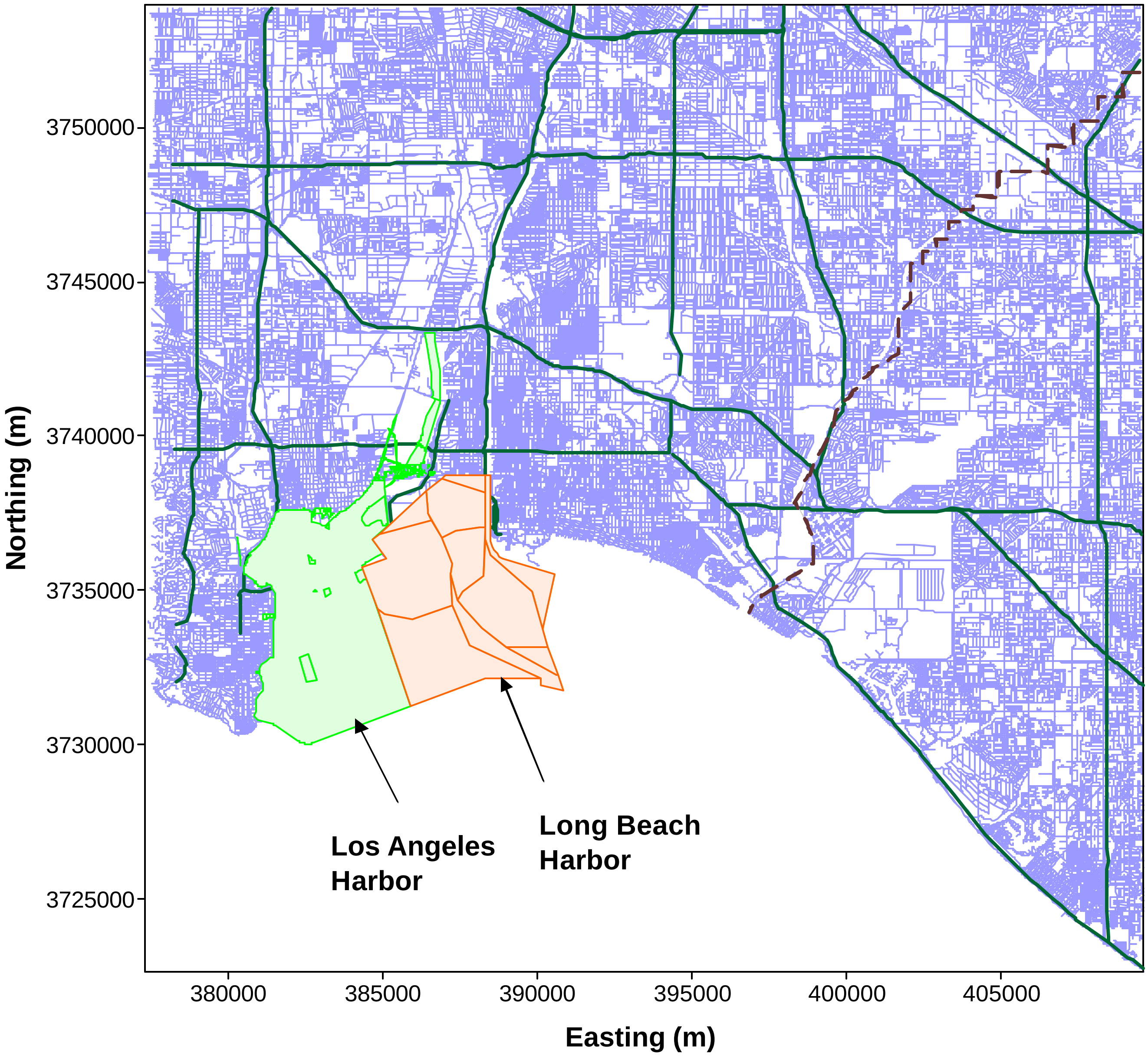

Figure 5a. Modeling Receptor Domain for the Ports of Los Angeles and Long Beach

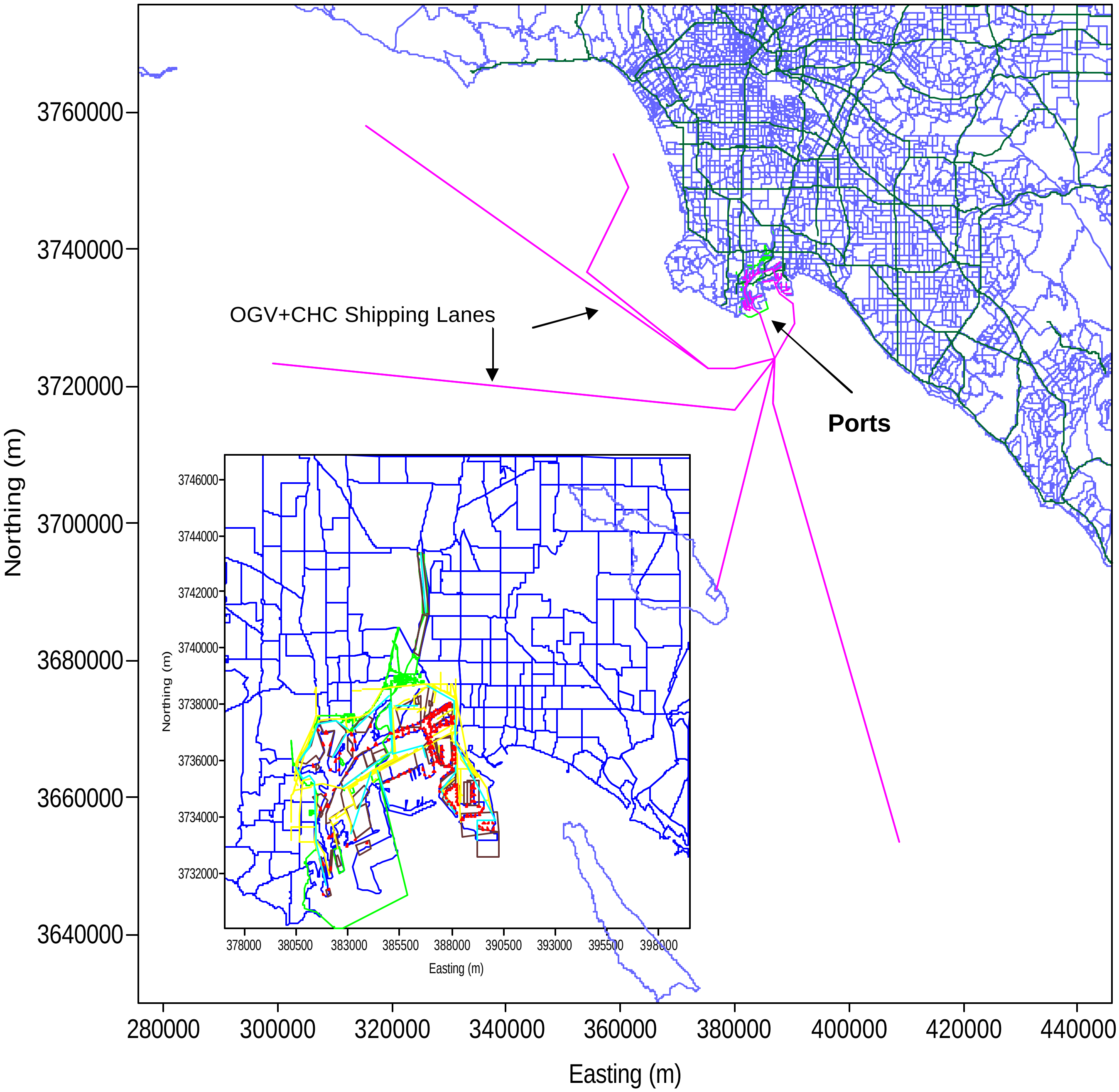

Figure 5b. Depiction of the Emission Source Locations (On the electronic version of the document, the following color codes are used to designate emission sources: Magenta = OGV+CHC, Dark Brown = CHE, Yellow = IPT, Blue = IPL, Red = Hotelling)

C. Model Parameters

The emission sources in the ports are characterized as area sources except for ship hotelling, which is modeled as individual point sources. Model parameters for area sources include emission rate/strength, release height, lengths of X and Y sides of rectangular areas or vertices for polygons, and initial vertical (σ_{zo}) dimensions of the area source plume. Model parameters for point sources include emission rate, stack height, stack diameter, stack exhaust temperature, and stack exhaust exit velocity.

The OGV emissions are simulated as area sources. Starcrest provided the coordinates to establish links. The link widths in the ports and in the shipping lanes over the ocean water surface are assumed to be 160 m and 800 m, respectively. Commercial harbor craft emissions are simulated similar to the OGVs. The links are identical to those of OGVs. Cargo handling equipment emissions are simulated as area sources with the polygon features of the dispersion model. Locomotive emissions are also simulated as area sources. The links were established based on the nodes provided by Starcrest and/or estimated by ARB staff. Each link width is assumed to be 20 m. The terminal and off-terminal heavy-duty trucks are simulated similar to the railroad locomotives, except that the link width is assumed to be 35 m (three lanes in each direction + 3 meters wake width on each side). As mentioned previously, the hotelling emissions from ship auxiliary engines are simulated as individual point sources at the berths. Because stack information was not available for individual engines, the average stack height data (43 meters) provided in the Starcrest inventory report was applied to all hotelling engines. The modeling parameters for each of the emission source categories are summarized in Table 7.

Table 7: Emission Source Model Parameters

Model Parameter	OGVs	CHC	CHE	RAIL	TRUCK	HOTEL
Release Height (m)	50	6	2.4 – 3.9	5	4	H =43 m T = 618 K V = 16 m/s D = 0.5 m
Link Width (m)	-	-	-	20	35	
Link Width in Ports (m)	160	160	-	-	-	
Link Width in Shipping Lane (m)	800	800	-	-	-	
σ_{zo} (m)	23.26	2.79	1.1 – 1.8	2.33	1.86	

Note: OGV = Ocean-going vessels, CHC = commercial harbor craft, CHE = cargo handling equipment, H = release height, T = exhaust temperature, V = exhaust exit velocity, and D = stack diameter.

D. Spatial and Temporal Allocation of Emissions

Starcrest provided spatial emission allocation for all source categories at POLA and for three source categories - cargo handling equipment, In-port locomotives, and In-port trucks at POLB. ARB staff used GIS mapping to allocate the emissions for POLB OGVs, hotelling, and commercial harbor craft based on the descriptions provided by Starcrest. ARB staff temporally allocated all the emission sources at both ports based on discussions with terminal operators and locomotive representatives. The assumptions for the temporal distribution of the emissions are listed in Table 8. The ARB staff assumed that the temporal distribution of the emissions is the same for both ports.

Table 8: Temporal Distribution of Diesel PM Emissions at POLA and POLB

Category	Time Period	Activity Distribution	Hours Per Day
Ocean-Going Vessel	4 am – 8 pm	80%	16
	8 pm – 4 am	20%	8
Hotelling	midnight - midnight	100%	24
Harbor Craft	6 am – 6 pm	80%	12
	6 pm – 6 am	20%	12
Cargo Handling	8 am – 5 pm	80%	9
	5 pm – 3 am	15%	10
	3 am – 8 am	5%	5
Trucks	6 am – 6 pm	80%	12
	6 pm – 6 am	20%	12
Locomotives	midnight - midnight	100%	24

E. Meteorological Data

Meteorological data are selected on the basis of spatial and temporal representativeness. There are two available meteorological measurement sites around the ports: Wilmington and North Long Beach[1] (see Figure 6). The Wilmington site is about one mile away from the ports and the measurements were collected in 2001. The North Long Beach site is about four miles away from the ports where data are archived for 1981. The South Long Beach site in Figure 6 is an air quality monitoring site where meteorological data are not archived. Normally five years of the latest consecutive meteorological data are preferred by U.S. EPA for long term dispersion analyses. However, one year of data are acceptable if the data are site specific according to U.S. EPA. Therefore, ARB staff believe the Wilmington data to be the better data with respect to spatial and temporal representativeness.

The meteorological data from the Wilmington site includes hourly wind direction, wind speed, and atmospheric temperature. Atmospheric stability, rural mixing height, and urban mixing height are developed following the U.S. EPA guidance. Figure 7 presents the wind rose and Figure 8 provides the wind and stability class frequency distributions for the meteorological conditions at the Wilmington site. Based on the yearly statistics, the annual average wind speed at Wilmington is 1.8 m/s with the predominant wind directions from the northwest (about 22 percent of the time) and from the south (about

[1] The King Harbor meteorological monitoring station is located about 10 miles northwest of the ports on the ocean-side. To determine if diesel PM emissions transported on the ocean-side would be better simulated using King Harbor meteorological data we conducted a sensitivity study (detailed in Appendix C) and found that there is not a significant difference between using Wilmington and using King Harbor meteorological data sets based on the population-weighted risks in the modeling domain.

14 percent of the time). For the ISCST3 air quality model, urban dispersion coefficients are used because the area at the impacted receptors is comprised of industrial, commercial and compact residential land uses.

