Analysis of Diesel Particulate Matter Health Risk Disparities in Selected US Harbor Areas

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Objectives. People near major transportation emissions sources experience higher exposure to hazardous pollutants. We present population size and demographic composition estimates for exposure to diesel particulate matter (DPM) exhaust from US harbor activities.

Methods. We examined 43 US marine harbor areas to determine outdoor, ambient concentrations from port-related DPM emissions and then determined intake fractions of those emissions in each harbor area. We estimated the distribution of health risk by combining ambient concentrations with exposure and carcinogenic risk factors. We assessed demographic differences by stratifying the health risks by race/ethnicity and income.

Results. Intake fractions for 42 of the harbor areas ranged from 0.02×10^{-6} to 3.66×10^{-6}. A DPM-affected population of more than 4 million has a risk level greater than 100 per million; a population of 41 million, a risk level greater than 10 per million. Most exposures occur in a small number of marine harbor areas. Low-income households and both Hispanics and non-Hispanic Blacks are overrepresented in the affected populations.

Conclusions. The most important factor for predicting DPM intake fractions for harbor activities is the proximate population density. The largest uncertainty in predicting DPM carcinogenic health risk is the carcinogenic inhalation unit risk factor. (*Am J Public Health.* 2011;101:S217–S223. doi:10.2105/AJPH.2011.300190)

Evidence has shown that people living in close proximity to major transportation sources such as roads experience higher exposure to pollutants that are directly emitted by motor vehicles.[1] At least 1 study has suggested that residents nearby marine harbor areas are exposed to significantly higher concentrations of pollution, including particulate matter.[2]

Our 2-fold purpose was (1) to compare harbor areas across the United States with respect to the diesel particulate matter (DPM) inhalation intake fraction (i.e., the intake-to-emissions ratio) and (2) to estimate the size and demographic composition of populations experiencing enhanced carcinogenic health risk as a result of exposure to DPM emitted from activities in US harbor areas.

METHODS

First, for each of 43 US marine harbor areas, we used the American Meteorological Society–Environmental Protection Agency Regulatory Model (AERMOD) dispersion model[3] to determine a 3-year average spatial distribution of DPM concentrations resulting from activity at the harbors (Figure 1). Next, we applied exposure factors to the concentration estimates to assess the exposure concentrations at block group centroids in the vicinity of the harbor areas. We then combined these exposure concentrations with breathing rates and population totals to estimate the aggregate mass of DPM inhaled by populations living in the vicinity of the harbor areas and compared the inhaled mass with the emitted mass to calculate inhalation intake fractions:

$$\text{Intake Fraction} = \frac{\sum_{\text{Population}} \text{Exposure Concentration} \times \text{Breathing Rate}}{\text{Emission Rate}} \quad (1)$$

