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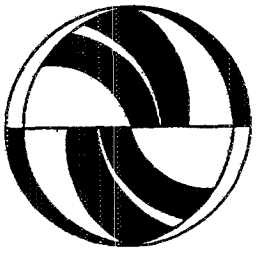

The Social Cost of the Health Effects of Motor-Vehicle Air Pollution

Donald R McCubbin
Mark A Delucchi

Working Paper
UCTC No 321

The University of California
Transportation Center

University of California
Berkeley, CA 94720

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The Social Cost of the Health Effects of Motor-Vehicle Air Pollution

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REPORTS IN THE SOCIAL-COST SERIES

There are 20 reports in this series. Each report has the publication number UCD-ITS-RR-96-3 (#), where the # in parentheses is the report number:

Report 1: The Annualized Social Cost of Motor-Vehicle Use in the U.S., 1990-1991: Summary of Theory, Methods, Data, and Results (M. Delucchi)
Report 2: Some Conceptual and Methodological Issues in the Analysis of the Social Cost of Motor-Vehicle Use (M. Delucchi)
Report 3: Review of Some of the Literature on the Social Cost of Motor-Vehicle Use (J. Murphy and M. Delucchi)
Report 4: Personal Nonmonetary Costs of Motor-Vehicle Use (M. Delucchi)
Report 5: Motor-Vehicle Goods and Services Priced in the Private Sector (M. Delucchi)
Report 6: Motor-Vehicle Goods and Services Bundled in the Private Sector (M. Delucchi, with J. Murphy)
Report 7: Motor-Vehicle Infrastructure and Services Provided by the Public Sector (M. Delucchi And J. Murphy)
Report 8: Monetary Externalities of Motor-Vehicle Use (M. Delucchi)
Report 9: Summary of the Nonmonetary Externalities of Motor-Vehicle Use (M. Delucchi)
Report 10: The Allocation of the Social Costs of Motor-Vehicle Use to Six Classes of Motor Vehicles (M. Delucchi)
Report 11: The Cost of the Health Effects of Air Pollution from Motor Vehicles (D. McCubbin and M. Delucchi)
Report 12: The Cost of Crop Losses Caused by Ozone Air Pollution from Motor Vehicles (M. Delucchi, J. Murphy, J. Kim, and D. McCubbin)
Report 13: The Cost of Reduced Visibility Due to Particulate Air Pollution from Motor Vehicles (M. Delucchi, J. Murphy, D. McCubbin, and J. Kim)
Report 14: The External Cost of Noise from Motor Vehicles (M. Delucchi and S. Hsu) (with separate 250-page data Appendix)
Report 15: U.S. Military Expenditures to Protect the Use of Persian-Gulf Oil for Motor Vehicles (M. Delucchi and J. Murphy)
Report 16: The Contribution of Motor Vehicles and Other Sources to Ambient Air Pollution (M. Delucchi and D. McCubbin)
Report 17: Tax and Fee Payments by Motor-Vehicle Users for the Use of Highways, Fuels, and Vehicles (M. Delucchi)
Report 18: Tax Expenditures Related to the Production and Consumption of Transportation Fuels (M. Delucchi and J. Murphy)
Report 19: Some Comments on the Benefits of Motor-Vehicle Use (M. Delucchi)
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LIST OF ACRONYMS AND ABBREVIATIONS AND OTHER NAMES

The following are used throughout all 20 reports of the series, although not necessarily in this particular report

AER = *Annual Energy Review* (Energy Information Administration)
AHS = *American Housing Survey* (Bureau of the Census and others)
ARB = Air Resources Board
BLS = Bureau of Labor Statistics (U. S. Department of Labor)
BEA = Bureau of Economic Analysis (U. S. Department of Commerce)
BTS = Bureau of Transportation Statistics (U. S. Department of Transportation)
CARB = California Air Resources Board
CMB = chemical mass-balance [model]
CO = carbon monoxide
dB = decibel
DOE = Department of Energy
DOT = Department of Transportation
EIA = Energy Information Administration (U. S. Department of Energy)
EPA = United States Environmental Protection Agency
EMFAC = California's emission-factor model
FHWA = Federal Highway Administration (U. S. Department of Transportation)
FTA = Federal Transit Administration (U. S. Department of Transportation)
GNP = Gross National Product
GSA = General Services Administration
HC = hydrocarbon
HDDT = heavy-duty diesel truck
HDDV = heavy-duty diesel vehicle
HDGT = heavy-duty gasoline truck
HDGV = heavy-duty gasoline vehicle
HDT = heavy-duty truck
HDV = heavy-duty vehicle
HU = housing unit
IEA = International Energy Agency
IMPC = Institutional and Municipa Parking Congress
LDDT = light-duty diesel truck
LDDV = light-duty diesel vehicle
LDGT = light-duty gasoline truck
LDGV = light-duty gasoline vehicle
LDT = light-duty truck
LDV = light-duty vehicle
MC = marginal cost
MOBILE5 = EPA's mobile-source emission-factor model.
MSC = marginal social cost
MV = motor vehicle
NIPA = National Income Product Accounts
NO_X = nitrogen oxides