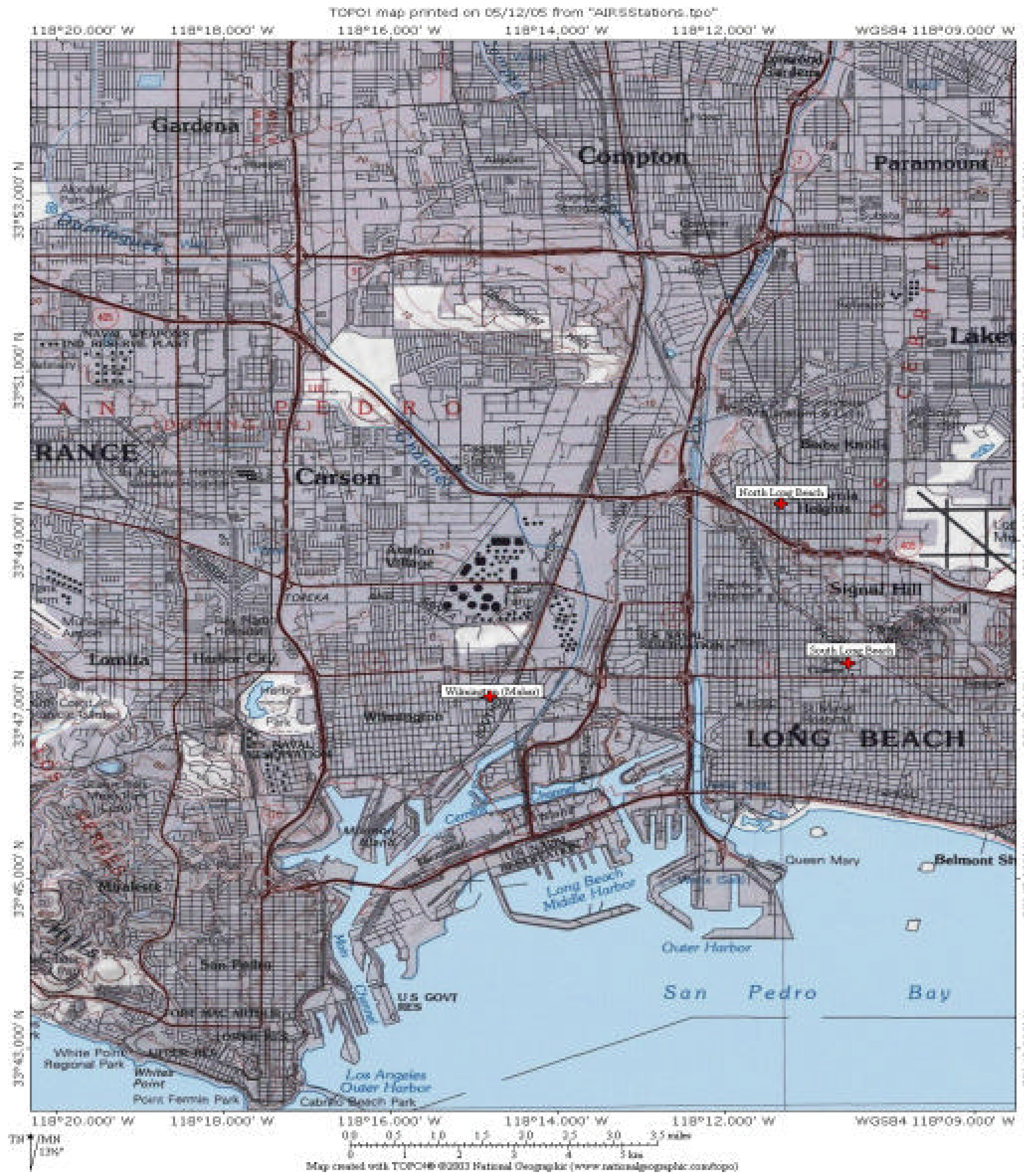

Figure 6: Locations of Surface Meteorological Measurement Sites around the Ports

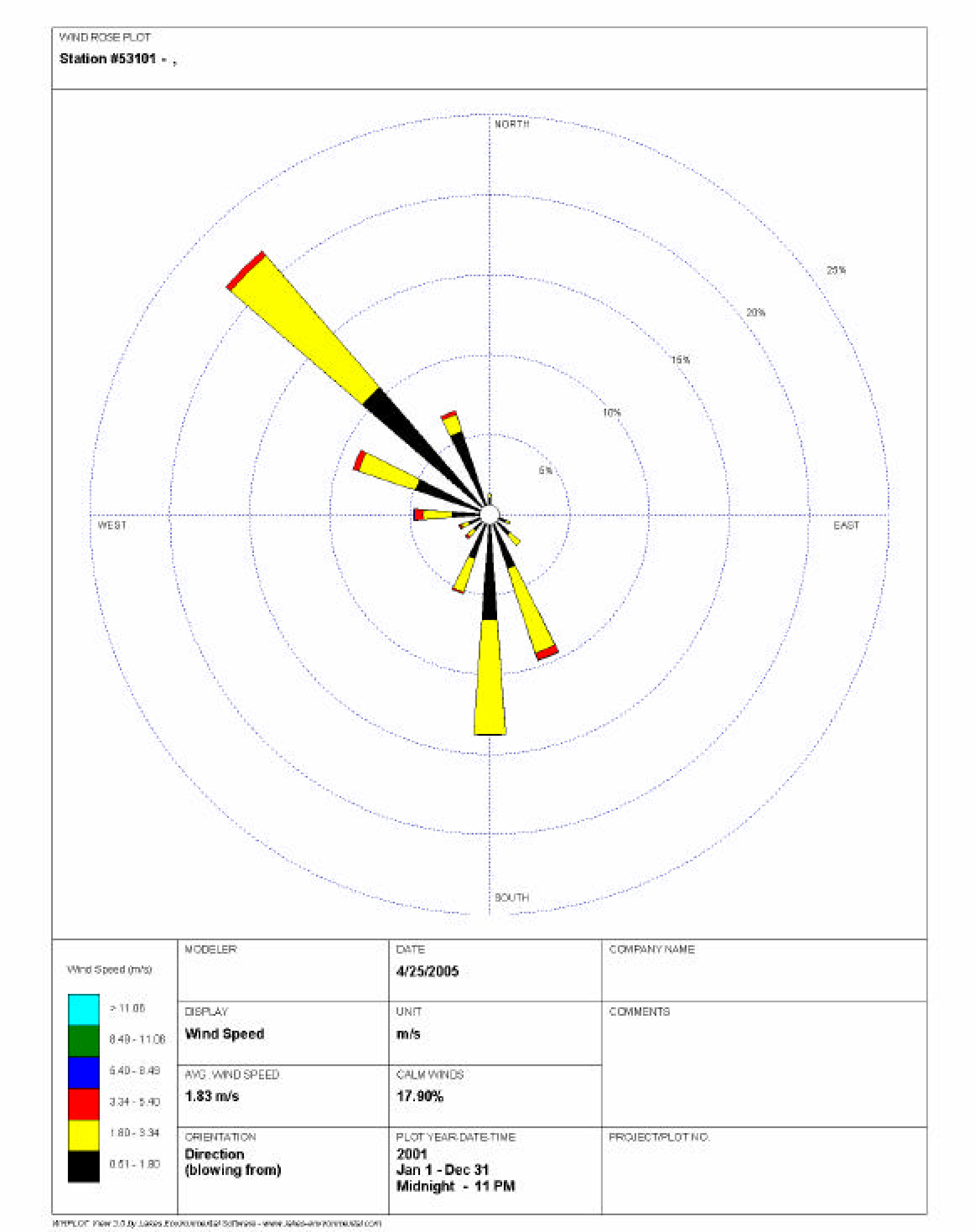

Figure 7: Wind Rose for the Period 1/1/01 to 12/31/01 at the Wilimington Meteorological Site

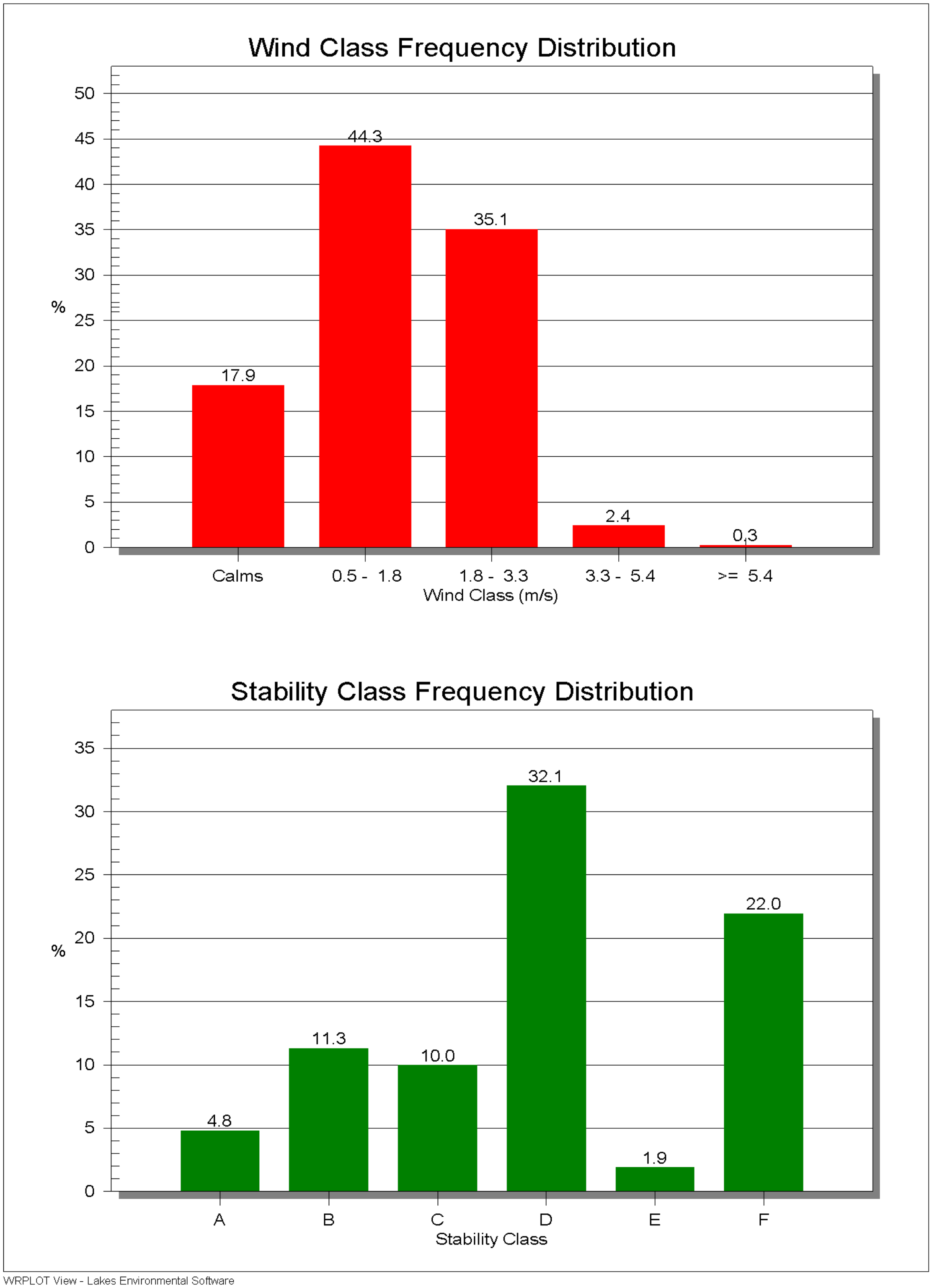

Figure 8: Wind Speed and Stability Class Frequency Distribution at Wilmington Meteorological Site.

IV. EXPOSURE ASSESSMENT

In this chapter, we briefly describe the OEHHA guidelines on health hazard risk assessment and how we used the guidelines to characterize potential cancer risks associated with exposure to diesel exhaust from the ports. We also present preliminary air dispersion modeling results for the ports.

A. OEHHA Guidelines

The Air Toxics Hot Spots Program Risk Assessment Guidelines: The Air Toxics Hot Spots Program Guidance Manual for Preparation of Health Risk Assessments (OEHHA guidelines, 2002a) outlines a tiered approach to risk assessment, providing risk assessors with flexibility and allowing for consideration of site-specific differences. Tier- 1 is a standard point-estimate approach that uses a combination of the average and high-end point-estimates. This approach will be used in this risk assessment.

The OEHHA guidelines recommend that all health hazard risk assessments present a Tier-1 evaluation for the Hot Spots Program, even if other approaches are also presented. For Tier-1, OEHHA provides two values for breathing rate, one representing an average and another representing a defined high-end value. The average and high-end of point-estimates are defined in terms of the probability distribution of values for that variate. The mean (65th percentile) represents the average values for point-estimates and the 95th percentile represents the high-end point-estimates from the distributions identified in the OEHHA guidelines. In 2004, ARB recommended the interim use of the 80th percentile value (the midpoint value of the 65th and 95th percentile breathing rate) as the minimum value for risk management decisions at residential receptors for the breathing pathway. The 80th percentile corresponds to a breathing rate of 302 Liters/Kilogram-day (302 L/Kg-day). This risk assessment will use the 302 L/Kg-day value and will assume that the receptors will be exposed for 24 hours per day for 70 years. If a receptor is exposed for a shorter amount of time to the annual average concentration of diesel PM the cancer risk will be proportionately less.

The relationship between a given level of exposure to diesel PM and the cancer risk is estimated by using the diesel PM cancer potency factor. A description of how the diesel cancer potency factor was derived can be found in the Proposed Identification of Diesel Exhaust as a Toxic Air Contaminant (ARB, 1998) and a shorter description can be found in the Air Toxics Hot Spot Program Risk Assessment Guidelines, Part II, Technical Support Document for Describing Available Cancer Potency Factors (OEHHA 2002b). The use of the diesel unit risk factor for assessing cancer risk is described in the OEHHA Guidelines. The potential cancer risk is estimated by multiplying the inhalation dose by the cancer potency factor (CPF) of diesel PM (1.1 $(mg/kg\text{-}d)^{-1}$).

B. Exposure Assessment

A number of variables can have significant impacts on exposure. These include emission estimates, meteorological conditions, and exposure duration of residents. The emissions affect the risk levels linearly; as emissions increase, so does the risk. Meteorological conditions can have a large impact on the resultant ambient concentration of a toxic air pollutant with higher concentrations found along the predominant wind direction. Key variables in human exposure are a person's proximity to the emission plume, how long he or she breathes the emissions (exposure duration), the person's breathing rate, and body weight. The longer the duration of exposure, the greater the potential risk.

C. Risk Characterization

Risk characterization is defined as the process of obtaining a quantitative estimate of risk, including a discussion of its uncertainty. The risk characterization process integrates the results of air dispersion modeling and relevant toxicity data (e.g., diesel PM cancer potency factor) to estimate potential cancer or noncancer health effects associated with contaminant exposure. It is important to note that no background or ambient diesel PM concentrations are incorporated into the risk quantification. The risk assessment only considers the cancer risk by the inhalation pathway because the risk contributions by other pathways of exposure are known to be negligible relative to the inhalation pathway and difficult to quantify.

As stated in Chapter III, the modeling receptor domain of 20 mi x 20 mi with a grid resolution of 200 m x 200 m was used in the modeling exercise. The effective land area (excluding the Port property and the over water region) is about 255 square miles. The population within the modeling receptor domain is about 2 million based on the U.S. Census Bureau's year 2000 census data. The risk numbers, impacted areas, and affected population presented below are based on the effective land area within the modeling domain; that is, the risk, the area, and the population within the ports property and over the ocean surface are excluded from this analysis. Note that if the modeling domain expands, the risks, impacted areas, and affected population presented in this analysis would be changed.

<u>Risk Characterization for All Emission Sources</u>

Figure 9 shows the risk isopleths for all diesel PM emission sources from POLA and POLB superimposed on a map that covers the ports and the nearby communities. The risk contour of 100 in a million exceeds the modeling receptor domain in the north direction of the ports, which is about 10 miles away from the ports boundary. The area with predicted cancer risk levels in excess of 100 in a million within the modeling receptor domain is estimated to be about 94,000 acres, which is 57 percent of the effective land area within the modeling receptor domain (see Table 9). The area in which the risks are predicted to exceed 200 in a million is also very large, covering an area of about 29,000 acres (18 percent of the effective land area within the modeling receptor domain). The areas with the greatest impact have an estimated potential cancer risk of over 500 in a million, which cover about 2 percent of the effective land area within the domain. The risk isopleths of 1000 and 1500 in a million occur on port property and the nearby ocean surfaces, which is not included in this study because people do not reside in these areas.

Using the U.S. Census Bureau's year 2000 census data, we estimated the population within the isopleth boundaries. As shown in Table 10, the affected population numbers for the risk ranges of 100-200, 200-500, and over 500 have been estimated to be about 724,000, 360,000, and 53,000, which account for 37, 18 and 3 percent of the total population within the modeling domain, respectively. In other words, nearly 60 percent of 2 million people live in the area around the ports that has predicted risks of greater than 100 in a million. Note that the risk isopleth of 10 in a million is not shown in Figure 9 because it exceeds the modeling receptor domain. Spatially, the emission sources are located at various locations on port property and the outside of the breakwater, thus the contributions of these emission sources to the nearby neighborhoods would be different. Below, we discuss the contributions from the various sources at the ports to the community risks.

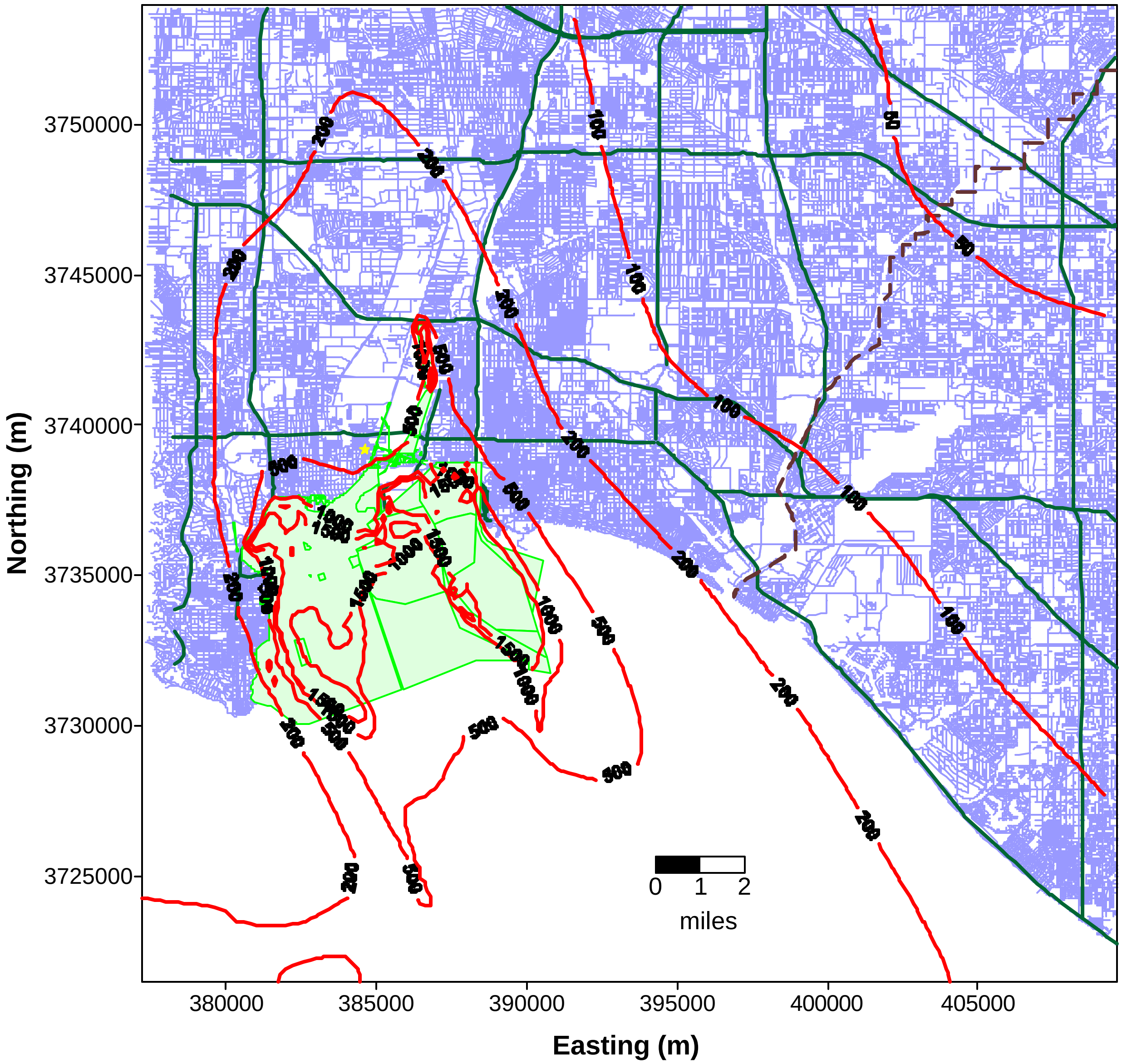

Figure 9. Estimated Diesel PM Cancer Risk from All Diesel-Fueled Engines at POLA and POLB (Wilmington Meteorological Data, Urban Dispersion Coefficients, 80th Percentile Breathing Rate, Total Emissions = 1,760 TPY, Modeling Receptor Domain = 20 mi x 20 mi, Resolution = 200 m x 200 m)

Risk Characterization for Individual Emission Sources

The different emission sources are used at various locations on the ports property in the harbor and over ocean beyond the breakwater. Thus, the contributions of these emission sources to exposures in the nearby neighborhoods are different. As shown in Tables 9 and 10, the emissions from cargo handling equipment and on-port trucks resulted in areas within the nearby communities having risk levels exceeding 500 in a million while the highest risk levels associated with the other categories were between 200 and 500 in a million. Within the model domain, ship hotelling emissions and cargo handling equipment impacted the largest areas and affected more people than the other sources of emissions when considering the risk levels greater than 100 in a million. When considering risk levels greater than 10 in a million, all the port sources, other than in-port trucks and locomotives had similar impacts, affecting at least 119,000 acres and at least 1.4 million people. By source location, the impacts resulting from the in-port emissions (within breakwater) are much larger than those resulting from the out-port emissions (outside of breakwater), although the emission magnitude of the former is less than the latter (750 TPY vs 1010 TPY). Quantitatively, within the modeling receptor domain, the population-weighted risk resulting from the in-port emissions is about 4.5 times of that resulting from the over water out-of-port emissions.

