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Assessment of Relative Exposure of Minority and Low-Income Groups to Outdoor Air Pollution

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ASSESSMENT OF RELATIVE EXPOSURE OF MINORITY AND LOW-INCOME GROUPS TO OUTDOOR AIR POLLUTION

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SUMMARY

This study examines potential exposure of minority or low-income populations to outdoor air pollution and compares concentrations of these populations in areas with elevated air pollution levels with those of nonminority or non-low-income populations. The analysis focuses on the National Ambient Air Quality Standards criteria pollutants and on air toxics, and it uses both ambient and emissions measures. Two major, multicounty metropolitan areas — Houston, Texas, and Detroit, Michigan — are employed to demonstrate the methodology. These two metropolitan areas differ in patterns of population distribution, degrees of residential segregation, types and distribution of industrial facilities, and climatic region of the country.

Air pollution exposure indices for Census tracts are calculated for each pollutant measure on the basis of hazard intensity, population distance to the hazard source, and percentage of the population group potentially exposed to the hazard. These indices are employed to examine levels of disproportionate exposure to air pollution for minority (African-American and Hispanic) and low-income populations. Disproportionate exposure is determined by comparing the minority or low-income population indices to the indices for White or non-low-income populations.

Similar patterns of disproportionate potential exposure and of disproportionate minority and low-income population concentrations in higher-pollution tracts are found in both metropolitan areas. Both minority and low-income populations also generally are underrepresented in the tracts with low levels of pollution. The consistency of these patterns between the two metropolitan areas is somewhat surprising, given the differences in population distribution and facility concentration between them. Specifically, minorities and low-income persons are much more concentrated in the core (Wayne) county in the Detroit metropolitan area than are the majority and non-low-income populations. Such overrepresentation of minorities and low-income persons is not found in Harris County, the core county of the Houston metropolitan area.

Patterns of disproportionate exposure differ slightly between the minority groups and metropolitan areas. The most consistent pattern of disproportionate exposures is for low-income populations in the two metropolitan areas. Hispanic exposures are more consistently disproportionate over the various indices than those of Blacks, especially in the Houston metropolitan area. Overall,

however, the similarities between the minority groups and metropolitan areas greatly outweigh the differences: For most pollution indices in both metropolitan areas, minorities and low-income populations are disproportionately at risk to air pollution exposure when compared with the nonminority and non-low-income populations.

1 INTRODUCTION

A diverse research effort, conducted by both federal agencies and scholars in academia, has addressed the issue of environmental justice. Recent environmental justice studies have generally focused on the demographics of areas close to hazardous waste facilities; landfills; Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) sites; and Superfund sites (e.g., GAO 1983; United Church of Christ 1987; Bullard 1990; Hird 1993; Zimmerman 1993; Anderton et al. 1994). Recent efforts at the federal and state levels to determine risk-related priorities in allocating resources for research and remediation have found that hazardous wastes present much lower health effect risks than air pollution does (EPA 1990a, California Comparative Risk Project 1994). Past research findings, funded in part by the U.S. Department of Energy (DOE), showed disproportionately high levels of substandard air quality exposure for minority and low-income populations (Wernette and Nieves 1992). This study is a continuation of that earlier research.

A major milestone in the development of the environmental justice issue occurred in February 1994, when President Clinton signed Executive Order 12898. The Order called for all federal agencies to make achieving environmental justice a part of their missions. DOE then developed and published a Departmental Environmental Justice Strategy (DOE 1995), as required by the Executive Order. This study complements the efforts undertaken pursuant to the DOE Strategy. Specifically, the methods and analytical techniques demonstrated in this study will facilitate the analyses of multiple and cumulative exposure required to implement the Executive Order and DOE Strategy.

This report examines the extents to which minority and low-income populations reside in areas with elevated air pollution levels, compared with nonminority and non-low-income populations. This examination is accomplished by analyzing residential demographic patterns and the distributions of various types of air pollutants in two major metropolitan areas: Houston, Texas, and Detroit, Michigan. Section 1.1 reviews previous research on this topic. Section 2 describes the geographic areas, data, and variables used in the study. The methods employed in the analysis of both population concentrations and relative exposures of population groups are described in Section 3. The fourth section presents the findings and discusses their significance. Section 5 of this report summarizes the major findings and compares them with those from previous research on the distribution of air quality.

1.1 OVERVIEW OF PREVIOUS AIR QUALITY DISTRIBUTION STUDIES

Over the past 25 years, both national and regional studies have examined the distribution of air pollution exposure among some racial and income groups that make up the U.S. population. Findings from these studies are summarized in Table 1. The spatial units of analysis range in size from metropolitan areas to Census block groups. Regardless of the spatial unit of analysis, the pollutants examined, or the geographical area, the findings of disproportionate exposure of minority and low-income populations are remarkably consistent.

Most of the studies use ambient concentrations of pollutants to represent exposure. However, of the five recent studies of air toxics, three used emissions and two used proximity to facilities as a proxy for exposure. Previous studies neither combined ambient and emissions measures nor included both criteria pollutants and air toxics.

Our earlier work (Wernette and Nieves 1992) examined air quality status and demographics for all counties in the contiguous 48 states. Subgroup percentages were compared for populations residing in areas designated as being in attainment or nonattainment status relative to the National Ambient Air Quality Standards (NAAQS) for five criteria pollutants: particulate matter, carbon monoxide, ozone, sulfur dioxide, and lead. The investigation found that Blacks and Hispanics were likely to benefit the most from improvements in air quality mandated by the 1990 Clean Air Act Amendments. These groups were most likely to benefit because they were exposed to the worst air quality conditions of the population groups.

Percentages of both Blacks and Hispanics living in nonattainment areas were found to be higher than percentages of Whites for four of the five pollutants. Concentrations of both the minority populations and the pollutants were found to vary substantially in different regions of the country. To determine if the national-level findings were merely a result of such regional patterns, minority percentages were compared with White percentages in nonattainment areas in each region. The minority percentage exceeded that for Whites in three-quarters of the comparisons covering five pollutants and four regions. In short, the study showed a pervasive pattern of disproportionate concentrations of minority groups in nonattainment counties, at both the national and regional levels.

The study also found that low-income populations resided in nonattainment counties in greater proportions than nonpoor populations but in lower proportions than minority populations. Comparisons of minority and White percentages for counties that were in nonattainment status for two or more NAAQS showed that minorities were overrepresented, when compared with Whites, in counties that were in nonattainment status for multiple (two, three, or four or more) air pollutants. The study also examined urban-rural differences in the numbers of facilities per county producing air pollution. Findings based on facility location were consistent with those based on ambient air quality. Facilities tend to be concentrated in urban areas with above-average concentrations of minority populations.

TABLE 1 Summary of Previous Study Findings Regarding Air Pollution Exposure Levels of Minority and Low-Income Populations

Source	Date	Pollutant	Geographic Area (unit of analysis)	Findings
Lave & Seskin	1970	Particulates	114 metropolitan areas	Death rate increases with particulate level and with % non-White and % poor
Burch	1971	CO, NO_x, hydrocarbons	New Haven, CT (block groups)	% of Whites with high exposure exceeds % of Blacks for CO and hydrocarbons; % of Blacks is higher for NO_x; low income is clearly associated with higher exposure
Freeman	1972	Particulates, sulfates	Washington, DC, St. Louis, and Kansas City (tract)	Exposure is greater for average Black family than average poor family
Zupan	1973	Particulates, SO_2	New York City area (county)	Low-income population % increases with pollution levels
Kruvant	1975	CO, hydrocarbons, NO_x, SO_2, particulates, ozone	Washington, DC (tract)	Poor and Blacks are most likely to be exposed
McCaull	1976	CO, SO_2, hydrocarbons, particulates	Washington, DC (tract)	Chances of being exposed to pollutants are greatest for poor and for Blacks
Asch & Seneca	1978	Particulates, NO_2, SO_2	284 cities in 23 states (city)	Exposure is higher for low-income groups; particulate exposure is higher for low-income, non-White, and aged groups
			Chicago, Cleveland, and Nashville (tract)	Higher-income families are greater % of population in less polluted tracts; poor are overrepresented in most-polluted tracts and underrepresented in least-polluted tracts
Gelobter	1989	Particulates, sulfates, SO_2, NO_x, ozone, CO	National (county)	Minorities are disproportionately exposed to combination of pollutants; disparity in exposure of poor increased in early 1980s

TABLE 1 (Cont.)

Source	Date	Pollutant	Geographic Area (unit of analysis)	Findings
Brajer & Hall	1992	Ozone, particulates	California South Coast Air Basin (31 districts)	Income levels are negatively related to ozone exposure levels; Blacks and Hispanics have higher levels of exposure to ozone, possibly because of more time spent outdoors; PM10 results are generally consistent with those for ozone
Wernette & Nieves	1992	Ozone, SO_2 particulates, proximity to air polluting facilities	National (county)	Disproportionately higher %'s of Blacks and Hispanics are in nonattainment areas; exposure level of low-income group is less than that of Blacks and Hispanics; locations of air polluting facilities are disproportionately associated with minority concentrations
Burke	1993	Proximity to TRI facilities	Los Angeles County (tract)	Number of facilities per tract increases with increasing minority % of population and with decreasing income; Hispanics are most disproportionately exposed
Szasz et al.	1993	TRI emission quantities	Los Angeles (tract)	Proximity is greater for minorities and low-income groups
Pease & Morello-Frosch	1995	Toxic emissions from point and area sources	San Francisco Bay area (tract, zip code)	Equity of exposure distribution varies, with point sources being more inequitable than smaller area sources; point sources disproportionately expose minorities and the poor
Perlin et al.	1995	TRI listed chemicals	National (county)	Emissions are greater in higher-income counties; exposure levels of Blacks, Hispanics, Asians, and other race populations are disproportionately high
Pollock	1995	Proximity to TRI facilities	Florida (block groups)	Proximity is greater for minorities, especially Blacks; low-income Whites are as proximate as total population mean; Hispanics reside closer, Blacks much closer

1.2 PURPOSE AND SCOPE OF STUDY

This study has both substantive and methodological purposes. Substantively, it focuses on determining whether the patterns of disproportionate potential exposures to diminished air quality of minorities when compared with nonminorities, which were found at the county level, also exist at a subcounty level. To accomplish this, two metropolitan areas that differ in population density, level of residential segregation, and region of the country were chosen for study. The study compares the potential air pollution exposure of population groups in these two metropolitan areas in order to answer two distinct questions: (1) Do different minorities, with different levels of residential segregation, experience different degrees of potential air pollution exposure, or are their experiences in this regard more similar than different? (2) Are the disproportionate exposures of groups related to regional factors, or are they fairly constant across regions?

The methodological purposes of the study are twofold. One purpose is to develop and test a method of using available air quality data to screen for differences in population exposures among spatial areas. The second concerns the extent to which findings of disproportionate exposure depend on the exposure measures employed (e.g., ambient concentrations versus emissions). To measure potential exposure, an index is constructed that incorporates hazard intensity, distance of the population from the hazard source, and percentage of the population potentially exposed to the hazard. The index is employed with two qualitatively different measures of hazard exposure: air pollution emissions and ambient concentrations of air pollutants. Within this analysis, findings for emissions and air quality measures for "criteria" pollutants are compared with those for toxic pollutants. For substantive purposes, findings are compared between population groups and between the two metropolitan areas. For methodological purposes, comparisons are made between pollutant categories and between the ambient and emissions measures of hazard exposure.

2 STUDY AREAS, DATA, AND VARIABLES

Because violations of air quality standards occur more commonly in urban than rural counties, metropolitan areas were chosen for study. Within metropolitan areas, this study uses Census tracts as the spatial unit of analysis to reflect conditions at a "neighborhood" level. Since conducting the analysis at this level of geographic resolution required substantial data development, budget limitations dictated restriction of the study to two metropolitan areas. Analytical and data issues, including the basis for selecting Detroit and Houston, the definitions of population groups, and the measures of pollution levels, are discussed in this section.

2.1 SELECTION OF METROPOLITAN AREAS

The selection of the metropolitan areas was undertaken with several criteria in mind. It was considered important to examine the distribution of air pollution exposure among racial/ethnic and income groups in cities where it had not been previously analyzed. Priority was given to cities that have substantial minority populations and that are located in different regions of the country with different economic bases. Of the top 10 metropolitan areas ranked by total minority population, Dallas, Detroit, Houston, Miami, Philadelphia, and San Francisco had not been previously studied with regard to issues related to air quality distribution. Detroit and Houston were selected because they had the lowest air quality (in terms of criteria pollutant measures in 1989) of the cities in this group. Air quality has been improving in both cities, however. By 1992, Detroit met all of the NAAQS, and Houston met all but the standard for ozone. There are no national standards for exposure to air toxics.

The Detroit and Houston study areas are specified by their respective Primary Metropolitan Statistical Areas (PMSAs),[1] as defined by the U.S. Bureau of the Census. For Detroit, the core county is Wayne, and the additional PMSA counties are Lapeer, Macomb, Monroe, Oakland, and St. Clair. Harris is the core county in Houston, and the other counties are Chambers, Fort Bend, Liberty, Montgomery, and Waller. We chose PMSAs as the geographical area of analysis because of their strong internal economic links, which include labor markets, residential markets, and associated commuting patterns.

The minority populations in these two PMSAs tend to be concentrated in the core counties: Harris County, Texas, and Wayne County, Michigan. Given the high between-county differences in residential concentrations of population groups in these two metropolitan areas, including only

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1 "If an area that qualifies as an Metropolitan Area has more than one million persons, primary metropolitan statistical areas (PMSAs) may be defined within it. PMSAs consist of a large urbanized county or cluster of counties that demonstrates very strong internal economic and social links, in addition to close ties to other portions of the larger area" (U.S. Department of Commerce 1992).

these two core counties in the analysis would potentially bias the findings by excluding large portions of the White population from the geographical area analyzed. Consequently, all of the counties that make up the PMSAs were included in the study area.

Both of these PMSAs are part of larger Consolidated Metropolitan Statistical Areas, which include other PMSAs. In our judgment, expanding the study areas to include those other PMSAs would diminish the focus of the study. There are no assurances, of course, that the air pollution emissions studied affect only individuals within the two PMSAs evaluated and not individuals in adjacent PMSAs. For the study purposes, however, PMSAs appear to best represent contiguous geographic areas that function as regional economic units.

2.2 DEFINITION OF STUDY GROUPS

The study focuses on the three largest racial/ethnic groups in each metropolitan area — Whites, Blacks/African-Americans, and Hispanics — and on low-income populations. We use two reference groups: Whites for the racial/ethnic group comparisons and individuals with above-poverty-level incomes for the income group comparison. The population data were taken from the 1990 population census, as compiled in Landview II,[2] and data on populations with below-poverty-line incomes were added from U.S. Bureau of the Census STF 3A database.

All racial and ethnic characteristics in the 1990 census are based on respondents' self-identifications. They were to choose from the categories of White, Black or African-American, Asian or Pacific Islander, Eskimo or Native American, or Other race. In addition, respondents were asked whether they were of Hispanic ethnicity. Since Hispanics may be of any race, the Hispanic category is not comparable to the White or African-American racial designations. This situation has the consequence of reducing any differences in exposures found by comparing Whites and the two minority groups, Hispanics and Blacks, since some Hispanics are also counted in the White and Black groups. This effect would likely be most pronounced in the comparisons for Houston, where approximately 15% of all Whites identify themselves as being of Hispanic ethnicity. Subtracting these White Hispanics from the larger White population would likely reduce the White exposure indices and thus increase the magnitude of the White/Hispanic and White/Black differences. This inaccuracy could be corrected by using more refined Census data, but it was not done in this study because the focus was not on developing precise estimates but on testing the methodology.

Data on the low-income population (or population below the poverty line) are based on the definitions employed by the U.S. Bureau of the Census. Poverty status is determined by comparing

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[2] This information system software with mapping capability was developed by the U.S. Environmental Protection Agency (EPA), U.S. Bureau of the Census, and National Oceanic and Atmospheric Administration. It is available from the Bureau of the Census. It incorporates data on demographic, economic, and physical features with data on environmental pollution.

family or household 1989 income to thresholds based on family size, age of householder, and number of related children under 18 present in the household. The threshold for a family of four was 1989 income below $14,990 (U.S. Department of Commerce 1992).

2.3 CHOICE OF AIR POLLUTION EXPOSURE MEASURES

The most accurate method of measuring an individual's exposure to air pollutants is to equip the person with an individual monitor. Studies employing this method have shown that total exposure is determined more by indoor than outdoor air quality (Sexton and Ryan 1988). However, outdoor air quality directly affects indoor air quality, in that stable gaseous and fine particle pollutants enter buildings with little loss in concentration (Cupitt et al. 1995). Still, outdoor air quality measures taken at a limited number of locations can only provide a crude indicator of individual exposures. Indoor concentrations of various pollutants may be either substantially higher (due to the contribution of indoor sources) or lower than outdoor concentrations.

Given the cost and the difficulty of conducting a study that makes use of personal monitoring, proximity-weighted measures of both ambient air quality and pollutant emissions from major point sources are used as a proxy for outdoor exposure. The air quality and the facility emission categories of measures provide some cross validation, in that both include NAAQS "criteria" pollutants and selected air toxics. The measures employed are categorized in Table 2.

The distance from the geographic centroid of each Census tract to each of the monitors or facilities was calculated for use as a weighting factor. In effect, the degree to which air quality or emissions data are treated as representing conditions in a given Census tract depends on the proximity of the monitor or facility to that tract. Data sources and issues are discussed below.

2.3.1 Ambient Air Quality

State environmental protection agencies collect data on concentrations of various pollutants in ambient air at monitoring installations that are generally located in the areas that have been found to have the worst air quality. The pollutant monitors tend to be concentrated in urban centers or located downwind from major point sources of emissions, except for those intended for background measurements. In contrast, ozone monitors are more dispersed throughout metropolitan areas, since ozone formation affects broader areas. Overall, the air quality monitoring data represent some locations where air quality problems have been experienced in the past or where they could reasonably be expected to occur. However, the spatial coverage of the monitoring system is relatively sparse, and values for locations between monitoring installations can only be interpolated. Houston has roughly the same number of monitoring installations as Detroit but is a third larger in area.

TABLE 2 Air Pollution Exposure Measures Employed

	Concentration in Ambient Air		Emission from Facility	
Category of Substance	Pollutant	Data Source[a]	Pollutant	Data Source[a]
Criteria pollutants	Carbon monoxide	AIRS	Carbon monoxide	AFS
	Ozone	AIRS	Nitrogen dioxide	AFS
	Fine particulates	AIRS	Fine particulates	AFS
	Sulfur dioxide-annual	AIRS	Sulfur dioxide	AFS
	Sulfur dioxide-24 hour	AIRS		
Air toxics	Beryllium	AIRS	Volatile organic compounds	AFS
	Copper	AIRS	Benzene	TRI
			1,3-butadiene	TRI
			Methylene chloride	TRI
			Toluene	TRI
			1,1,1-trichloroethane	TRI

[a] EPA, AIRS = Aerometric Information Retrieval System, 1992; AFS = AIRS Facility System (i.e., AIRS Facility Database), 1992; TRI = Toxic Release Inventory, 1992.