NPTS = Nationwide Personal Transportation Survey
OECD = Organization for Economic Cooperation and Development
O_3 = ozone
OTA = Office of Technology Assessment (U. S. Congress; now defunct)
PART5 = EPA's mobile-source particulate emission-factor model
PCE = Personal Consumption Expenditures (in the National Income Product Acccounts)
PM = particulate matter
PM_{10} = particulate matter of 10 micrometers or less aerodynamic diameter
$PM_{2.5}$ = particulate matter of 2.5 micrometers or less aerodynamic diameter
PMT = person-miles of travel
RECS = Residential Energy Consumption Survey
SIC = standard industrial classification
SO_X = suflur oxides
TIA = *Transportation in America*
TSP = total suspended particulate matter
TIUS = *Truck Inventory and Use Survey* (U. S. Bureau of the Census)
USDOE = U. S. Department of Energy
USDOL = U. S. Department of Labor
USDOT = U. S. Department of Transportation
VMT = vehicle-miles of travel
VOC = volatile organic compound
WTP = willingness-to-pay

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11. THE SOCIAL COST OF THE HEALTH EFFECTS OF MOTOR-VEHICLE AIR POLLUTION IN THE UNITED STATES

11.1 BACKGROUND

Motor vehicles and their related emission sources, such as petroleum refineries, emit many different kinds of air pollutants, which affect human health in a variety of ways. These health effects create a large economic cost to society. In this report, we estimate the social cost of many of the health effects of motor-vehicle air pollution.

The relationship between changes in emissions related to motor-vehicle use and changes in health welfare (measured in dollars) can be modeled in three steps: 1) relate changes in emissions to changes in air quality; 2) relate changes in air quality to changes in physical health effects; and 3) relate changes in physical health effects to changes in economic welfare. We have made a detailed model of this sort to estimate the cost of the health effects of motor-vehicle air pollution[1].

We estimate the human-health cost of motor-vehicle air pollution in the entire U.S., in urban areas of the U.S., in rural areas of the U.S., and in 11 major metropolitan statistical areas (MSAs): Boston, Denver, Houston, Los Angeles, Minneapolis, New York, Philadelphia, Phoenix, St. Louis, Spokane, and Washington D. C. We consider six types of motor vehicles: light-duty gasoline and diesel vehicles, light-duty gasoline and diesel trucks, and heavy-duty gasoline and diesel trucks. We estimate the number and type of health effects, and the monetized value of these effects, including total dollar costs, dollar costs per vehicle-mile of travel, and dollar costs per kg of pollutant emitted. Finally, we include an analysis of the three main sources of the costs: direct emissions from motor vehicles, emissions of road-dust particulate matter, and "upstream" emissions from gasoline stations, refineries, vehicle manufacturing, and so on.

11.1.1 Emissions and air quality

We estimate the *status quo* air quality in 1990, and then estimate the effect of reducing motor vehicle emissions by 10% and 100%, and reducing all anthropogenic emissions by 100%. We represent the *status quo* with measurements of actual ambient air quality at air-quality monitoring sites (EPA, 1993d). To estimate air quality without 10% or 100% of motor-vehicle related emissions, we use a simple model of emissions, dispersion, and atmospheric chemistry, developed in Report #16 in the social-cost series listed at the beginning of this report and summarized in Chapter 11.5.

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[1]Alternatively, we could have tried to use hedonic or household production studies to estimate the value of air pollution reduction but, as we discuss in Chapter 11 4, these sorts of studies have significant shortcomings For a recent review of the literature on the air pollution damages of transportation, see Krupnick (1995) See also the recent methodological reviews by Krupnick (1993) and Cifuentes and Lave (1993) For a recent estimate of air-pollution damages in Los Angeles, see Small and Kazimi (1995)

We estimate the effects of a specific, "marginal" change in pollution: the difference between actual pollution and, what pollution would have been had there been either a 10% or a 100% reduction in motor vehicle-related emissions. We emphasize two points here. First, it is useful to consider a marginal change because the formation of ambient pollution from emissions of pollutants is a nonlinear process, and to some extent the effect of ambient pollution on people's health is nonlinear. Second, when we say "motor vehicle-related," we include emissions from motor vehicles' tailpipes, road dust, the production of motor fuel at refineries, emissions from the servicing of motor vehicles, emissions from road construction, and so on.

11.1.2 Air pollution and health effects

We estimate the cost of four "criteria" pollutants (carbon monoxide, nitrogen dioxide, ozone, and particulate matter) and six "toxic" air pollutants (formaldehyde, acetaldehyde, benzene, 1,3-butadiene, gasoline particulates, and diesel particulates). The estimation methods for the criteria pollutants are different than the methods for the toxic air pollutants. Table 11.1-1 summarizes the pollutants and health effects covered in our analysis.

Criteria pollutants. We reviewed hundreds of clinical, animal, and epidemiological studies of the health effects of various pollutants, and constructed exposure-response functions for each criteria pollutant (ozone, carbon monoxide, etc.) and each of a variety of health effects (for example, asthma, or headaches). These functions relate the change in health effects to the change in exposure. We have developed mortality-risk estimates for those pollutants, such as fine particles, which according to some studies are associated with mortality. For most pollutants and health effects, we have established upper and lower-bound estimates of the effects of exposure (Table 11.1-1).