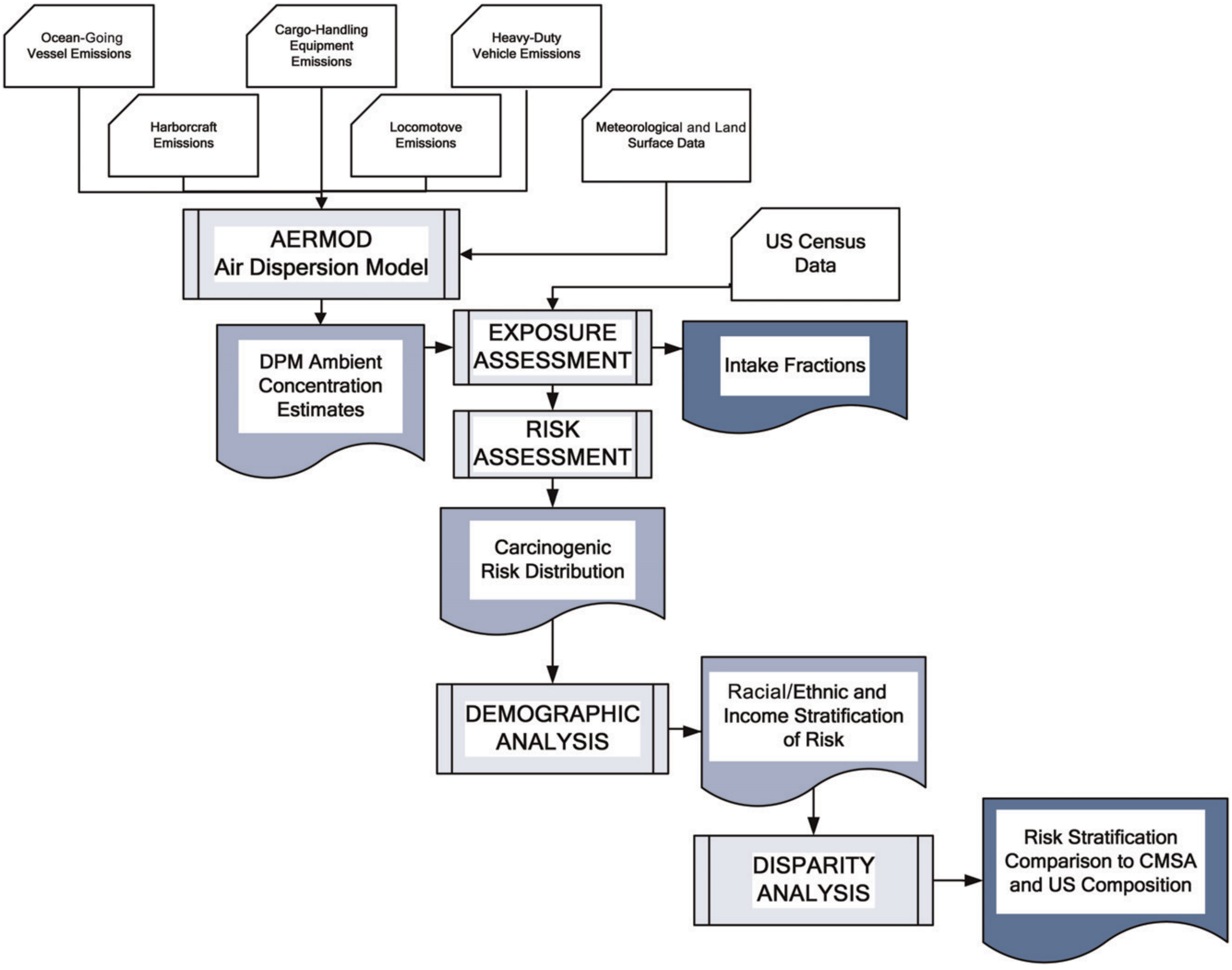
The magnitude of the intake fraction for any harbor area will depend on the meteorology, the proximate population density, and the proximate population activity patterns. A higher intake fraction means that a given level of emission creates more health risk because a larger fraction of the emitted mass is delivered to human lungs.

We also combined the exposure concentrations with a carcinogenic risk factor for DPM estimated by the California Office of Environmental Health Hazard Assessment (OEHHA)[4] to evaluate the carcinogenic health risk for lifetime (70-year) exposure for residents of each US Census Bureau block group in the vicinity of the harbor areas. We followed this evaluation with a demographic analysis of those populations with health risks exceeding 10 per million and 100 per million to determine their racial/ethnic composition and the distribution of household income. Finally, we performed a disparity analysis to compare these racial/ethnic and household income compositions with those of the associated metropolitan statistical area (MSA), the United States, or both. Additional details on the air quality analysis methodology are reported elsewhere.[5]

Identification of Marine Harbor Locations

We selected the 43 marine harbor areas to characterize a range of ports of interest across the country (Table A available as a supplement to the online version of this article at http://www.ajph.org). Using a combination of US Department of Agriculture Geospatial Data Gateway aerial imagery[6] and US Census Bureau census block boundaries[7], we digitized each marine harbor area and subsequently refined it to best represent the areas of interest.

Generally, we specified the footprint for each harbor area to include all areas of marine-related activity for the general waterway area; we did not limit it to the jurisdiction of the proximate Port Authority. We did this to (1) include all engines and equipment associated with harbor areas, regardless of whether the equipment was operated in association with a Port Authority facility or a nearby private



Note. AERMOD = American Meteorological Society–Environmental Protection Agency Regulatory Model; CMSA = consolidated metropolitan statistical area; DPM = diesel particulate matter. Income composition data were taken from the 2000 US Census.

FIGURE 1—Analysis overview.

