A Closer Look at Air Pollution in Houston: Identifying Priority Health Risks

A summary of the *Report of the Mayor's Task Force on the Health Effects of Air Pollution*

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ABSTRACT

Air pollution levels in the City of Houston are considered to be unacceptable by knowledgeable experts and the general public and are likely to cause air-pollution related health effects for Houston residents. Pollutant levels are driven by many sources including: tailpipe emissions from cars, trucks and buses; toxic pollutants emitted into the air by more than 400 chemical manufacturing facilities, including 2 of the 4 largest refineries in the U.S.; the petrochemical complex along the Houston Ship Channel and the Port of Houston; and many small operations spread geographically across Greater Houston, such as surface coating processes, dry cleaners, gas stations, printing processes, restaurants, charcoal barbecues, and gasoline-fueled lawn maintenance equipment.

Mayor Bill White's Task Force on the Health Effects of Air Pollution was formed to identify priority pollutants for the City of Houston. The Task Force considered information on health effects (California EPA & OEHHA, 2002; California OEHHA, 2005; U.S. EPA, 2005, 2006d, 2006e, ATSDR) and both modeled (U.S. EPA, 2006a) and measured ambient pollutant concentrations (U.S. EPA, 2006b, 2006c) to assign 179 air pollutants (hazardous air pollutants [HAPs] and criteria pollutants) to 1 of 5 risk categories: definite, probable, possible, unlikely and uncertain. A dozen of these substances were judged to pose a definite risk to human health. Finally, the distribution of these risks was found to be far from equal. The substances identified as definite risks were found in greater numbers in several East Houston neighborhoods adjacent to the Houston Ship Channel. Full results of the Task Force work can be found in their Report to the Mayor (Sexton, et al., 2006).

INTRODUCTION

The Mayor's Task Force on the Health Effects of Air Pollution was formed in 2005 following a meeting between Houston's Mayor Bill White and the President of the University of Texas Health Science Center at Houston, Dr. James T. Willerson. Mayor White asked Dr. Willerson to use the expertise of the UT Health Science Center to answer a critical science policy question:

> *"Which ambient air pollutants are most likely to cause significant health risks for current and future residents of Houston?"*

To answer the Mayor's question, the Task Force was formed under the auspices of the Institute for Health Policy based at the University of Texas School of Public Health. It is composed of environmental health experts from The University of Texas School of Public Health, The University of Texas Medical Branch at Galveston, The University of Texas M.D. Anderson Cancer Center, Baylor College of Medicine, and Rice University. These scientists surveyed available information on air pollution-related health risks relevant to the Greater Houston area (consisting of the 10 county, Houston – Sugar Land – Baytown metropolitan statistical area (MSA) as defined by the U.S. Census Bureau as of 2003) and used scientific judgment to distinguish among different levels of chronic risk likely to be experienced by Houston residents. The results of the work of the Task Force were presented as a Report (Sexton, et al., 2006) to Mayor Bill White on June 12, 2006. The Mayor subsequently announced plans to use the priority rankings as guidance for new initiatives in air monitoring and pollution control.

The Task Force judged twelve pollutants to be at levels which present a definite risk to current and/or future residents of the Houston area. Definite risk pollutants were defined by the Task Force as substances for which there was compelling and convincing evidence of significant risk to the general population or vulnerable subgroups at current ambient concentrations. Pollutants which were judged to present a definite risk include ozone, fine particulate matter ($PM_{2.5}$), diesel particulate matter and nine hazardous air pollutants (HAPs): 1,3-butadiene, chromium VI, benzene, ethylene dibromide, acrylonitrile, formaldehyde, acrolein, chlorine and hexamethylene diisocyanate. Further description of the ranking procedure used by the Task Force can be found below.

BODY

The Task Force focused on a subset of all chemical pollutants (or classes of pollutants) likely to be present in urban airsheds and known or suspected to harm people at sufficiently elevated concentrations. National Ambient Air Quality Standards (NAAQS) have been promulgated by the U.S. EPA for six pollutants. The Task Force focused on two of these pollutants – ozone and particulate matter. The Clean Air Act also lists 188 pollutants as Hazardous Air Pollutants (HAPs) based on concerns about their toxicity, and the Task Force focused on 176 of these (based on readily available data) and diesel particulate matter. Most of these pollutants are emitted directly into the air from one or more of four, major source categories: mobile sources, including both (1) on-road emissions from motor vehicles and (2) off-road emissions from ships, trains, airplanes, and heavy construction equipment; (3) industrial point sources, such as petroleum refineries along the Ship Channel; and (4) area sources such as dry cleaners and gas stations. A few of the substances investigated, such as ozone, are secondary pollutants and are not directly emitted, but are formed from complex reactions among chemical precursors in the atmosphere.