2.3.1.1 Criteria Pollutants

The NAAQS specify maximum allowable levels of six air pollutants, collectively referred to as the "criteria" pollutants: ozone, lead, nitrogen dioxide, sulfur dioxide, carbon monoxide, and fine particulates (with a diameter of less than 10 microns). These substances have been selected for regulation because of their potentially negative impacts on human health. Monitoring data are used as the basis for determining compliance with the NAAQS. The standards for each of these pollutants are listed in Table 3.

Data for 1992 from the EPA's Aerometric Information Retrieval System (AIRS) are employed in this analysis for five measures, pertaining to four of the six criteria pollutants. The rest of the pollutant measures collected by the air quality monitoring system were omitted from the analysis because of data limitations. Locations of the monitoring installations within the core county and the larger metropolitan area are shown for Detroit in Figure 1 and Houston in Figure 2. The measures employed and the data ranges for the Detroit and Houston metropolitan area monitors are listed in Table 4. The upper ends of all of these ranges are within the limits of the NAAQS listed in Table 2, except for ozone in levels in Houston. The Detroit area was not in violation of any of the standards in 1992, although there had been violations previously. These ranges represent a substantial improvement in air quality in both areas during the past decade.

TABLE 3 Summary of National Ambient Air Quality Standards

Pollutant	Primary Standard
Particulates (PM10)	Annual arithmetic mean not to exceed 50 μg/m^3 Second-highest 24-hour average not to exceed 150 μg/m^3
Sulfur dioxide (SO_2)	Annual arithmetic mean not to exceed 80 μg/m^3 (0.03 ppm) Second-highest 24-hour average not to exceed 365 μg/m^3 (0.14 ppm)
Carbon monoxide (CO)	Second-highest 8-hour average not to exceed 9 ppm (10 mg/m^3) Second-highest 1-hour average not to exceed 35 ppm (40 mg/m^3)
Nitrogen dioxide (NO_2)	Annual arithmetic mean not to exceed 0.053 ppm (100 μg/m^3)
Ozone (O_3)	Maximum 1-hour average not to exceed 0.12 ppm (235 μg/m^3) on more than 1 day annually
Lead (Pb)	Maximum quarterly average not to exceed 1.5 μg/m^3

Source: EPA (1991a).

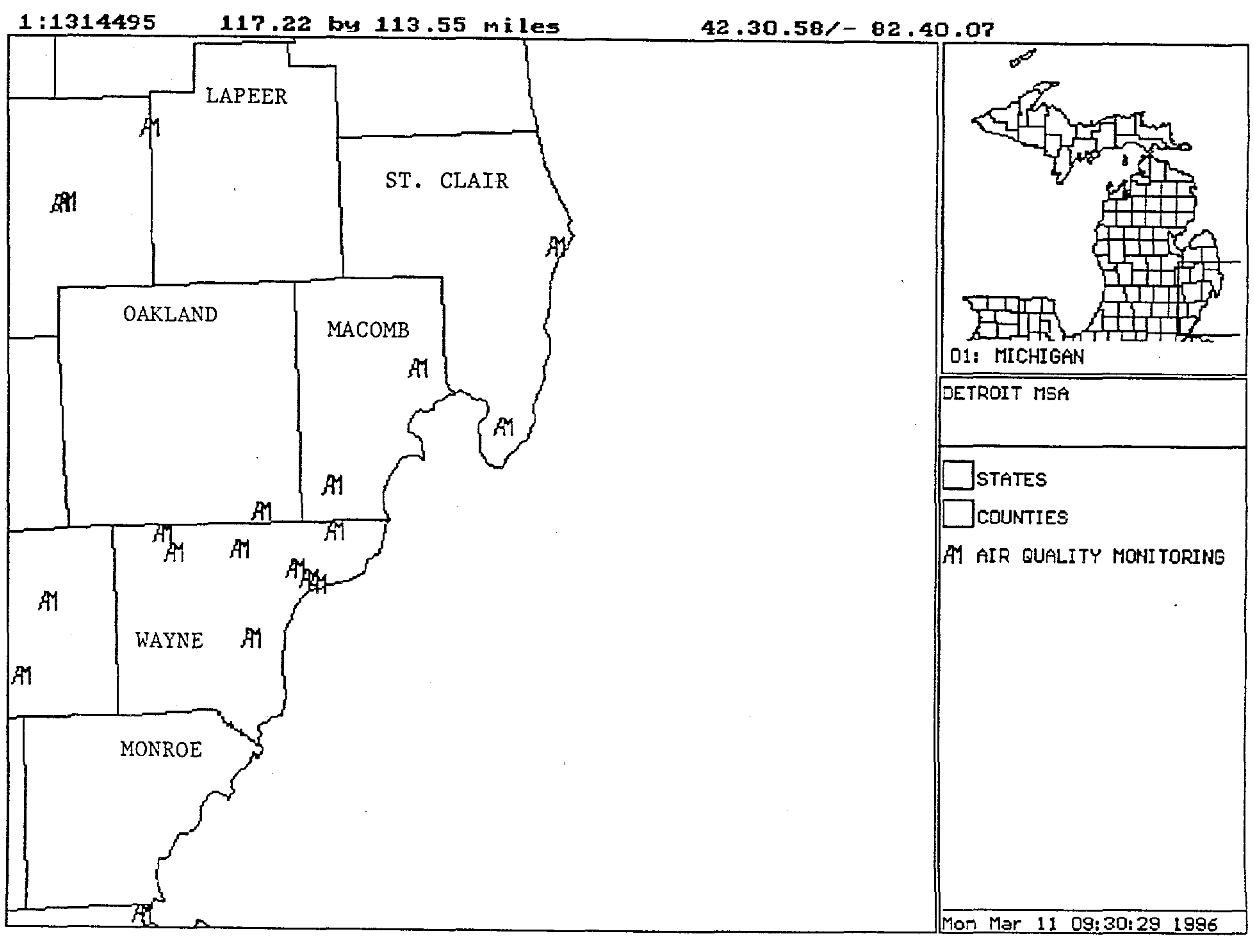


FIGURE 1 Locations of Criteria Pollutant Monitoring Stations in the Detroit Metropolitan Area

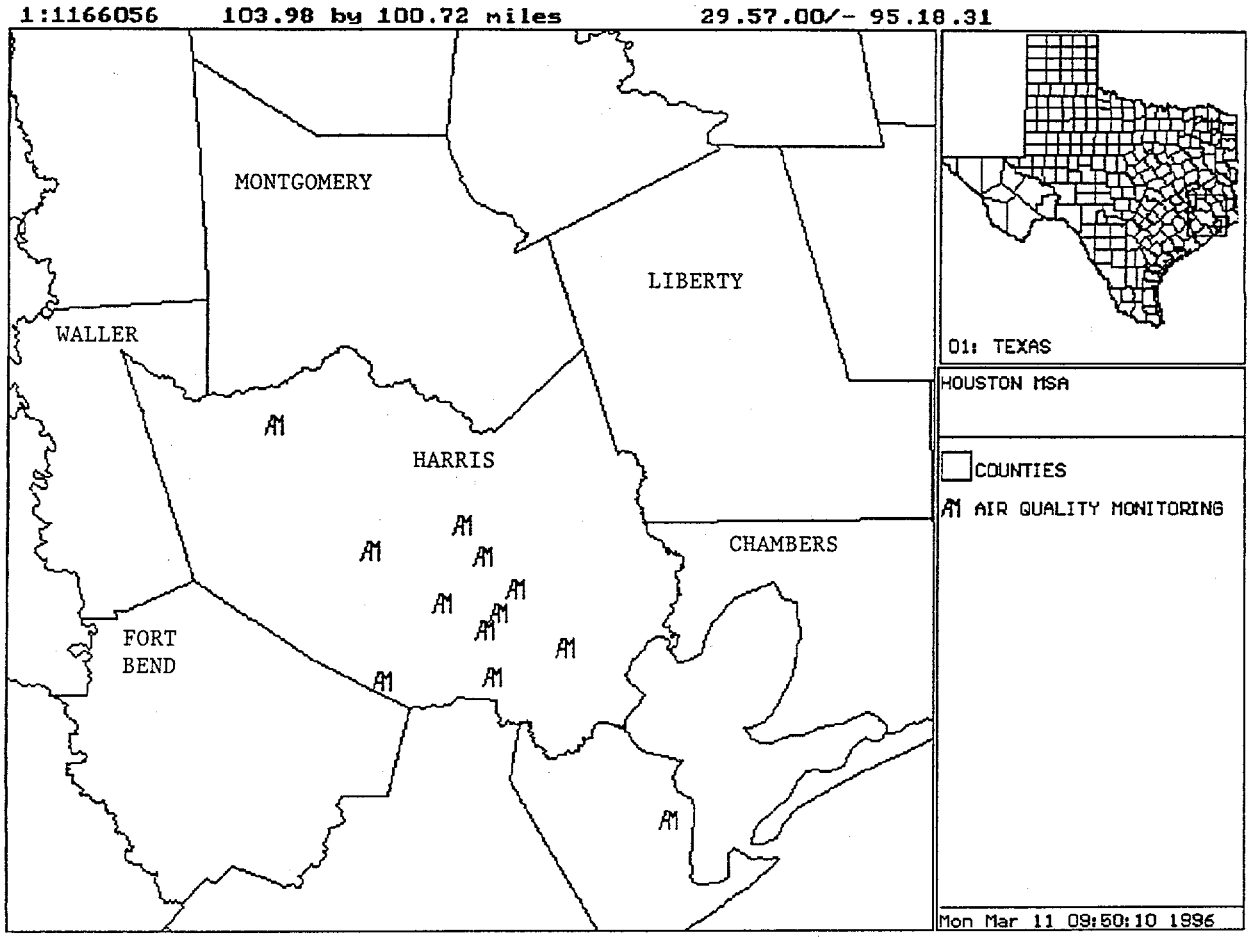


FIGURE 2 Locations of Criteria Pollutant Monitoring Stations in the Houston Metropolitan Area

2.3.1.2 Air Toxics

Data for some of the 189 substances designated as hazardous air pollutants (also referred to as air toxics) under the Clean Air Act Amendments of 1990 are also collected as part of the air quality monitoring system. Only a limited number of substances are monitored, however, and there are fewer monitors for them than for the criteria pollutants. Data ranges and numbers of monitors for the air toxic measures are listed in Table 4. Locations of the monitors are displayed in Figure 3 for Detroit and Figure 4 for Houston. Data for some monitors that are located outside the metropolitan area boundaries are included in the analysis because they are closer to some Census tracts than monitors within the metropolitan counties. The data are taken from the AIRS Quick Look File for 1990.

For hazardous air pollutants, the data coverage in the Detroit and Houston areas was most complete for beryllium and copper. These measures were included in the analysis primarily on the basis of data availability and only secondarily on the basis of their health risk, since there are other

TABLE 4 Air Pollution Measures and Data Ranges for the Detroit and Houston Primary Metropolitan Statistical Areas from 1992 AIRS

		Detroit		Houston	
Category of Substance	Air Pollution Measure	Range	No. of Monitors	Range	No. of Monitors
Criteria pollutants	COMAX8 — Second-highest 8-hour average of carbon monoxide (ppm)	3-5	10	2-8	6
	OZONEMAX — Second-highest daily 1-hour average of ozone (ppm)	0.06-0.12	20	0.1-0.2	16
	PM10MAX — Second-highest 24-hour average of particulates ($\mu g/m^3$)	40-73	5	52-102	7
	$SO_2$24HR — Second-highest 24-hour average of sulfur dioxide ($\mu g/m^3$)	36-110	11	28-118	11
	SO_2ANN — Annual arithmetic mean of sulfur dioxide ($\mu g/m^3$)	12.9-20.7	7	4.2-18.6	11
Air toxics	BERYLLIUM — Second-highest (ng/m^3)	0.1-2.25	11	0.15-0.38	3
	COPPER — Second-highest ($\mu g/m^3$)	17.43-22.25	5	16.5- 39.85	3

toxic substances present in the outdoor air in concentrations that pose more of a risk. Beryllium is a carcinogen, and inhalation of both beryllium and copper has been linked to respiratory system disorders in workers exposed at much higher concentrations than those found in outdoor air (EPA 1990b).

There are no federal standards for airborne toxics that are directly comparable to the NAAQS for criteria pollutants. Ambient concentrations of both beryllium and copper are substantially lower than the limits on occupational exposure. The beryllium concentration in Detroit appears to be lower than the limit specified in the Michigan state guidelines (0.0004 $\mu g/m^3$ averaged over a year).[3] Michigan does not have a standard for copper. In Houston, the copper concentrations appear to exceed the Texas guideline for 30-minute samples (1 $\mu g/m^3$). Whether they also exceed the guideline for annual copper concentration (0.1 $\mu g/m^3$) cannot be determined from this data summary.

[3] Information from a National Air Toxics Information Clearinghouse database of state guidelines.

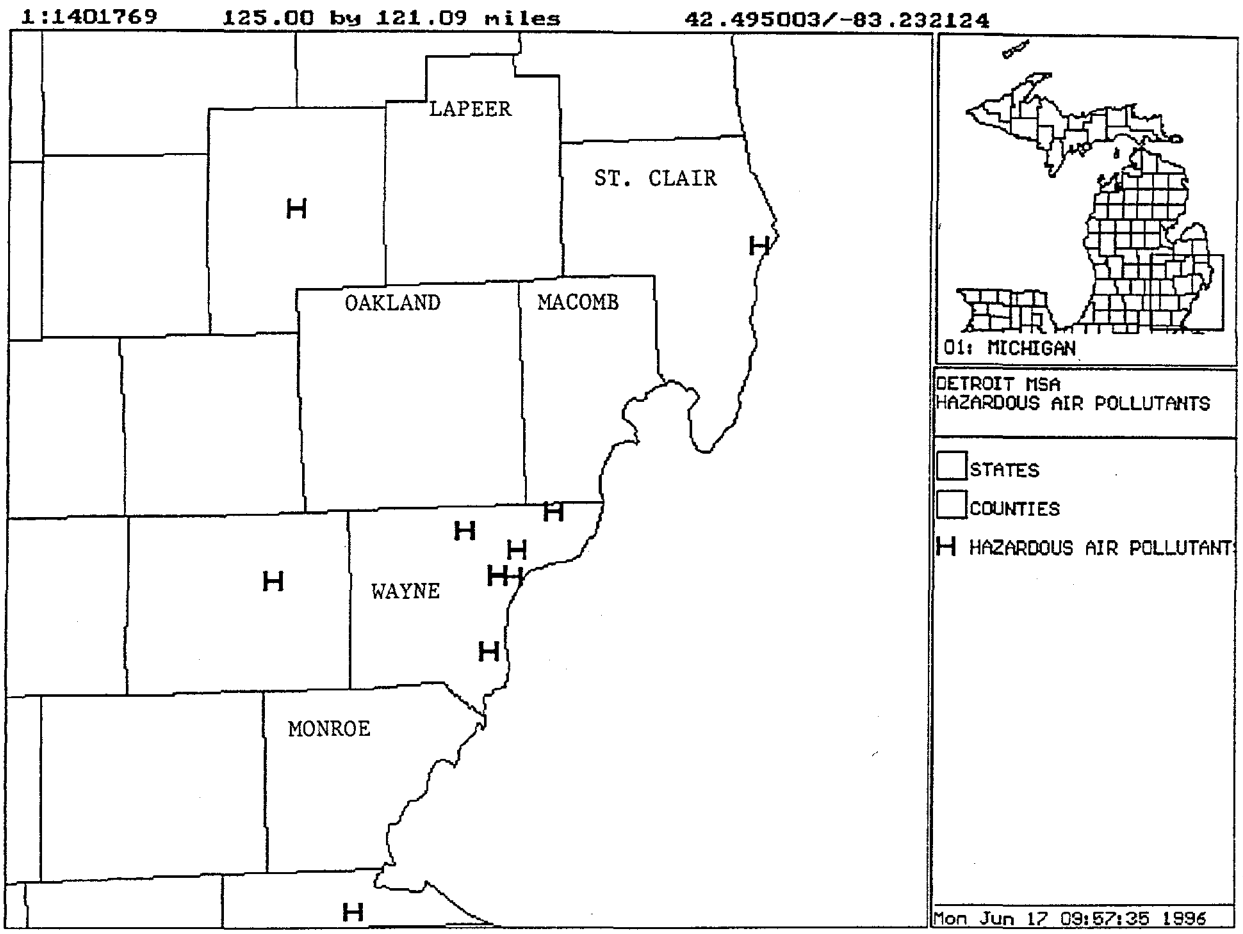


FIGURE 3 Locations of Hazardous Air Pollutant Monitoring Stations in the Detroit Metropolitan Area

2.3.2 Air Pollutant Emissions from Facilities

Data for criteria and toxic emissions from large point sources of air pollution are also used in this analysis to supplement the ambient air quality measures. These data are of two major types: data for precursor emissions related to ambient concentrations of criteria pollutants and data for toxic emissions. The criteria-pollutant-related data are from the AIRS Facilities Database, and the toxic emissions data are from the Toxic Release Inventory, both of which are discussed below. The analysis includes facilities that are located in both the study area and the contiguous counties. Facilities in the contiguous counties are included because many of them are closer to the study area Census tracts than any facilities within the study area itself.