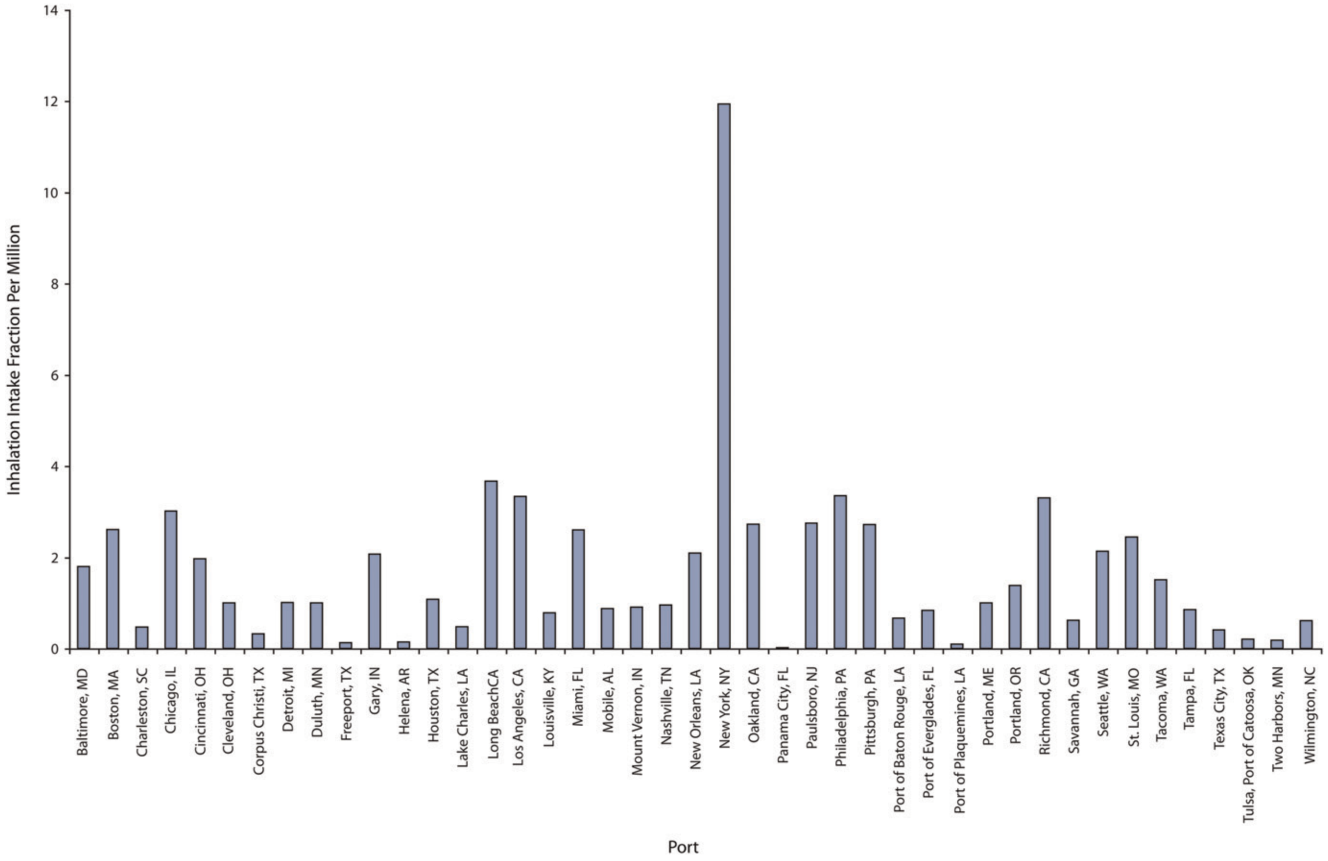
facility, and (2) ensure that the designated area for the air dispersion modeling was consistent with the activity data on which the emission estimates were based.

Emission Estimates

The Environmental Protection Agency (EPA) provided 2 data sets of port emissions[8,9]. Because all the emission sources included in this study were diesel powered, we took the fine particulate matter ($PM_{2.5}$) values to represent DPM. Some cargo-handling equipment is fueled by natural gas, but its contribution to particulate matter emissions is negligible compared with that of diesel-powered equipment.

The first data set included emissions from category 1 and category 2 engine-powered vessels (primarily harbor craft) by county for 2002. This file contained data on emissions of criteria and hazardous air pollutants, aggregated by county and source category code. From it, we extracted $PM_{2.5}$ values for counties that contained the ports of interest. We then scaled these values to 2005 emission levels by applying a growth factor of 1.046, derived from EPA emission projections for commercial marine diesel engines.[10] For all but 2 of the selected ports, we took harbor craft emissions from the EPA-provided data. For the Ports of Los Angeles and Long Beach, California, however, we used the harbor craft emission values from their published port-specific emission inventories.[11,12] The second data set provided by the EPA contained year 2005 emissions for category 3 engine-powered vessels (primarily ocean-going and deep-draft vessels) categorized by individual ports by mode of operation.