In general, a exposure-response function has the following form:

$$\Delta E = f(\Delta P, O) = f(PI, PP, O)$$

where:

ΔE = the change in the effect of interest (in this case, human health)

ΔP = the change in ambient air pollution

O = other variables (such as population in the county, or the incidence rate of a health problem or cause of death; see Chapter 11.3)

PI = the initial pollution level (estimated from data on actual ambient air quality in counties in the U.S.; see Chapter 11.2)

PP = the pollution level after the change in pollution -- in our analysis, the level had there been no motor-vehicle-related emissions (detailed in Report #16 in the social-cost series listed at the beginning of this report.).

Our estimate of the health effects of particulate matter, which is by far the most damaging pollutant, accounts for several important factors: 1) the likelihood

that smaller particles are more damaging than larger particles, 2) that geological material is less damaging than combustion material, and 3) that particulate-matter emission inventories are seriously mis-estimated.

Toxic air pollutants. Whereas the cost of the criteria pollutants is estimated on the basis of human epidemiological studies and ambient air-quality data, the cost of toxic air pollutants is estimated on the basis of unit-risk numbers and exposure to pollution in micro-environments. Unit-risk functions relate the probability of getting a particular type of cancer (e.g., leukemia) to the amount of exposure to a particular toxic air pollutant (e.g., benzene). Details are given in Chapter 11.6.

Note that our estimate of the cost of gasoline and diesel particulates as toxic air pollutants does not double-count any of the costs of particulate matter as a criteria pollutant, because the end points are different (lung cancer in the case of gasoline and diesel particulates, and acute respiratory deaths, acute cardiovascular deaths, and chronic cardiopulmonary deaths in the case of particulate/criteria pollutant).

11.1.3 Valuation of health effects

In the last step, we estimate the economic value of the estimated health effects. Our estimates of the dollar value of health effects are derived from studies of the value of lost work days, of restricted activity, of tolerating certain symptoms, and so on. When we estimate the value of life, which is the most important valuation parameter in the analysis, we distinguish future deaths from current deaths, and deaths that would have occurred soon anyway even if there were no pollution.

The total health cost then is equal to the change in the effect of interest (ΔE above; e.g., number of deaths due to motor-vehicle particulate air pollution) multiplied by the dollar value per effect (e.g., the value of life).

11.1.4 Summary of results

The most important result we found is the large cost of particulate matter pollution, and the potentially large contribution of motor vehicles to ambient particulate levels (Chapter 11.7). Generally, combustion emissions of particulate matter and precursors to particulate matter cause the greatest health costs, by far.

Particulates appear to cause a number of respiratory ailments, including chronic illness and mortality. Chronic illness and especially mortality are the most costly health effects because of the value that society places on avoiding them. Very small particulates formed from combustion processes and from atmospheric gases appear more harmful than larger, more soil-based particulates. Motor-vehicle use results in both types of emissions. Motor vehicles contribute the smaller, more dangerous particulates directly from tailpipe emissions and indirectly from the large amounts of "precursor" gases that they give off such as nitrogen dioxide. Motor vehicles also emit large amounts of fairly coarse soil-based particulates from road dust -- dust kicked up into the atmosphere from moving vehicles. Determining the relative harmfulness of these two classes of particulates (combustion vs. dust particles) has important policy implications. We model a variety of assumptions that try to capture the range of plausible values for these factors.

Carbon monoxide, nitrogen dioxide, ozone, sulfur dioxide and toxics appear to have much smaller effects than particulates. Aside from their contribution to particulate formation, emissions of nitrogen dioxide, sulfur dioxide and volatile organic carbon are relatively unimportant. Interestingly, in the cost ranking, ozone, which is formed from the interaction of nitrogen oxides and volatile organic carbon, is nearly in last place, well behind particulates, and less damaging even than carbon monoxide and nitrogen oxides. In part this might be due to our inability to capture all of the effects of ozone. Nevertheless, it appears that air pollution policy has focused too heavily on ozone control and not enough on particulate control.

11.1.5 Sources of uncertainty

There is considerable uncertainty at every stage of the modeling process. We review some of the uncertainties below, and discuss them in more detail in the relevant chapters of the report.

When estimating the *status quo* exposure (Chapters 11.2 and 11.6), we used a county average, which may poorly reflect the exposure levels of many people. Furthermore, we did not have ambient data in many areas, particularly rural areas, and had to rely on data in the same region of the country. When estimating ambient pollution levels after reducing motor vehicle emissions by 10% and 100% (Chapter 11.5 and Report 16), we used a simple model of pollution formation that took into account the average location of emission sources to main population concentrations, and for particulates that took into account the relative potency of particulates. We only looked at the emission sources in a particular air quality control region (AQCR), when determining how to allocate the cause of a particular county's ambient pollution level to different emission sources. We did not -- and could not without a much more sophisticated model -- account for the movement of pollution across AQCRs, as may occur with emissions from power plants with very high emission stacks.

In determining the health effects of ambient exposure (Chapters 11.3 and 11.6), there is uncertainty regarding the types and magnitudes of effects caused and the pollutants that are responsible. We could not estimate certain health effects that appear to occur and we did not treat certain populations as more or less susceptible to pollution. Particulates appear to have a particularly severe effect on the elderly population, however the difference has not been well quantified. Moreover, where we can quantify the health effects, we cannot rule out the possibility that other pollutants are involved. But perhaps most importantly, we could not reliably determine the effects of particulates based on their composition and size, and were forced to use a variety of assumptions that present a range of plausible values

Finally, there is considerable uncertainty in the valuation of health effects. We have used lower and upper bounds; in most cases, the upper bound is at least four times the lower bound. This difference by itself of course increases the uncertainty in the final damage estimates by a factor of four or more.