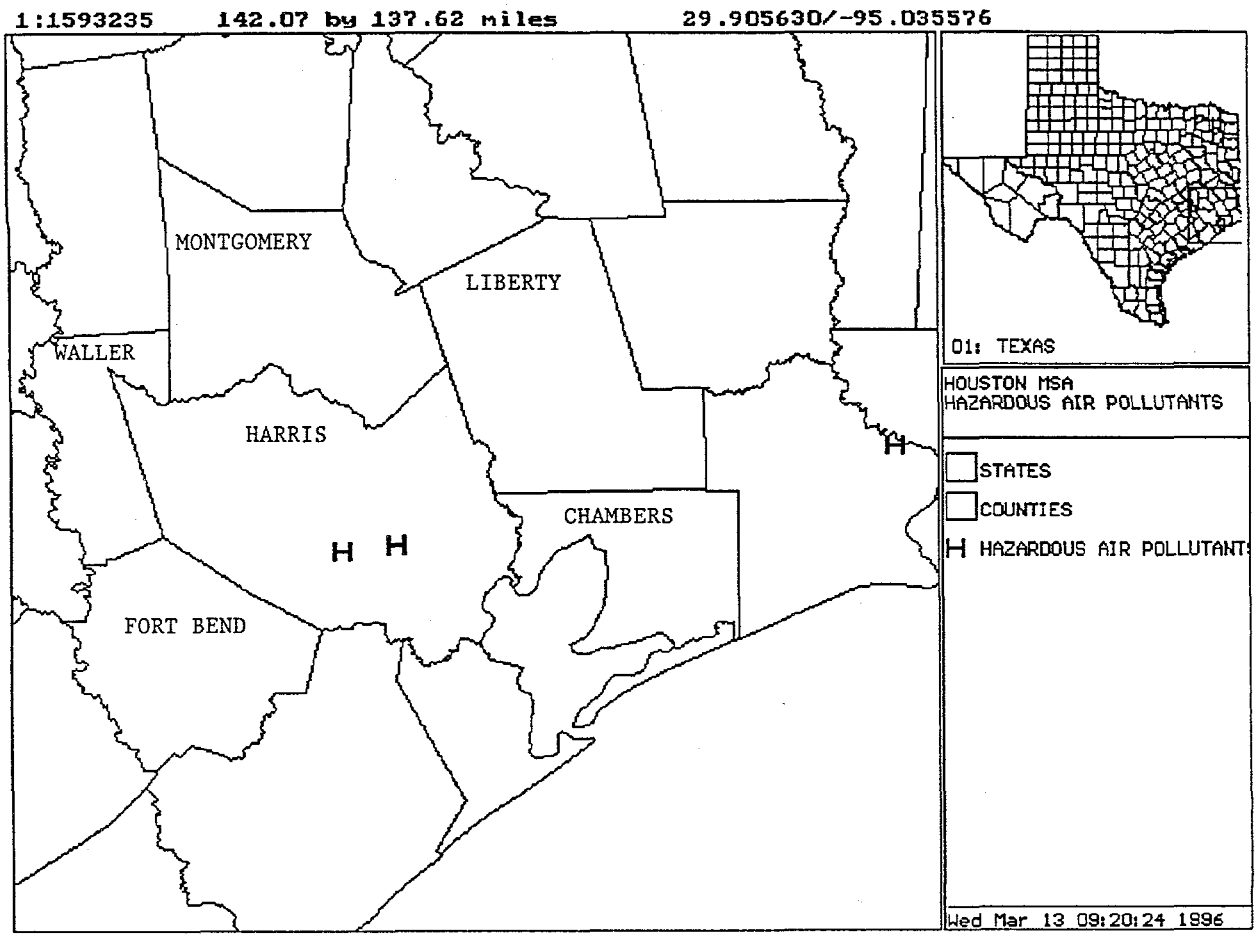


FIGURE 4 Locations of Hazardous Air Pollutant Monitoring Stations in the Houston Metropolitan Area

2.3.2.1 AIRS Facility Database

Data for manufacturing facilities with emissions of one ton or more annually of carbon monoxide, nitrogen dioxide, fine particulates, sulfur dioxide, or volatile organic compounds are taken from the EPA's AIRS Facility Database. Most of the data are for 1990, but some records are for 1985. Lead emissions are also covered by this database, but were omitted from the analysis because lead emissions were reported by such a small number of facilities. Emissions from manufacturing facilities contribute to ambient levels of the criteria pollutants but are not the only source of pollution (for some pollutants, they are not even the dominant source). Emissions from industrial processes range from 5% to more than 40% of total emissions, depending on the pollutant category (EPA 1991b). The transportation, utility, commercial, residential, and agricultural sectors and natural sources also contribute substantially to ambient concentrations of pollutants.

Table 5 lists the total emissions (tons) of each of the pollutants studied and the number of facilities in each metropolitan area and core county reporting these emissions. Locations of these facilities within the core and metropolitan area counties are shown in Figures 5 and 6 for Detroit and 7 and 8 for Houston. The category of pollutants referred to as volatile organic compounds comprises a wide range of substances, not all of which are threats to human health. This category includes the five toxic substances for which emissions are analyzed separately in this study (benzene, 1,3-butadiene, methylene chloride, 1,1,1-trichloroethane, and toluene). Total emissions of each pollutant are substantially greater in Houston than in Detroit, but the quantity emitted per individual source is considerably lower. Since the Houston area is only a third larger than the Detroit metropolitan area, both emissions and numbers of facilities per square mile are considerably greater in Houston. The data coverage for Detroit, and especially for Wayne County, appears to be incomplete, however, in that there are many facilities listed in the database for which no emissions are reported in 1990. An additional difference between the pattern of emission source locations in the two metropolitan areas is worthy of note: sources of each of the five criteria pollutants are much more concentrated in the core county (Harris) in Houston than they are in the core county (Wayne) in Detroit.

TABLE 5 Total Emissions and Numbers of Major Emissions Source Facilities[a] in the Detroit and Houston Primary Metropolitan Statistical Areas, by Pollutant, from 1992 AIRS

	Detroit			Houston		
		No. of Facilities			No. of Facilities	
Pollutant Type	Weight (tons)	Entire PMSA	Wayne County	Weight (tons)	Entire PMSA	Harris County
Carbon monoxide	13,410	56	12	131,785	225	106
Nitrogen dioxide	177,190	58	14	317,529	263	128
Particulates (PM10)	3,550	18	0	6,656	93	47
Sulfur dioxide	193,383	50	12	202,463	110	56
Volatile organic compounds	45,939	72	10	233,830	413	209

[a] Facilities with emissions of at least 1 ton/yr.

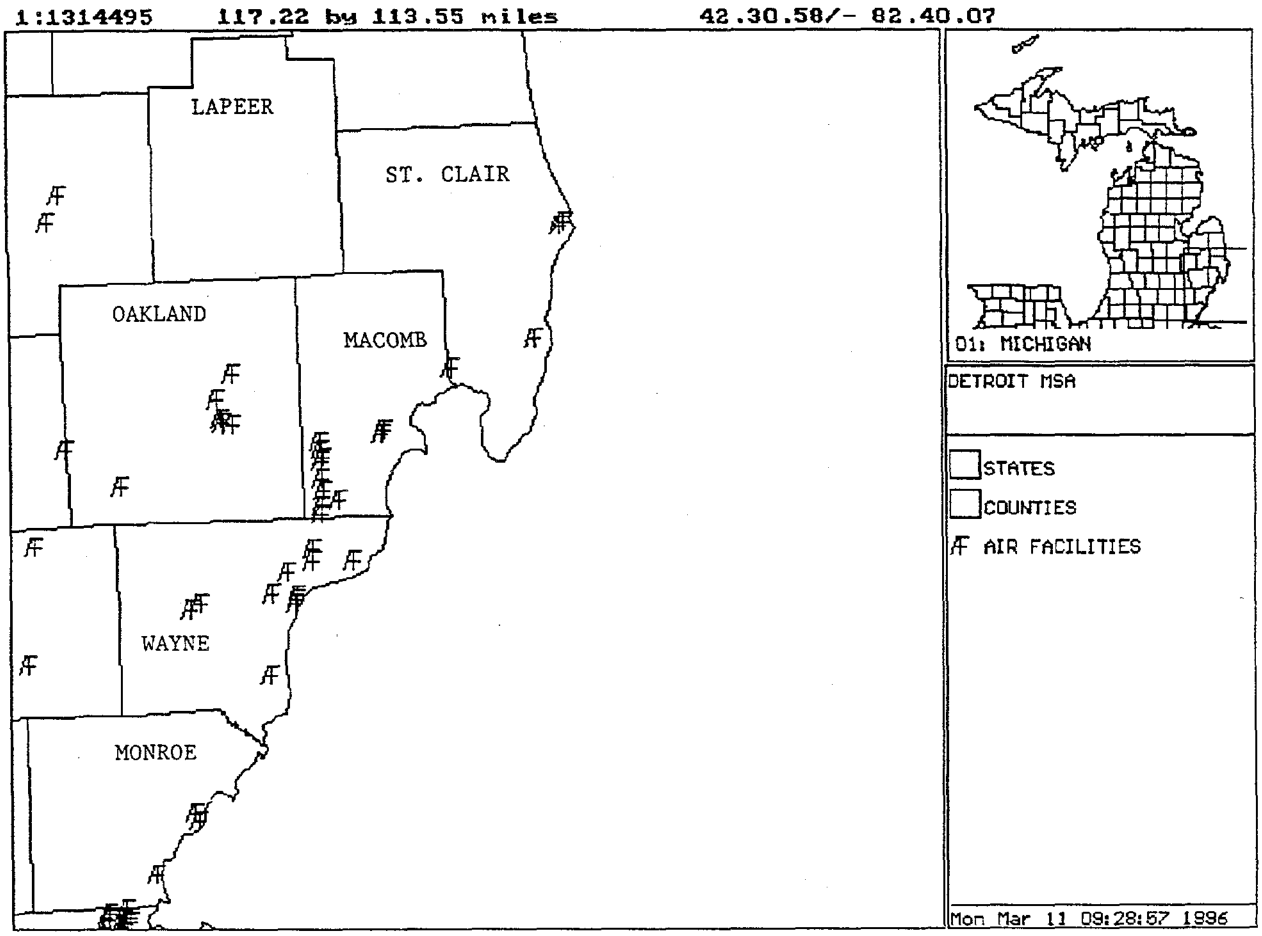


FIGURE 5 Locations of AIRS Facility Database Sites in the Detroit Metropolitan Area

2.3.2.2 Toxic Release Inventory

Five toxic substances were selected for study on the basis of their relatively high toxicity, high carcinogenic potency, or both. The relatively large quantities released and large numbers of emitting facilities in both study regions were also selection criteria. On the basis of their toxicity and volume, all of these substances except 1,3-butadiene have been designated by the EPA as priorities for emission reduction. These toxic emission measures provide a much clearer indication of health threat than the broader category of volatile organic compound emissions reported by the AIRS Facilities Database. The numbers of reporting facilities in the EPA's Toxic Release Inventory (TRI) database for 1992 for the Detroit and Houston metropolitan areas are shown in Table 6. Both the total quantities emitted and the number of emitting facilities are greater in Houston than in Detroit. On a per-square-mile basis, emissions of these toxics are substantially higher in Houston. Locations of the facilities in each metropolitan area are shown in Figures 9 and 10 for Detroit and Figures 11 and 12 for Houston.

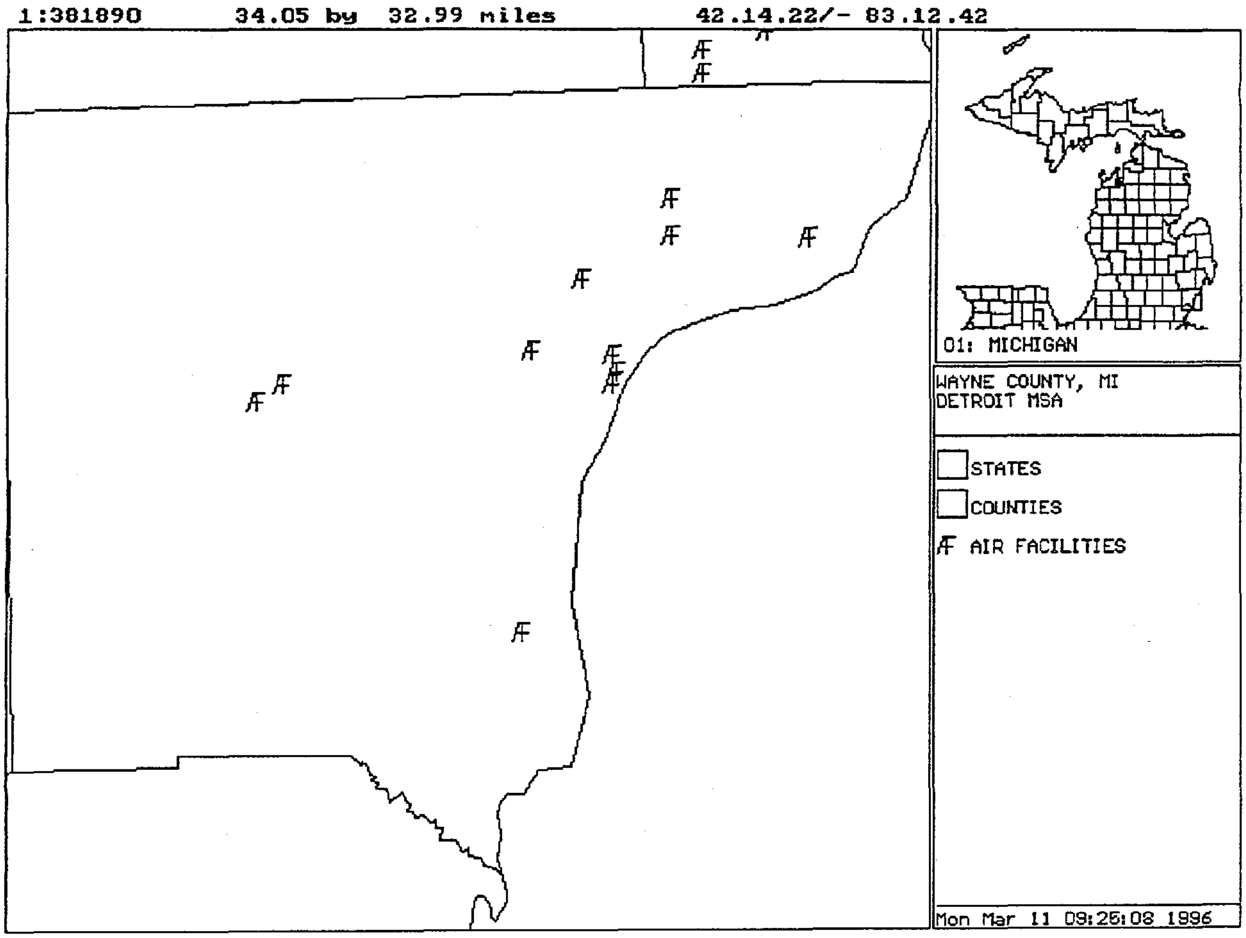


FIGURE 6 Locations of AIRS Facility Database Sites in Wayne County, Michigan

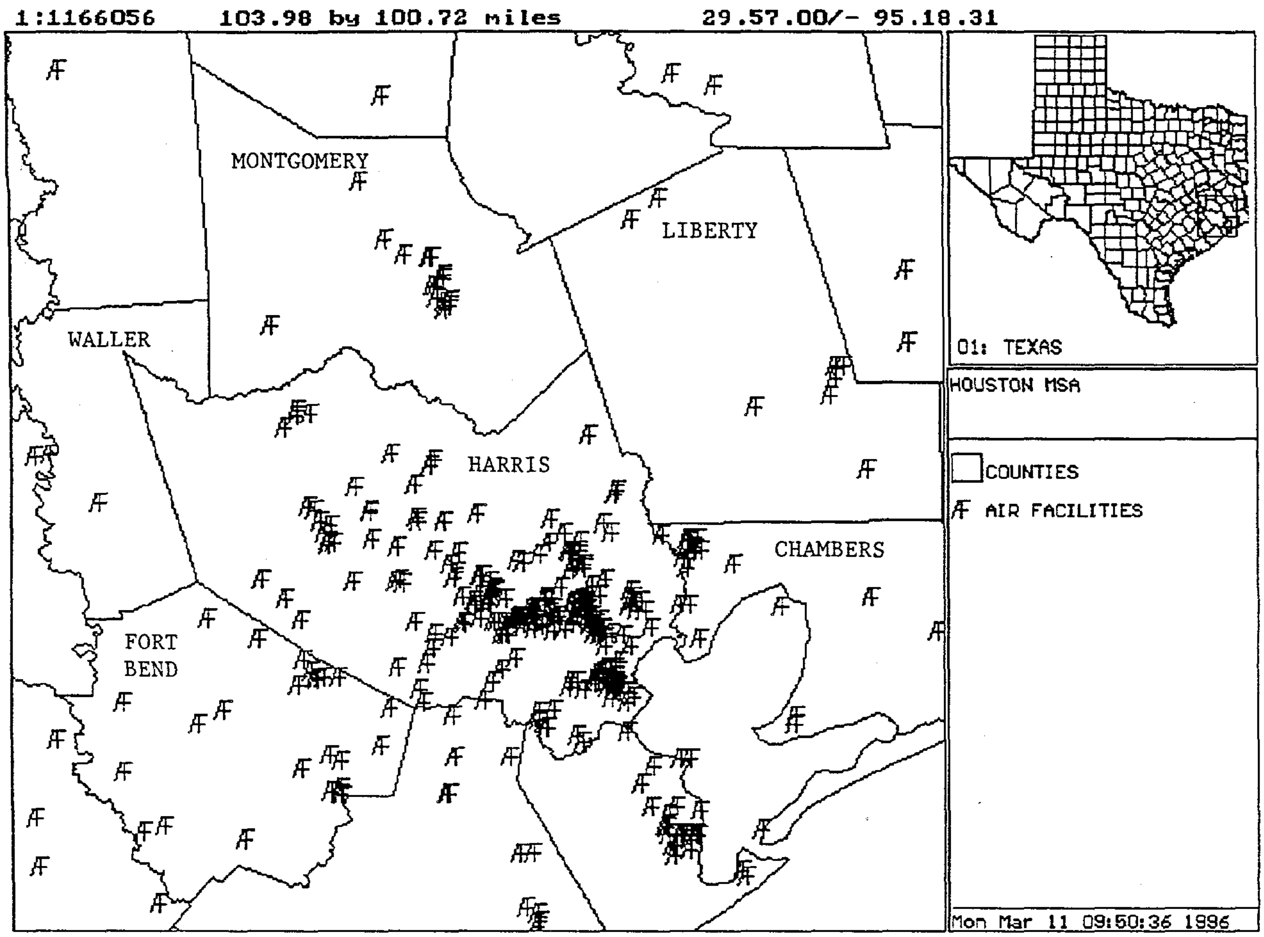


FIGURE 7 Locations of AIRS Facility Database Sites in the Houston Metropolitan Area