Table 9: Summary of Area Impacted by Risk Levels and Activity Categories (Acres)

Risk Level	OGV	HOTEL	CHC	CHE	IPT	IPL	COMBINED
Risk > 500	0	0	0	50	50	0	2,500
Risk > 200	110	2,036	20	410	160	40	29,000
Risk > 100	227	12,700	750	4,100	376	160	94,000
Risk > 10	163,435	160,470	125,250	119,000	29,750	11,240	163,435

Table 10: Summary of Population Affected by Risk Levels and Activity Categories (Number of People)

Risk Level	OGV	HOTEL	CHC	CHE	IPT	IPL	COMBINED
Risk > 500	0	0	0	3,200	205	0	53,000
Risk > 200	18	46,020	5,000	11,100	1,780	680	411,200
Risk > 100	1,810	221,567	22,960	82,000	8,270	4,330	1,135,000
Risk > 10	1,977,760	1,949,850	1,516,515	1,444,000	422,910	213,430	1,977,770

Notes:

1. OGV – Ocean-going vessels; HOTEL – Ship's auxiliary engine hotellng; CHC – Commercial harbor crafts; CHE –Cargo handling equipment; IPT – In-Port trucks; IPL – In-Port locomotive.
2. The model receptor domain of 20 mile x 20 mile for urban dispersion coefficients with a grid resolution of 200m x 200m was used. The effective modeling receptor domain (excluding the port properties and the ocean water) is estimated to be about 255 square miles. The calculations here are ONLY based on the effective modeling receptor domain.
3. The 80th percentile breathing rate for adults over 70-year lifetime was assumed.
4. Meteorological data from Wilmington (2001) are used for POLA and POLB.
5. The risks within both ports and over the ocean water were excluded for calculations of average risks and affected areas.
6. The estimated population in this Table is ONLY based on the modeling receptor domain using the U.S. Census Bureau's year 2000 census data.
7. If the modeling receptor domain expands, the numbers of population and area affected would be increased.
8. The combined column provides the population affected and area impacted for the cumulative impacts from all the emission sources. The individual impacts are not additives since the combined impacts are greater than the sum of the individual sources. For example, cargo handling equipment and commercial harbor craft emissions may impact the same location and population. While individually the impacts may result in cancer risk levels between 100 and 200 in a million, when you combine the impacts, the resulting risks could be greater than 200 in a million.

Below, we provide additional discussion on each of the contributions of each of the emission source categories and present the predicted risk isopleths for individual sources.

Ocean-Going Vessels

Figure 10 presents the predicted risk isopleths for the diesel PM emissions from the OGVs (transiting and maneuvering emissions only). The area impacted by these emissions is very large (has a large footprint) and many of the risk isopleths extend beyond the boundaries of the modeling receptor domain. The area within the modeling domain in which the cancer risks are predicted to be greater than 100 in a million is small, covering an area of about 227 acres with a population size of 1,800. The potential cancer risk levels between 50 to 100 in a million are located in nearby areas north of the ports. All areas within the modeling receptor domain are predicted to have an estimated potential cancer risk of over 10 in a million. From the point of view of the emission magnitude, OGVs contributed about half of the total emissions (940 of 1,760 TPY). This disproportional phenomenon can be attributed to the fact that the diesel PM emissions from OGVs are distributed over a very wide area and most of these emissions (about 96 percent) are emitted from the offshore shipping lanes which begin approximately 5 miles beyond the port breakwater and extend to about 50 miles away from the ports. In other words, only a small portion of the transiting and maneuvering emissions (about 4 percent) are emitted in the ports. In addition, the vessels have an average physical stack height of 43 meters above the water surface (final plume rise modeled as 50 m), resulting in diluted plumes over a wide area.

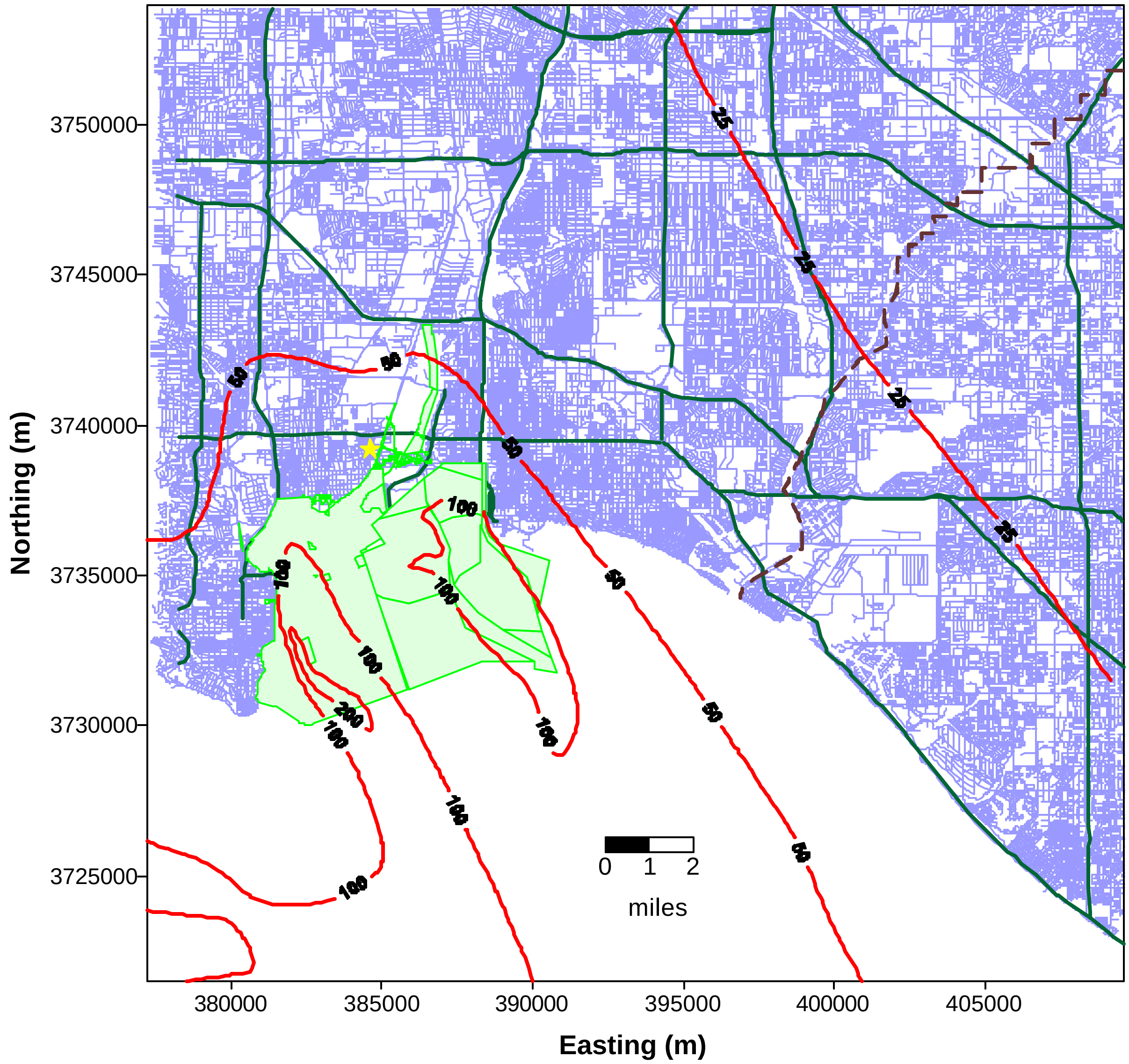

Figure 10. Estimated Diesel PM Cancer Risk from Ocean-Going Vessel's Activity at POLA and POLB (Wilmington Meteorological Data, Urban Dispersion Coefficients, 80th Percentile Breathing Rate, Emission = 942 TPY, Modeling Domain = 20 mi x 20 mi, Resolution = 200 m x 200 m)

Hotelling

The emissions from ship auxiliary engines' hotelling resulted in a significant risk impact to the nearby communities. As shown in Figure 11, the potential cancer risk level ranges from 50 to 200 in a million. The area in which the risks are predicted to exceed 100 in a million has been estimated to be about 12,700 acres with a population of 221,600. Hotelling emissions from auxiliary engines result in cancer risk levels over 10 in a million in about 98 percent of the effective modeling domain. Compared to the OGVs, the emission from the auxiliary engines hotelling is approximately 36 percent of the OGVs (343 TPY vs 942 TPY), but the predicted population-weighted average risk from the hotelling is about 1.5 times of that from the OGVs. This is not surprising because the emissions from hotelling activities are located within the ports, which are close to nearby communities.

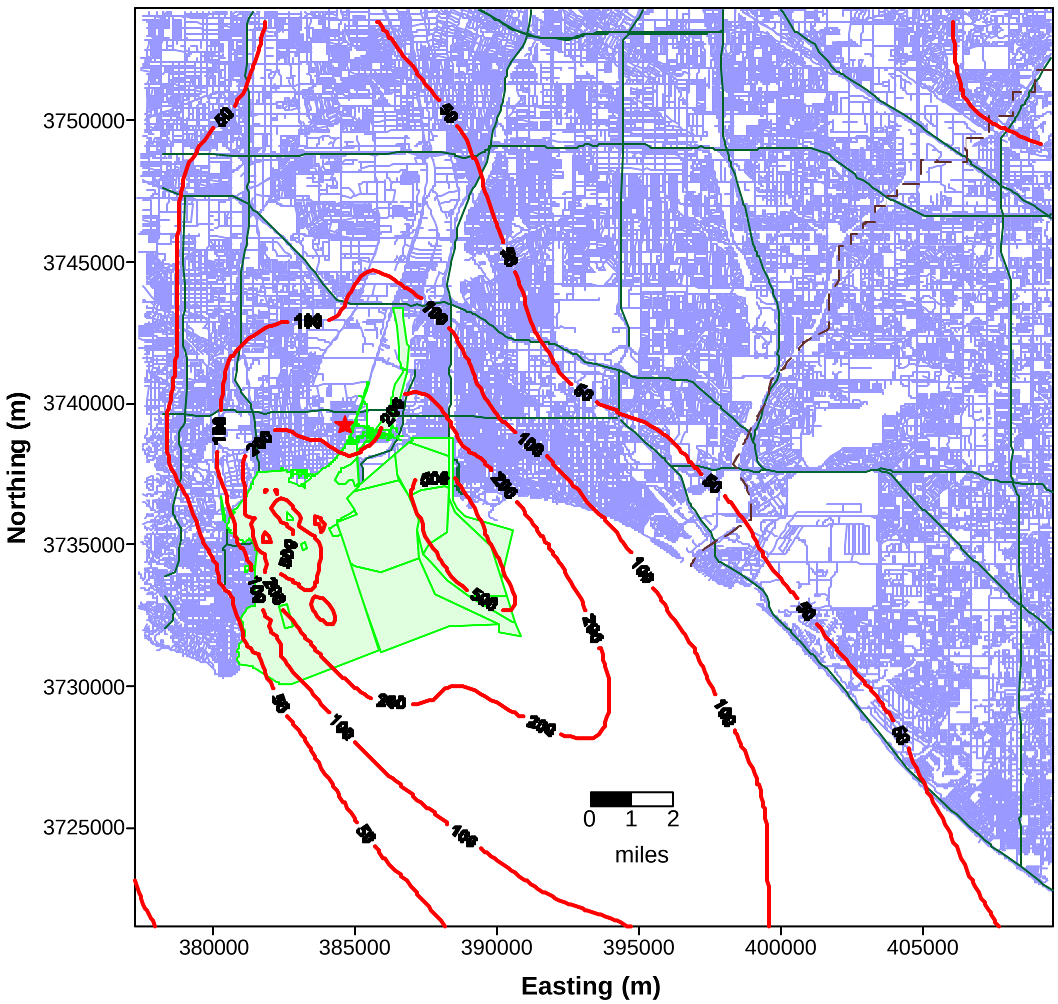

Figure 11. Estimated Diesel PM Cancer Risk from Ship Auxiliary Engines' Hotelling at POLA and POLB (Wilmington Meteorological Data, Urban Dispersion Coefficients, 80th Percentile Breathing Rate, Emission = 343 TPY, Modeling Domain = 20 mi x 20 mi, Resolution = 200 m x 200 m)

Commercial Harbor Craft

The emissions from commercial harbor craft resulted in a moderate risk level in the nearby communities around the ports (Figure 12). The area in which the risks are predicted to exceed 100 in a million has been estimated to be about 750 acres with a population of 23,000. Overall, about 77 percent of the effective modeling receptor domain have estimated cancer risk levels of over 10 in a million due to emissions from commercial harbor craft.

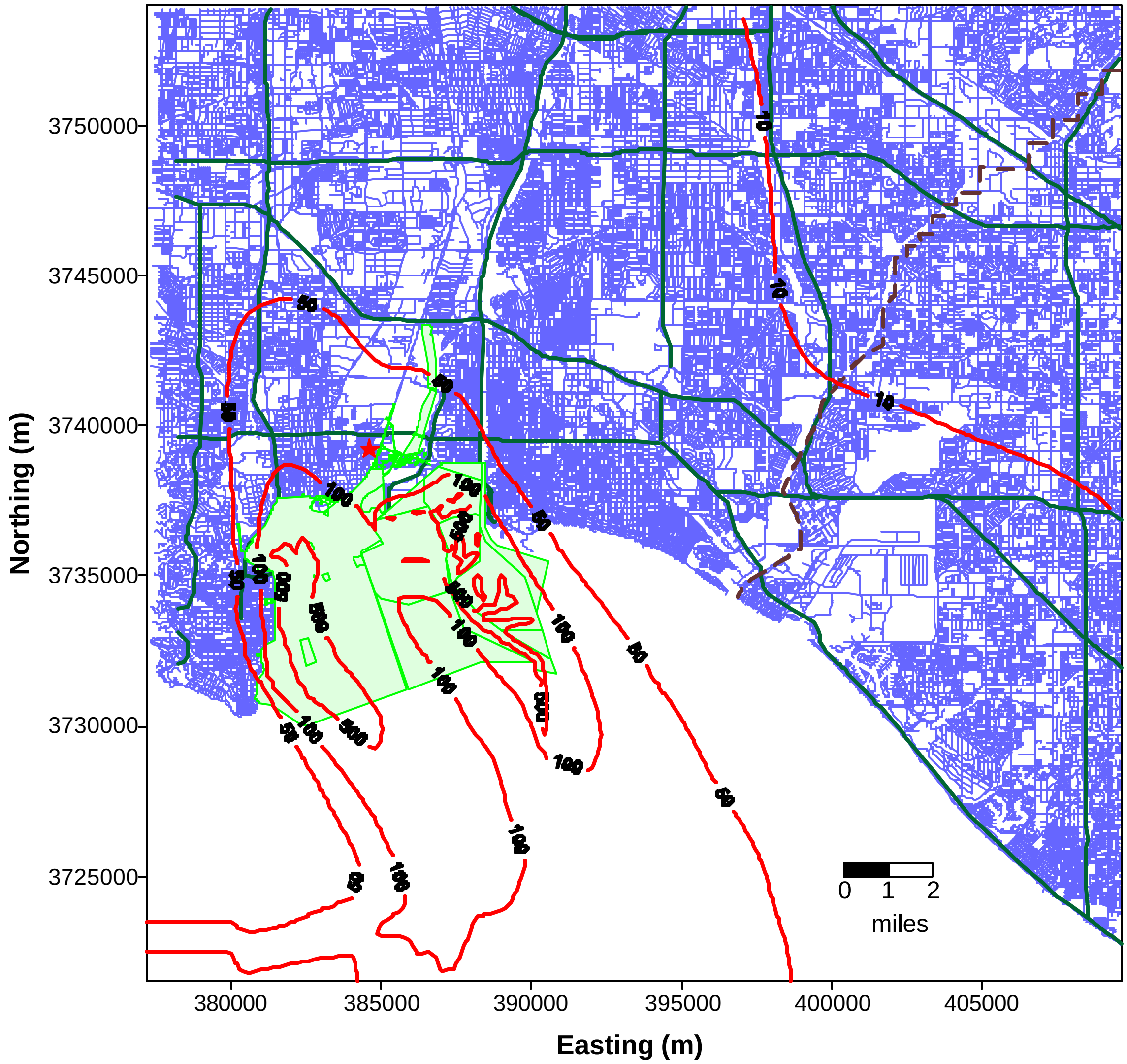

Figure 12. Estimated Diesel PM Cancer Risk from Commercial Harbor Craft Vessel Activity at POLA and POLB (Wilmington Meteorological Data, Urban Dispersion Coefficients, 80th Percentile Breathing Rate, Emission = 244 TPY, Modeling Domain = 20 mi x 20 mi, Resolution = 200 m x 200 m)

Cargo Handling Equipment

The ground-based activities of cargo handling equipment generated an estimated emission of about 172 TPY, which accounts for about 10 percent of the total emissions inventory for the ports. The emissions resulted in significant risk impacts on the nearby residential areas. As shown in Figure 13, the area in which the risks are predicted to exceed 100 in a million has been estimated to be about 4,100 acres with a population of 82,000. For the highest risk level of over 500 in a million, the impacted areas have been estimated to be about 50 acres and about 3,200 people living around the ports are exposed to the risk level. Overall, about 73 percent of the effective modeling receptor domain has an estimated risk level of over 10 in a million and about 73 percent of 2 million people who are living in the domain are exposed to the risk level. From Figure 13, we can see that the finger-like isopleth jutting to the north exists. This is caused by sources located within the narrow finger-like port property that contribute about 17 TPY of emissions to the downwind direction area (north). Based on the population-weighted spatial average risk, the emission sources from cargo handling equipment are the second biggest contributor to the nearby communities.