<u>Ranking Process</u>
The Task Force used a systematic process to survey the available information and compare relative risks among air pollutants in Houston. There are health-based standards (NAAQS), as well as abundant health effects and extensive exposure data for the two criteria pollutants – ozone and particulate matter. Therefore, assignment of ozone to a particular risk category was based on how often, and by how much, ambient concentrations exceeded the NAAQS. No such ambient concentration exceedances were found for $PM_{2.5}$ concentrations in 2000 through 2005 so the ranking was based on the weight of the evidence indicating that exposures at or below the existing standard may contribute to increased morbidity and mortality. The task of assigning HAPs to particular risk categories was more difficult for three reasons: there are currently no health-based standards, as there are for ozone and $PM_{2.5}$; there tends to be less data on linkages between exposure and effects; and measurements of ambient concentrations are generally spotty or completely lacking.

To obtain estimates of ambient concentrations for as many HAPs as possible, the Task Force used modeled annual average concentrations for 1999 from EPA's National-Scale Air Toxics Assessment (NATA) (U.S. EPA, 2006a). Results from NATA's Assessment System for Population Exposure Nationwide (ASPEN) model provided estimated ambient concentrations for 176 HAPs and diesel particulate matter in 895 census tracts (each with approximately 4,000 inhabitants) included in the 10-county Greater Houston area. The NATA values were derived using a computerized air dispersion model that combined 1999 airborne emissions data from outdoor sources, including point, mobile (on-road and non-road), area, and background sources with Houston-specific meteorological variables. The model also took into consideration the breakdown, deposition and transformation of pollutants in the atmosphere after their release. The Task Force supplemented these data with measured 2004 annual concentrations for 50 pollutants (49 HAPs plus a diesel particulate matter surrogate) from 20 monitoring sites in and around Houston – 14 in Harris County, 4 in Galveston, 1 in Brazoria, and 1 in Montgomery. These data were obtained from EPA's Air Quality System (U.S. EPA, 2006b, 2006c). The Task Force requested HAPs data from the EPA's AQS for a range of years. The data were assessed, and it was determined that 2004 was the most complete of the recent years available for analysis. Therefore, all analyses of AQS data were based on 2004 (U.S. EPA, 2006b, 2006c).

To get a sense of relative health risks associated with estimated ambient concentrations of HAPs, the Task Force used health-related toxicity values developed for health risk assessments by either the U.S. EPA or the California Office of Environmental Health Hazard Assessment (OEHHA), whichever value was most stringent (health protective) (California EPA & OEHHA, 2002; California OEHHA, 2005; U.S. EPA, 2005, 2006d, 2006e). In instances when no value was developed by US EPA or California OEHHA, health risk values from other available sources were used (ATSDR). A detailed table of health risk values is presented in the Report (Sexton, et al., 2006). For carcinogens, estimates were based on their respective unit risk values (UREs), which represent the excess lifetime cancer risk estimated to result from continuous lifetime exposure to an average concentration of 1 microgram per cubic meter ($\mu g/m^3$) of a certain pollutant in the air. For noncarcinogens, estimates were based on comparison of estimated ambient concentrations with their respective chronic non-cancer inhalation health values. These values are expressed as reference concentrations (RfCs) – used by U.S. EPA, reference exposures levels (RELs) – used by California OEHHA, or minimum risk levels (MRLs) - used by Agency for Toxic Substances and Disease Registry (ATSDR). Although from different sources they are conceptually similar and represent estimates of the continuous lifetime inhalation exposure concentrations to a particular chemical that are likely to cause no adverse effects. RfC's, RELs and MRLs represent a variety of health endpoints, including but not limited to effects on respiratory, cardiovascular, immune, reproductive, developmental and neurological systems. Chronic, non-cancer endpoints represented by RfCs, RELs and MRLs can be found in **Tables 1 and 2** for pollutants which were judged to be definite and probable risks to Houston residents by the Task Force. In some cases, a pollutant may have both a URE and an RfC for cancer and non-cancer assessments.

Each HAP was assigned initially to a specific risk category contingent on how measured or modeled annual-average concentrations translated into comparative risk estimates using established UREs (carcinogens) and RfCs, RELs, or MRLs (noncarcinogens). Initial risk-category assignments were adjusted, as necessary, based on evaluation of additional information about relative emission quantities and number of census tracts or monitoring stations affected and the professional judgment of the Task Force members. Summary information about the risk categories can be found in the subsequent section.