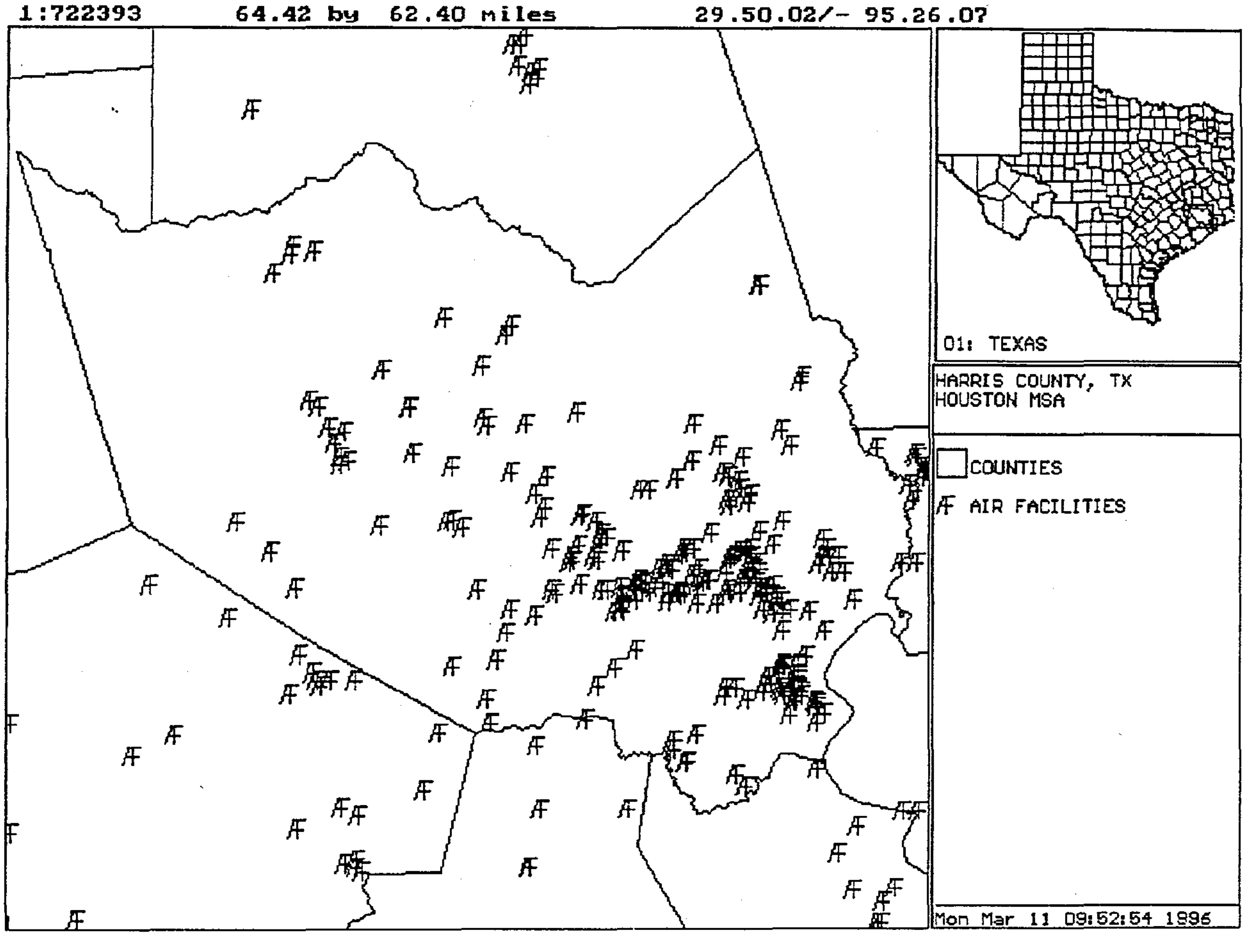


FIGURE 8 Locations of AIRS Facility Database Sites in Harris County, Texas

TABLE 6 Total Emissions and Number of Source Facilities in the Detroit and Houston Primary Metropolitan Statistical Areas, by Pollutant, from 1992 TRI

	Detroit			Houston		
		No. of Facilities			No. of Facilities	
Pollutant Type	Weight (lb)	Entire PMSA	Wayne County	Weight (lb)	Entire PMSA	Harris County
Benzene	97,041	25	9	3,566,806	62	29
1,3-Butadiene	999	3	1	1,531,185	41	18
Methylene chloride[a]	284,992	21	9	966,557	19	14
1,1,1-Trichloroethane	904,079	50	20	1,163,157	42	28
Toluene	5,840,612	81	28	5,692,598	93	56

[a] Dichloromethane.

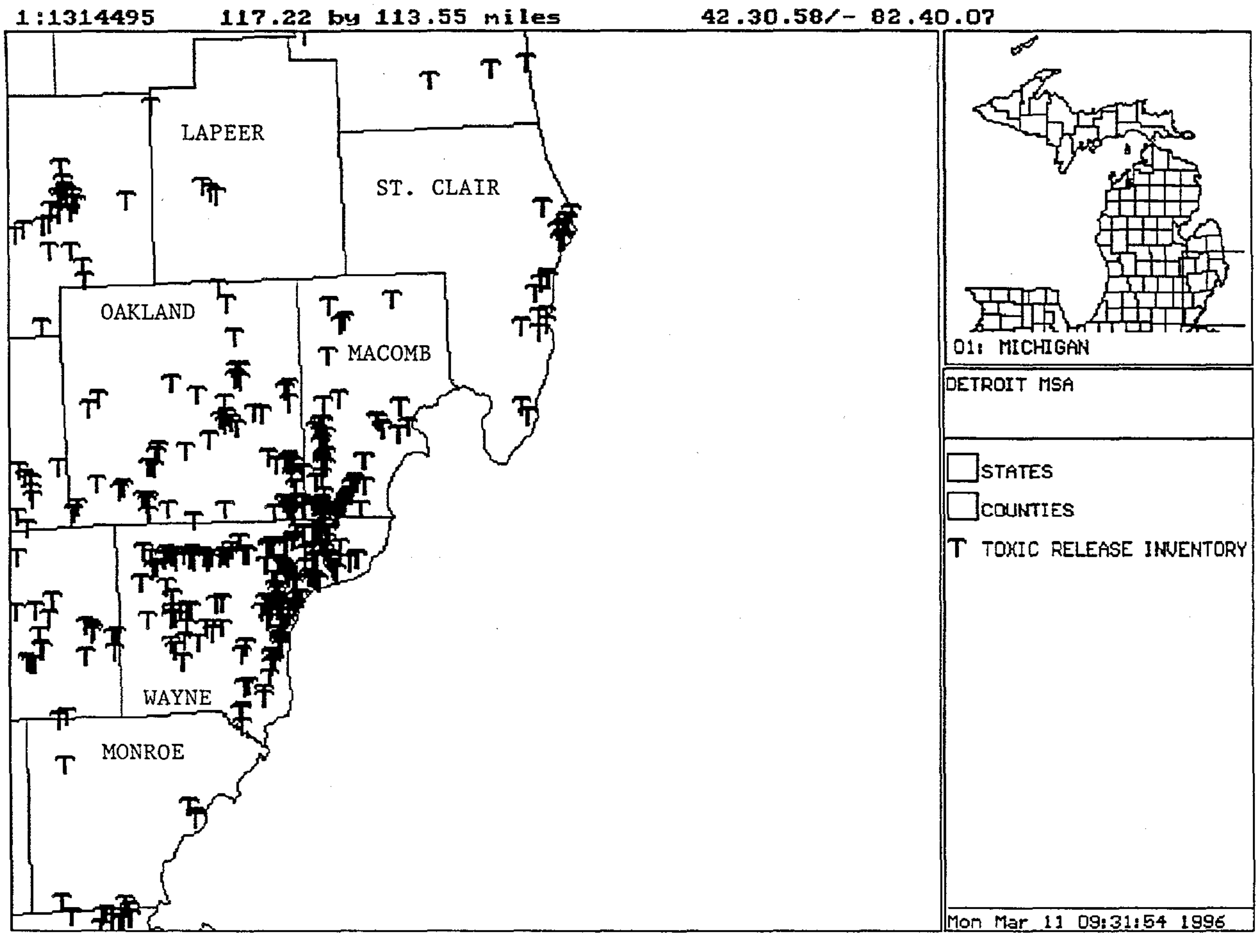


FIGURE 9 Locations of Toxic Release Inventory Sites in the Detroit Metropolitan Area

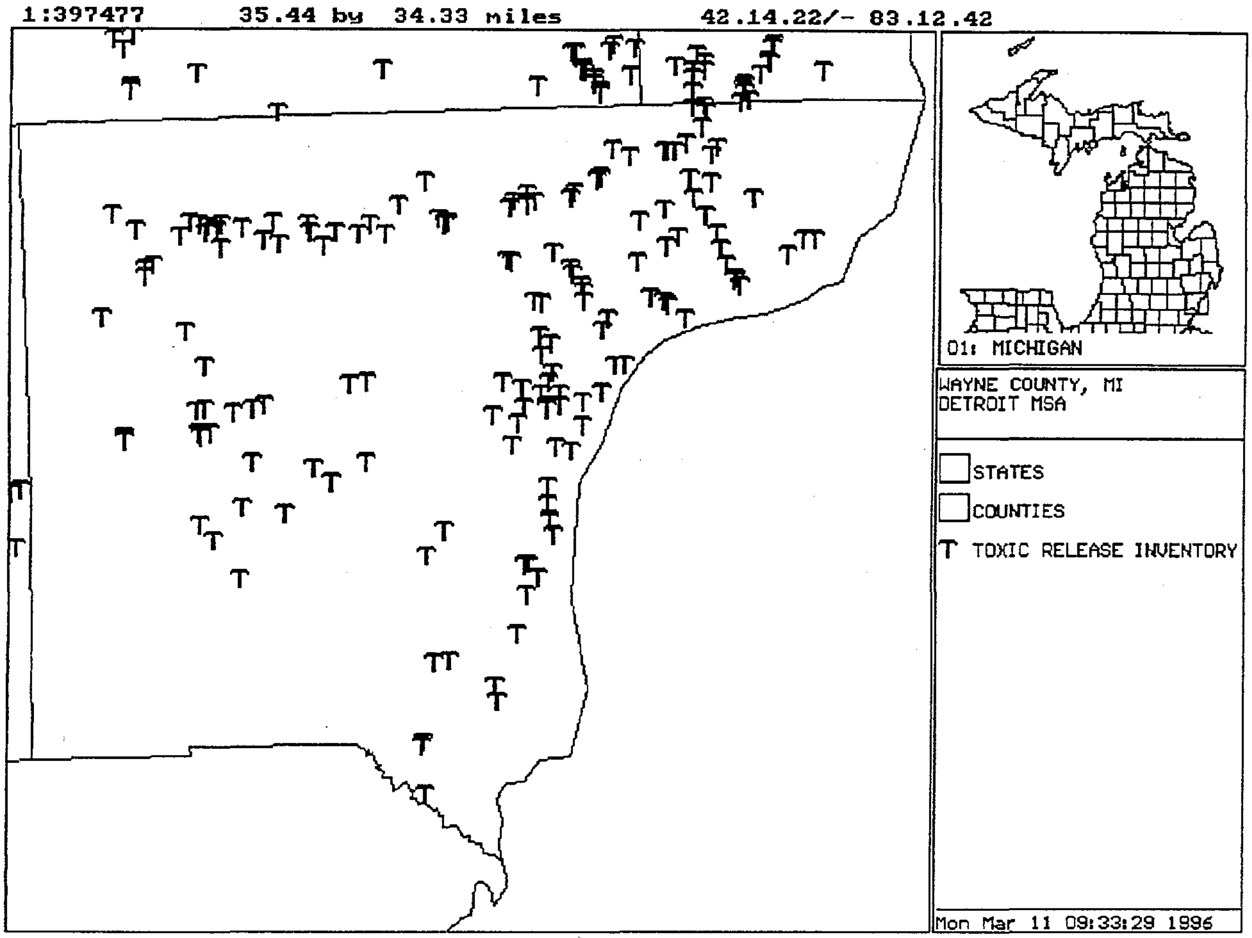


FIGURE 10 Locations of Toxic Release Inventory Sites in Wayne County, Michigan

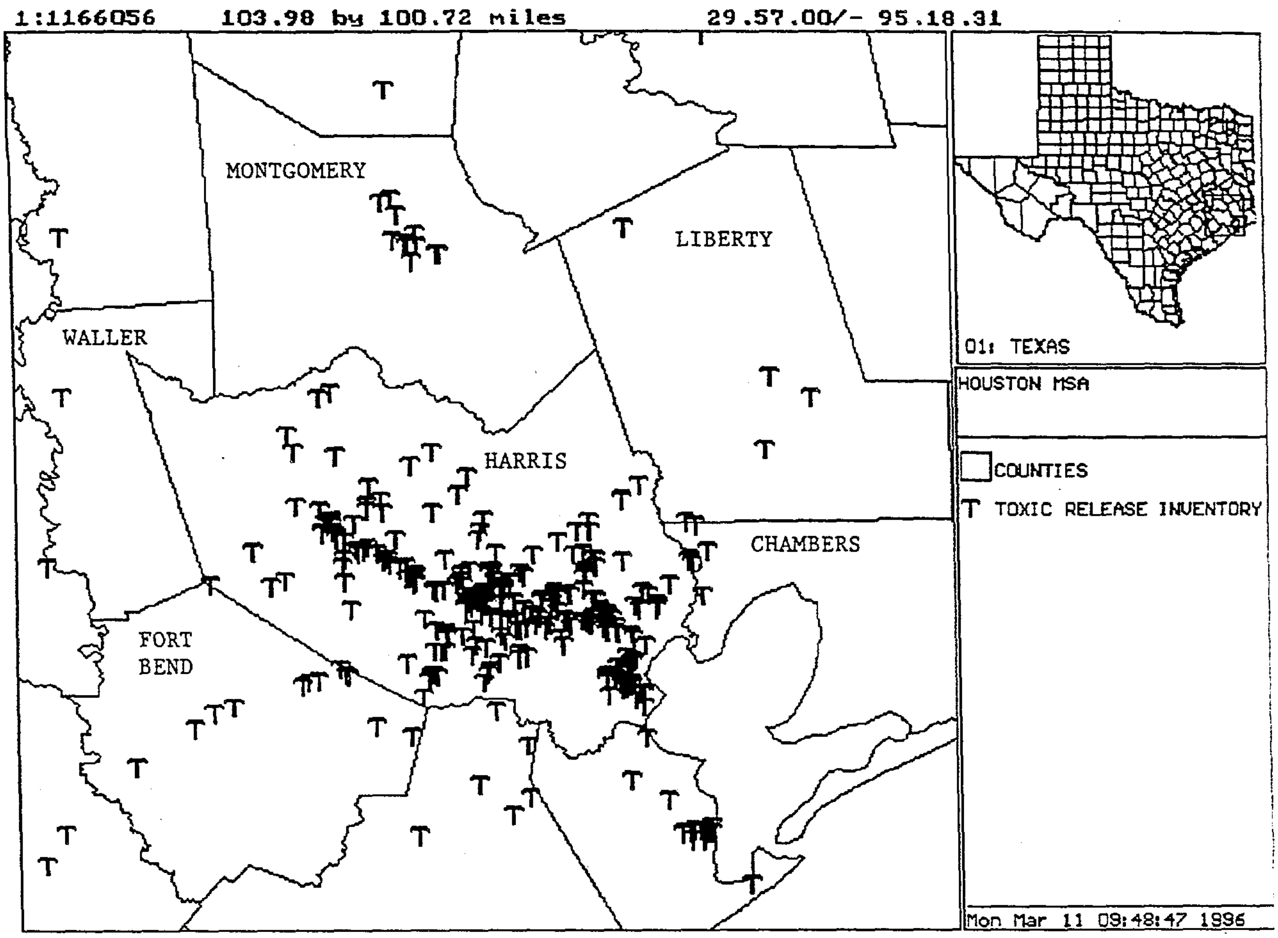


FIGURE 11 Locations of Toxic Release Inventory Sites in the Houston Metropolitan Area

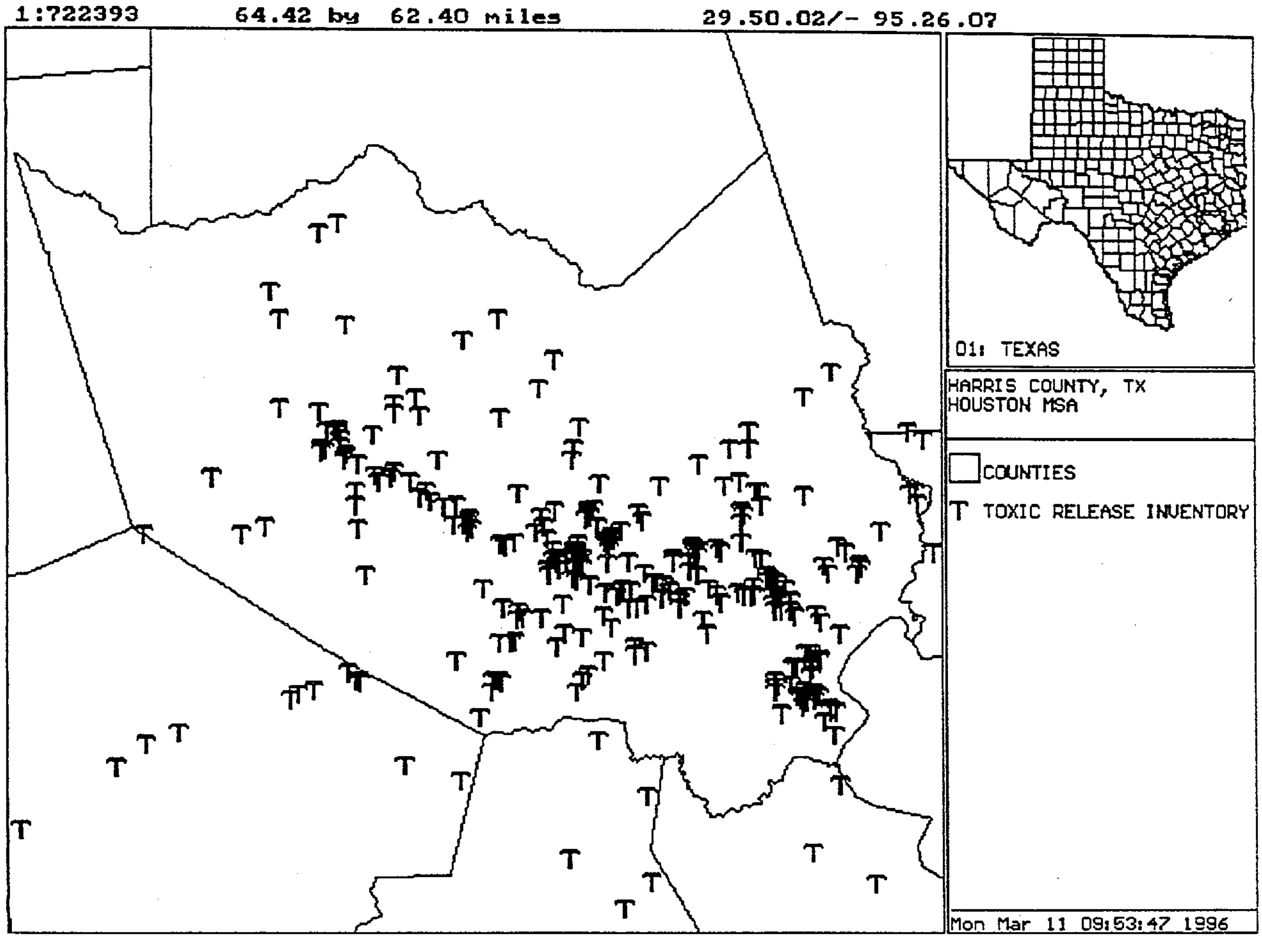


FIGURE 12 Locations of Toxic Release Inventory Sites in Harris County, Texas

3 METHODOLOGY

A number of demographic variables related to patterns of potential pollution exposure are employed in our study. The numbers of individuals in the various population groups and their relative concentrations in the various counties are relevant to patterns of air pollution exposures. The sizes, in square miles, of the counties and metropolitan areas are also relevant, given that our indices use distance and distance squared in measuring potential exposure. In that context, the population densities, in terms of persons per square mile, are also important to explain differences in patterns of potential exposure between metropolitan areas. These variables are discussed here and used in the comparisons that follow.