We derived port-specific $PM_{2.5}$ emissions from the truck, rail, and cargo handling equipment based on estimated activity following current port emission guidance.[13] We used the resulting emissions data for the 43 ports (Table A available as a supplement to the online version of this article at http://www.ajph.org.). In 4 of



Note. Income composition data were taken from the 2000 US Census.

FIGURE 2—Intake fractions of diesel particulate matter emissions from selected US ports.

the 43 cases, emission from the cargo handling equipment, truck, and rail sectors were aggregated.

We included in the modeling temporal variations in emission strengths. These variations were taken to be both seasonal and annual (SEASHR format), based on values from the Emissions Modeling System for Hazardous Air Pollutants (EMS-HAP),[14] in which they are disaggregated by source category codes.

Emission Source Characterization, Location, and Meteorology

Given the lack of specific information on the precise locations of the emission releases in many ports, we represented each of the ports as having 2 or more area sources, with vertices of each source determined by the digitized footprint of that harbor area. Emissions were uniformly distributed (horizontally) throughout the areas.

The assumption underlying the area source characterization is that emission releases are equally as likely to occur anywhere within the generalized boundary of the harbor area. Although this approach removes any bias associated with allocation of source locations, it likely does not represent the actual emissions sources well, which could be particularly true for the vessel categories; the location of their activity is largely limited to specific areas (often the edges) of the harbor complex. Although in principle this approach could lead to underestimation of emission densities and the corresponding affected areas by overstating the initial horizontal dispersion, sensitivity tests have suggested that, at least for medium-sized ports, the size of the predicted concentration isopleths are not very sensitive to the source characterization.

To incorporate vertical variation in emissions release, we simulated 2 area sources with the same horizontal layout but differing vertical locations. We derived emission release heights for individual source categories from those reported for the Ports of Los Angeles and Long Beach.[15] These values were aggregated on the basis of the median contribution to emissions from each source category. We determined the average initial vertical dimension by averaging the individual elements in quadrature, the method typical for standard deviations.

As a result, we assumed ocean-going and deep-draft vessel emissions to be released from an elevated area source at 50.0 meters above ground level and an initial vertical dimension of 23.0 meters. All other sources of DPM emissions, such as heavy-duty vehicles (trucks), locomotives, cargo handling equipment, and harbor craft showed much less variation in actual release height. Thus, we combined these sources into a single area source polygon with

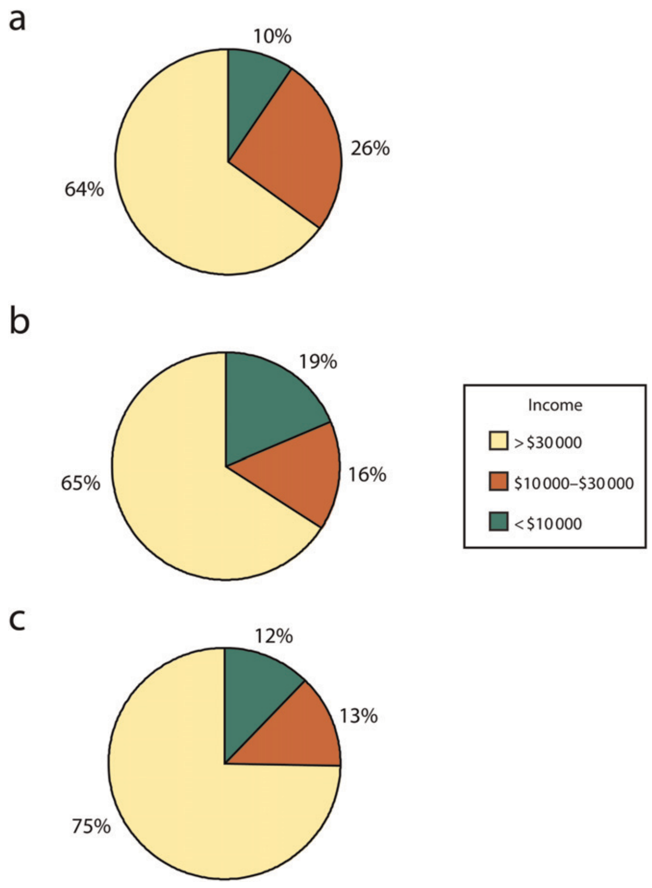


FIGURE 3—Income composition of aggregate households for year 1999 (a) across the United States (b) with diesel particulate matter cancer risk > 100 per million resulting from emissions from 43 selected US ports (c) with diesel particulate matter risk > 10 per million resulting from emissions from 43 selected US ports.

a release height of 4.4 meters and an initial vertical dimension of 2.1 meters.