11.1.6 Report Organization

In Chapter 11.2, we present a number of the issues involved in estimating the *status quo* exposure for "criteria" pollutants that we consider -- carbon monoxide, nitrogen dioxide, ozone, and particulates. (We treat toxic pollutants differently; see the discussion in Chapter 11.6.)

Chapter 11.3, examines the health effects of carbon monoxide, nitrogen dioxide, ozone and particulates. Chapter 11.6 discusses how we quantify the link between exposure to toxics and the formation of cancer.

In Chapter 11.4, we discuss how we value health effects. Chapter 11.5 summarizes how we model the contribution of motor vehicles to ambient air quality. In Chapter 11.7, we discuss our results.

TABLE 11.1-1. POLLUTANTS AND QUANTIFIED HEALTH EFFECTS IN THIS STUDY

Criteria Pollutants	Health Effect[a]	Population in Lower Bound	Population in Upper Bound
Carbon Monoxide (CO)	Headache	All Ages	All Ages
	Hospitalization	Adults (> 65)	Adults (> 65)
	Mortality	Adults (> 65)	Adults (> 65)
Nitrogen Dioxide (NO_2)	Excess Phlegm	All Ages	All Ages
	Eye Irritation		
	Sore Throat		
Ozone (O_3)	Asthma Attacks	All Asthmatics	All Asthmatics
	Eye Irritation	Adults (> 17)	All Ages
	Lower Respiratory Illness	Non-Asthmatics (> 17)	Non-Asthmatics of All Ages
	Upper Respiratory Illness	Adults (> 17)	All Ages
	Any other symptom (ARD2)	none	All Ages
Particulates ($PM_{2.5}$, PM_{10}, TSP)	Asthma Attacks	All Asthmatics	All Asthmatics
	Respiratory-Related Restricted Activity Days (RRAD)	Non-Asthmatics	Non-Asthmatics
	Air Obstructive Disease (AOD)	All Ages	All Ages
	Mortality	All Ages	All Ages
Toxic Pollutants	**Type of Cancer Caused**		
Acetaldehyde	Oral Cavity and Pharynx	All Ages	All Ages
Benzene	Leukemia	All Ages	All Ages
1,3-Butadiene	All Sites	All Ages	All Ages
Diesel Particulates	Lung	All Ages	All Ages
Formaldehyde	Oral Cavity and Pharynx	All Ages	All Ages
Gasoline Particulates	Lung	All Ages	All Ages

[a]The health effects are discussed and quantified in the sections below on the individual pollutants Note that these are the quantified effects, there are some effects, such as the effect of CO on heart disease in persons under the age of 65, that we could not estimate Some of the terms are defined in Table 11 3-1

11.2 POLLUTION EXPOSURE

The production, distribution and combustion of gasoline and diesel produces hundreds of compounds -- many of which are transformed into yet other compounds by atmospheric chemistry involving solar radiation, water vapor, and pollutants from other processes. Most of these pollutants are harmful. A comprehensive analysis to consider all of the pollutants and all of their effects is well beyond the scope of our effort here. Instead, we include in our analysis those pollutants for which we have air-quality data and dose-response functions: carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), particulates (of two kinds), acetaldehyde, benzene, 1,3-butadiene, and formaldehyde. We do not include sulfur dioxide (SO_2) because there is no dose-response function (we discuss this more below), and we do not include lead because it has been phased out of gasoline.

Table 11.2-1 gives the National Ambient Air Quality Standards (NAAQS) for five so-called "criteria" pollutants.

11.2.1 Exposure To Criteria Pollutants

We estimate people's exposure to criteria pollutants using the county average of air quality monitors. This is broadly consistent with, but not necessarily identical to, the way in which exposure is estimated in the epidemiological studies that we use to estimate dose-response functions. For example, Schwartz and Zeger (1990: 63) used observations from an air-quality monitor two and a half miles from the study population. Dockery et al. (1992: 364) used a single monitor in St. Louis and in Knoxville to estimate people's exposure in each city. Ostro and Rothschild (1990: 240) used airport visibility data to estimate exposure to fine particulates in a metropolitan statistical area (a group of urban counties). Because we can not replicate *exactly* how each researcher chose to estimate exposure, we use the county average of all air quality monitors.[1]

Of course, air-quality monitors obviously are not perfect estimates of people's exposure (Lipfert et al., 1988: 3; Schwab, 1990; Lippmann and Lioy, 1985: 245). Monitors may be miles from people and even if the monitors are in the center of a city, the monitor can not capture the variability in exposure levels that inevitably occurs. However, the proper objective is not necessarily to estimate exposure as accurately as possible, but rather to replicate as closely as possible the exposure estimates in the epidemiological studies that we use to estimate dose-response functions. (That is, the epidemiological studies that we use relate observed responses to a specific model of exposure, and so to use these studies to predict responses, we must use the same model of exposure as in the original studies.)

We note that variability in pollution levels is less of a problem for ozone and fine particulates, because they disperse relatively uniformly. Portney and Mullahy (1986) found that there was little difference between using ozone readings from the

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[1]We use data, supplied by the EPA (1993d), for all air monitoring stations in the U S , and weight all observations equally Future work should perhaps weight more heavily those monitors most closely associated with population exposure

monitor nearest to their study population versus the average readings from all monitors within a five, ten and twenty mile radius.