To provide an environmental justice perspective on potential exposures of minority and low-income populations to air pollution, this study uses exposure indices that permit a comparison of population group exposures. The exposure indices are calculated at the Census tract level, and the methodology is adapted to incorporate a distance measure. As a result, exposure is not treated as though it stops at spatial unit boundaries (as it has been in many studies, where only the residents of the spatial unit containing the facility are assumed to be exposed). This index formulation implies that everyone in a metropolitan area is affected by all of the hazards within it and that the degree of risk to the population is dependent on residential distance. Exposure indices are calculated separately for each population group and for each hazard or pollutant evaluated. Census tract level indices are added to create a summary measure that represents the potential exposure of each population group, given its distribution throughout the metropolitan area. These summary measures are then compared to evaluate relative exposures of each group.

3.1 METHODOLOGY EMPLOYED FOR ANALYSIS OF SEGREGATION

Spatial segregation of residential areas is a necessary, but not sufficient, condition for disproportionate distribution of environmental impacts among racial/ethnic groups. If two population groups are equally dispersed over N spatial units in an area (so that the percent of Group A in Unit X equals the percent of Group B in Unit X, for all units), the possibility of disproportionate impacts on the two groups, by almost any measure, would be nonexistent.

We employ the "index of dissimilarity" to measure the extent to which the population groups are disproportionately concentrated in particular spatial units. This index for a population group can vary from zero to one, where one means that the group is completely segregated and zero means that there is no spatial segregation of the group from nongroup members. The index of dissimilarity gives the percentage of Blacks (or any other group) who would have to move to achieve a constant proportional representation of each group in each area (Massey and Denton 1993, p. 20).

The following equation is used to calculate the indices of dissimilarity for each of the population groups:

$$D_s = \frac{1}{2} \sum_{c=1}^{m} | P_{c,s_1} - P_{c,s_2} | ,$$

where

P = percentage of population group members in the study area residing in the spatial unit,
c = spatial unit,
m = number of spatial units in the study area, and
s = population group.

The || means that the absolute values of the differences in population percentages are used (i.e., the sign on the difference is ignored). Population group P_2 is defined as the population not included in P_1, such that if P_1 consists of Blacks, P_2 consists of non-Blacks.

3.2 EXPOSURE ASSESSMENT

Developing absolute measures of population exposure requires such a large resource investment that the number and scope of such studies have been very limited. When absolute measures are lacking, exposure indices provide a means of evaluating relative exposures among areas or population groups. While this approach is useful, it raises issues regarding the definition of the reference group and whether the exposures of any of the groups are potentially injurious to health. Although the health risks from exposures are not evaluated, the issue is addressed by selecting hazards whose health impacts have been documented and by indicating the ranges of ambient concentrations for comparison with standards based on health impacts (Section 2.3.1).

The exposure index approach was demonstrated by Perlin et al. (1995) in a national study that used TRI data at the county level. Because this approach incorporates a measure of the hazard level, it is much more of a risk indicator than a measure that is based solely on proximity to a manufacturing or waste facility. In addition to the measure of hazard level and the percentage of the study area population exposed, as implemented in the Perlin et al. (1995) study, the indices calculated in this study explicitly incorporate population distance from each hazard measurement point. The index formula used in this study allows an examination of the effects that different assumptions regarding the attenuating effect of population distance from a hazard have on population exposure estimates. Straight-line distances were calculated from the geographic centroid of each Census tract to the latitudinal and longitudinal position of each monitoring station or source facility.

We calculated the exposure indices by using both a linear distance measure and distance squared. Incorporating a measure of population distance from each hazard reduces the problem identified in previous environmental-justice-related studies (e.g., Greenberg 1993; Zimmerman 1994) that the findings may be affected by the size of the unit of analysis.

An exposure index is calculated separately for each hazard type, such as ozone or benzene, and incorporates the levels of the hazard at multiple sources or monitoring points in the study area. The formula includes a hazard measure (H), such as quantity of emissions or ambient concentration of a pollutant, and a measure of population distance from the hazard (1/D). As a result, the hazard level associated with each source that is treated as affecting each spatial unit declines with increasing distance between the hazard source and the spatial unit. The formula also includes the proportion of each group's total population in all spatial units in the study area facing the potential exposure conditions particular to each unit. To characterize potential exposure conditions within any given spatial unit of the study area, the index weights each hazard occurrence by its distance from that spatial unit and then sums over all of the occurrences of that type of hazard to create a hazard-specific and group-specific potential exposure measure for the entire study area:

$$I_{j,s} = \sum_{c=1}^{m} \sum_{i=1}^{n} (H_i \times \frac{1}{D_c}) P_{c,s} ,$$

where

- I = distance-weighted population exposure index,
- H_i = measure of hazard level at the i^{th} facility or monitor at which levels of hazard j are measured,
- D_c = measure of distance from spatial unit centroid to point of hazard measurement,
- P = percentage of population group members in the study area residing in the spatial unit,
- c = spatial unit (Census tract),
- i = facility or monitoring site,
- j = hazard type,
- m = number of spatial units,
- n = number of facilities or monitors at which hazard j originates or is monitored, and
- s = population group.

Figure 13 illustrates the computation for one Census tract, which is potentially affected by three hazard sources, identified as x1, x2, and x3. To represent the hazard level experienced by

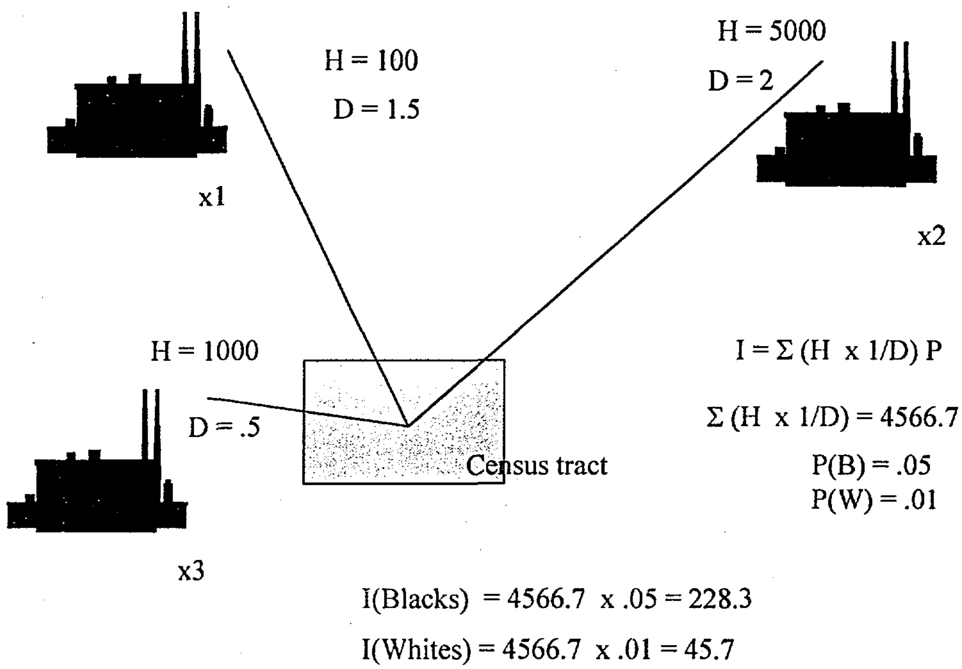


FIGURE 13 Illustration of Index Calculation

residents of the tract, the hazard value for each source facility is divided by its distance to the Census tract centroid, and the results for all sources are then summed. In this example, Source x1 contributes 66.7 hazard units ($I = H \times 1/D = 100 \times 1/1.5 = 66.7$); Source x2 contributes 2,500 units, and Source 3 contributes 2,000 units. Summing these numbers provides a hazard index of 4566.7 for this Census tract. All residents of a given Census tract are assumed to experience the same level of potential exposure to the hazard levels associated with that tract.

To calculate the exposure index for each population group, the hazard index for each tract is weighted by the percentage of the group's total area population that resides in each tract. In the example, 5% of all Blacks in the area live in the hypothetical tract, while only 1% of Whites live there. Consequently, 4566.7 is multiplied by 0.05 to determine the contribution of this tract to the Black exposure index (228.3) for the entire study area, and by 0.01 to determine the contribution to the White exposure index (45.7). The resulting exposure indices for each of the groups thus measure their weighted-average levels of potential exposure over the entire area.

To measure the degree of disproportionality of the potential exposure of minorities and low-income groups relative to the White population or higher-income group, the exposure indices of each minority or low-income group are divided by the exposure index for Whites. If the exposure index for Whites is less than that for a minority or low-income group, the proportionality measure is greater than one. When potential exposures are equal, the measure is equal to one. The measure is less than one when the White exposure index is greater than that of the study group. In the example shown in Figure 13, the Black exposure index would be divided by that for Whites — 228.3/45.7 = 4.996 — indicating disproportionate exposure of Blacks. No attempt is made to determine when differences in exposure are significant in a statistical sense. Instead, a number of exposure measures are examined, and a preponderance-of-evidence approach is employed to assess disproportionality.

4 FINDINGS

Findings for the distributions of population groups and of potential exposures are reported for the Detroit and Houston areas separately. The process of identifying the highest and lowest exposure Census tracts in both areas is then discussed, and the overall findings for both regions are compared.

4.1 DETROIT

4.1.1 Distribution of Population

Table 7 presents the percentages of the Detroit PMSA and Wayne County, Michigan, populations that are in the White or Black racial categories, that are Hispanic, and that are poor (i.e., income below the poverty line). The Detroit PMSA consists of six Michigan counties: Lapeer, Macomb, Monroe, Oakland, St. Clair, and Wayne. Wayne is the core county and has the largest population — almost half the total PMSA population. The Wayne County population differs from that of the entire PMSA in that Wayne County has higher percentages of minorities (especially Blacks) and of poor persons. The racial distribution of the population is shown in Figures 14 and 15, which present the percentage of Whites by Census tract for the Detroit PMSA and for Wayne County and the immediately surrounding area.

Table 7 also presents land areas and population densities. The Wayne County land area makes up less than one-sixth of the Detroit PMSA total. However, as was noted above, almost one-half of the Detroit PMSA population live in Wayne County. The resulting differences in population density are shown in the bottom row of Table 8; the population density in Wayne County is more than three times that of the PMSA as a whole. In densely populated areas, more people will be exposed per mile of distance from a pollution source than in less densely populated areas. If minorities and the poor are overrepresented in densely populated areas, higher proportions of these groups' populations will be exposed to nearby pollution sources.

Population group differences in potential air pollution exposure levels will reflect, to some degree, the extent of residential segregation. If two groups are living together in shared spatial units (e.g., Census tracts), they are likely to experience similar levels of air pollution. This is less likely to be the case, however, if the two groups are spatially segregated. The indices of dissimilarity presented in Table 8 show very high levels of segregation for Whites and Blacks, which are the two largest population groups in the area. Of the 1,177 Census tracts in the PMSA, 803 have an overrepresentation of Whites. Although the dissimilarity index for Blacks is higher than that for Whites, Blacks are overrepresented in only 358 Census tracts. Hispanics, in contrast to the other

TABLE 7 Land Area and Population Characteristics[a] in the Detroit Primary Metropolitan Statistical Area and Wayne County, Michigan, by Race/Ethnicity and Income Status, 1990

Feature	Detroit PMSA	Wayne County
White (%)	75.4	57.8
Black (%)	22.1	40.2
Hispanic (%)	2.0	2.4
Poor (%)	13.0	19.8
Total population	4,266,654	2,111,687
Land area (mi^2)	3,913	627
Population density (no. of persons/mi^2)	1,090	3,368

[a] Percentages in this table do not total 100 because Hispanics and poor people can be White, Black, or some other race.

Source: U.S. Bureau of the Census, 1990 Census of Population and Housing, STF 3A.

groups, are much less segregated, since only 38% of them would need to move from one Census tract to another for complete integration of the group. The poor population is somewhat more segregated, with an index of 0.5, but still much less segregated than Whites or Blacks.

4.1.2 Distribution of Exposures

The relative exposure measures for each population group and pollution measure are shown for the Detroit area in Table 9. Results are provided for both the linear and squared distance formulations, although the findings for distance squared are emphasized in the discussion. The distance squared formulation implicitly assumes that impacts fall disproportionately on the Census tracts closest to the emission source or pollution concentration.

For the ambient air quality measures, almost all of the relative exposure ratios exceed 1, indicating that the Black, Hispanic, and low-income groups are disproportionately exposed to all pollutants except particulates (PM10). The fact that Whites have the highest relative exposure to particulates is indicated by exposure ratios less than or equal to 1. On the basis of squared distance, all of the ratios (other than for PM10) reflect exposure levels that are more than 10% higher for the

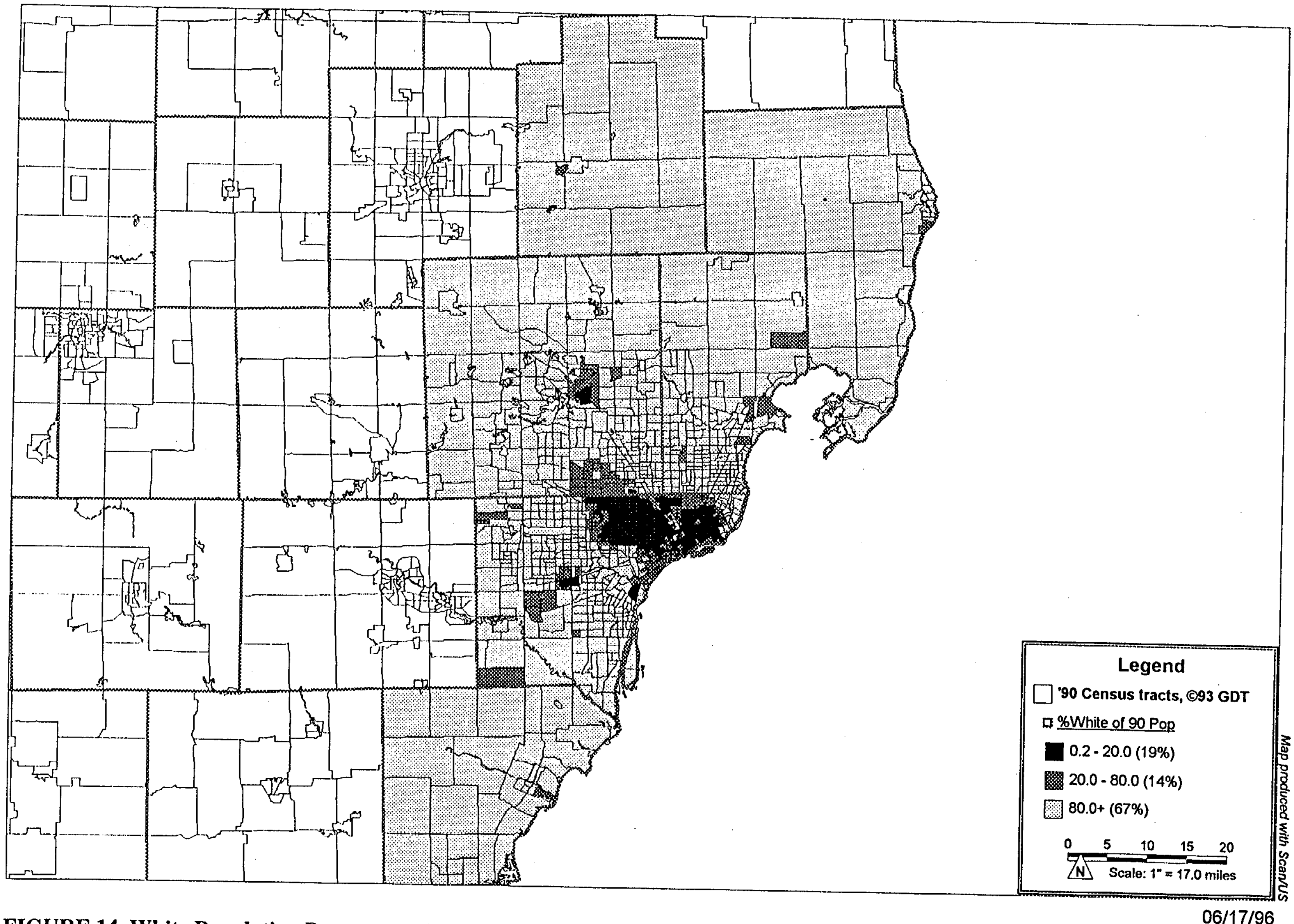


FIGURE 14 White Population Percentages in the Detroit Metropolitan Area, by Census Tract