<u>Final Risk Categories</u>

Using the process outlined above, the Task Force assigned each of the 179 air pollutants (176 HAPs modeled and/or monitored, ozone, fine particulate matter, and diesel particulate matter) to one of five comparative risk categories. Both modeled and monitored concentrations of pollutants were evaluated and compared to cancer risk estimates or reference concentrations. After initial placement into the categories outlined below, in **Table A**, pollutants were evaluated on a case by case basis based on the prioritization scheme determined by the Task Force. A full description of the risk ranking procedure can be found in Appendix 1 of the Report (Sexton, et al., 2006**)**. As can be seen in **Table A,** Definite Risk pollutants represent an excess lifetime cancer risk of greater than one in ten thousand people or a pollutant concentration greater than 100% of the reference concentration (RfC). In many cases, pollutants had both a unit risk value (URE) and reference concentration (RfC) and were evaluated for both cancer and non-cancer endpoints. If two different categories resulted, the pollutant was placed in the highest category.

Several studies have attempted to compare relative risks among selected chemical constituents in defined locations (Caldwell et al. 1998, Fox et al 2004, Morello-Frosch et al. 2000, Tam and Neumann 2004. Using generally similar methods and approaches as the Mayor's Task Force, such as employing ambient monitoring data or modeled concentrations to estimate exposure and relying on established reference values from government agencies to compare chronic health risks, these studies demonstrated that ambient levels of numerous urban air pollutants commonly exceed health-related benchmarks. The Task Force built on this methodology and added the expert judgment of eight academics to assign substances to one of five risk-based, ordered categories.

Table A Risk Ranking Categories

Risk Category	Definition	Number of Pollutants Classified	Number of Cancers per exposed population[1,3]	Non-Cancer Concentrations[2,3]
Definite	Compelling and convincing evidence pollutants represent significant risk to the general population or vulnerable subgroups at current ambient concentrations	9 HAPs + Ozone[4], $PM_{2.5}$[5] and diesel particulate matter	$>10^{-4}$	> 100 % RfC
Probable	Substantial corroborating evidence pollutants represent a significant risk under the right conditions	9	$10^{-4} – 10^{-5}$	75 – 100 % RfC
Possible	Partial or limited evidence suggesting pollutants might constitute a significant risk under certain circumstances	24	$10^{-5} – 10^{-6}$	50 – 75% RfC
Uncertain	Inadequate or insufficient evidence to ascertain whether pollutants pose a significant risk to the general population and vulnerable subgroups	118	$<10^{-6}$	<50% RfC
Unlikely	Suggestive evidence pollutants pose negligible or insignificant risk to the general population and vulnerable subgroups	16	No emissions	Not measured

[1]Calculated from Unit Risk Estimates (UREs)
[2]RfCs (Reference concentrations) are not a direct estimate of risk, but represent a concentration level at or below which adverse health effects are not likely to occur
[3]Pollutants were evaluate for either cancer or non-cancer endpoints, depending on the available data. In some cases pollutants were evaluated for both cancer and non-cancer endpoints, in which case, the pollutants were ranked in the highest category.
[4]Ozone was categorized as a definite risked based on Houston's non-attainment of the National Ambient Air Quality Standard (NAAAQS)
[5]$PM_{2.5}$ was categorized as a definite risk based on the weight of evidence indicating that exposures at or below the existing NAAQS standard may contribute to increased morbidity and mortality.

As shown in **Table 1**, 12 air pollutants were classified as "Definite Risks". The Task Force found that existing and projected ambient concentrations of two criteria pollutants – ozone and fine particles ($PM_{2.5}$) – are almost certainly causing respiratory and cardiopulmonary effects in some individuals as well as contributing to premature death. It was also determined that airborne concentrations of seven carcinogens – diesel particulate matter, 1,3-butadiene, chromium VI, benzene, ethylene dibromide, formaldehyde, and acrylonitrile – pose an unacceptable increased cancer risk. In addition, it was concluded that five substances – 1,3-butadiene (reproductive effects in addition to being a carcinogen), formaldehyde (respiratory effects), acrolein (respiratory effects), chlorine (respiratory effects), hexamethylene diisocyanate (pulmonary and respiratory effects), – are present at ambient concentrations which represent an unacceptable increased risk for chronic disease in Houston.

Table 1. Definite Risk Pollutants

Air Pollutant	Health Effects		Emission Source[1]			
	Cancer endpoint	Chronic endpoint	Point	Mobile		Area
				On Road	*Off Road*	
Ozone		Respiratory /Cardiovascular/Immune	N/A	N/A	N/A	N/A
Fine Particulate Matter (PM 2.5)	Yes	Respiratory /Cardiovascular	X	X	X	X
Diesel Particulate Matter	Yes	Respiratory		X	X	
1,3-Butadiene	Yes	Female reproductive	X	X	X	X
Chromium VI	Yes	Respiratory	X	X	X	X
Benzene	Yes*	Immune	X	X	X	X
Ethylene Dibromide (Dibromoethane)	Yes	Male reproductive*	X			X
Acrylonitrile	Yes	Respiratory	X			X
Formaldehyde	Yes	Respiratory; Eyes*	X	X	X	X
Acrolein	No	Respiratory	X	X	X	X
Chlorine	No	Respiratory	X			X
Hexamethylene Diisocyanate	No	Respiratory	X			X

[1]Emissions taken from the National Emission Inventory (NEI), 1999; [2]Only chronic health effects associated with chronic health value used in the analysis are depicted in the table; *Health effects shown in human studies. All other health effects are from animal studies.