11.2.2 Estimating Exposure and Treatment of Missing Data

We have no air pollution observations for the majority of the 3,000-plus counties in the U.S. and we have an incomplete set of observations for the rest (EPA, 1993d). To fill incomplete observation sets, we interpolate, and for counties with no observations we use as a proxy a county in one of the ten Federal regions in the U.S..

We aggregate our air pollution observations in the four ways dictated by the epidemiological studies that we use. We estimate the daily one-hour maximum pollution level, the daily average, the annual average and the cumulative hours of exposure above various cutoffs. We consider each in turn.

11.2.2 1 Estimating The One-Hour Daily Maximum Pollution Level

The one-hour daily maximum is the hour in the day with the highest average pollution level. Unfortunately, it is very common for one or more observations to be missing, because the data are not being collected, the air monitor is being serviced or for other reasons. The missing observations might have been the highest. Faced with missing observations, we must either pick the highest of the remaining hours or ignore the observations from that day. We use two algorithms to determine the one-hour maximum -- one used by the California Air Resources Board (CARB) and the other by the EPA:

i) CARB (1992: 42) uses the highest of the available observations in a day if there at least six observations for each 1/3 day (hours 0 through 7, 8 through 15, and 16 through 23), and they are missing no more than two consecutive hourly observations.

ii) The EPA uses the highest of the available observations in a day if at least 75% of the observations (at least 9 hours) are available between 9 AM and 9 PM (see "Protection of Environment." Title 40 *Code of Federal Regulations.* Part 50, 1995 ed.).

We use CARB's method to estimate the one-hour maximum for CO and NO_2, because we estimate the health effects of CO and NO_2 using the work of Schwartz and Zeger (1990), who obtained their data from CARB.[2]

Our estimates of the health effects of ozone are derived from the work of Holguin et al. (1985), Kinney and Ozkaynak (1991), Ostro et al. (1993), and Whittemore and Korn (1980). We do not know which algorithm these studies used to estimate the one-hour maximum for ozone. We assume they used the EPA method, and so use the EPA method ourselves.[3]

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[2]We also use Morris et al (1995), but it is unclear which algorithm they used

[3] With both methods there is a possibility that the true one-hour maximum could be missing If the authors of the health effects studies used these methods, however, then we should also or our results will be biased

Filling in Missing Days of Data for the One-Hour Daily Maximum in Counties with Some Data

Some days either do not have enough observations to meet the CARB or EPA criterion, or else have no observations at all. To estimate these missing days observations, we considered two interpolation methods.

i) In their nationwide study of the health effects of ozone, Krupnick and Kopp (1988) placed the daily one-hour maximums recorded over the ozone season in "bins" of ten ppb width (there were 36 bins because the peak ozone value was 360 ppb) and scaled up the number of observations in each bin so that the total number of observations in the bins equaled the number of days in the ozone season. For example, if one bin had 50% of the observations then they assigned 50% of the missing observations to that bin, replacing the missing observations with the value of the midpoint of the bin.

ii) In their study of the effect of air pollution on mortality, Kinney and Ozkaynak (1991) used the average of eight air pollution monitors to estimate exposure in Los Angeles County. When one monitor did not have an observation for a day, they used the other monitors in the county to estimate the missing observation.

$$x_{ijk} = \bar{x}_{jk} \cdot \frac{\bar{x}_{ik}}{\bar{x}_{k}}$$

where.

x_{ijk} = one-hour maximum reading missing from monitor i, on day j, in year k

$\bar{x}_{jk}$ = mean of other monitors' reading for day j

$\bar{x}_{ik}$ = annual mean of one-hour maximum readings for station i and year k

$\bar{x}_{.k}$ = annuals mean across stations for all stations with a one-hour maximum

There are drawbacks to Kinney and Ozkaynak's procedure. If a county does not have an observation from any monitor for a given day, we can not estimate that day's observation. We considered using monitors in nearby counties; however, such a procedure is unrealistic to consider for all 3110 counties in the U.S.

We chose to use Krupnick and Kopp's method, but with a few changes to make the estimated pollution levels account for seasonal differences.

For CO and NO_2, we use a two-stage binning method. In the first stage we consider the observations from a county in two-month blocks which allows us to control for differences in pollution levels that may occur over the course of the year If there are six or more observations in a block we use the binning method on the available data in the block. If there are fewer than six observations in a block we go to the second stage which collects the remaining missing observations and assumes

that they have the same distribution as the observations found over the course of the year.

For ozone, we use observations from the ozone season separately from the non-ozone season. (Table 11.2-2 gives the ozone season for each state in the U.S.) In the first stage of binning for the ozone season we use two-month blocks; for ozone seasons with an odd number of months (e.g., Idaho's April through October ozone season), we use either July or August separately. After the first stage of binning we estimate any remaining missing observations using all observations from the ozone season.