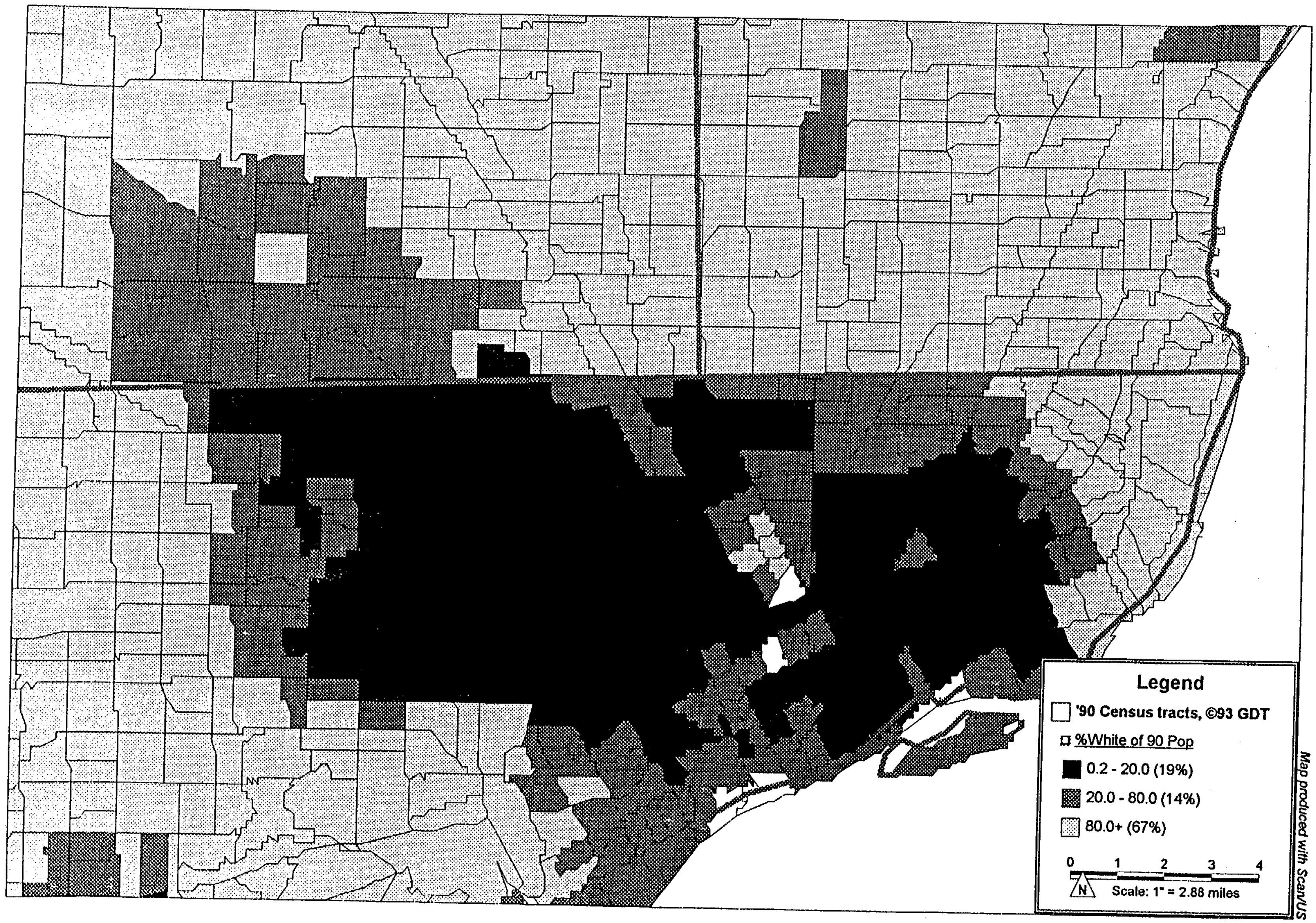


FIGURE 15 White Population Percentages in Wayne County, Michigan, by Census Tract

TABLE 8 Indices of Dissimilarity for Population Groups in the Detroit Primary Metropolitan Statistical Area, 1990

Population Group	Indices of Dissimilarity	Number of Census Tracts with Group Overrepresentation
White	0.80	803
Black	0.87	358
Hispanic	0.38	249
Poor	0.50	393

study groups than for the reference groups (i.e., ratios greater than 1.1). The degree of disproportionate potential exposure to the criteria pollutants is largest for Blacks. For potential exposure to toxic metals, it is largest for Hispanics. The pattern is quite similar for the two ambient air toxic measures. Except for PM10, the ratios show that the potential exposure level of low-income populations for all of the ambient measures, including both criteria pollutants and air toxics, is disproportionately high.

There is more variation among the groups in the results for facility emissions. The most consistent evidence of disproportionate potential exposure is for the low-income population. For that group, potential exposures are proportionate for only one category: methylene chloride emissions. Indeed, Whites are more exposed to methylene chloride emissions than any of the study groups. Blacks are less exposed to emissions of criteria pollutants but are disproportionately exposed to volatile organic compounds; a broadly defined category that includes air toxics. Blacks are also found to be disproportionately exposed to all of the air toxics other than methylene chloride. For Hispanics, the ratios show evidence of disproportionate potential exposure to most of the pollutants in both the criteria pollutant and air toxic categories.

4.2 HOUSTON

4.2.1 Distribution of Population

Table 10 presents the percentages of the Houston PMSA and Harris County, Texas, populations that are White or Black, that are Hispanic, and that have 1989 income below the poverty line. The Houston PMSA consists of six counties: Chambers, Ft. Bend, Harris, Liberty, Montgomery, and Waller. Harris clearly has the largest population, with 85% of the population of the entire PMSA.

TABLE 9 Relative Air Pollution Exposure Ratios for Minority and Low-Income Populations in the Detroit Primary Metropolitan Statistical Area under Two Distance Formulations

	Linear Distance			Distance Squared		
Pollution Measure	Black/ White	Hispanic/ White	Below Poverty/ Above Poverty	Black/ White	Hispanic/ White	Below Poverty/ Above Poverty
Criteria Pollutant Concentration in Ambient Air						
COMAX8	1.915	1.352	1.450	5.615	1.764	2.995
OZONEMAX	1.339	1.067	1.174	3.400	1.187	2.083
PM10MAX	0.876	1.012	0.882	0.280	0.881	0.452
SO_2ANN	1.928	1.387	1.621	6.743	1.988	3.827
$SO_2$24HR	1.634	1.253	1.428	5.010	1.654	3.331
Air Toxic Concentration in Ambient Air						
BERYLLIUM	1.500	1.931	1.446	3.321	7.389	3.294
COPPER	1.267	2.095	1.378	1.253	9.626	3.111
Criteria Pollutant Emissions from Facilities						
CO	0.979	0.983	1.002	1.037	1.484	1.326
NO_X	0.926	1.032	1.040	0.688	2.432	1.965
PM10	0.986	1.017	1.060	0.647	0.928	1.292
SO_2	0.943	1.040	1.050	0.676	2.660	2.059
VOC	1.281	1.020	1.179	8.440	1.599	3.965
Air Toxic Emissions from Facilities						
BENZENE	1.214	1.446	1.211	1.851	3.423	2.070
BUTADIENE	1.019	1.105	1.048	1.736	2.070	1.542
METHCLR	0.884	0.958	0.903	0.523	0.897	0.763
TOLUENE	0.999	0.980	1.042	1.548	0.986	1.694
TRICLRETH	1.091	1.080	1.064	1.422	1.186	1.254

TABLE 10 Land Area and Population Characteristics[a] in the Houston Primary Metropolitan Statistical Area and Harris County, Texas, by Race/Ethnicity and Income Status, 1990

Feature	Houston PMSA	Harris County
White (%)	66.4	64.7
Black (%)	18.5	19.2
Hispanic (%)	21.3	22.9
Poor (%)	14.9	15.5
Total population	3,322,025	2,818,199
Land area (mi^2)	5,921	1,729
Population density (no. of persons/mi^2)	561	1,630

[a] Percentages in this table do not total 100 because Hispanics and poor people can be White, Black, or some other race.

Source: U.S. Bureau of the Census, 1990 Census of Population and Housing, STF 3A.

The Harris County population has slightly higher percentages of the two minority groups and poor persons than does the entire PMSA. The fact that these differences are so slight reflects the fact that 85% of the PMSA population resides in Harris County. The percentage of Whites by Census tract is shown in Figure 16 for the whole Houston PMSA and in Figure 17 for Harris County and the area that immediately surrounds it.

Table 10 also presents land areas and population densities. The Harris County land area makes up less than 30% of the land in the Houston PMSA. As was noted above, however, 85% of the Houston PMSA population lives in Harris County, making its population density almost three times that of the PMSA as a whole. The population densities are shown in the bottom row of Table 9.

As indicated earlier, population group differences in air pollution exposure are more likely if the groups are residentially segregated. The indices of dissimilarity presented in Table 11 show moderate levels of segregation for Whites and Hispanics and a somewhat higher segregation level for Blacks. Whites are overrepresented in 404 of the 697 Census tracts in the PMSA. Although the Black index of dissimilarity is higher than that for Whites, Blacks are overrepresented in only 198 Census tracts, suggesting a high degree of overrepresentation in some tracts. Hispanics are slightly

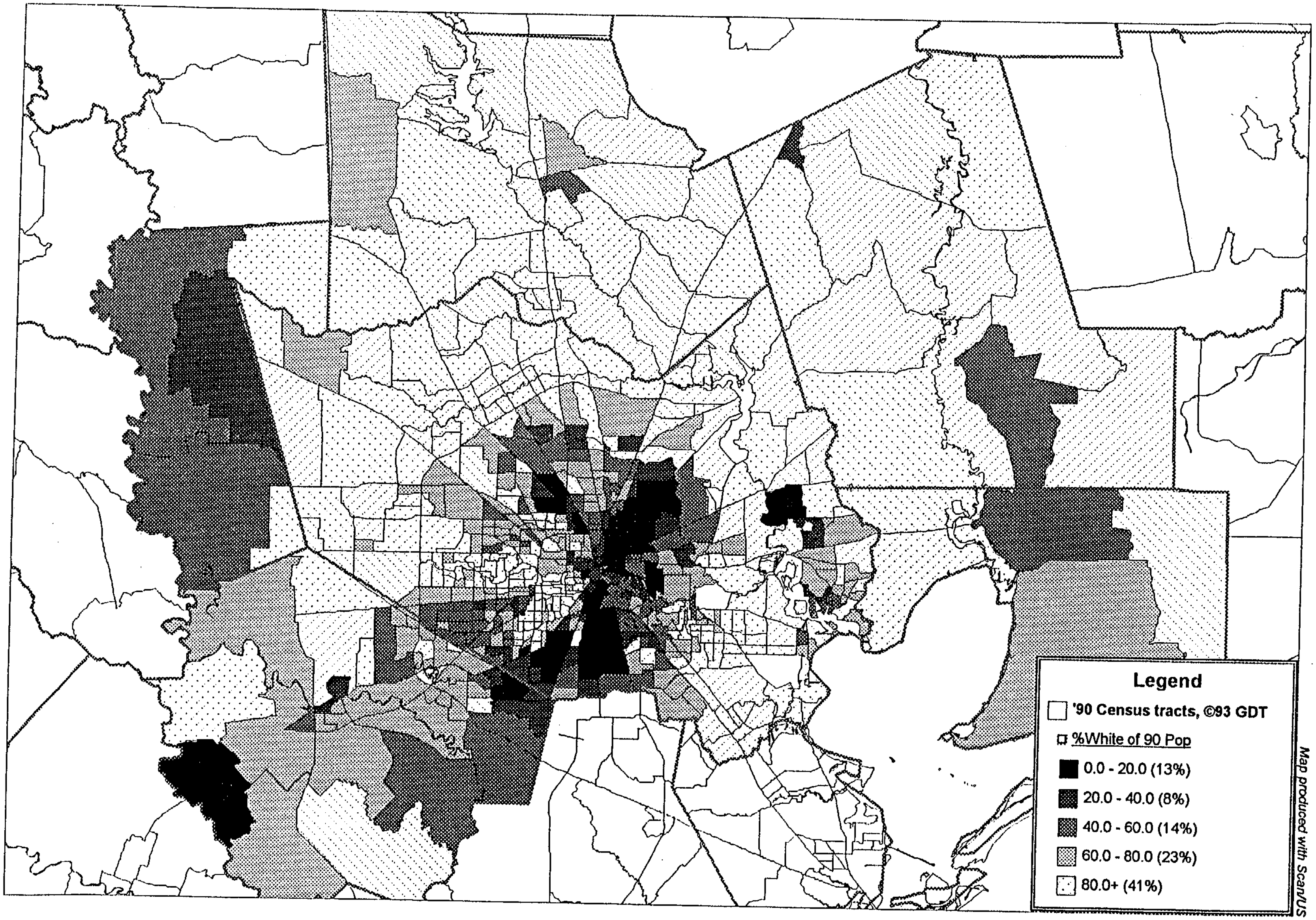


FIGURE 16 White Population Percentages in the Houston Metropolitan Area, by Census Tract

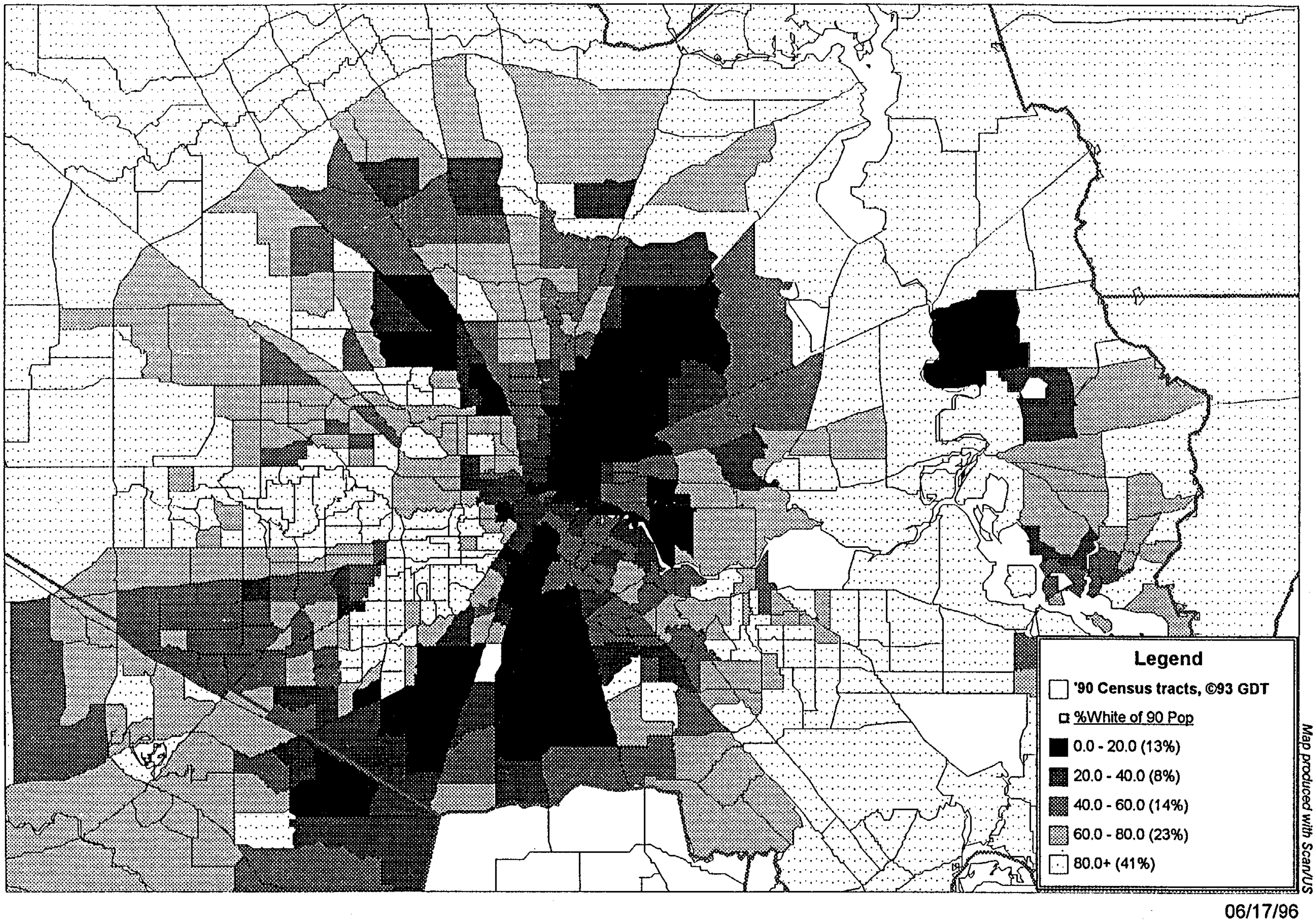


FIGURE 17 White Population Percentages in Harris County, Texas, by Census Tract

TABLE 11 Indices of Dissimilarity for Population Groups in the Houston Primary Metropolitan Statistical Area, 1990

Population Group	Indices of Dissimilarity	Number of Census Tracts with Group Overrepresentation
White	0.49	404
Black	0.61	198
Hispanic	0.45	241
Poor	0.38	323

less segregated than Whites, since only 45% of them would need to move from one Census tract to another for complete integration of the group. The poor population is less segregated than any of the racial/ethnic groups, with an index of 0.38.

4.2.2 Distribution of Exposures

The exposure ratios for Houston in Table 12 show consistently disproportionate potential exposure to all of the ambient and emissions measures for Hispanics and to all but carbon monoxide for the low-income population (when a value of 1.1 is used as the criterion for disproportionate exposure). In the case of the ambient air quality measures for both criteria and toxic pollutants, Hispanics are most highly exposed to the criteria pollutants, and Blacks to the two air toxics. Blacks are also disproportionately exposed to two of the five criteria pollutants. Overall, it appears that minorities and low-income populations are disproportionately located in areas with poorer ambient air quality.

Ratios for the facility emissions show disproportionate potential exposure for Hispanics and the low-income group for both the criteria and toxic pollutant measures, but the ratios are not as high as for the ambient measures. The ratios indicate that Blacks are at least 10% less exposed to facility emissions and air toxics than Whites, except for three pollutants. Thus, overall, Blacks have lower potential exposure to facility emissions when the distance squared assumption is used in the exposure index. A linear distance assumption indicates that exposures of Blacks and Whites are about equal. The inconsistency of the findings based on emission measures, in conjunction with the disproportionate exposure of Blacks to ambient pollution, suggests that causes of ambient concentrations of pollutants other than facility sources, such as vehicle emissions, may be substantially affecting ambient air quality in Black residential areas.