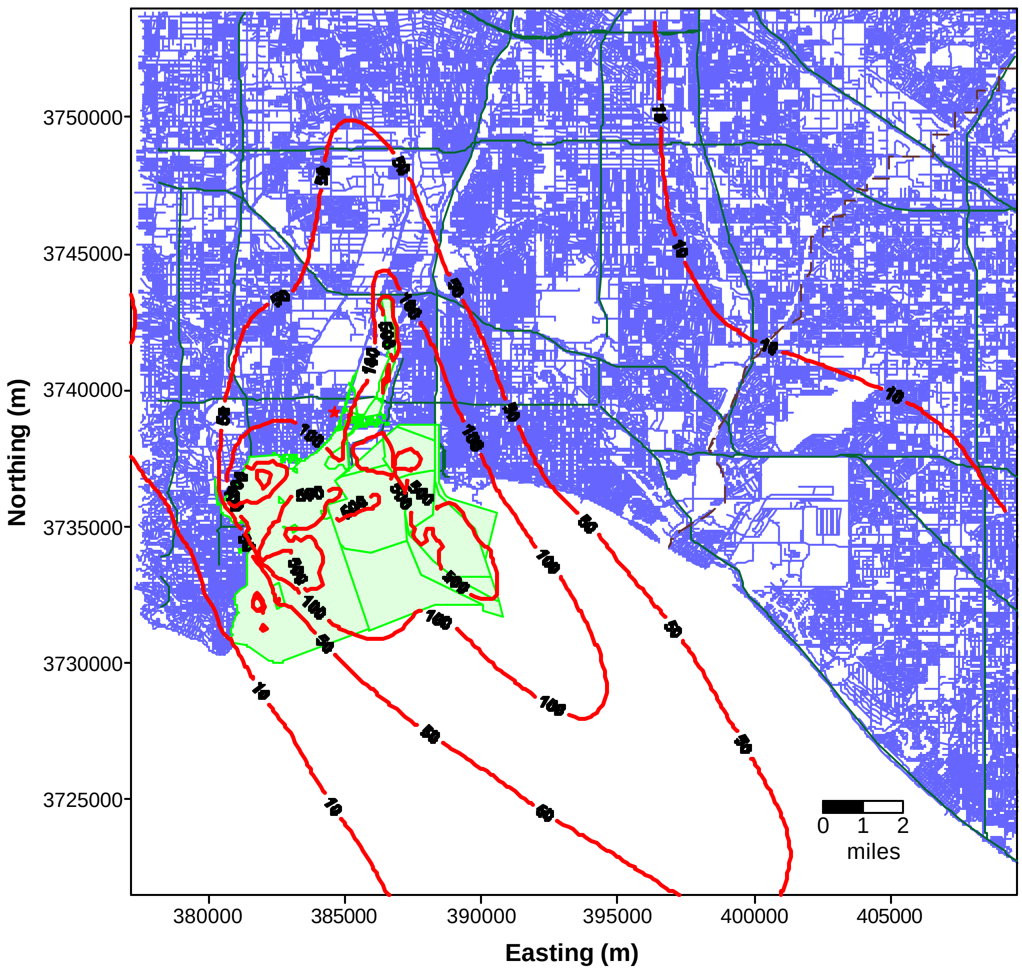

Figure 13. Estimated Diesel PM Cancer Risk from Cargo Handling Equipment Activity at POLA and POLB (Wilmington Met Data, Urban Dispersion Coefficients, 80th Percentile Breathing Rate, Emission = 172 TPY, Modeling Domain = 20 mi x 20 mi, Resolution = 200 m x 200 m)

In-Port Trucks and Locomotives

Compared with other emission sources, the emissions from in-port heavy-duty trucks and locomotives are relatively small, accounting for about 3 percent of the emissions inventory. These ground-based emissions resulted in localized health risk impacts. As shown in Figures 14 and 15, the higher risk level of 100 to 200 in a million occurs on port property. The exposure risk level to the nearby residents is relatively small. For in-port heavy-duty trucks, about 18 percent of the effective modeling domain has an estimated risk level of over 10 in a million, affecting about 21 percent of the residents within the model domain. Similarly, for in-port locomotives, about 7 percent of the effective modeling receptor domain has an estimated risk level of over 10 in a million, affecting about 11 percent of the residents. It is important to note that there are emissions of heavy-duty trucks and locomotives that are released beyond the boundaries of the ports and impact residents living along freeways, rail yards and rail corridors, and distribution centers. The impacts from these emissions (e.g., freeway diesel PM) are not included in this analysis.

In this study, we did not consider the diesel PM emissions of on-road heavy-duty trucks and locomotives related to port activities that occur off-port boundary within the SCAB (regional emissions). We estimated the off-port regional diesel PM emissions to be about 206 TPY for the both ports, or 10 percent of the total port-related emissions (206 TPY vs 1,970 TPY). These regional emissions are distributed throughout the SCAB and may result in localized health impacts to people who are live near freeways and railroad corridors within the SCAB. These health impacts will be evaluated in future studies.

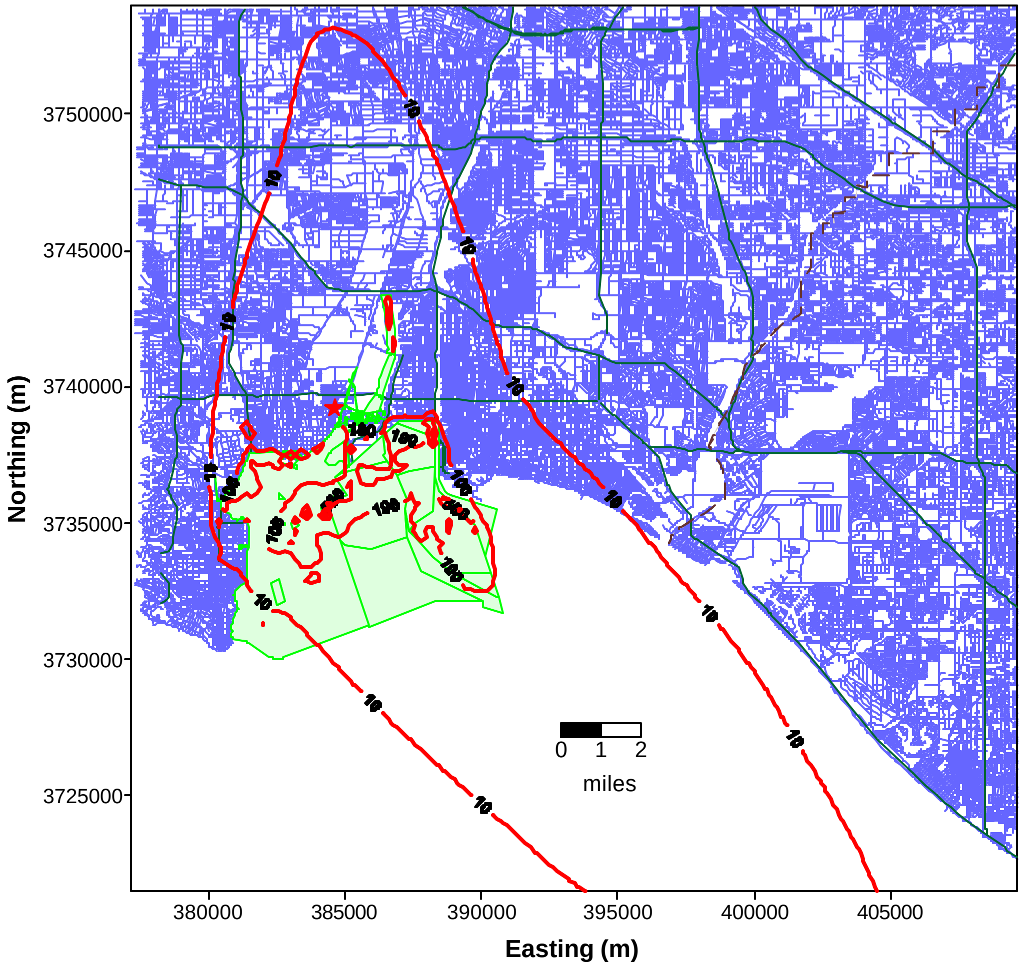

Figure 14. Estimated Diesel PM Cancer Risk from In-Port Heavy Duty Trucks at POLA and POLB (Wilmington, Meteorological Data, Urban Dispersion Coefficients, 80th Percentile Breathing Rate, Emission = 41 TPY, Modeling Domain = 20 mi x 20 mi, Resolution = 200 m x 200 m)

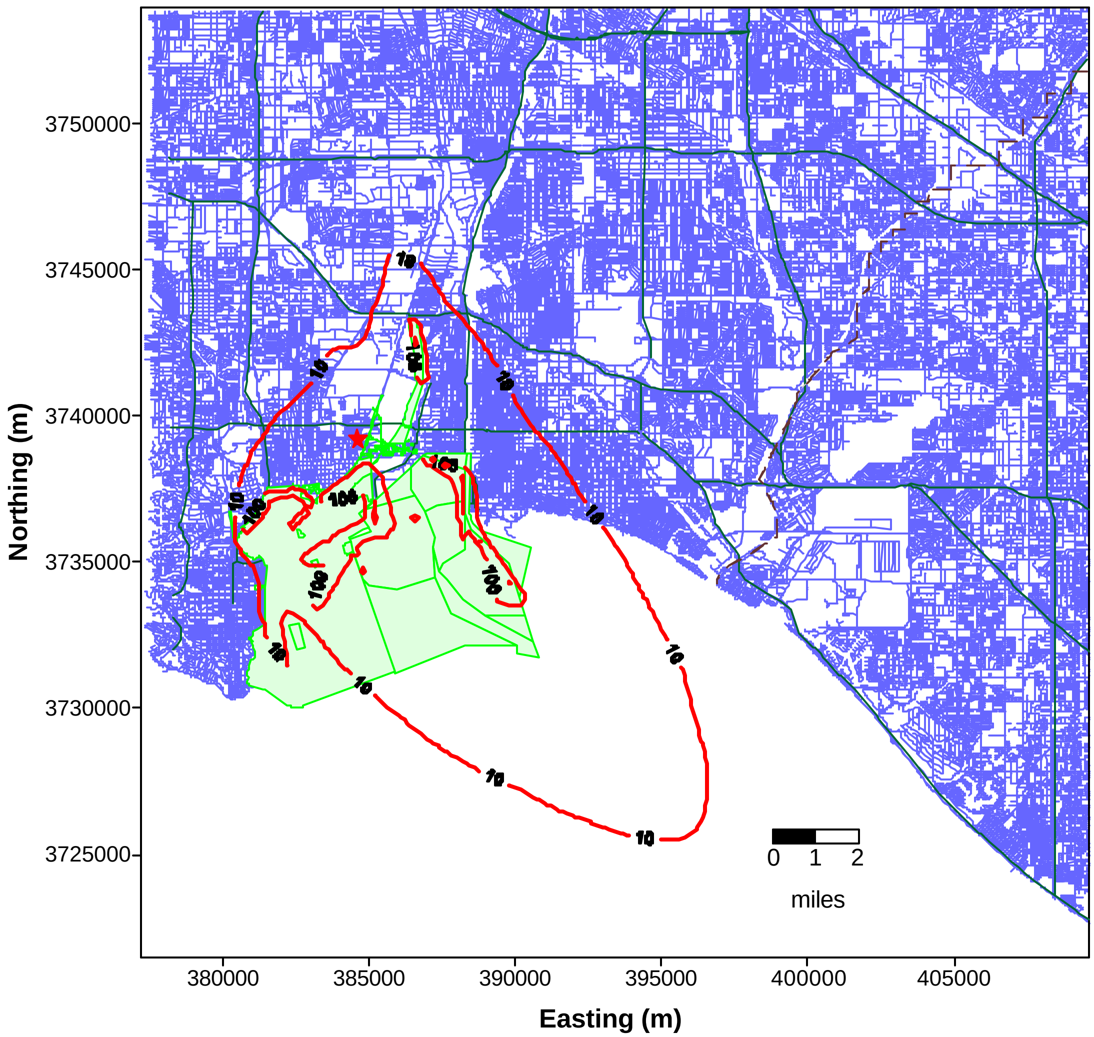

Figure 15. Estimated Diesel PM Cancer Risk from In-Port Locomotive Activity at POLA and POLB (Wilmington, Meteorological Data, Urban Dispersion Coefficients, 80th Percentile Breathing Rate, Emission = 18 TPY, Modeling Domain = 20 mi x 20 mi, Resolution = 200 m x 200 m)

In-Port vs Out-of-Port Emissions

As mentioned previously, a comparison between the impacts from in-port, i.e., those emissions that occur on port land-based property and within the breakwater zone, and the out-of-port, i.e., those emissions from oceangoing ships and harbor craft that occur beyond the breakwater, was made. Although the in-port activities generate fewer emissions than the out-of-port activities (750 TPY vs 1010 TPY), the in-port emissions resulted in much higher health risk level in the nearby communities than the out-of-port emissions (see Figures 16 and 17). Quantitatively, based on the population-weighted average cancer risk within the modeling domain, the potential cancer risk level resulting from the in-port activities is about 4.5 times of that resulting from the out-of-port activities. Possible reasons have been explained above. That is, there are greater distances between the out-of-port emission sources and the receptors in the nearby communities. This analysis identifies the emission sources within the ports as the most significant to health risk to the nearby communities.

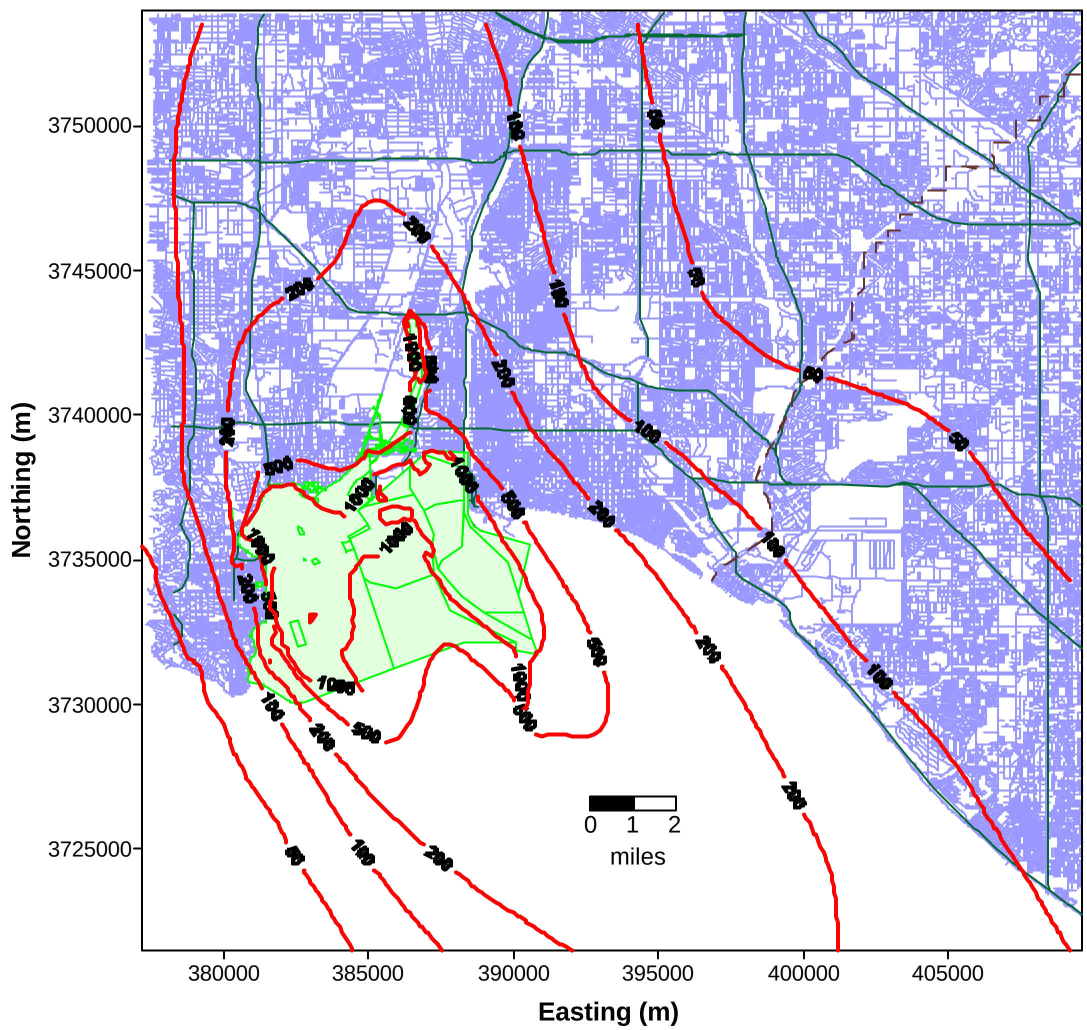

Figure 16. Estimated Diesel PM Cancer Risk from All In-Port Diesel Engine Activity at POLA and POLB (Wilmington, Meteorological Data, Urban Dispersion Coefficients, 80th Percentile Breathing Rate, Emission = 750 TPY, Modeling Domain = 20 mi x 20 mi, Resolution = 200 m x 200 m)