The evidence is not as strong but nevertheless persuasive that an additional 9 air pollutants are likely to pose unacceptable health risks at concentrations measured or modeled in Houston air. These substances were designated as "Probable Risks," and included eight carcinogens – vinyl chloride, acetaldehyde, ethylene dichloride, naphthalene, arsenic compounds, carbon tetrachloride, ethylene oxide, 1,1,2,2-tetrachloroethane – and one pollutant – acetaldehyde (respiratory effects in addition to being a carcinogen) – that has chronic non-cancer effects. These are shown in **Table 2**.

Table 2. Probable Risk Pollutants

Air Pollutant	Health Effects: Cancer endpoint	Health Effects: Chronic endpoint[2]	Emission Source[1]: Point	Mobile: On Road	Mobile: Off Road	Area
Vinyl Chloride	Yes	Alimentary (liver)	X			X
Acrylic Acid	No	Respiratory	X			X
Acetaldehyde	Yes	Respiratory	X	X	X	X
Ethylene Dichloride (1,2-Dichloroethane)	Yes	Alimentary (liver)	X			X
Naphthalene	Yes	Respiratory	X	X	X	X
Arsenic Compounds (Inorganic may including Arsine)	Yes	Development	X			X
Carbon Tetrachloride	Yes	Alimentary (liver)	X			X
Ethylene Oxide	Yes	Nervous	X			X
1,1,2,2-Tetrachloroethane	Yes		X			X

[1]Emissions taken from the National Emission Inventory (NEI), 1999; [2]Only chronic health effects associated with chronic health value used in the analysis are depicted in the table. All health effects are from animal studies.

In summary, the Task Force surveyed data on ambient concentrations (from the U.S. EPA and the Houston monitoring network) for 179 air pollutants that might potentially affect the health of Houstonians. Of these 179 pollutants, 137 HAPs have related health-based values (from the U.S. EPA and California OEHHA) and 2 pollutants (ozone and fine particulate matter) are regulated by National Ambient Air Quality Standards. After reviewing the evidence, it was the collective opinion of Task Force members that, currently and into the foreseeable future, 12 substances are definite risks, 9 are probable risks, 24 are possible risks, 118 are uncertain risks, and 16 are unlikely risks. The most appropriate focus for additional public health concern and effort is initially on the 21 substances ranked as either definite or probable risks. As shown in Tables 1 and 2, they represent a combination of carcinogens and noncarcinogens emitted by a diversity of source categories.

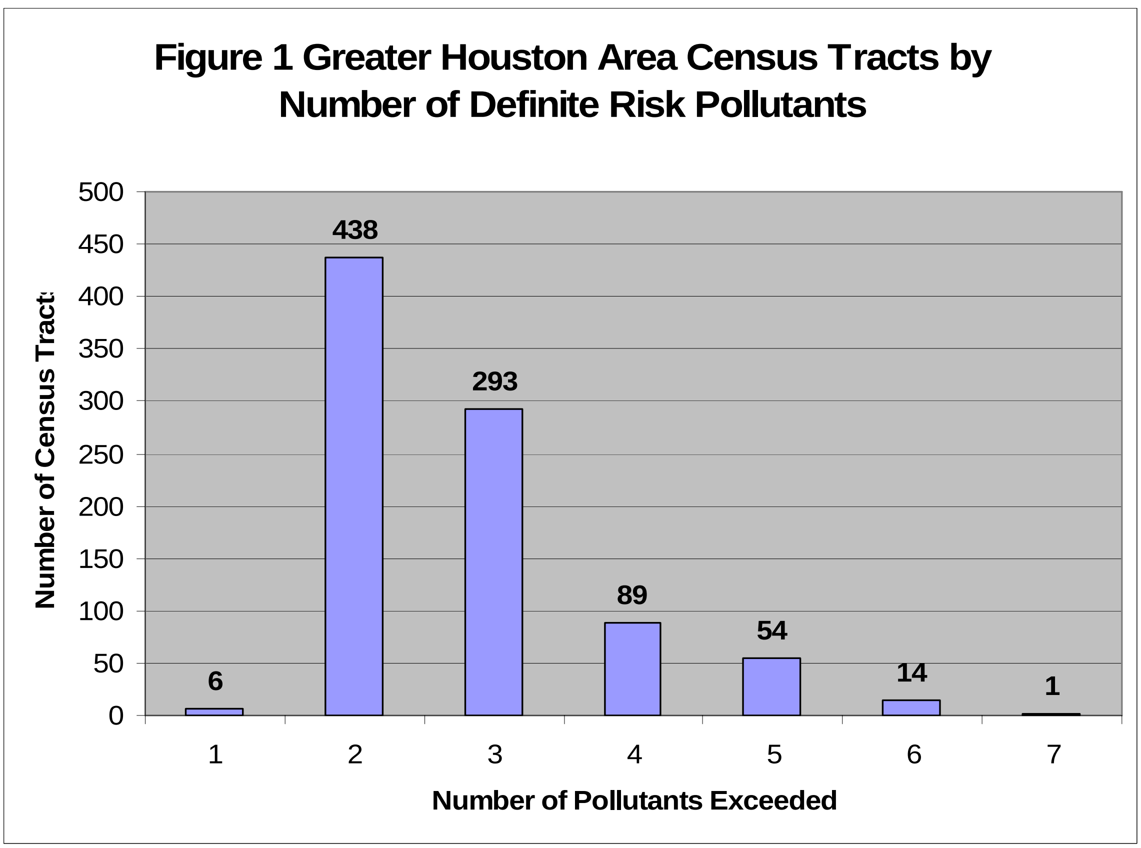
A Case Study – Cumulative Risks in a Vulnerable Community