We simulated each of the 43 harbor areas for 3 years using meteorological data processed with the AERMET (version 06341) preprocessor.[16] For each harbor area, we initially selected 3 surface stations from the National Oceanic and Atmospheric Administration–National Climatic Data Center database Quality Controlled Local Climatological Data and 2 upper air sites from the Forecast Systems Laboratory–National Climatic Data Center (now Global Systems Division) Radiosonde Data Archive on the basis of proximity. We then selected the data sets that were relatively complete for the 2004–2006 time period and that best represented conditions for the harbor area.

Exposure Factors

We derived exposure factors from ambient and exposure concentration estimates reported by the EPA for the National-Scale Air Toxics Assessment (NATA) for 2002.[17] For nonroad mobile source emissions, encompassing numerous categories of equipment and vehicles used outdoors in addition to those associated with port activities (i.e., pleasure craft, locomotives, aircraft, construction equipment, agricultural equipment, forestry equipment, and consumer equipment), the NATA estimated ambient concentrations in each census tract with the Assessment System for Population Exposure Nationwide (ASPEN) air dispersion model.[18] NATA estimated exposure concentrations with the Hazardous Air Pollutant Exposure Model (HAPEM5),[19] which is a probabilistic exposure model that simulates the movement of individuals among geographic locations (i.e., home and work) and microenvironments (e.g., outdoors, indoors at home, in vehicle). Because most people spend most of their time indoors, where particulate matter concentrations from outdoor sources are generally lower than corresponding outdoor concentrations, exposure estimates provided by HAPEM5 are more realistic than exposure assessment methods that assume people are continuously exposed to outdoor concentrations in the vicinity of their homes.

We calculated the exposure factors for each census tract in the vicinity of each harbor area as the ratio of the reported DPM exposure concentration to the ambient concentration for the nonroad mobile source emissions category. We applied each tract-specific exposure factor to each census block group lying within the tract. The median national exposure factor was 0.45, with 95% of the values ranging from 0.41 to 0.60.

Breathing Rates and Risk Factor

We derived an average population breathing rate from the EPA-recommended long-term gender- and age-specific breathing rates.[20] We combined them in a weighted average, using the age and gender composition of the 2000 US population as weights. The resultant population average breathing rate was 14.6 cubic meters per day.

We took a carcinogenic inhalation unit risk of 0.0003 microgram per cubic meter^{-1} for lifetime (70-year) exposure to DPM from California's OEHHA Toxicity Criteria Database.[4] This value was determined by the California Air Resources Board's DPM Scientific Review Panel to be a reasonable estimate.[21] In its *Health Assessment Document for Diesel Exhaust*,[22] the US EPA concluded that diesel exhaust is likely to be carcinogenic to humans at environmental exposure levels that the public faces, classifying it as a probable human carcinogen. However, the EPA has not quantified the risk.

Demographics

We derived population levels and demographic stratifications for each US census block group with carcinogenic health risks exceeding 10 per million and 100 per million from 2000 US Census data. The primary demographic categories of interest were income level and race/ethnicity.