Estimating the Pollution Level in Counties Without Pollution Data

Counties with no air quality monitors probably have relatively low pollution levels, because the air pollution monitors presumably are placed where there are pollution problems. We use the county with the lowest annual average pollution level in each of ten regions in the U.S. as a proxy for the counties with no observations. For CO and NO_2, we use the 10 regions established by the EPA for administrative purposes and choose the two counties (one urban and one rural) with the lowest annual average pollution level as the proxy for the other counties in the region.[4] For ozone, we group counties by the nine ozone seasons and use the same procedure as we do for CO and NO_2.

11.2.2.2 Estimating The Daily Average Pollution Level

We use the daily average PM_{10} level to estimate the effects of particulates on mortality and chronic illness, the daily average TSP level to estimate the effects of particulates on asthma, and the daily average $PM_{2.5}$ level to estimate the effects of particulates on respiratory-related restricted activity days (RRADs) and mortality. Here, too, there are plenty of missing observation, in large part because the norm is to collect particulate measurements every six days. We describe first how we fill-in missing observations for counties with data, and then address counties with no particulate data at all.

Estimating Particulate Exposure In Counties With Some Particulate Data

For counties with particulate data, we determine the daily average PM_{10} and TSP levels in two stages; the process for filling in TSP observations is exactly analogous to the PM_{10} case.

i) We consider each county separately, and divide the year into six two-month blocks. If there are any observations for PM_{10} in a two-month block, then we fill in the rest of the observations using Krupnick and Kopp's "binning" method, discussed above. We then use the "binning" method to fill in any remaining missing observations in the year.

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[4]There are few rural CO monitors so we chose to use the lowest of both urban and rural counties as the proxy for rural areas The states in each EPA region are given in Table 11.2-2

ii) If a county does not have PM_{10} observations but does have TSP observations then we used the national ratio between PM_{10} and TSP to adjust the TSP data to determine the PM_{10}.[5] For example, if the PM_{10}/TSP ratio is 0.6 and the TSP level is 100 $\mu g/m^3$ then the PM_{10} level equals 60 $\mu g/m^3$. After converting the TSP observations, we use Krupnick and Kopp's "binning" method to fill in the rest of the missing observations for the two-month block. We then use the "binning" method to fill in any remaining missing observations in the year.

Estimating Particulate Exposure In Counties Without Particulate Data

To estimate the pollution level in counties with no data, we use a two-stage procedure; the process for filling in TSP observations is exactly analogous to the PM_{10} case.

i) If a county has no PM_{10} data and has TSP data, then we adjusted the TSP observations by multiplying them by the national PM_{10}/ TSP ratio.

ii) For counties with no data, we use a proxy to estimate the pollution level. We use the county in the same EPA region with the lowest annual average PM_{10} level, on the assumption that air-pollution monitors are placed where there are pollution problems.

There are not enough $PM_{2.5}$ observations for us to use them directly to estimate RRADs. Instead, to estimate the daily average $PM_{2.5}$ concentration, we simply multiply the daily PM_{10} level by the national $PM_{2.5}/PM_{10}$ ratio.

11.2.2.3 Estimating The Annual Average County Pollution Level

We use the annual average CO level to estimate the effects of toxics, and we use the annual average $PM_{2.5}$ level to estimate the effects of particulates on long-term mortality.

For CO, the county must have observations for 10% of the days over the course of a given year.[6] For counties with insufficient observations, we use as a

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[5]It is a fairly common procedure to assume that there is a constant relationship between PM_{10} and TSP, and Simpson (1992) found that the ratio of PM_{10} to TSP observations from Brisbane, Australia stayed constant over the course the year

To calculate the PM_{10}/TSP ratio, we take the annual average ambient level of PM_{10} and TSP for each county in the U S that has measurements of both pollutants, and then take an average of these ratios

[6]Previous work set a relatively high criterion (50% or 75%) for the inclusion of any given monitor Because we are interested in estimating the effects of pollution in all counties in the U S., we use a lower standard of completeness, under the assumption that a few observations is a better estimate of the county pollution level than the use of a proxy, such as the county with the lowest pollution level in that region

Johnson et al (1992b 4) assumed that a monitor must have 75% of its maximum possible observations in order for it to be included in their data set, when estimating the carboxyhemoglobin levels caused by ambient CO The EPA (1992a 2-2), in its estimates of national ambient levels of criteria pollutants, used monitoring data if 50% of the observations were available Portney and Mullahy (1990), when estimating the effect of ozone and TSP on chronic disease, used a monitor if it had at least half the maximum number of observations

proxy the county with the lowest annual average pollution level in the region, taking into account whether the county is urban or rural. For $PM_{2.5}$, we use the annual average of the daily $PM_{2.5}$ readings, based on the daily PM_{10} level adjusted by the national $PM_{2.5}/PM_{10}$ ratio.

11.2.2.4 Estimating the Cumulative Hours of Exposure

Following Abbey et al. (1991b; 1993; 1995), we use the cumulative hours of PM_{10} exposure to estimate the effect of particulates on chronic disease. Each day above a given threshold (e.g., 100 $\mu g/m^3$) contributes 24 hours to the year's hours of exposure.