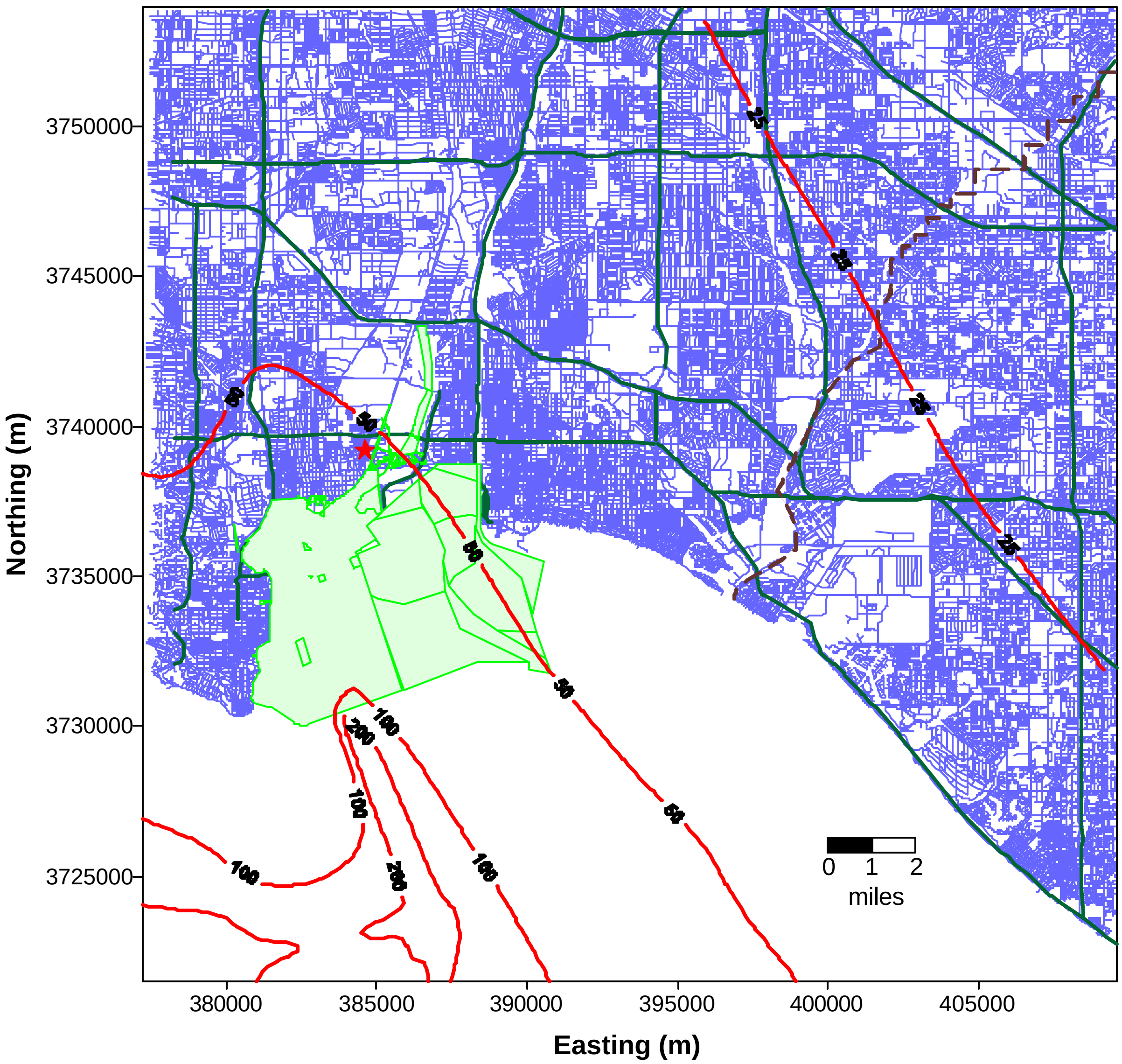

Figure 17. Estimated Diesel PM Cancer Risk from All Out-of-Port Diesel Activity at POLA and POLB (Wilmington, Meteorological Data, Urban Dispersion Coefficients, 80th Percentile Breathing Rate, Emission = 1010 TPY, Modeling Domain = 20 mi x 20 mi, Resolution = 200 m x 200 m)

D. Estimation of Non-cancer Health Endpoints

A substantial number of epidemiologic studies have found a strong association between exposure to ambient particulate matter (PM) and adverse health effects (CARB, 2002). As part of this study, ARB staff conducted an analysis of the potential non-cancer health impacts associated with exposures to the model-predicted ambient levels of directly emitted diesel PM (primary diesel PM) within the modeling domain. The non-cancer health effects evaluated include premature death, asthma attacks, work loss days, and minor restricted activity days.

Ambient levels of directly emitted diesel PM were predicted for 200 meter by 200 meter grid cells within the modeling domain, and the populations within each grid cell were determined from U.S. Census Bureau year 2000 census data. Using the methodology peer-reviewed and published in the Staff Report: Public Hearing to Consider Amendments to the Ambient Air Quality Standards for Particulate Matter and Sulfates, (PM Staff Report) (CARB, 2002), we calculated the number of annual cases of death and other health effects associated with exposure to the PM concentration modeled for each of the grid cells. The totals over the entire modeling area were then calculated. For each grid cell, each health effect was estimated based on concentration-response functions derived from published epidemiological studies relating changes in ambient concentrations to changes in health endpoints, the population affected, and the baseline incidence rates. The selection of the concentration-response functions was based on the latest epidemiologic literature, as described in the PM Staff Report (CARB, 2002) and in Lloyd and Cackette (2001).

Based on our analysis, we estimate that the average number of cases per year that would be expected in the modeling area is as follows:

- 29 premature deaths (for ages 30 and older), 14 to 43 deaths as 95% confidence interval (CI);
- 750 asthma attacks, 180 to 1300 as 95% CI;
- 6,600 days of work loss (for ages 18-65), 5,600 to 7,600 as 95% CI;
- 35,000 minor restricted activity days (for ages 18-65), 28,000 to 41,000 as 95% CI.

Several assumptions were used in our estimation. They involve the selection and applicability of the concentration-response functions to California data, exposure estimation, subpopulation estimation, baseline incidence rates, and the threshold. These are briefly described below.

- Premature death calculations were based on the concentration-response function of Krewski et al. (2000). The ARB staff assumed that concentration-response function for premature mortality in the model domain is comparable to that in the Krewski study. It is know that the composition of PM can vary by region, and not all constituents of PM have the same health effects. However, numerous studies have shown that the mortality effects of PM in California are comparable to those found in other locations in the United States, justifying our use of

Krewski et al's results. Also, the U.S. EPA has been using Krewski's study for its regulatory impact analyses since 2000. For other health endpoints, the selection of the concentration-response functions was based on the most recent and relevant scientific literature. Details are in CARB's PM Staff Report (CARB, 2002).

- The ARB staff assumed the model-predicted exposure estimates could be applied to the entire population within each modeling grid. That is, the entire population within each modeling grid of 200 m x 200 m was assumed to be exposed uniformly to modeled concentration. This assumption is typical of this type of estimation.

- The ARB staff assumed the grid cell population had similar age distributions as the county in which it was located. The subpopulation used for each health endpoint was calculated by multiplying the all-age population for each grid cell by the county-specific ratio of the subpopulation used for the endpoint over the all-age population. For example, mortality estimates were based on subpopulations age 30 or more estimated from ratios of people over 30 over the entire population, specific for each county. These estimates were needed because information on the particular subpopulation in each modeling grid was not available.

- The ARB staff assumed the baseline incidence rates were uniform across each modeling grid, and in many cases across each county. This assumption is consistent with methods used by the U.S. EPA for its regulatory impact assessment. The incidence rates match those used by U.S. EPA.

- Another assumption pertains to the threshold, the lowest level at which health impacts can be assessed. There is some evidence that the PM effect coefficient may be larger at lower levels of PM and smaller at higher levels. However, we assumed no threshold in our calculations. That is, the effects can be estimated down to zero.

It should be noted that because the estimates apply to a limited modeling domain (20 miles by 20 miles), the affected population is small, and hence the overall estimated health impacts are smaller than estimates made on a statewide basis. In addition, to the extent that only a subset of health outcomes is considered here, the estimates should be considered an under-estimate of the total public health impact.

E. Unquantifiable Adverse Health Effects

In this analysis, we did not quantify all possible health adverse effects associated diesel PM emitted from Ports. For example, the effects of diesel PM on infant mortality, premature births, and low birth weight are not presented. Appendix D provides a brief overview of potential health effects of diesel PM not captured in the quantitative risk assessment and non-cancer health evaluation.

F. Comparison with Monitoring Results

In this section, we compare the potential cancer risks from this modeling study to the diesel PM risks based on ambient monitoring results from the Port of Los Angeles's (POLA) monitoring conducted during the period February 9 through August 5, 2005, and from ARB's 2002 Wilmington monitoring data collected as part of the Children Health Study. We also compare this study results with the South Coast Air Quality Management District (SCAQMD)'s second Multiple Air Toxic Exposure Study (MATES-II). (SCAQMD, 2000)

<u>Comparison with POLA's Monitoring Results</u>

The POLA is currently conducting an air quality monitoring program on Port property and in the nearby communities. The primary objective of this monitoring is to estimate the ambient levels of diesel PM in proximity to the Port that are due to operational activities at the Port .

There are four monitoring stations deployed within the Port and in the nearby communities (see Figure 18). The Wilmington community station is the primary monitoring station located about one mile north of the Port boundary. Due to its proximity to Port operations and the prevalence of onshore wind flows, this station has the potential to experience elevated ambient diesel PM impacts from Port emissions. The San Pedro station is located within the San Pedro community, on the Liberty Hill Plaza Building. This location is near the western edge of Port emission sources and adjacent to residential areas in San Pedro. The other two stations – Coast Boundary Station and Source-Dominated Station, are located within the Port property.

Each monitoring station measures PM_{10}, and $PM_{2.5}$. The PM samples are analyzed for elemental carbon (EC), a component of air pollution that has been used as indicator of diesel PM. The monitoring stations collect samples over specific 24-hour periods in three-day intervals over a 12-month period. In its latest update, the POLA has released the measured EC 24-hr average concentrations for the period from February 9 to August 5, 2005. To estimate the concentration of diesel PM based on the monitored concentrations of EC, ARB staff used an EC to diesel PM ratio of 0.5. The ratio of EC to diesel PM has been reported to be 0.375 to 0.75 in literature. (Shi, et al., 2000, Pierson, et al., 1983, and Hildemann et al., 1991)

Table 11 shows the potential cancer risks based on the modeling results compared to those calculated using the monitored EC concentrations for the Wilmington and San Pedro monitoring sites. It can be seen that there is excellent agreement between the predicted cancer risk levels based on modeling and the cancer risk levels based on the monitoring data at both monitoring sites. A comparison was not made for the other two monitoring sites because they are located within the port property. Any risks within the port property are not reported in this study because of issues associated with the proximity of the emission sources and on port receptors.

Comparison with ARB's Wilmington Monitoring Results

The ARB conducted air monitoring in Wilmington from May 2001 to July 2002 as part of the Children's Environmental Health Program. Two monitoring sites were chosen – Wilmington and Hawaiian. Wilmington site is located near Wilmington Park Elementary School and the Hawaiian site is located at Hawaiian Elementary School (also see Figure 18 for locations). The ambient levels of EC were monitored at the two sites, but about 70 percent of the samples collected were below the detection limit of 1.0 µg EC/m^3. It is assumed that all measurements below the limit are arbitrarily assumed to be 0.5 µg EC/m^3. The monitoring results are summarized and compared with our predicted results (see Table 11). It also can be seen that the predicted results compare favorably with the monitored results at the two sites.

Table 11. Comparison of the predicted potential cancer risks with measurements conducted by POLA and ARB (cases per million)

Location	Port of L. A. monitoring results	ARB SB 25 monitoring results	Model prediction
Wilmington Community	585	N/A	600
San Pedro	533	N/A	500
Wilmington School	N/A	450	470
Hawaiian School	N/A	710	650

Note:

1. The ratio of elemental carbon (EC) with diesel PM has been reported to be 0.375 to 0.75 by literature. A ratio of 0.5 is used in this calculation;
2. For POLA's monitoring program, the measured EC 24-hr average concentrations over the half year from February 9 to August 5, 2005 are reported;
3. For ARB SB 25 Wilmington monitoring study, about 70% of the samples collected were below the detection limit of 1 ug EC/m^3. It is assumed that all measurements below the limit are arbitrarily assumed to be 0.5 $ugEC/m^3$;
4. For the detailed monitoring programs and results, please check POLA and ARB's web sites.

Figure 18. Air Quality Monitoring Stations for the POLA and ARB Programs
(Courtesy of POLA, http://www.portoflosangeles.org)

Comparison with the SCAQMD MATES-II Study

We also compared the modeling results to the SCAQMD's second MATES-II study. The MATES-II study indicated the modeled potential risk in the grid cell containing the Wilmington air quality monitoring station is 1,187 potential cancer cases per million due to diesel PM emissions from port activities, freeways, and other sources of diesel PM.

This Wilmington grid cell is approximately 2 miles north of the ports. Our modeling study shows a risk level of about 450 cases in a million in the same general vicinity. In the nearby residential areas within one mile from port boundaries, cancer risk levels (from diesel PM emissions as well as other toxics) ranged from 1000 to 1500 cases in a million based on the MATES-II study. Our study shows a cancer risk range of 500 to 1000 cases in a million from diesel PM emissions. The differences can be attributed to different modeling configurations. For example, MATES-II used the Urban Airshed Model (UAM) model, a grid based model with 2 km grid cells, while our study used the ISCST3 model, a Gaussian plume model. In addition, MATES-II simulated diesel PM from all sources (e.g., port activities and freeway emissions) for the 1998 base year while our study was limited to diesel PM from port activities for the year 2002. Also the MATES-II study released ocean-going emissions near ground level (within the first horizontal layer of the UAM). Our study released ocean going emissions at 50 meters above "ground" (sea level) which will result in greater dispersion of emissions.

G. Uncertainty and Limitations

Risk assessment is a complex process which requires the integration of many variables and assumptions. Due to these variables and assumptions, there are uncertainties and limitations with the results. Generally, the assumptions are designed to be health protective so that the estimates of risks to individuals are not underestimated. Below is a discussion of uncertainty associated with the key elements used in a risk assessment. These key elements are the heath risk values, the air dispersion modeling used to predict diesel PM concentrations, and the model input parameters.

Uncertainty Associated with Health Values

Scientists often use animal studies to predict how a chemical affects humans in the development of health values that are then used in a risk assessment. Scientists cannot be sure that humans will respond exactly the same way as animals do to a chemical. Also, animals used in these studies are often given very high doses of a chemical to produce negative health effects. These doses are much higher than what people are actually exposed to in the environment. When available, as is the case with diesel PM, scientists use studies of people exposed at work to develop health values to estimate potential cancer risk from environmental exposures. This can introduce uncertainty in the potential risk estimated for the general public because there is a wide range of responses among all individuals, and there can be a wider range of responses in the general public than in the workers in an epidemiology study. In addition, for diesel PM, the actual worker exposures to diesel PM were based on limited monitoring data and were mostly derived based on estimates of emissions and duration of exposure. Different epidemiological studies also suggest somewhat different levels of risk. When the Scientific Review Panel (SRP) identified diesel PM as a toxic air contaminant, they endorsed a range of inhalation cancer potency factors (1.3×10^{-4} to 2.4×10^{-3} $(\mu g/m^3)^{-1}$) and a risk factor of 3×10^{-4} $(\mu g/m3)^{-1}$, as a reasonable estimate of the unit risk. From the unit risk factor an inhalation cancer potency factor of 1.1 $(mg/kg\text{-}day)^{-1}$ may be calculated.

Uncertainty Associated with Air Dispersion Modeling

As mentioned previously, there is no direct measurement technique for diesel PM. This analysis used air dispersion modeling to estimate the concentrations to which the public is exposed. While air dispersion models are based on the state-of-the-art formulations, there are uncertainties associated with the models. The primary purpose of this study was to prioritize emission sources/categories from the Ports operation which are to be regulated. The U.S. EPA Industrial Source Complex – Short Term (ISCST) model was selected for use in this study because of our experience using this model and it was the U.S. EPA's preferred air dispersion model at the time this analysis was performed.

Uncertainty Associated with the Model Inputs and Domain

The model inputs include emission rates, emission release parameters, meteorological conditions, and dispersion coefficients. Each of the model inputs has uncertainty associated with it. Among these inputs, emission rates and meteorological conditions have the greatest affect on modeling results. The emission rate for each source was calculated from the emission inventory. The emission inventory has several sources of uncertainty including: emission factors, equipment population and age, equipment activity, load factors, and fuel type and quality, The uncertainties in the emission inventory can lead to over predictions or under predictions in the modeling results. To minimize uncertainty, we relied on the most current information available.

Meteorological conditions can play a key role in predicted pollutant concentrations. These meteorological parameters include wind speed, wind direction, atmospheric stability, and ambient temperature. For this modeling study, we used wind data from the Wilmington site. We assumed that this wind data was applicable over the entire study area (400 square miles). This is a conservative (health protective) assumption and will tend to over predict the impact of emissions somewhat, particularly for emissions released offshore.