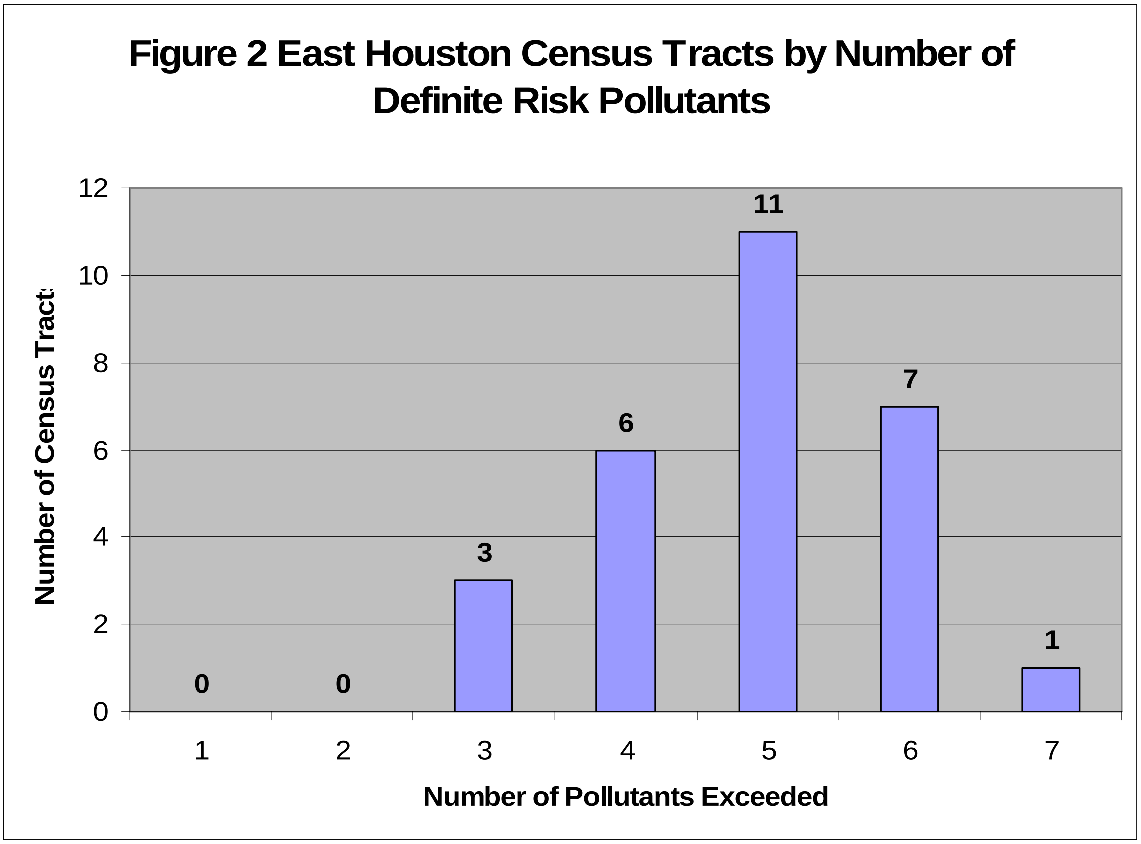
People may be more vulnerable to pollution's health effects for a variety of reasons including whether they live closer to high concentrations of pollutants, already suffer from disease or disability, have inadequate means to cope with stresses, or fewer resources to recover. The neighborhoods of East Houston share many of these characteristics and provide a concrete example of how different risks can add up when they are concentrated in a few areas. The Task Force conducted an analysis of this region using the same methods which were used for the 10 county Houston Metropolitan Statistical area and outlined above.