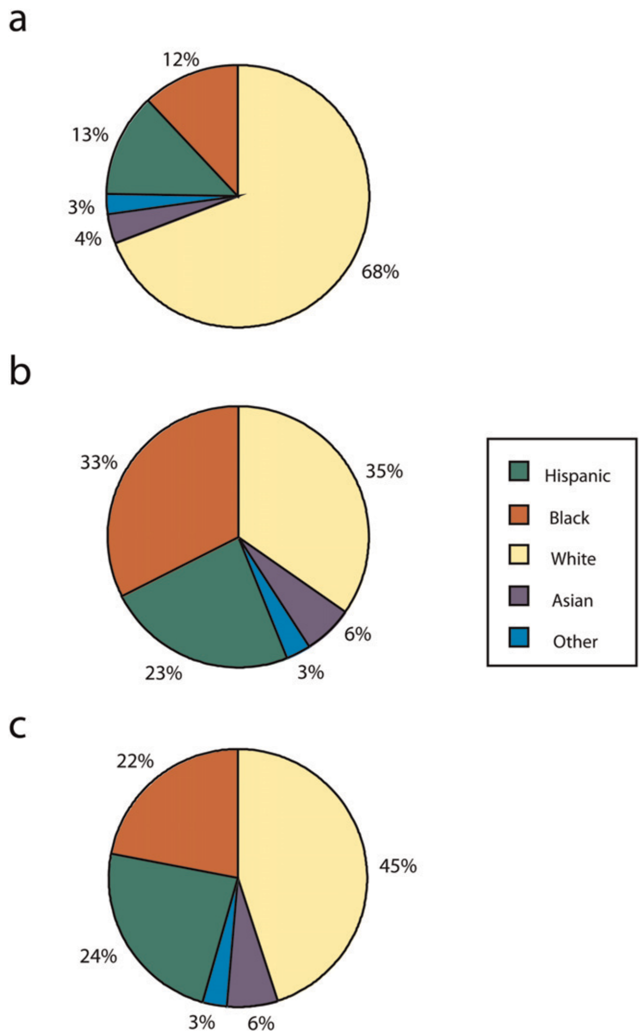


FIGURE 4—Racial/ethnic composition of year 2000 population (a) across the United States, (b) with diesel particulate matter cancer risk > 100 per million resulting from emissions from 43 selected US ports, and (c) with diesel particulate matter risk > 10 per million resulting from emissions from 43 selected US ports.

We calculated the number of households for the following year 1999 income groupings by combining census block group data from the indicated variables extracted from the 2000 US Census Summary File 3[23] (with census variable codes in parentheses): total households (P052001); less than $10 000 (P052002); $10 000 to $29 999 (P052003–P052006); and $30 000 or more (P052007–P052017).

We extracted these race/ethnicity variables from the census block group data in the 2000 US Census Summary File 3: total population (P007001); non-Hispanic White alone (P007003); non-Hispanic Black or African American alone (P007004); non-Hispanic American Indian or Alaska Native alone (P007005); non-Hispanic Asian alone (P007006); non-Hispanic Native Hawaiian or Pacific Islander alone (P007007); some other non-Hispanic race alone (P007008); 2 or more non-Hispanic races (P007009); and Hispanic or Latino (P007010).

RESULTS

We calculated intake fractions for each of the 43 selected ports (Figure 2). The results generally showed higher intake fractions for ports located in larger metropolitan areas because of their higher population density. With the exception of New York, New York, the intake fractions ranged from 0.02×10^{-6} to $3.66 \times 10^{-6.}$ The intake fraction for New York was about 12×10^{-6}. We also compared the income and racial/ethnic compositions of the aggregate populations exceeding risk thresholds to the composition of the overall US population (Figures 3 and 4). We also compared the populations exceeding risk thresholds at individual ports and the composition of the MSA or consolidated MSA (CMSA) in which the port is located (Tables B–E and pie charts, available as supplements to the online version of this article at http://www.ajph.org.)

Total Populations

The results suggest that more than 4 million people would be exposed to harbor-related annual average DPM concentrations that, according to the California OEHHA cancer potency estimate,[4] exceed a 100-per-million carcinogenic health risk if the exposure concentration were maintained for 70 years. Some double counting of populations that reside in the vicinity of more than 1 port (e.g., the Ports of Long Beach and Los Angeles, CA) may have occurred. However, almost half the population at risk resides in the vicinity of the New York harbor area (48%). Four marine harbor areas showed fewer than 50 exposures.

For the 10-per-million risk level, the corresponding population is more than 41 million. In this case, more than 60% of the exposures occur near 6 marine harbor areas: New York (28%); Houston, Texas (9%); Long Beach (8%); Los Angeles (6%); Miami, Florida (6%); and Philadelphia, Pennsylvania (5%).

Household Income Composition

The population analysis results suggest that, at the higher 100-per-million carcinogenic risk level, low-income households (i.e., 1999 income <$10 000) are overrepresented in the aggregate affected population compared with the overall US population by a factor of almost 2.

For the lower 10-per-million risk level, which covers a larger area, the difference is smaller. The proportion of low-income households in the affected population was about 20% higher than it was in the overall US population.