TABLE 12 Relative Air Pollution Exposure Ratios for Minority and Low-Income Populations in the Houston Primary Metropolitan Statistical Area under Two Distance Formulations

	Linear Distance			Distance Squared		
Pollution Measure	Black/ White	Hispanic/ White	Below Poverty/Above Poverty	Black/ White	Hispanic/ White	Below Poverty/Above Poverty
Criteria Pollutant Concentration in Ambient Air						
COMAX8	1.260	1.438	1.280	0.654	1.497	1.009
OZONEMAX	1.288	1.490	1.294	0.873	2.934	1.780
PM10MAX	1.383	1.527	1.347	1.972	2.353	1.666
SO_2ANN	1.406	1.664	1.390	1.177	4.341	2.382
$SO_2$24HR	1.342	1.701	1.397	1.024	4.486	2.450
Air Toxic Concentration in Ambient Air						
BERYLLIUM	1.565	1.573	1.421	3.084	2.270	1.524
COPPER	1.437	1.530	1.365	2.521	2.235	1.544
Criteria Pollutant Emissions from Facilities						
CO	0.989	1.105	1.069	0.758	1.404	1.193
NO_X	1.007	1.095	1.050	0.709	1.132	1.412
PM10	1.029	1.189	1.096	0.800	1.641	1.714
SO_2	1.090	1.191	1.086	1.117	1.800	1.946
VOC	1.017	1.185	1.104	0.748	1.495	1.663
Air Toxic Emissions from Facilities						
BENZENE	1.007	1.168	1.091	0.671	1.277	1.439
BUTADIENE	1.131	1.318	1.179	0.985	2.014	1.899
METHCLR	0.996	1.135	1.078	0.795	1.536	1.711
TOLUENE	1.006	1.189	1.107	0.718	1.421	1.554
TRICLRETH	1.327	1.424	1.334	1.736	4.122	3.855

4.3 TRACTS WITH HIGH VERSUS LOW EXPOSURE FROM MULTIPLE POLLUTANTS

The exposure measures presented in Tables 9 and 12 provide a summary of relative exposure levels across an entire study area. We also examined the distribution of hazard levels among Census tracts within each metropolitan area. This examination was accomplished by identifying the 5% of Census tracts having the highest and lowest exposure levels for each pollution variable and then totalling the number of hazards for which a tract is in one of these groups. We first evaluated correlations among the hazard variables (hazard level weighted by distance squared) within each study area. Because the beryllium and copper ambient exposure measures were highly correlated in both areas, we considered only beryllium in differentiating between most and least exposed tracts. A similar situation for SO_2 annual and hourly measures led to use of only the annual measure. While there is some overlap between the VOC measure and the five air toxic emissions measures, all are included in the analysis because the VOC measure also includes many other pollutants.

Values of the hazard measure weighted by distance squared for each variable were then ranked from low to high, with the lowest 5% of tracts coded "- 1" and the highest coded "1". These codes were then totalled to indicate the number of pollutants for which a Census tract fell into the most or least exposed group. Such a summation effectively treats each type of hazard equally, offsetting a high rating on one measure with a low rating on another. Such offsetting rarely occurred, however, since only a very few tracts fell into both the most and least exposed groups for pollutants within the set considered. The results of this analysis must be interpreted cautiously, since the values do not represent health risks but are only indicators of relative levels of potential hazard from multiple pollutants.

Table 13 shows the number of Census tracts in the most and least exposed groups in each metropolitan area. For all pollution measures, 156 tracts in Detroit fell into the least exposed 5% percent of all tracts on at least one of the hazard measures, with 19 tracts in the least exposed

TABLE 13 Number of Census Tracts in the Most and Least Exposed Groups in the Detroit and Houston Primary Metropolitan Statistical Areas

Exposure Group	No. of Hazard Measures for Which Tract Fits in Group	No. of Tracts in Exposure Group: Detroit	No. of Tracts in Exposure Group: Houston
Low	1 or more	156	71
	5 or more	63	47
	10 or more	19	29
High	1 or more	382	180
	5 or more	13	38
	10 or more	0	2
Total tracts in PMSA		1,177	697

category for 10 or more measures. Houston has 71 tracts in the least exposed group for one or more hazard measures and almost half of that number are in the least exposed group for 10 or more measures. In both Detroit and Houston, there are substantially fewer tracts in the least exposed category than in the most exposed. These findings indicate that both cities are characterized by a relatively small number of quite unpolluted tracts and a much larger number of tracts with hazards from one or more pollutants. However, the number of tracts in the most exposed group for five or more hazards is relatively small: 13 in Detroit and 40 in Houston (of which two are in the 10 or more hazard category). In the most exposed tracts, it is possible that the hazard level for each pollutant might actually be low enough that even the "high" hazards present minimal health risks. This analysis does not indicate that the tracts with higher potential hazards associated with multiple pollutants have serious health effect risks but identifies those tracts for which a health risk assessment may be warranted. It is also possible that a number of pollutants that have a low hazard level but that cause the same type of health effect could result in additive health risks.

Identifying the most and least exposed Census tracts permits an evaluation of relative exposures to multiple pollutants for different racial/ethnic and income groups actually living in each tract. The average population group proportions (i.e., group percentages of total tract population) in tracts in the most and least exposed groups are shown in Table 14. Findings are shown for the most and least exposed tract groups, defined by summing over all pollutant measures. All of the t-tests indicated significantly different population group proportions in the most and least exposed tract groups, with the most exposed tracts having much higher percentages of minority and low-income populations and lower percentages of Whites. When the two regions are compared, minorities and

TABLE 14 t-Tests on Population Group Mean Percentages in Most and Least Exposed Tract Groups for All Pollutants

	Detroit			Houston		
	Mean Population (%)			Mean Population (%)		
Population Group	Least Exposed Group	Most Exposed Group	t-Value[a] on Difference in Means	Least Exposed Group	Most Exposed Group	t-Value[a] on Difference in Means
White	94.5	64.3	9.516	82.7	54.3	7.190
Black	2.5	31.8	-9.263	10.9	25.1	-3.460
Hispanic	1.4	3.4	-3.428	9.5	34.4	-7.825
Poor	6.0	21.6	-9.769	14.1	25.0	-5.433

[a] All are significantly different, with $p < 0.001$.

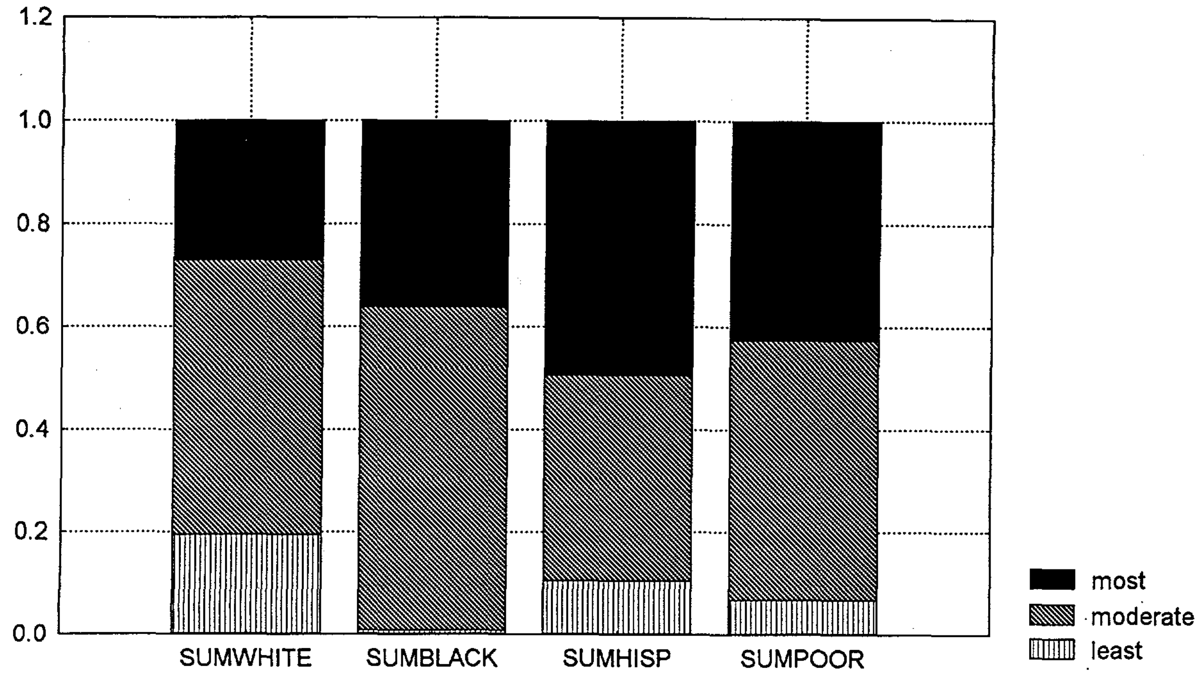
low-income populations in Detroit are found to be more underrepresented in the least exposed tracts than they are in Houston. Results are comparable in magnitude and significance level for the most and least exposed tracts when the ambient and emission measures are considered separately.

The cumulative percentages of the total populations of each group that reside in the least, moderately, and most exposed Census tract groups are shown in Figure 18a for Detroit and 18b for Houston. Although there are differences in the population percentages exposed at each level, the pattern of disproportionate potential exposure is similar for both regions. The percentages of the group population in the least and most exposed tract groups are closer to equal for Whites than for the other groups in both regions. All of the other groups have a substantially higher percentage of the population in the most polluted rather than the least polluted tracts. Of the groups, Hispanics are most overrepresented in the most exposed tracts, followed by the low-income population, and then by Blacks. Virtually half of the small Hispanic population in Detroit is located in the most exposed tracts. While the proportion of Blacks in the most exposed tracts is not as high, their representation in the least exposed tracts in the Detroit area is the lowest of all of the categories. Thus, this perspective on the data also indicates disproportionate exposure potential for minority and low-income populations regardless of the region.

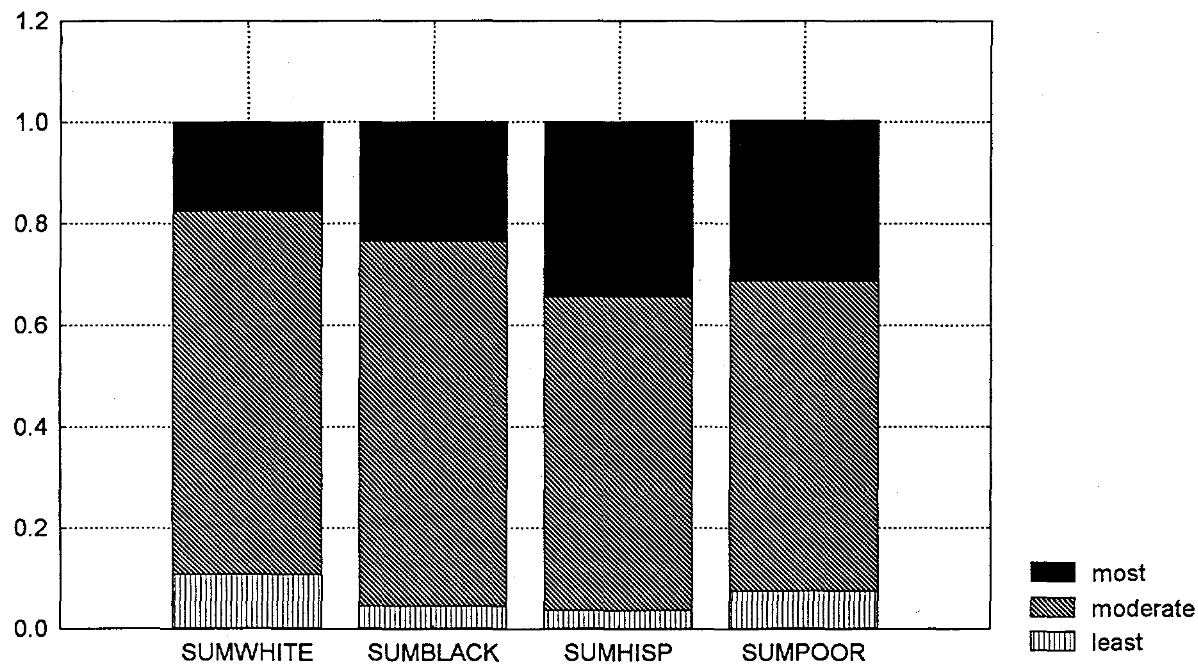
The spatial distribution of the most and least exposed tracts is shown in Figures 19 and 20 for Detroit and Figures 21 and 22 for Houston, overlain with the percentage of Whites in the total population. For each area, the second figure shows more details on the core county area. Tracts that are members of the most and least exposed groups are indicated by icons. The least exposed tracts are generally located at the periphery of the metropolitan area, while those with the highest hazards are clustered in the central city and along industrial corridors. It is apparent from the maps that the relationship between racial composition and hazard level varies sufficiently, so the percentage of White population in both the most and least exposed groups varies widely among tracts. Of course, the exposure of some predominantly White tracts to elevated pollution levels, as indicated on the maps, may be largely accounted for by the inclusion of Hispanics or low-income populations in the White category.

4.4 COMPARISON OF FINDINGS ACROSS REGIONS

As was discussed in the previous sections, similar patterns of disproportionate concentrations of minority and low-income populations in higher-pollution areas occur in both metropolitan areas. Conversely, both of these population groups are generally underrepresented in the areas with low levels of pollution, on the basis of the measures employed in this study. The consistency of these patterns for the two metropolitan areas is somewhat surprising given the differences in population distributions and facility concentrations between the two metropolitan areas.



a. Detroit



b. Houston

FIGURE 18 Cumulative Percentage of Metropolitan Area Population Residing in Least, Moderately, and Most Exposed Tracts, by Population Group

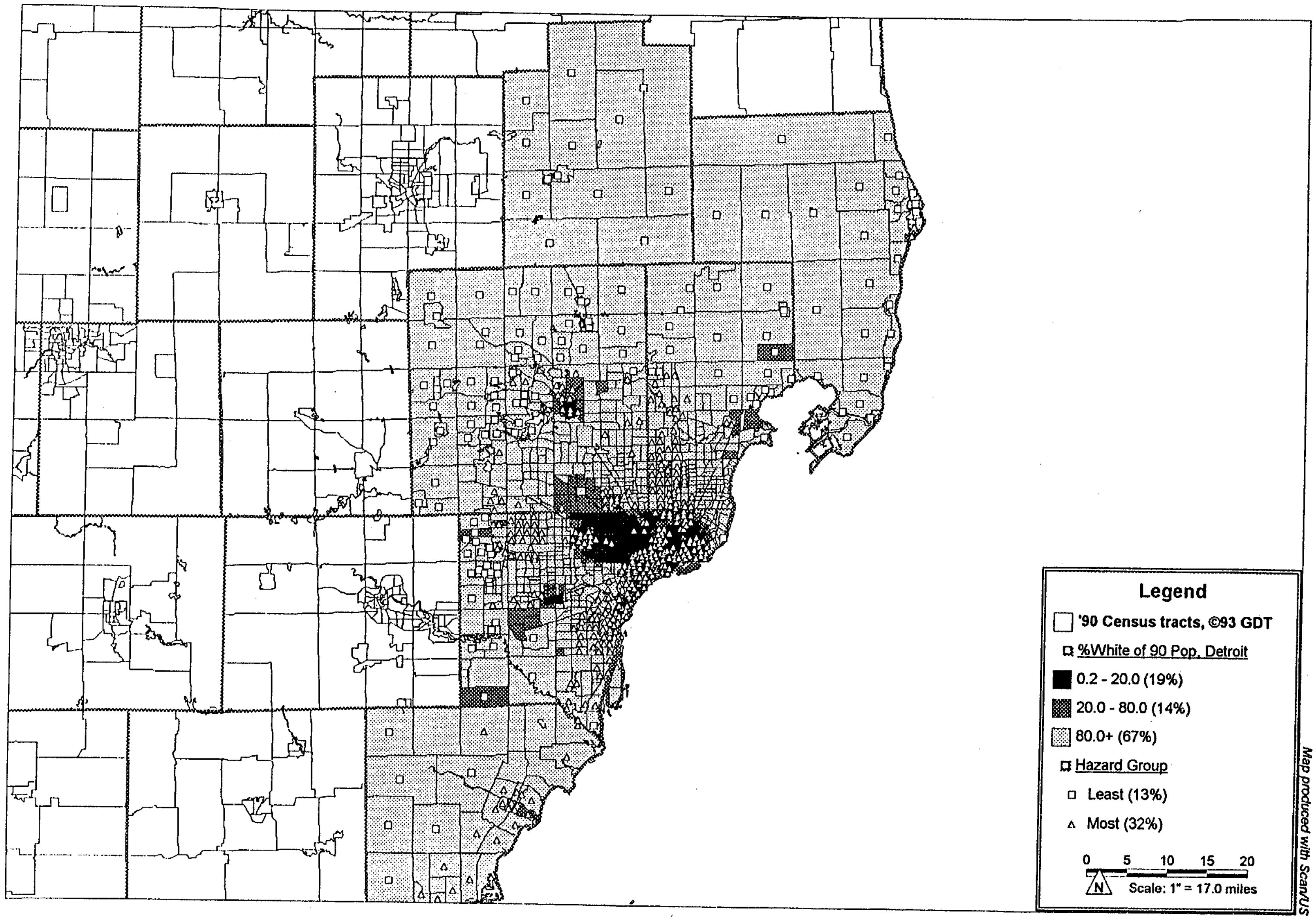


FIGURE 19 Distribution of Tract Hazard Groups and White Population Percentages in the Detroit Metropolitan Area

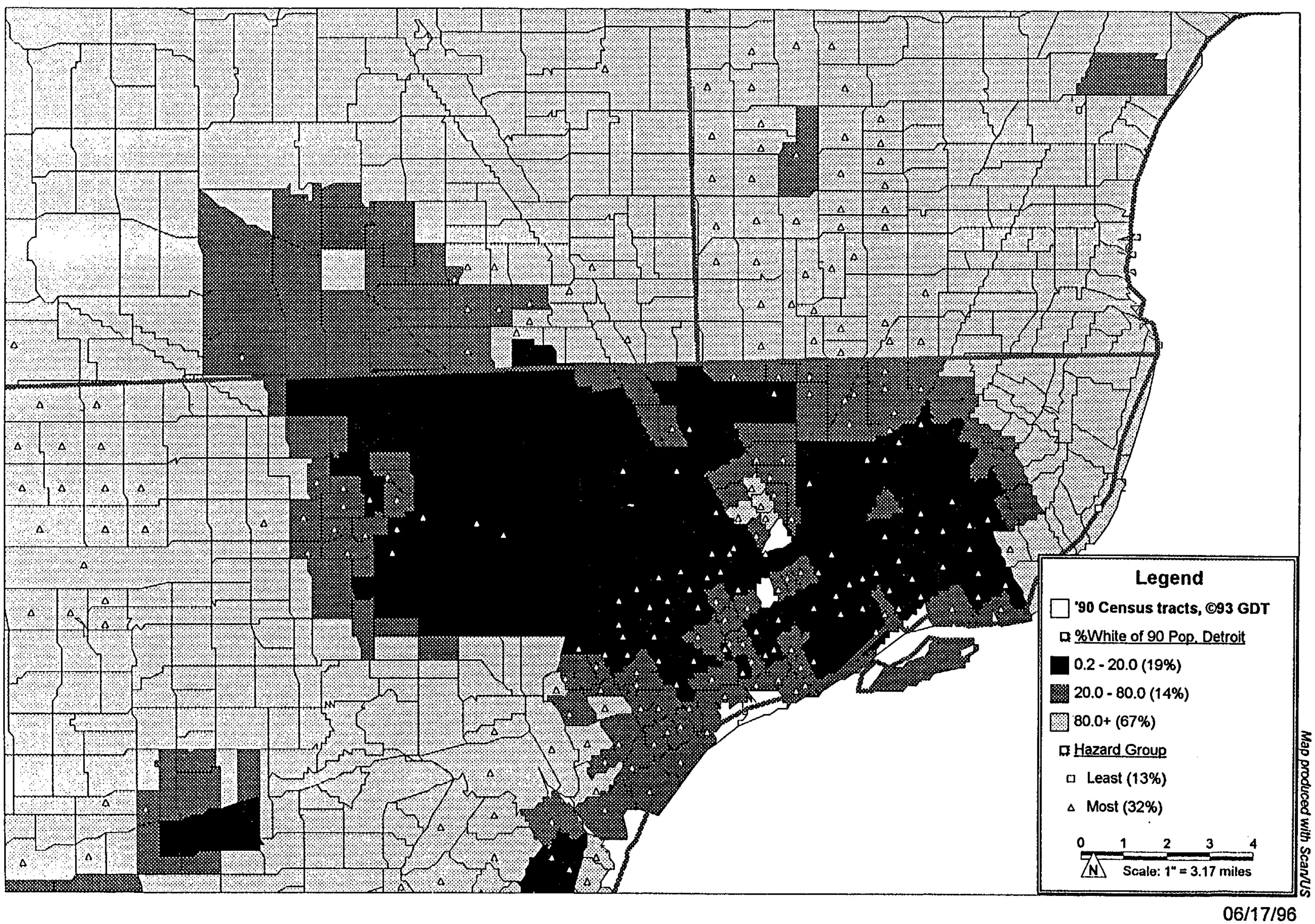


FIGURE 20 Distribution of Tract Hazard Groups and White Population Percentages in Wayne County, Michigan