About half of the point sources for air pollution in the Greater Houston area are concentrated on the eastern side of Harris County. Over twenty of the largest industrial sources are located in East Houston. The Port of Houston, and the Ship Channel that feeds it, passes through the middle of this area and generates a variety of hazardous pollutants, adding to those from the nearby industrial sources. Four major highways intersect this area including, Interstate Highways 10, 610 and 45 and State Highway 225; each generating substantial pollution from high traffic density. Within the City of Houston, there are nine super-neighborhoods that span this area: Denver Harbor/Port Houston, Pleasantville, Clinton Park/Tri-Community, Magnolia Park, Lawndale/Wayside, Harrisburg/Manchester, Pecan Park, Park Place, and Meadowbrook/Allendale. On the basis of location alone these neighborhoods appear far more vulnerable to health risks than others in Greater Houston.

More detail can be provided by the National Scale Air Toxics Assessment (NATA) 1999 (U.S. EPA, 2006a), since it has modeled concentrations of pollutants at the level of the census tract. There are 895 census tracts in the Greater Houston area, and 28 of these are located in the nine super-neighborhoods in East Houston. If we consider only the 12 pollutants whose concentrations and toxicity put them in our highest risk category, most census tracts have one or two pollutants present at this high level. Ozone, for example is relatively pervasive. The revealing contrast comes in the comparison between the total picture of the 895 census tracts and a closer look at the 28 that make up our super-neighborhoods.

Figure 1 shows the tally of how many census tracts register harmful concentrations (that is, at the level of a definite health risk) for one or more pollutants in the Greater Houston area. Over 80 percent of all census tracts show three or fewer pollutants at a level that high. **Figure 2** below gives the corresponding tally for our East Houston neighborhoods. None of the East Houston census tracts have fewer than 3 pollutants in the highest risk category. Almost 90 percent of the census tracts located here have four or more pollutants present. Further, the one tract in the entire Houston area that has seven pollutants present at our highest risk level falls in one of these neighborhoods. Of the tracts throughout Greater Houston that have 6 or more pollutants, fully half of them appear in East Houston.





The way these pollutant concentrations are distributed disproportionately in East Houston neighborhoods suggests a greater burden of exposure for residents there, as compared to those living in other parts of the city. If we consider that the effects of exposure to each different pollutant can be cumulative, then neighborhoods with 5 or more pollutants present will face a higher lifetime risk of cancer or chronic disease than those where only one or two of these pollutants are found.

If we factor in other dimensions of vulnerability, then the overall risks to health increase still further. The median level of family income in our 9 super-neighborhoods is more than 30 percent lower than for the City of Houston; over a quarter of the residents fall below the poverty level. Almost 20 percent of the residents have less than a ninth grade education. These neighborhoods have some of the highest uninsured rates for health coverage in Harris County.

Consider the census tracts that have 6 or 7 of the 12 pollutants found at levels that pose a definite risk to health. Two super-neighborhoods account for the majority of these tracts: Clinton Park/Tri-Community and Harrisburg/Manchester, the latter containing the tract with 7 pollutants. Harrisburg/Manchester is the poorer of the two; the median per capita income (drawn from the U.S. Census for 2000) is $8,820. For Clinton Park, it is $9,529. As a reference point, the City of Houston reaches $21,701. These are neighborhoods where residents live on less than half of the income of their fellow Houstonians.

In Harrisburg/Manchester, 37 percent of the residents have less than a high school education, and 32 percent fall below the Federal poverty level – double the rate for the surrounding county. In Clinton Park, 27 percent have less than a high school education, and the same percent fall below the poverty level. The residents in these neighborhoods are also segregated by race or ethnicity. Clinton Park is over 90 percent African-American. Harrisburg/Manchester is 88 percent Hispanic. Further, the pattern of land use shows pockets of residences surrounded by industrial sites, either disposal lagoons for dredged material from the Ship Channel at Clinton Park or fence lines behind heavy industry for Harrisburg/Manchester. The conditions necessary for healthy lifestyles, economic sustenance and quality of life for residents are fewer here than in most neighborhoods.

Aside from vulnerability, there is also the question of whether the sources of the pollutants posing the highest risks are the same in East Houston as in the rest of the Greater Houston area. As it turns out, they are typically not the same. For East Houston, NATA attributes 7 of the top 12 pollutants to point sources; for the Greater Houston area, this number drops to 3. East Houston had no pollutants where area sources dominated among those in the definite risk category; Greater Houston had 1. Between on-road and non-road mobile sources, the most dramatic difference is for diesel particulate matter: over 90 percent of the modeled concentrations in East Houston neighborhoods are attributed to non-road mobile sources compared to three-quarters of the total in Greater Houston.