Many individual harbors showed even more pronounced overrepresentation of low-income households compared with their proportion of the MSA or CMSA population in which the harbor is located (Tables B-E and pie charts available as a supplement to the online version of this article at http://www.ajph.org). For example, for the 100-per-million risk level, the proportion of low-income households in the affected population is more than 5 times as high as the proportion in the overall MSA–CMSA population of Nashville, Tennessee, and Oakland, California; more than 4 times as high as that of Cincinnati, Ohio; and 3 times as high as that of Cleveland, Ohio, and Paulsboro, New Jersey.

Racial/Ethnic Composition

Both non-Hispanic Blacks and Hispanics were overrepresented in the aggregate affected population at both risk levels compared with the overall US population. Non-Hispanic Blacks made up a proportion of the affected population that was almost double their proportion of the overall US population for the 10-per-million risk level and almost 3 times as much as their proportion for the 100-per-million risk level. The corresponding values for Hispanics were approximately double their proportion of the US population for both risk levels.

Many individual harbors showed even more pronounced overrepresentation of non-Hispanic Blacks and Hispanics compared with their proportion of the MSA or CMSA population in which the harbor is located (Tables B-E and pie charts available as supplements to the online version of this article at http://www.ajph.org). For example, for the 100-per-million risk level, the proportion of non-Hispanic Blacks in the affected populations was more than 7 times as high as the proportion in the overall CMSA population of Oakland; almost 5 times as high as that of Gary, Indiana; and more than 4 times as high as that of Chicago, Illinois and Nashville. For the same risk level, the proportion of Hispanics in the affected populations was more than 6 times as high as the proportion in the overall CMSA population of Paulsboro and 5 times as high for Cleveland.

DISCUSSION

We applied the AERMOD dispersion model to estimates of emissions from marine sources, including category 1, 2, and 3 marine compression ignition engine activities at 43 marine harbor areas nationwide to estimate the incremental increase to ambient DPM concentrations from marine activities. We then used these estimates to evaluate and compare emission intake fractions among harbor areas and to assess the size and demographic composition of the proximate populations exposed to enhanced carcinogenic health risk.

The intake fraction analysis suggested that proximate population density is the most important factor, with New York harbor showing a value more than 3 times as high as any of the other 42 harbors. The population analysis suggests that more than 4 million Americans are exposed to DPM concentrations resulting from emissions from 43 selected marine harbor areas that pose a carcinogenic risk of more than 100 per million, according to the California OEHHA cancer potency estimate and assuming the exposure concentration is maintained for a 70-year lifetime. The corresponding estimate for the 10-per-million risk level is more than 41 million.

These estimates have several sources of uncertainty, including air dispersion modeling assumptions, population exposure modeling assumptions, and the many data elements we have discussed. The largest and most important uncertainty is the carcinogenic inhalation unit risk factor. Although the California Air Resources Board deemed the value used here to be a reasonable estimate, it also stated that the range based on human epidemiological studies spans a factor of approximately 18, ranging from 1.3×10^{-4} to 2.4×10^{-3} micrograms per cubic meter^{-1}. Although the EPA has concluded that DPM is a probable human carcinogen, it considered the available data too uncertain for quantification. Using a different risk factor would change the size of the estimated population subjected to the threshold risk levels used for this study. Alternatively, the risk thresholds could be recharacterized as representing different risk levels than those suggested here. For example, if the risk factor was half the value used here, the population estimated to be subject to a 100-per-million carcinogenic risk would have a revised risk of 50 per million.

Regardless of the true value of the threshold risk levels, the demographic analysis suggested that low-income households (<$10 000 in 1999), non-Hispanic Blacks, and Hispanics are overrepresented in the aggregate affected population compared with the overall US population, in some cases by a factor of 2 or 3. At some individual facilities, the overrepresentation of these populations is even more pronounced when compared with the population of the MSA or CMSA in which the harbor is located.

In March 2008, the EPA promulgated new emission standards for locomotives and marine compression ignition engines to help reduce the health risks we have highlighted. ■

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Contributors

A. Rosenbaum designed the air quality and health risk analyses and wrote the article. S. Hartley designed the air quality analysis, performed the air quality and health risk analyses, and wrote the article. C. Holder performed the health risk analysis.

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Note. Any opinions, findings, conclusions, or recommendations are those of the authors and do not necessarily reflect the views of ICF International or the US Environmental Protection Agency.

Human Participant Protection

No protocol approval was required because no human research participants were involved in this study.

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