Another critical meteorological condition that can affect pollutant concentration is the mixing height. The greater the mixing height, the greater the volume of air is available to dilute the pollution concentration. For this modeling study, we assumed an average annual mixing height of about 700 meters. This value compares favorably with U.S. Navy mixing height measurements at Point Mugu and San Nicholas Island. (Lee Eddington, 2006)

As stated previously, a model domain of 20 miles x 20 miles was used in this study because of the ISCST model's limitation. In reality, the impacts of diesel PM from the Ports in the nearby communities exceed the model domain. Based on some preliminary modeling estimates, we believe that an additional six million people outside the modeling study area are exposed to an annual average diesel PM concentration of about 0.08 μg/m^3. Additional study using a long range transport model may be conducted to better address the full impacts outside of this model domain.

<u>Unquantified Adverse Effects</u>

It is not possible to quantify all possible adverse health effects associated with diesel PM emitted from Ports. This is because peer-reviewed methodologies to quantify all of the health effects do not currently exist. Appendix D provides a brief overview of potential health effects from port-related emissions not captured in the quantitative risk assessment and non-cancer health evaluation.

V. SUMMARY OF FINDINGS

The study evaluated the diesel PM emissions on a mass basis and with respect to what impacts those emissions have on potential cancer risks in communities near the ports. With respect to the mass emissions, the combined diesel PM emission from both ports is estimated to be about 1,760 tons per year in 2002. This represents a significant component of the regional diesel PM emissions for the South Coast Air Basin at about 21% of the total basin wide diesel PM emissions in 2002.

Focusing only on the on-port diesel PM emissions, as shown in Figure 19, the emission from ship activities (maneuvering, transiting, and hotelling) account for the largest percentage of emissions at about 73% followed by commercial harbor craft vessels (14%), cargo handling equipment (10%), in-port heavy-duty trucks (2%), and in-port locomotives (1%).

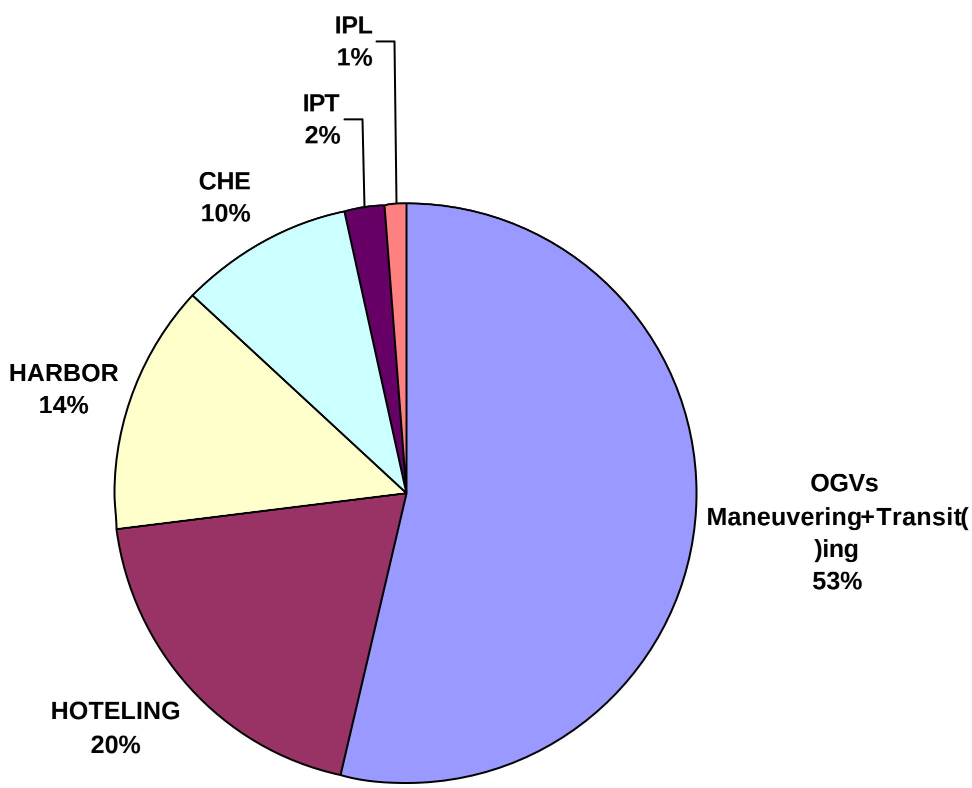

Figure 19: Distribution of Diesel PM Emissions by Source Categories for POLA and POLB in 2002

The combined diesel PM emissions from the ports result in elevated cancer risk levels over the entire 20 mile by 20-mile study area. In areas near the Port boundaries, potential cancer risk levels exceed 500 in a million. As one moves away from the ports, the potential cancer risk levels decrease but continue to exceed 50 in a million for almost the entire modeling domain. Potential cancer risk and the number of acres impacted for several risk ranges are summarized as follows:

- Risk levels greater than 500 in a million (based on 70 years of exposure) occur over about 2,500 acres in which about 53,000 people live.

- Risk levels between 200 and 500 in a million occur over about 26,500 acres in which about 360,000 people live.

- Risk levels between 100 and 200 in a million occur over about 64,500 acres in which about 724,000 people live.

- Risk levels between 10 and 100 in a million occur over about 70,000 acres in which about 843,200 people live.

- The overall, almost all people living within the modeling domain (about 2 million) are exposed to a risk level of greater than 50 in a million and about 97 percent of the areas within the domain are impacted at or above this risk level.

The exposure assessment demonstrated that the land-based or near dock diesel PM emissions were responsible for greater impacts than the emissions that occurred outside the breakwater. Quantitatively, within the modeling receptor domain, the population-weighted risk resulting from the in-port or near dock emissions is about 4.5 times of that resulting from the over-water out-of-port emissions. The results from the exposure assessment also revealed that the contribution of the individual emission sources to the community exposures does not follow the same relationship as the mass emissions. Ship hotelling emissions, while responsible for about 20 percent of the mass emissions, were the emissions that resulted in the largest area and population impacted where the potential cancer risks were greater than 200 in a million (see Figures 20 and 21). Hotelling emissions are also responsible for 34 percent of the total risk in the model domain based on the population-weighted average risk. The second highest category was cargo handling equipment which is responsible for about 22 percent of the total risk in the model domain based on the population-weighted average risk followed by commercial harbor craft, and in-port heavy-duty trucks. When considering risks greater than 10 in a million, all categories except in-port heavy-duty trucks and in-port locomotives affected more than 1.4 million people and impacted more than 119,000 acres where residents live. For the in-port trucks and locomotives, the risk level of greater than 10 in a million affected about 423,000 people and impacted about 30,000 acres.

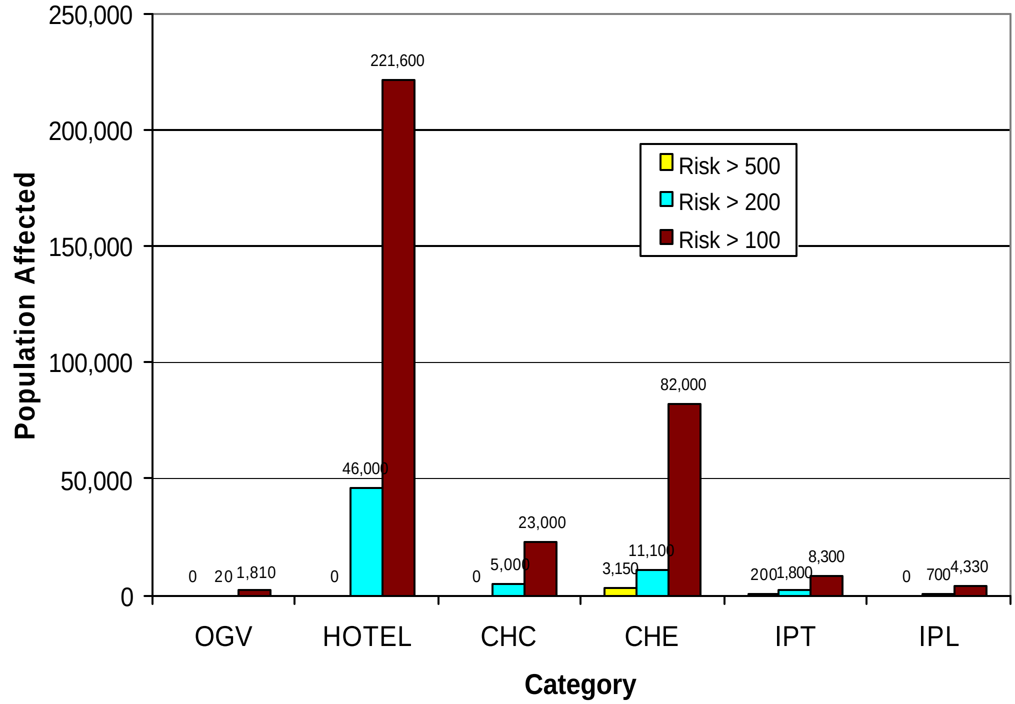

Figure 20: Population Affected within the Model Domain by Cancer Risk Levels and Source Categories

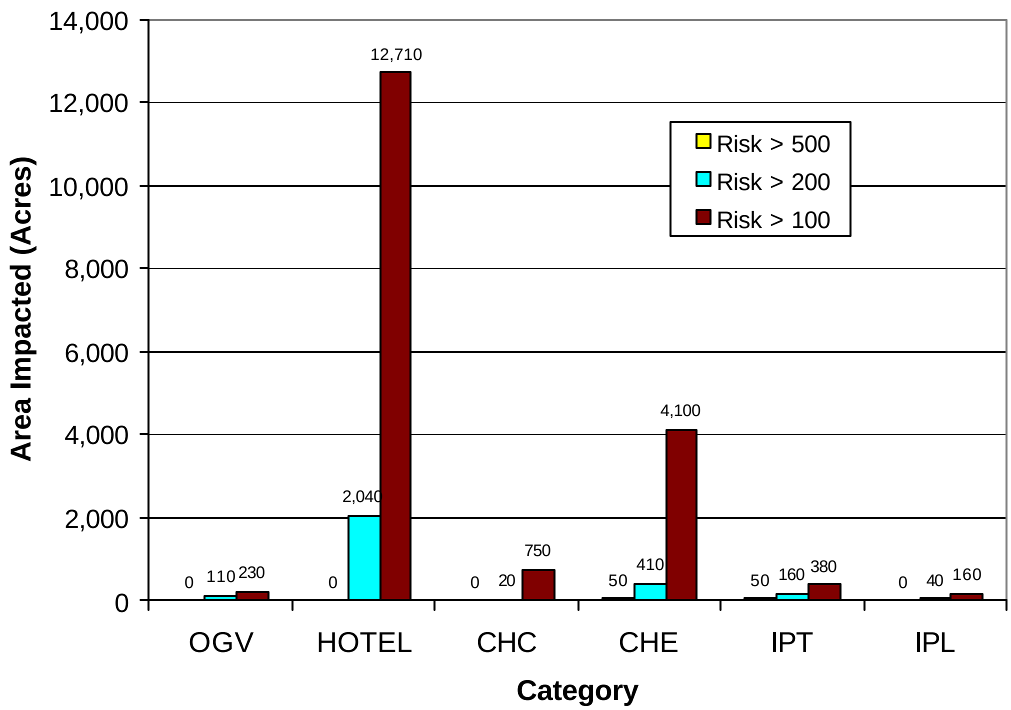

Figure 21: Residential Areas Impacted within the Model Domain by Cancer Risk Levels and Source Categories

The relationship between the various source categories is summarized below. Based on the mass emissions, population-weighted average risk, the size of areas impacted, and the number of people affected, the emission sources or categories can be ranked as the follows:

- By the mass emissions
  OGV > HOTEL > HARBOR > CHE > TRUCK > LOCO

- By the risk level (population weighted):
  HOTEL > CHE ˜ OGV > HARBOR > TRUCK > LOCO

- By the area impacted (R > 100 in a million):
  HOTEL > CHE > HARBOR > TRUCK > OGV > LOCO

- By the population affected (R > 100 in a million):
  HOTEL > CHE > HARBOR > TRUCK > LOCO > OGV

- By the area impacted (R > 10 in a million):
  OGV > HOTEL > HARBOR > CHE > TRUCK > LOCO

- By the population affected (R > 10 in a million):
  OGV > HOTEL > HARBOR > CHE > TRUCK > LOCO

In conclusion, emissions from cargo handling equipment and hotelling emissions from ocean-going vessel auxiliary engines are the primary contributors to the high potential cancer risk levels near the ports. Reducing emissions from these two categories will have a dramatic effect on reducing the cancer risk levels in nearby communities. Emissions from commercial harbor craft, in-port trucks, in-port rail, and ocean-going vessel (transit and maneuvering activities) do not contribute greatly to the near source risk, but are an important contributor to elevated cancer risk levels over a very large area. While emissions from these source categories do not have a major role in the near port risk levels, they are significant contributors to the overall elevated risk levels in the study area. Addressing the emissions from these sources, while not as critical for reducing near port risk levels, is critical if we are to significantly reduce the exposure of a large population (over 2 million people) to cancer risk levels in the 50 in a million range.

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Appendix A

Methodologies for Developing Source Category Emission Inventories

A. Port of Los Angeles

Starcrest prepared an emission inventory for all emission sources using 2001 as the baseline year. The inventory utilizes activity-based approach and focuses on emissions of diesel PM for all significant sources operating in the Port. In addition to in-port activities, emissions from railroad locomotives and on-road trucks transporting port cargo were also estimated based on the activity that occurs outside the Port, but within the South Coast Air Basin boundaries. Only on-port emissions were evaluated in this exposure assessment. The basic methodologies for developing source category diesel PM emission inventory are briefly described as follows:

<u>Ocean-Going Vessels</u>

Starcrest staff used the activity-based approach to estimate emissions from various types of ocean-going vessels (auto carriers, bulk carriers, containerships, cruise ships, general cargo ships, ocean-going tugboats, refrigerated vessels, roll-on roll-off ships, and bulk liquid tankers). The approach was chosen because it makes use of actual location-specific information and can account for site-specific and/or activity-specific emissions levels. For OGVs, emissions were estimated as a function of vessel power demand (expressed in kW-hrs) multiplied by an emission factor (expressed in g/kW-hr). The basic equation for calculating emissions is as follows:

$$E = MCR * LF * A * EF \qquad (A1)$$

Where E is the emission, MCR is the maximum continuous rated engine power (kW), LF is the load factor (unitless), A is the activity (hours), EF is the emission factor (g/kW-hr).

For propulsion engines, the load factor is defined as a ratio of a vessel's power output at a given speed to the vessel's MCR power. At normal service speed, a ship probably has a load factor of close to 80%. For intermediate speeds, the load factor was calculated as:

$$LF = (AS / MS)^3 \qquad (A2)$$

Where AS is the actual speed (knots), and MS is the maximum speed (knots).

For propulsion engines, the diesel PM emission factors of 1.92 and 0.72 g/kW-hr were used for slow speed and medium speed operation modes, respectively. Note that if an engine load is below 20%, an adjustment factor should be applied. The following equations can be used to calculate the adjustment factors for diesel PM when the load is at or lower than 20%:

$$AF = 9.8238 * (LF)^{-0.8117} \qquad \text{(A3)}$$

Where AF is the adjustment factor for diesel PM (unitless), and LF is the load factor (in percent). Note that if the load factor were 20%, the adjustment factor would be 1.

For auxiliary engines, emissions were estimated following the same logic as for propulsion engines but differed in estimating load factors, which were based on data available in technical literature. The emission factors of 0.30 g/kW-hr for distillate oil and 1.5 g/kw-hr for residual oil were used for both medium-speed and high-speed diesel engines.

For vessel hotelling at berth, emissions were estimated using the same logic as for auxiliary engines except for activity data. The activity utilized the default hotelling times (in hours) which were obtained from the Port's vessel call database and then averaged by terminal and ship type. So, the default hotelling times (see Table 2.31 in the Report of Los Angeles) represent average hotelling times for each ship type and can be used when terminal-specific hotelling times are not available.

<u>Harbor Craft</u>

The harbor craft vessels are categorized as: assist tugboats, towboats and push boats, ferries and excursion vessels, crew boats, work boats, government vessels, dredges and dredging support vessels, commercial fishing vessels, and recreation vessels. The emissions associated with the harbor vessels are generated within the port and out at ocean. Based on the survey conducted by CARB, the percentages of time spent within the port harbor, up to 25 miles, and from 25 to 50 miles are 54, 35, and 11 percent, respectively.

The basic equation used by Starcrest to estimate harbor vessel emissions is:

$$E = PW \times Act \times LF \times EF \qquad \text{(A4)}$$

Where E is the emission (g/yr), PW is the engine's power (kW), Act is the activity (hr/yr), LF is the load factor, and EF is the emission factor (g/kW-hr).

The activity data (engine information and operation time per year) were obtained from the ARB's survey. The emission factors were obtained from the EPA's database (EPA, 1999, ''Final Regulatory Impact Analysis: Control Emissions from Compression-Ignition Marine Engines", EPA420-R-99-026). The deterioration rates were not taken into account for the emission estimates. The engine load factors were obtained from the

EPA NON-ROAD model. For assist tugboats, a 31% average engine load factor was used, and for the other categories, the 43% engine load factor was assumed.

Cargo Handling Equipment

Cargo handling equipment consists of various types of off-road equipment and vehicles used to move cargo within terminals and other off-road areas. The emission estimates were estimated using ARB OFFROAD model.