Several monitoring sites where one or more of the pollutants in the definite risk category are currently being measured are also located in these East Houston neighborhoods. Since these sites record ambient concentrations, the levels present in any given census tract cannot be accurately determined without considering factors such as wind direction and temperature. Nonetheless, the sites that register high concentrations in these neighborhoods recorded annual average concentrations for 2004 that exceeded the health value thresholds for posing definite health risks. Three of these monitoring sites are contained in or adjacent to the neighborhoods that also had the largest number of definite risk pollutants, based on NATA modeled estimates for 1999.

In sum, East Houston neighborhoods that face a number of vulnerabilities based on their marginal social and economic standing also carry a heavier burden of health risks from breathing pollutants in their air. They tend to be located closer to major point sources than most other neighborhoods in the Greater Houston area and to be nearer to major transportation corridors. The burden of these risks taken together poses special needs in these neighborhoods.

<u>Caveats</u>

It is critical to understand that assessment of air pollution-related health risks is not an exact science. Today, improved air quality in most American cities, and the fact that cause-and-effect relationships are less well-defined at lower ambient concentrations, make it necessary to use statistical techniques, along with appropriate scientific assumptions and approximations to estimate the number of "theoretical" deaths from air pollution likely to occur under artificial (but hopefully realistic) exposure scenarios.

Efforts to measure air pollution-related risks (both morbidity and mortality) directly are stymied by an array of problems that make it difficult to establish causality between typical levels of urban air pollution and connected adverse health effects. Among the common obstacles that normally confront risk assessors are the following:

- Incomplete understanding of disease etiology;
- Wide range of non-environmental causes for most diseases to which environmental agents contribute;
- Environmental pollutants often enhance or exacerbate, rather than only cause disease or dysfunction
- Lack of suitable methods, measurements, and models to a) estimate exposure, dose, and effects, and b) characterize variability over individuals, time, and space;

- Deficiency of surveillance and reporting systems for exposure and environmentally-related health outcomes;
- Long latency period from exposure to negative health consequences for many environmentally-induced diseases (e.g., lung cancer);
- Real-world exposures occur not to a single pollutant, but to complicated mixtures of environmental agents that vary both temporally and spatially;
- Observed health endpoints (e.g., lung damage) may not be the primary target of the environmental agent (e.g., immune system); and
- Inherent variability among individuals in terms of biological (e.g., genetic) susceptibility to environmentally-induced illness and injury.

It is also important to keep in mind that the Task Force considered only a specific and narrowly defined type of risk – namely the harmful chronic (long-term) effects of human inhalation exposure to estimated annual-average outdoor concentrations of 179 chemical pollutants. Air pollution can also cause acute (short-term) effects in people, as well as serious impairment to ecological resources (e.g., fish, wildlife) and damage to social welfare (e.g., poor visibility, degraded property values). The Task Force also did not consider persistent bioaccumulative HAPs which may be of particular concern due to their long residence time in the body and tendency for a large body burden. People are exposed to other chemical, biological, and physical agents in the air they breathe, and real-life exposures are not just to outdoor air pollutants but also to airborne contaminants inside residences, cars, workplaces, restaurants, and other settings. Also, certain substances in Houston's ambient air may pose significant health risks, including photochemical degradation products and short-lived intermediates that are not well understood because of their complex photochemistry. Consideration of these and other potentially noteworthy factors, such as cumulative effects from simultaneous or sequential exposure to multiple stressors by various pathways and routes, were explicitly excluded from this initial assessment to make the task manageable and feasible within time and resource constraints.

It should be noted that there are also limitations in the NATA ASPEN concentrations. For example, there is evidence (U.S. EPA 2007) that the NATA may underestimate actual monitored concentrations for some compounds, including metals such as chromium, lead, manganese and nickel (underestimated by >75%) and volatile organic compounds such as acetaldehyde, benzene and formaldehyde (underestimated by ≥50%). The NATA results also present only a partial picture of risks from air toxics as risks from non-inhalation routes of exposure (ingestion and dermal) and long range transport of persistent bioaccumulative HAPs from other locations into Houston are not considered in the model.

Finally, it should be remembered that the Task Force used only data that were on hand or easily obtainable to complete its assessment. Ambient concentration estimates by census tract were only available for one year (1999), and monitoring data from 20 stations in Houston were only available for a small fraction of HAPs, and only analyzed in depth for 2004 as this was the most recent complete year. The Task Force used "off-the-shelf" health values (UREs and RfCs/RELs/MRLs) from the U.S. EPA (U.S. EPA, 2005, 2006d, 2006e) and the California OEHHA (California EPA & OEHHA, 2002; California OEHHA, 2005) to estimate health risks, implicitly assuming that these unmodified risk values were uniformly applicable to the Houston situation and population.