11.2.3 Emissions from natural sources, and natural background pollution levels

To estimate the effects of motor-vehicle pollution, we estimate ambient pollution with (PI) and without (PP) motor-vehicle related emissions, taking into account all sources of pollution including natural sources. The ambient pollution with motor vehicles (PI) is the actual ambient air pollution measured at air-quality monitoring networks throughout the U. S. As explained in Report #16 in the social-cost series listed at the beginning of this report, we estimate the ambient air pollution without motor vehicles (PP) as follows:

$$\text{Assume } \frac{PP}{PI} = \frac{PP^*}{PI^*}$$

$$PP = PI \times \frac{PP^*}{PI^*}$$

where:

PP = the estimated actual pollution level, without motor-vehicle-related emissions

PI = the actual ambient pollution level (data from air-quality monitors; discussed in Reports 11, 12, and 13)

PP* = the modeled level of pollution, without motor-vehicle related emissions

PI* = the modeled level of total ambient pollution

Ambient pollution PP* and PI* is modeled as a function of emissions, dispersion, and atmospheric chemistry. For the purposes of this discussion, we may assume that PP*/PI* is proportional to the ratio of total emissions excluding motor-vehicle emissions to total emissions, where total emissions (T) consists of known emissions from natural sources (N), motor vehicles (M), and other sources (O):

assume

$$\frac{PP^*}{PI^*} = \frac{N+O}{N+M+O}$$

$$PP = PI \times \frac{N+O}{N+M+O}$$

(1)

Equation (1) is the simplest form for our model. However, the difficulty with equation (1) is that the data for N, emissions from natural sources, often are missing or incomplete (EPA, 1994a, 1995a, 1995b).

There are three ways to deal with missing or incomplete data for N: 1) estimate the missing data; 2) use instead an estimate of the natural background pollution concentration (PB) due to natural sources; or 3) combine the known N with estimate of the natural background pollution that remains on account of the unknown N. The first method is self-explanatory. With the second method, we in essence assume that the ratio of total anthropogenic pollution without motor vehicles to total anthropogenic pollution is equal to the ratio of total anthropogenic emissions without motor-vehicle emissions to total anthropogenic emissions:

$$\frac{PP-PB}{PI-PB} = \frac{O}{M+O}$$

$$PP = PB + (PI-PB) \times \frac{O}{M+O}$$

(2)

where:
PB = natural background pollution
PP-PB = total anthropogenic pollution without motor vehicles
PI-PB = total anthropogenic pollution

That the background concentration due to natural sources (PB) is proportional to emissions (N), as shown in equation (2), can be derived from equation (1):

$$PP = PI \times \frac{N+O}{N+M+O}$$

$$PB = PI \times \frac{N}{N+M+O}$$

$$PP = PB + \frac{PI \times O}{N+M+O}$$

$$PB \times N + PB \times M + PB \times O = PI \times N$$

$$N = \frac{PB \times M + PB \times O}{PI - PB}$$

$$PP = PB + \frac{PI \times O}{\frac{PB \times M + PB \times O}{PI - PB} + M + O}$$

$$PP = PB + \frac{PI \times O \times (PI - PB)}{PB \times M + PB \times O + M \times PI - M \times PB + O \times PI - O \times PB}$$

$$PP = PB + \frac{PI \times O \times (PI - PB)}{M \times PI + O \times PI}$$

$$PP = PB + (PI - PB) \times \frac{O}{M+O}$$

Equation (2) is the general form of our model: if PB is taken to be zero, and O includes N, then equation (2) becomes equation (1). Thus, where we have good, complete data on N, we assume that PB = 0, and include N in O. Alternatively, if we have no data on N, we use an estimate of PB. We also can use PB and N both, so long as the total contribution of natural sources is in effect exactly and completely apportioned between N and PB. (That is, we can estimate a fraction of the natural emissions, and then estimate PB such that it accounts for the remaining, unestimated natural emissions.)

The question, then, is whether we work solely with emissions N, solely with the background concentration PB, or with some combination of both. In the case of PM, we use emissions (N). In the case of CO, NO_X and ozone, we use a combination of N and PB.

Whenever we use PB, we can proceed in two ways: a) assume that natural sources contribute a constant fraction of ambient pollution, or b) assume that natural sources contribute a constant concentration to ambient pollution levels. Obviously, neither method is perfect: the true natural background pollution concentration is neither fixed nor a fixed percentage of total ambient pollution. Both the natural pollution level, and the fraction of total emissions that are from natural

sources, vary over time and space. The advantage of the fixed-percentage approach is that it can represent the variation in the natural pollution level that occurs, say, between seasons, and that it always results in a background pollution level that is less than observed ambient pollution levels. The disadvantage is that it ignores the fact that anthropogenic pollution levels are typically more variable than natural pollution levels [7] On this last score the fixed-concentration assumption is preferred. We will use it here, whenever we use an estimate of PB.

11.2.3.1 Carbon Monoxide -- Natural Level

Natural sources of CO include plant emissions, oxidation of natural hydrocarbons, forest wildfires, oceans and methane oxidation. Our inventory only includes wildfire emissions, which are less than 5% of global emissions (Wuebbles and Edmonds, 1988: 50). Hence, we use an estimate of the natural background concentration (PB) and the available emission inventory, N.

Seiler and Junge (1970: Table 1) took CO measurements in many areas across the globe and found that CO in "clean air conditions" ranges between 0.1 and 0.2 ppm. Similarly, Graedel and Crutzen (1989: 62) reported that "clean atmospheres" in the Northern Hemisphere have 0.1 to 0.2 ppm CO. The EPA (1991: 4-15) reported that the average concentration of CO is 0.9 ppm and natural sources contribute 40% of emissions, which very roughly suggests a background rate of 0.3 to 0.4 ppm In our lower bound case, we assume a background rate of 0.4 ppm, and in our upper bound case we assume 0.1 ppm.