The basic equation for calculating emissions of off-road equipment and vehicles is as follows:

$$E = EF \times HP \times LF \times Act \times FCF \qquad \text{(A5)}$$

Where E is the emission (tons), EF is the emission factor (g/hp-hr), HP is the average rated horsepower for the equipment type and horsepower category (HP), LF is the load factor (assumed average percentage of full load), Act is the equipment activity (hrs/yr), and FCF is the fuel correction factor.

The activity data were collected by the Port from the terminal operators. The OFFROAD model was run in “by-model year” mode, meaning that the model took into account emission factors for specific model year group, and the number of pieces of equipment in each of the subgroups. The equipment was grouped based on horsepower range as: up to 25 hp, 26-50 hp, 51-120 hp, 121-175 hp, 176-250 hp, 251-500 hp, 501-750 hp, and 751hp and up. Within the groups, the horsepower and annual hours of use were averaged, and the averages were input into the model.

The emission factors can be expressed as a combination of the base emission factor for the equipment model year (g/hp-hr) plus a deterioration factor, that is:

$$EF = EF_{base} + DF \qquad \text{(A6)}$$

Where EF_{base} is the base emission factor for a given horsepower range and model year (g/hp-hr), and DF is the deterioration factor (estimate of emission increase as an engine ages, expressed as g/hp-hr-hr). The OFFROAD model assumes that the equipment’s annual operating hours have been constant over the life of the equipment. The model also assumes that deterioration continues as a constant rate over the life of the equipment. The equation for the deterioration factor is:

$$DF = DF_{base} \times Act \times Age \qquad \text{(A7)}$$

Where Act is the equipment activity (hrs/yr), and Age is the age of equipment (yrs).

Railroad Locomotives

Railroad operations are classified into two types of activities: line haul and switching. Starcrest staff used two methods to estimate emissions. For in-port switching operations, the emissions were estimated based on the throttle notch data and schedule/operational information provided by the switching companies along with U.S. EPA data on emission rates by throttle notch. Off-port switching emissions were estimated using throttle notch, U.S. EPA emission factors, and fuel use data provided by the railroad companies. For the line haul operation within the Port, emissions were estimated based on schedule and throughput information provided by terminal operators and on U.S. EPA operational and emission factors. For off-port line haul operations, the emissions were estimated using detailed cargo movement and fuel use information provided by the line haul companies.

Heavy-Duty Vehicles

For this emission inventory, heavy-duty diesel-fueled vehicle (HDV) activity has been divided into two components: on-road (off-terminal) travel and on-terminal operations. For estimating on-terminal HDV emissions, Starcrest staff collected on-terminal traffic information, including gate operation schedules, on-terminal speeds, time and distance traveled on terminal while dropping off and/or picking up loads, and time spent idling at the entry and exit gates, through the interview with terminal personnel. For estimating on-road (off-terminal) HDV emissions, the off-terminal truck travel activity was developed by a consultant company (Meyer Mohaddes Associates, Inc. (MMA)) using a travel demand model. The on-road truck travel information included the number of trucks traveling on defined roadway segments, the distance and average speeds on those segments between defined intersections. Off-terminal and on-terminal emissions were estimated by multiplying the emission factors derived by EMFAC2002 by the time and distance parameters established for the terminals. Note that for on-terminal vehicles, there are two types of activity: engine running with vehicles moving a given speed, and engine idling with vehicles at rest.

B. Port of Long Beach

For POLB, Statcrest has developed emission inventories for three categories: cargo handling equipment, in-port locomotives, and in-port heavy-duty vehicles using 2002 as the base year. The methodologies used in estimating emissions for these categories are similar to those used in estimating corresponding emission inventories for POLA. To complete the emission inventories for POLB, ARB staff used the scale-up/down approaches to estimate the emissions for ocean-going vessels (cruises and hotelling) and harbor craft vessels.

OGVs (Cruise and Hotelling)

To estimate emissions from ocean-going vessels for POLB, ARB staff assumed that the unit emission for each OGVs type in POLB in 2002 is the same as that for the corresponding OGVs type from POLA in 2001. The emissions of each OGVs type for POLB in 2002 are estimated by multiplying the unit emission per call of POLA in 2001 by the call number of the corresponding OGVs type at POLB in 2002, that is:

$$E_{POLB,2002,i} = \frac{E_{POLA,2001,i}}{CN_{POLA,2001,i}} \, x \, CN_{POLB,2002,i} \quad \text{(A8)}$$

where $E_{POLB,2002,i}$ is the estimated emission of OGV type i at POLB for 2002, $E_{POLA,2001,I}$ is the emission of OGV type i at POLA for 2001 (known), $CN_{POLA,2001,i}$ and $CN_{POLB,2002,i}$ are the call numbers from POLA in 2001 and from POLB in 2002 for OGV type i, respectively.

<u>Harbor Craft</u>

To estimate emissions from harbor craft vessels operating at POLB, ARB staff used the estimates of emissions from harbor craft vessels from ARB's 2004 commercial harbor craft emission inventory. These emission estimates were based on information on vessels registered (California Department of Fish and Game), permitted (California Public Utilities Commission), or documented (U.S. Coast Guard) with a "home port" listed as "Long Beach." These vessels registered as "Long Beach" were then allocated to the nine categories (commercial fishing, charter fishing, ferries/excursion, crew and supply, pilot, tugs, tows, work boats, and others) using the harbor craft vessel composition developed in ARB's 2003 Commercial Harbor Craft Survey (released in 2004). The emissions of each category for POLB in 2004 were estimated using the emission density (emission/per vehicle per category) multiplied by the corresponding vessel number in each category, that is:

$$E_{POLB,2004} = \sum_{i=1}^{2} \sum_{j=1}^{9} \left(\frac{E_{statewide,2004}(i,j)}{N_{statewide,2004}(i,j)} \right) x \, N_{POLB,2004}(i,j) \quad \text{(A9)}$$

where $E_{POLB,\ 2004}$ is the estimated emissions for all harbor craft vessels at POLB for 2004, $E_{statewide,\ 2004}(i, j)$ is the estimated emission for engine type i and harbor craft vessel type j in the statewide for 2004, $N_{statewide,\ 2004}(i, j)$ and $N_{POLB,\ 2004}(i, j)$ are the numbers of harbor craft type j for engine type i in the statewide and in POLB for 2004 respectively, i is the index for engine type (propulsion and auxiliary), and j is the index for harbor vessel type (j = 1 to 9, defined above).

According to the NNI Calculator, the growth of harbor craft vessels from 2001 to 2005 in POLA is almost zero (0.1 percent). We assume that for POLB, the total emission of harbor craft vessels in the baseline year 2002 is equal to that in 2004 as calculated above.

Appendix B

Ship Auxiliary Engine Emission Factor Development

Public comments were received recommending a different PM emission factor than the one ARB used for auxiliary engines. To estimate diesel PM emissions from ship auxiliary engines, ARB staff used an average PM emission factor of 1.5 g/kw-hr for residual fuel oil with an average sulfur level of 2.5 wt. %. Several comments believed that ARB has overestimated the ship hoteling emissions because this emission factor is higher than other published sources (Entec 2002 and Environ 2002).

Concerning the Entec emission factor, ARB staff contacted David Cooper of IVL, the primary author of the Entec report, to understand the development of the Entec emission factor. Mr. Cooper indicated that this was a composite emission factor developed from medium and high speed main engines and auxiliary engines. The data originated from IVL testing and Lloyds data. He indicated that the sulfur level of the residual oil tested ranged from 0.4 to 2.5%. ARB staff have estimated that the average sulfur level for this data set is in the vicinity of 1.5% for the composite emission factor. Therefore, ARB staff believe that 0.8 g/kw-hr is an appropriate emission factor for lower sulfur levels (near 1.5%), but is not representative for 2.5% fuel sulfur levels.

While ARB staff does not have a complete list of the cited IVL data, we believe the PM emissions, where fuel sulfur is included, may have originated from Environment Canada.

In developing the ARB's original emission factor of 1.5 g/kw-hr, ARB staff used an average emission factor of 1.7 g/kw-hr for 3% fuel sulfur as reported in Table 3-8 of the Environ 2002 report. The emission factor for 2.5% fuel sulfur was estimated using a relationship between fuel sulfur and emissions, originally developed by EPA and making slight adjustments in the brake specific fuel consumption rate needed to convert from kg/tonne to g/kw-hr.

Figure B-1 shows the Environment Canada (MSED 97-04) PM emissions data as a function of fuel sulfur, using data where fuel sulfur was reported. The relationship between emissions and fuel sulfur content was estimated by a curve fit of the data. The ARB estimated emission factor, the Entec composite emission factor and the Environ estimated emission factor are also indicated on the figure.

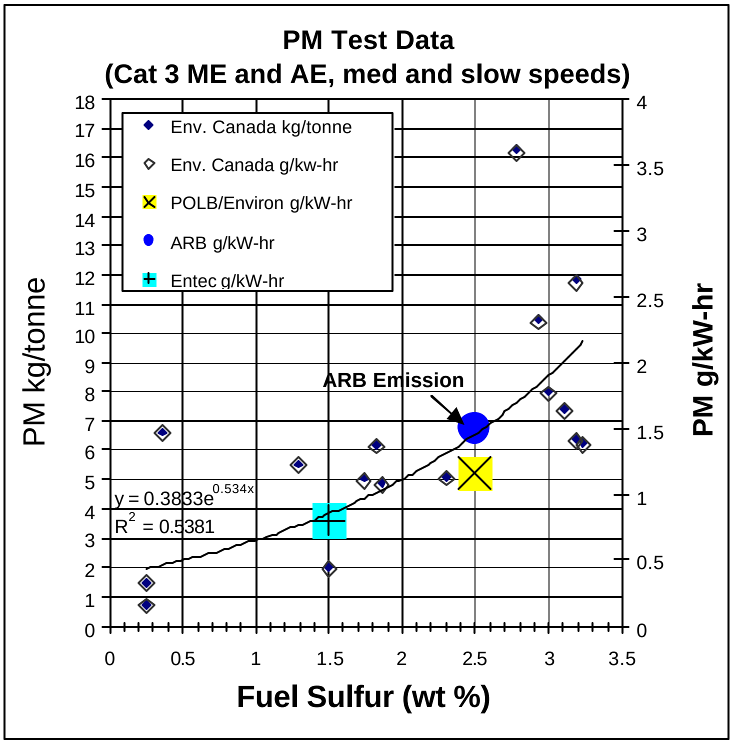

Figure B-1. PM emissions as a function of fuel sulfur from Environment Canada (MSED 97-04)

Concerning the Environ emission factor, ARB staff believes that the methodology Environ used to adjust the emission factor is based on a curve fit of category 3 main engine data from three sources: one data point from Maeda 2004, one data point from Fleisher 1998, and six data points representing a partial data set from Environment Canada 1997 (reported as Lloyds). The relationship developed for PM emission factor as a function of fuel sulfur provides an estimation of 1.16 g/kw-hr at 2.5% sulfur using the Environ methodology.

ARB staff do not agree with the use of the partial data set from Environment Canada when a more complete set including data from auxiliary engines is available. The Environment Canada report includes a total of 12 data points for Category 3 main and auxiliary engines, where fuel sulfur is reported. ARB staff used a similar methodology (shown in Figure A-1), but included the larger data set from Environment Canada, where sulfur levels were reported. This methodology provides an estimate of 1.5 g/kw-hr for a fuel sulfur level of 2.5%.

Based on an analysis of the widely cited Environment Canada study (MSED 97-04), ARB staff recommend the use of an average emission factor 1.5 g/kw-hr for an average residual oil fuel sulfur level of 2.5 wt. %.

Appendix C

Comparison of Estimated Diesel PM Cancer Risks from Ocean-Going Vessel Activity Outside of the Breakwater using Wilmington and King Harbor Meteorological Data Sets

Purpose. As discussed in the main report, about 95% of ship's emissions (maneuvering + transiting) are generated in the outside shipping lanes of the breakwater. Due to the blocking effect of the Palos Verdes Hills, wide variations in meteorological conditions could occur within the Ports and in the outside (ocean side) of the Ports. We conducted a sensitivity study to investigate possible effects of ocean side meteorological conditions on the cancer risk in the Port's nearby communities using King Harbor meteorological data set and compare to what we conducted in the main report using Wilmington meteorological data.

Meteorological Data. Among available meteorological monitoring sites around the Ports, we have chosen King Harbor site as representative to the ocean side. King Harbor is about 10 miles the northwest of the Ports (see Figure C-1). The wind rose for King Harbor site is presented in Figure C-2. The annual average wind speed is about 2.93 m/s, which is higher than that of Wilmington site (1.83 m/s). The winds were predominantly from the west approximately 15%, west-southwest approximately 22%, and southwesterly about 18% of the time, with wind speeds ranging from 0.5 to 11 m/s. As showed in Figure C-3, the data has a higher frequency of atmospherically stable conditions (stability E and F) compared with Wilmington met data (37% vs 24%).

Modeling Approach. We used the same air quality model (ISC), modeling receptor domain, modeling parameters, emission rate, and receptor spacing as what we utilized in the main report except for the meteorological data. Note that the emissions resulting from OGVs within the breakwater are not included in the sensitivity run.

Modeling Results. Estimated diesel PM cancer risks in the nearby communities around the Ports within the modeling domain using two different meteorological data sets (Wilmington and King Harbor) are presented in Figure C-4. Within the modeling domain, the contour lines of 100 and 200 in a million lie in the southwest ocean water surface of the Ports for both meteorological data sets. As with the population-weighted cancer risks within the domain, Wilmington data set resulted in 4% higher risk than King Harbor data set. The population-weighted impact difference between using Wilmington and using King Harbor meteorological data sets is not significant. In other words, using Wilmington or King Harbor meteorological data for out-of-port diesel PM emissions does not alter our conclusions drawn in the main report.

Conclusions. There does not appear to be a significant difference between using the Wilmington or King Harbor meteorological data in terms of the population-weighted cancer risks within the defined modeling receptor domain.