CONCLUSIONS

The identification of ozone, $PM_{2.5}$, and diesel particulate matter as definite health risks is relatively straightforward owing to the comparatively large data base on adverse health effects that exists for each substance, along with clear evidence that people are exposed to outdoor levels considered unsafe. The picture is generally less certain and more problematic for the HAPs, which include a diverse mix of carcinogens and systemic toxicants. These air pollutants historically have received less regulatory attention, and ambient concentrations and exposure-effect relationships tend to be less well characterized. Accordingly, unambiguous assignment of these substances to a particular risk category is often hindered by incomplete and inadequate data, making it necessary in many instances to use scientific judgment as a basis for extrapolating beyond the limited or nonexistent data base.

Despite these difficulties, the Task Force found convincing evidence that 12 HAPs are definite health risks for Houstonians – 4 carcinogens, 4 systemic toxicants, 2 substances that are both, ozone, and fine particulate matter. Another 9 (7 cancer-causing agents, 1 toxicant, and 1 that is both) were designated probable risks because the Task Force deemed there was sufficient, although less compelling evidence that they currently pose significant health risks for people living in Houston. Although available data were partial and uneven, the Task Force also decided there was sufficient suggestive evidence to justify labeling an additional 24 substances – 20 carcinogens, 2 systemic toxicants, and 2 that are both – as possible health risks at ambient concentrations in Houston air. A further 16 substances, all carcinogens, were found to represent unlikely health risks because there are no known emissions in the Houston area and/or modeling suggested that ambient levels are likely to be negligible.

The intrinsic challenges of comparing HAPs-related health risks are illustrated by the fact that 118 (67%) of the 176 HAPs examined by the Task Force were assigned to the uncertain risk category. This decision was based on their collective judgment that there is insufficient evidence on hand to ascertain whether these substances currently pose a significant threat to the health and well being of Houston residents. In short, it was not possible to say, with an acceptable degree of certainty, whether these pollutants are a health risk or not. Obviously, from a public health perspective this leaves us in an unsatisfying situation, wherein we lack the necessary scientific information to distinguish among definite, probable, possible, and unlikely health risks. Only targeted research aimed at filling critical data gaps and resolving crucial uncertainties will allow us eventually to (a) determine the appropriate risk category for HAPs presently listed as uncertain risks, and (b) verify the risk assignments for HAPs in other categories.

Notwithstanding the inherent scientific uncertainties, the results of the assessment further reinforce the prevailing opinion of many experts that ambient air pollution in Houston is harmful to exposed individuals and populations. Furthermore, we know that air pollution-related health risks disproportionately affect those most vulnerable – the young, the elderly, the sick, the pregnant, the unborn, and the poor. Cumulative health risks from combined effects of concurrent exposure to multiple air pollutants are a particular concern in vulnerable populations. Socio-economically disadvantaged groups, for example, are more likely to live near industrial facilities and busy roadways where air pollution levels are typically elevated. Moreover, they are also more likely to work in hazardous occupations, to reside in dilapidated housing with inadequate air conditioning, to eat a substandard diet, to smoke cigarettes and drink alcohol, and to generally live more stressful and less healthful lifestyles. It therefore makes sense from a public health perspective to direct attention and resources toward high-risk groups so as to anticipate and prevent adverse effects, if possible. Failing that, emphasis should be placed on stopping or limiting exposures that damage the health and well being of the most vulnerable in our society.

As we look for cost-effective solutions, it is imperative to understand and acknowledge that air pollution is a by-product of our culture and our way of life. It is produced as a direct result of choices we make, both individually and collectively, about energy sources, technologies, economic activities, and lifestyles. While the relative contribution of a particular source or source category may vary from place to place, it is the blending together of combined emissions from numerous point, mobile, and area sources that makes Houston's air quality unhealthful. Thus, control efforts should be directed toward all sources since focusing on a single type of source, no matter how obvious or obnoxious, is unlikely, by itself, to solve the problem.

In summary, the Task Force views the comparative risk process as a *decision tool* for organizing and analyzing information about air pollution in a manner that will aid decision makers as they choose among competing priorities. It is not, in their opinion, a *decision rule* that automatically and inevitably leads to a specific conclusion about resource allocation. The Task Force recommended that their risk rankings be used as a useful adjunct to other relevant information, and that results will contribute to informed decisions not only about how to use available resources more effectively and efficiently, but also about how to justify the need for additional funding. They recommend that decision makers avoid using the findings as a detailed road map that provides precise directions about how to move forward; instead, they recommend that they use results as a compass to help determine appropriate directions for development of an overarching strategy to address Houston's air pollution problem.

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