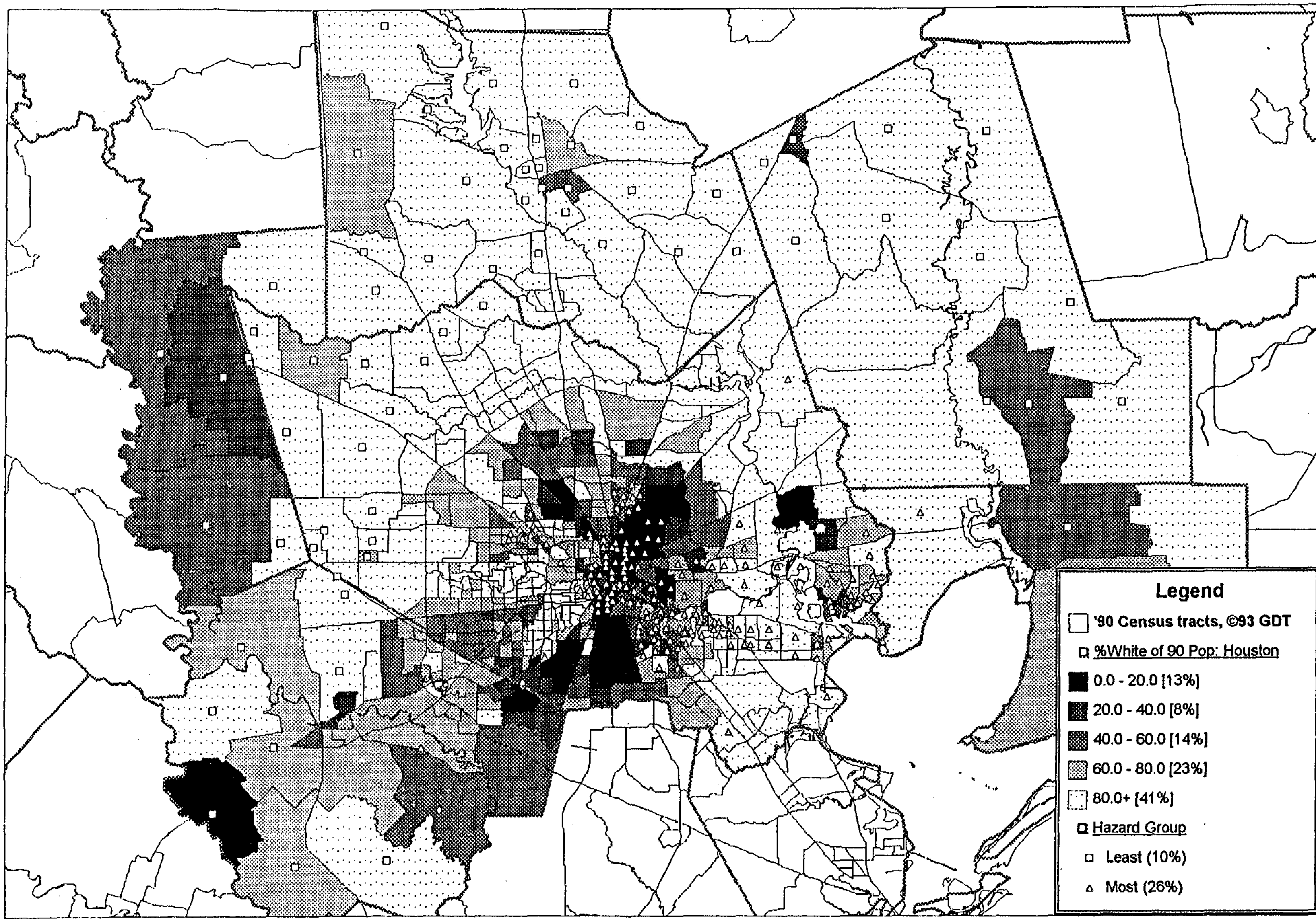


FIGURE 21 Distribution of Tract Hazard Groups and White Population Percentages in the Houston Metropolitan Area

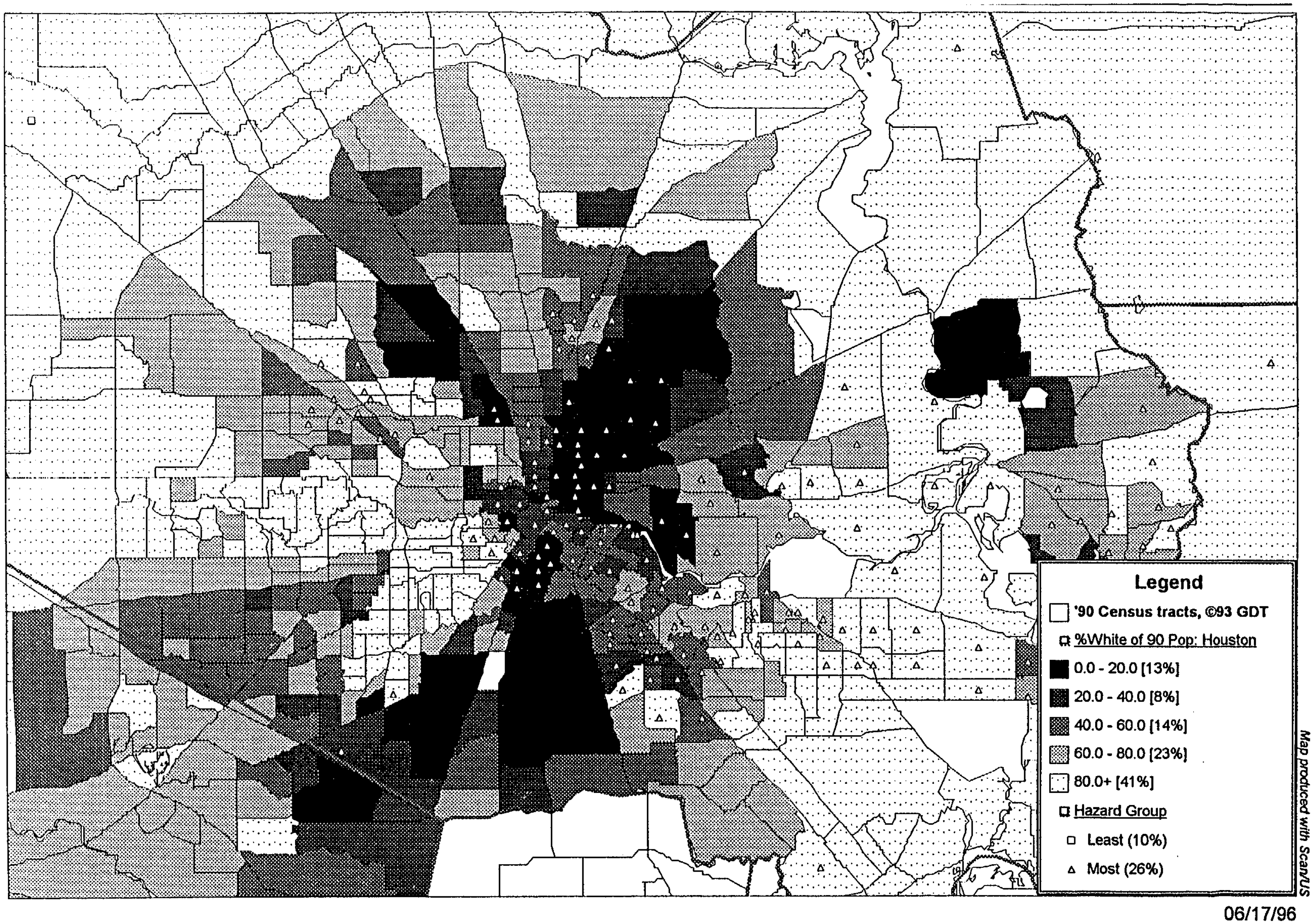


FIGURE 22 Distribution of Tract Hazard Groups and White Population Percentages in Harris County, Texas

Table 15 presents the percentages of each population group and of the population as a whole that reside in the two core counties (Wayne and Harris) of the Detroit and Houston PMSAs. Two differences in the metropolitan areas are immediately evident. First, the total population is much more concentrated in the core county in Houston (84.8% of the area population) than it is in Detroit (49.5%). (The Houston core county is almost three times greater in land area.) Second, minority and poor populations are less concentrated in the core county in Houston than in Detroit, when compared with the total population and with Whites. In Houston, Blacks are only 3.2 percentage points overrepresented in Harris County when compared with the distribution of the total population. The overrepresentation of Hispanics and the poor in the core county is of a similarly small magnitude.

In contrast, the differences in group concentrations in Detroit's core county are much larger. Although 49.5% of all persons in the Detroit PMSA live in Wayne County, only 38.9% of Whites do. The percentages of the two minority groups that reside in Wayne County are much higher (90% for Blacks and 59% for Hispanics) than is the percentage of the total population residing there. The poor are likewise disproportionately concentrated in Wayne County. The demographic structures of the two metropolitan areas differ significantly: the Detroit PMSA's population is less concentrated overall in the core county, but the minority and low-income populations are disproportionately concentrated there. In contrast, Houston's total population, and also its minority and low-income groups, are heavily concentrated in the core county. Consequently, variation in population group proportions among counties is smaller in the Houston area.

TABLE 15 Percentages of Detroit and Houston PMSA Group and Total Population Residing in the Respective Core County

	% of Population Living in Core County	
Population Group	Detroit (Wayne Co.)	Houston (Harris Co.)
White	37.9	82.7
Black	90.0	88.0
Hispanic	59.4	91.2
Poor	75.4	88.2
Total	49.5	84.8

Source: U.S. Bureau of the Census, 1990 Census of Population and Housing, STF 3A.

These county-level findings, combined with the higher indices of dissimilarity for Blacks, Whites, and low-income groups in the Detroit than in the Houston PMSA, indicate that residential segregation is greater in Detroit. To the extent that residential segregation is a necessary condition for disproportionate environmental exposure, these patterns would suggest that disproportionate minority exposure to pollutants could be greater in Detroit than in Houston. Residential segregation is, however, only one element affecting patterns of exposure to pollutants. The other is the concentration or distribution of the point sources of pollution, which is discussed below.

Table 16 presents the percentages of all major point source facilities, by pollutant type, that are located in the core counties of the two metropolitan areas. These percentages are based on the numbers of facilities presented in Tables 4 and 5. Regardless of the facility type, Houston has higher concentrations of facilities in its core county than does Detroit. This situation may reflect, in part, differences in the sizes of the two core counties. Not only is Harris County larger in size than Wayne County, but its size is a higher percentage of the total PMSA land area (29%) than is the case for Wayne County (16%). The greater core-county concentration of facilities in Houston helps to explain why Detroit, despite its higher level of residential segregation and higher concentrations of Blacks and poor in the core county, does not have a substantially higher level of disproportionate minority exposure to pollution than Houston.

TABLE 16 Percentages of Major Point Source Facilities in the Detroit and Houston PMSAs Located in the Respective Core County, by Pollutant

	% of Point Source Facilities Located in Core County	
Pollutant	Detroit (Wayne Co.)	Houston (Harris Co.)
Carbon monoxide	21	47
Nitrogen dioxide	24	49
Particulates (PM10)	0	40
Sulfur dioxide	24	51
Volatile organic compounds	14	51
Benzene	36	47
1,3- Butadiene	33	44
Methylene chloride	43	74
1,1,1-Trichloroethane	40	67
Toluene	35	60

Source: EPA, Aerometric Information Retrieval System, 1992, and Toxic Release Inventory, 1992.

Comparisons of the findings in Tables 15 and 16 make the consistent patterns of disproportionate pollution exposures identified earlier more striking. There are substantial differences between the two metropolitan areas in two dimensions that should be very important with regard to environmental justice issues: the concentration patterns of both population groups and the pollution point sources within the metropolitan areas. In Detroit, the pollution point sources are greatly decentralized (i.e., outside the core county), but the minority and low-income population groups are greatly centralized (i.e., in the core county). One would expect such a pattern to reduce levels of disproportionate exposure for the minority and poor groups. This is not the case, however, as shown by the exposure indices. In contrast, in Houston, the point sources are concentrated in the core county, but the concentration of minority and low-income populations in the core county is low relative to the population as a whole. The fact that disproportionate potential exposures are found in both PMSAs in spite of the population and facility distribution differences suggests that the factors affecting relative exposure levels are operating at the Census tract rather than at the county level. This implies that within counties, minority and low-income populations are concentrated relatively close to point sources of pollution.

5 CONCLUSIONS

By using a variety of measures, this study finds that minority and low-income populations have a disproportionately high potential for being exposed to air pollution in Detroit and Houston. This pattern is surprising, given that the spatial distributions of the populations and point sources of pollutants are very different in these two metropolitan areas. This result suggests that these patterns transcend the county-level spatial configuration of population groups and facilities in the metropolitan areas.

5.1 EFFECTIVENESS OF METHODOLOGY

Perlin et al. (1995) demonstrated the effectiveness of a hazard-weighted exposure index for identifying relative exposures of different population groups residing in the same study area. The study discussed here has carried this approach a step further by applying an index of exposure that is weighted by both hazard level and distance. By incorporating distance in the exposure index, exposure is measured as a continuous gradient rather than as an all-or-nothing condition. The form in which distance is incorporated allows the effect of various assumptions about the functional form of the relationship between distance and exposure levels to be evaluated. Depending on which distance formulation was incorporated (linear or squared distance), exposure indices varied enough to affect the findings on relative exposure for some groups for some exposure measures. However, when all of the exposure measures were considered, the variation was not sufficient to affect the overall findings regarding disproportionate exposure of minority and low-income groups.

The distance-weighted indices permit one to identify the spatial units in which the population has the greatest potential for being exposed to a range of hazards from multiple sources. This capability may be extremely valuable for screening purposes for multiple and cumulative exposure assessments. To demonstrate the methodology, we assumed that each of the hazards were equally serious. If supporting information were available, the relative seriousness of the hazards could be weighted in ranking the most and least exposed spatial units.

5.2 SUMMARY OF MAJOR FINDINGS

A range of hazard measures was used to analyze the relative exposure to air pollution of population groups in Detroit and Houston. Results clearly indicate a pattern of disproportionate exposure for minority and low-income groups in both metropolitan areas. This finding holds despite different patterns of group residential location, different industrial patterns, and different climatic regions.

For both metropolitan areas, the finding of disproportionate potential exposure is most consistent for the low-income population and for Hispanics. The potential exposure of Blacks to ambient air pollution is also clearly disproportionate, but findings related to facility emissions are less clear. In both regions, findings for Blacks vary with the emission measures examined, indicating that their potential exposure levels are higher than those of Whites for some hazards and lower for others. Also, in Houston, findings on Blacks' potential exposure to facility emissions based on the linear and squared distance formulations are inconsistent.

Findings with regard to relative exposures of population groups are summarized in Table 17. Potential exposures of the groups are designated as greater than, less than, or equal to those of the relevant reference group on the basis of a number of hazard measures for which the exposure ratios differ from a value of one (equality) by more than 10%. The distance-squared formulation, which more realistically represents the effects of pollution dispersion on exposure than does a linear distance assumption, shows strong evidence of disproportionately high exposure of the study groups, regardless of region or pollutant category. Overall, findings based on linear distance are less consistent, in that the exposure ratios indicate that groups are disproportionately exposed to ambient pollution concentrations but not to facility emissions. It should be noted that this analysis does not indicate that the disproportionate exposures are high in absolute terms (and therefore in health effect risks) but only that they are high relative to the reference groups. Assessing health effect risks from air pollution would require evaluation of the actual, rather than relative, ambient (and indoor) exposure levels.

Larger proportions of the minority and low-income populations live in the most polluted neighborhoods of each city than do Whites and those above the poverty line. In both cities, the proportion is highest for Hispanics and next-highest for the poor.

One of the issues raised in a number of environmental-justice-related studies has been that the spatial unit of analysis has been too large, or otherwise inappropriate, to accurately reflect the actual impact area. To address that problem, this study employed Census tracts, which form relatively compact spaces in metropolitan areas, as the spatial unit. Even with the use of more disaggregated data, the findings of disproportionate potential exposure of minority and low-income groups to environmental hazards are consistent with those of the other studies based on larger spatial units. Documentation of disproportionate air pollution exposures of minority and low-income groups dates back at least to the early 1970s.

TABLE 17 Summary of Findings on Relative Exposure, by Population Group and Exposure Measure[a]

Location	Exposure Measure	Black		Hispanic		Below Poverty	
		Distance	$(Distance)^2$	Distance	$(Distance)^2$	Distance	$(Distance)^2$
Detroit	Ambient air (7)	Greater (6)	Greater (6)	Greater (5)	Greater (5)	Greater (6)	Greater (6)
	Facility emissions (10)	Equal (7)	Greater (5)	Equal (8)	Greater (7)	Equal (8)	Greater (9)
Houston	Ambient air (7)	Greater (7)	Greater (5)	Greater (7)	Greater (7)	Greater (7)	Greater (7)
	Facility emissions (10)	Equal (8)	Less (7)	Greater (9)	Greater (10)	Equal (6)	Greater (10)

[a] Exposure indices (with values of +1% or −10%) are for minority groups relative to Whites and for those with below-poverty-level income relative to those with above-poverty-level income.

Distance = linear distance; $(Distance)^2$ = distance-squared formulation.

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