Figure C-1. Locations of Meteorological Monitoring Sites around the Ports

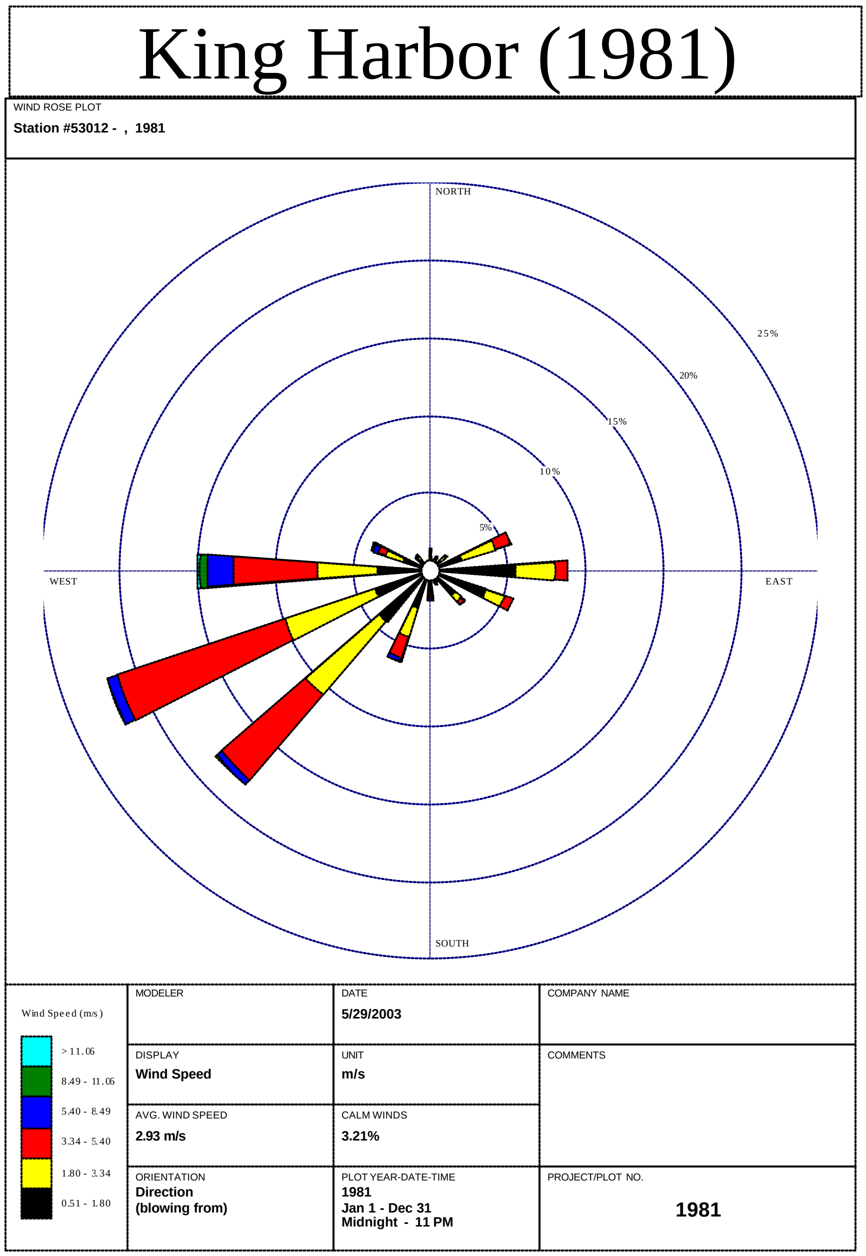

Figure C-2. Wind Rose for King Harbor Meteorological Site

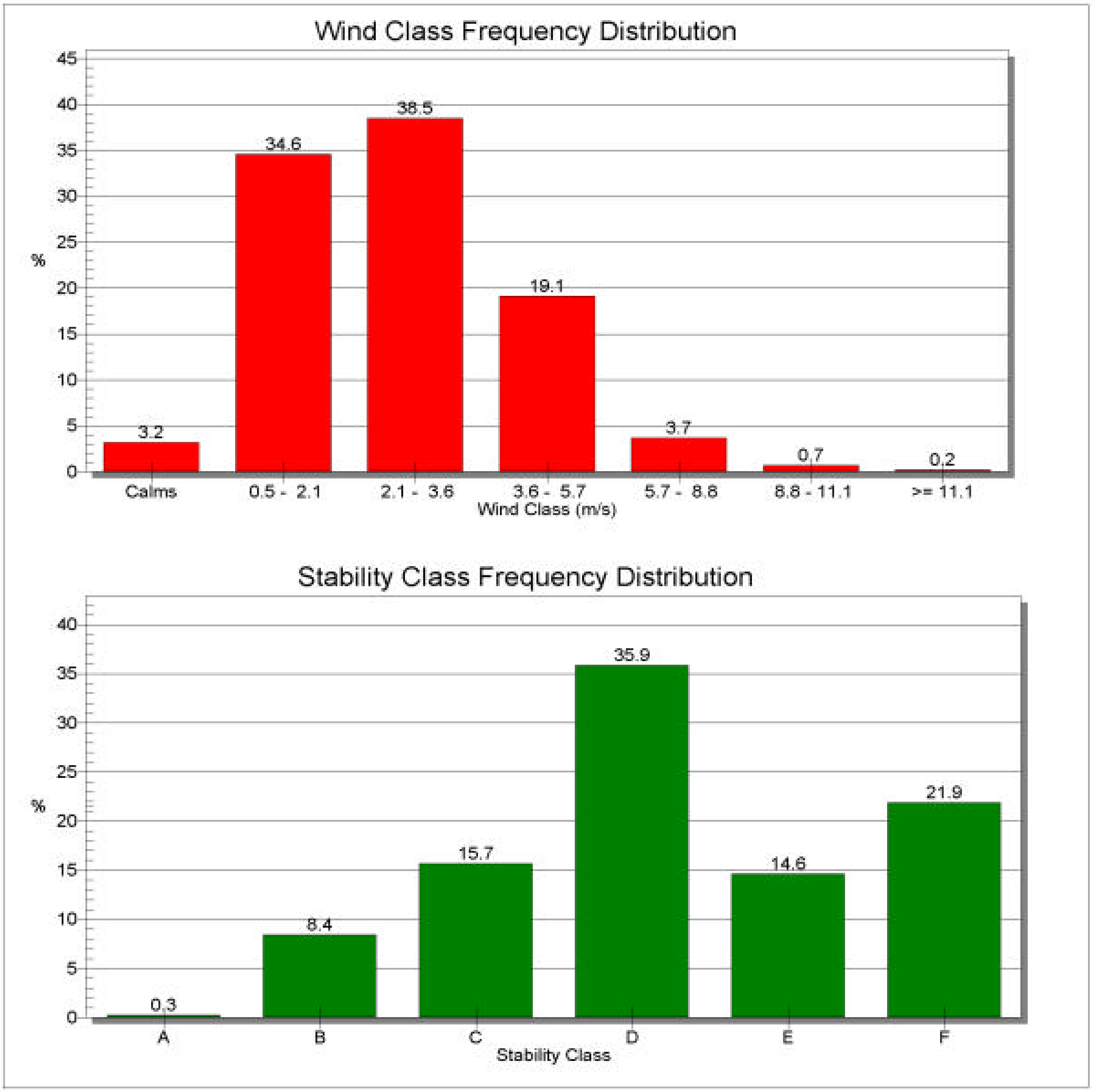

Figure C-3. Frequency Distributions of Wind Speed and Atmospheric Stability for King Harbor Meteorological Site

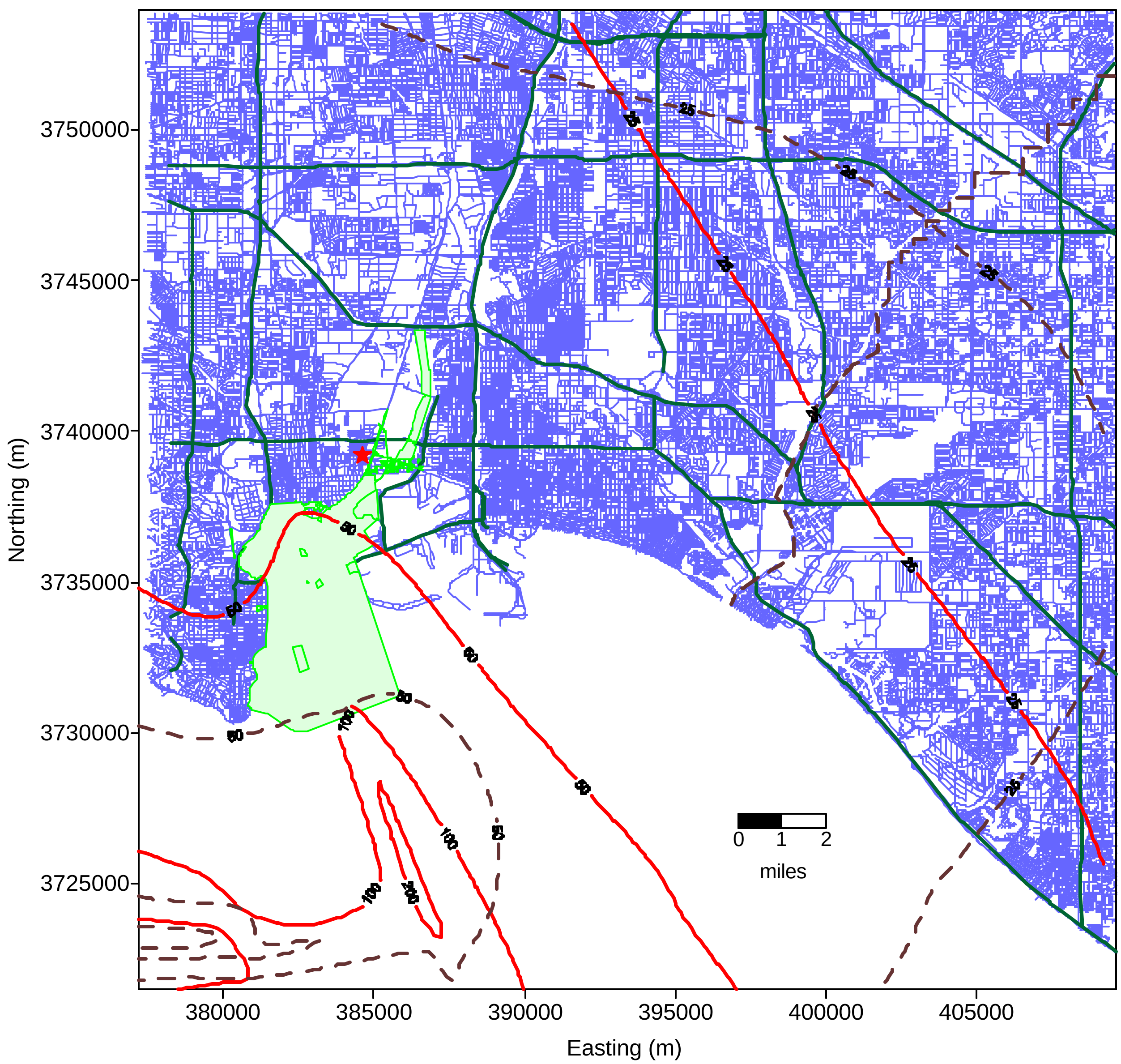

Figure C-4. Comparison of Estimated Diesel PM Cancer Risks from OGV's Activity in the Shipping Lanes outside of the Breakwater using Wilmington (solid lines) and King Harbor (dashed lines) Meteorological Data (Urban Dispersion Coefficients, 80th Percentile Breathing Rate, Emission= 904 TPY, Modeling Receptor Domain = 20 mi x 20 mi, Resolution = 200 m x 200 m)

Appendix D

Unquantifiable Adverse Health Effects

The combustion of fuel produces thousands of compounds that may affect human health. Although the earlier chapters of this document quantify the cancer and non-cancer risks of diesel exhaust particulate matter, there are additional health effects from PM and other pollutants that cannot yet be easily quantified. Information is rapidly evolving about the health impacts from airborne particulate matter, particularly ultrafines, and the mechanisms by which particulate matter, including that from diesel engines, induces health effects. When the diesel exhaust health risk assessment was conducted in 1998, we did not know about these other health impacts, and thus they are not quantified by current risk assessments. Additional resources are required to adequately characterize those non-cancer health risks which are quantifiable and it is important to initiate a comprehensive evaluation process of these potential health impacts over the next few years.

The following is a very brief overview of the health effects of diesel exhaust not captured in the earlier quantitative risk assessment and this field is rapidly evolving with new experimental findings and insights being published regularly. This chapter describes qualitatively some of those health risks. They include: adverse birth outcomes and non-quantified respiratory ailments in children, underlying physiological changes associated with heart disease and stroke, effects on the immune system, endocrine disruption, neurotoxicity, and risks resulting from multi-media exposures and cumulative impacts. It is important to note that some of these health effects (i.e., adverse birth outcomes, immune effects, and atherosclerosis) are measured at current ambient levels of particulate matter.

Birth Outcomes

Air pollution has been directly associated with low birth weight, preterm delivery, and cardiovascular birth defects (Maisonet *et al*., 2001;Ritz *et al*., 2000; Ritz *et al*, 2002; Ha *et al*, 2001; Gilboa *et al*, 2005; Wilhelm and Ritz, 2003, 2005). Preterm delivery and low birth weight are risk factors for infant mortality and life-long disability. Also, a number of studies have linked particulate air pollution to infant mortality (Woodruff *et al*, 1997, Hee-Ha *et al*, 2003; Bobak and Leon, 1999) from respiratory causes. There is not enough information at this time to identify the levels of exposure that pose a significant risk of these adverse effects.

Respiratory Ailments in Children

Traffic Studies

The health impacts of air pollution on children are of particular concern. Studies have shown associations between traffic-related pollution and effects in children, including chronic bronchitis symptoms, wheeze, cough, allergic rhinitis, asthma induction, and upper and lower respiratory tract infections (Jaakkola *et al*., 1991; Osterlee *et al*., 1996;Wjst *et al*., 1993; van Vliet *et al*., 1997; Venn *et al*, 2001; Kim *et al*., 2004). Recent evidence (Gauderman *et al*., 2004; Kunzli *et al*, 2004) indicates that air pollution exposure can impair lung function growth in children. The long-term consequences of lower lung function can include shorter lifespan, as lung function peaks in young adulthood and declines thereafter; lung function is the most significant predictor of mortality in the elderly (Schuneman *et al*. 2000; Hole *et al*., 1996).

Asthmagens

There are a number of indications in the occupational epidemiology literature (Delfino, 2002) and animal studies that some air toxics are associated with induction and exacerbation of asthma. These include chemicals that are products of fuel combustion, such as formaldehyde and acrolein. In addition, it has been shown in numerous studies that diesel exhaust particulate matter can enhance allergic asthma (Diaz-Sanchez 1999, 2000). Short-term exposure directly to diesel exhaust has also been shown to enhance airway responsiveness (Nordenhall *et al*, 2001). Urban particulate is associated with asthma exacerbation in numerous studies (Ostro *et al*., 1995, 2001;Delfino *et al*., 2002).

Heart Disease and Stroke

It is relatively straightforward to identify levels of airborne levels of PM that can cause death and to some extent illness from effects on the cardiovascular system. But air pollution is also associated with an increase in the underlying health conditions, such as atherosclerosis, that can increase the risk of both heart disease and stroke. Air pollutants that produce these effects include polycyclic aromatic hydrocarbons (PAHs), which produce atherosclerosis in animal models. Fine particulate matter was associated with increased atherosclerosis in humans (Kunzli *et al*, 2005), and in animals (Suwa *et al*., 2002). Heart attacks can be triggered by short-term exposure to traffic-related pollutants in those at risk (Peters *et al*. 2004). There are a number of published investigations and much ongoing research about the inflammatory processes underlying cardiovascular disease. Mechanisms underlying atherosclerosis involve inflammatory responses and oxidative stress triggered by particulate matter pollution (Li *et al*., 2002; Libby, 2002; Dick *et al*., 2003; Stone, 2004). Within the cell, toxicity to mitochondria (the energy generating subcellular organelle) results in cellular dysfunction and death (Hiura *et al*., 2000). Thrombotic events are likely also triggered by ultrafine particles (Schultz *et al*., 2005).

Carbon monoxide (CO) reduces available oxygen to the blood cells. Any chronic CO exposure, including exposures that result from port activities, likely contributes to underlying heart disease. Other air pollutants associated with fuel combustion, such as arsenic (present in some heavy fuel oils), may also play a role in cardiovascular diseases.

Some evidence exists that living near a major roadway with simultaneous exposure to traffic-related air pollution shortens life expectancy (Finkelstein *et al*, 2004; Hoek *et al*., 2002). One study showed that myocardial infarction is triggered following short-term exposure to elevated traffic pollution in cars, public transit, or on motorcycles or bikes

(Peters *et al*., 2004). Risk assessments that utilize air dispersion models to estimate "average" concentrations in a specific area may underestimate risk if that area is surrounded by major roadways.

Immune System Effects

Many studies have looked at the enhancement of the allergic response following intranasal instillation of diesel exhaust particles and may cause people to become allergic to airborne substances that they would not otherwise be allergic to (Nel *et al*, 1998, Diaz-Sanchez *et al*, 1999, 2000, Saxon and Diaz-Sanchez, 2000). Similar results have been obtained in animal models (Maejima *et al*, 2001). In addition, immune suppression (Burchiel *et al.*, 2004) has been observed in experimental animals exposed to diesel exhaust resulting in increased susceptibility to respiratory infection (Castranova *et al*., 2001). These responses are due to chemical components of diesel exhaust particulate that affect the proper functioning of the immune system. Other products of combustion, including PAHs and dioxins, also affect the immune system. The levels of exposure to these substances that can affect the immune system currently cannot be quantified.

Endocrine Disruption

Dioxins have been measured in exhaust from trucks. Dioxins and related compounds are known to disrupt thyroid hormone levels in the blood following exposure at levels found in the environment. Port activities likely contribute to the dioxin load in the immediate environment, but the effect on human health cannot be easily quantified. In addition, exposure of cells in culture and experimental animals to diesel exhaust has resulted in changes in reproductive hormones (Taneda *et al.*, 2000) resulting in decreased sperm production (Yoshida *et al*., 1999) and feminization of male rodent offspring (Watanabe and Kurita, 2001).

Neurotoxicity

Concerns are emerging about potential neurotoxicity from ultrafine particulate matter. It has been known for some time that very fine particles can cross membranes readily, including nervous system tissue. Recent studies on inhaled ultrafine particles indicate widespread distribution following exposure including into the brain cells (Oberdoerster *et al*., 2005). Oxidative stress was induced in the brain of fish exposed to nanoparticles in water (Oberdoerster, 2004). Mice exposed to concentrated airborne particulate matter (both fine and ultrafine) had elevated inflammatory markers in the brain compared to controls (Campbell *et al*., 2005). Thus, there is a real possibility of neurotoxicity from ultrafine particles.

Quality of Life

Some effects of air pollution are difficult to quantify, but may still be significant. For example, lost school days resulting from pollution-related respiratory ailments contribute to poorer learning, which may ultimately affect an individual's income as adults. While this is somewhat quantifiable, the overall quality of life that is affected by air pollution cannot be quantified, and therefore it is excluded from any benefits assessments. Similarly, the decrease in days of physical activity due to air pollution decreases overall health (particularly for children) by reducing exercise, and increasing obesity and related health problems such as diabetes and heart disease later in life. Similarly, it is not possible to quantify the social costs stemming from the reduced quality of life for children who have many restricted activity days due to exacerbation of asthma as a result of air pollution.

Atmospheric Transformation

Most risk assessments do not consider the effects of air pollutants that are created by chemical reactions in the atmosphere from other pollutants that are emitted from fuel combustion and other human activities. For example, nitrogen oxides and hydrocarbons emitted as a result of port activities contribute to the formation of ozone, the main component of urban smog and secondarily formed particulate matter. The impacts that port activities have on ozone and secondarily formed particulate matter formation have not been considered in assessments of port activities, but these impacts could be substantial.

Multi-media Exposure and Cumulative Impacts

It is not easy to estimate risks from exposures to pollutants that are initially airborne but then deposit onto surfaces and waterways. For example, goods movement activities contribute to non-point source runoff that contaminates coastal and bay waters with a number of toxicants, including PAHs, dioxins, and metals. Exposures to pollutants that were originally emitted into the air can also occur as a result of dermal contact, ingestion of contaminated produce, and ingestion of fish that have taken up contaminants from water bodies. These exposures can all contribute to an individual's health risk.

In most risk assessments, chemicals are evaluated without consideration of other pollutants that may add to the risks posed by the chemicals being assessed. The typical risk assessment does consider cumulative impacts on a specific organ of the body for multiple chemicals that originate from other sources of emissions in the area. However, there generally are no methods at present for evaluating cumulative impacts posed by exposures to multiple pollutants. For these reasons, it is often not possible to fully evaluate the health risks in a community that is impacted by multiple sources of pollution.

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