11.2.3.1 Nitrogen dioxide-- Natural Level

Natural sources of NO_X include lightning, microbial processes in the soil, forest wildfires, stratospheric oxidation of N_2O and oceans. The most important sources appear to be microbial processes in the soil and lightning, with both sources contributing about the same amount of emissions (EPA, 1993c: 4-12). Emissions from oceans are negligible. Our emissions inventory includes emissions from soils and wildfires, but not production from lightning or stratospheric oxidation of N_2O. It appears that lightning and stratospheric oxidation of N_2O account for about half of all natural emissions of NO_X (EPA, 1993c: 4-12). To account for the missing emissions, we considered scaling up the emissions inventory by a factor of two, but it is unlikely that NO_X emissions from the soil are well correlated with NO_X generated from lightning.

Instead, we chose to assume a natural background level of NO_2, although we recognize this has difficulties for several reasons. First, most of the available data on natural emissions or natural background levels pertain to NO_X, which comprises

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[7]The variation of anthropogenic sources occurs between seasons and geographic areas (types of fuels used, industrialization and population levels are important factors causing differences between geographic areas) Of course, the natural pollution level also varies between geographic areas and over time due to temperature, proximity to oceans, plant life, wildfires, volcanoes, and other factors However, as a rule variation in anthropogenic pollution is the main determinant of variation in air quality, natural sources (such as volcanoes and wildfires) rarely dominate anthropogenic sources

NO as well as NO_2. We assume that NO_X is equal parts NO and NO_2; i.e., that the ratio of NO and NO_2 in NO_X is 1:1. Second, the natural background concentration of NO_X varies greatly from over space and time, owing to variability in natural emissions of NO_X, and to the relatively short atmospheric residence time of NO_X (a few days, according to Logan, 1983: 10786). Third, it can be difficult to measure precisely the trace quantities of NO_X present in the atmosphere.

Due to these difficulties, the estimates of the background concentration of NO_X that we found vary by at least two orders of magnitude.[8]

- Logan et al. (1981: 7210) reviewed a number of estimates, including ground level estimates of NO in clean air in Wyoming and Colorado, and reported that the "few measurements available for NO and NO_2 in clean air," range from roughly 0.01 to 0.1 ppb.

- The EPA (1993c: Table 7-2) reported that "for isolated rural sites and coastal inflow areas in the United States, the NO_X concentrations generally range from a few tenths to one ppb." It added that remote maritime areas had NO_X concentrations ranging from 0.02 to 0.04 ppb, and measurements in remote tropical areas ranged between 0.02 and 0.08 ppb.

We attach more weight to terrestrial measurements, particularly when there is little chance that they will be contaminated by the anthropogenic pollution (it is common for urban pollution to be transported long distances). The remote tropical measurements may be the best indicator of natural pollution levels in the U.S., although we recognize that few areas in the U.S. resemble tropical areas.

In sum, it appears that the natural background level is between 0.01 and 0.20 ppb. We already have emissions from wildfires and microbial processes in the soil, which account for roughly half of natural emissions. So we use half of the estimated natural background rate: 0.005 ppb in our upper bound case and 0.1 ppb in our lower bound scenario.

11.2.3.3 Ozone -- Natural Level

As mentioned above, our treatment of ozone uses data on emissions of ozone precursors from natural sources (N), and data on background ozone levels (PB). The ozone formation equation discussed, in Report #16 in the social-cost series listed at the beginning of this report, takes into account the emissions of NO_X and VOC from soil and plants, but does not account for ozone that is injected from the stratosphere. To account for this, we have added a constant ozone contribution from the stratosphere.

A number of studies have estimated the ozone level in "clean" areas, which ostensibly are reasonably well isolated from anthropogenic sources[9]. The available

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[8] NO_X observations over the middle of the ocean often are an order of magnitude lower than observations in clean air on land

[9] It is not clear, however, if these areas are unaffected by long-range transport

estimates of the background ozone level agree reasonably well. We review these studies below, with an eye towards identifying the contribution of stratospheric ozone (which is the only "natural" emissions source not accounted for in our emissions inventory).

- Hoffer et al. (1982) measured ozone levels in the Mojave Desert between 1976-1979 and found the daily one-hour maximum readings stayed near 0.04 ppm throughout the year. However, these readings may have been influenced by the transport of pollutants from Los Angeles (Pryor and Hoffer, 1991).

- Evans et al. (1983) reviewed observations collected in 1979 from six remote sites in the United States in the National Air Pollution Background Network. The mean daily one-hour maximum ranged from 0.033 ppm in the winter to 0.049 in the summer.

- The EPA (1986: 5-105) found that the arithmetic mean of one-hour ozone observations in rural areas varied between roughly 0.02 and 0.04 ppm. However they could not be certain that these readings were free from urban pollution

- Altshuller (1987: 1416) reviewed a number of methods to estimate the background level and concluded that in the spring and summer the background level ranges between 0.01 ppm and 0.02 ppm.

- Lefohn (1990: 200-201) collected observations from clean sites in American Samoa; Barrow, Alaska; Mauna Loa, Hawaii; the South Pole; and various remote sites in the United States and Canada. The average one-hour maximum for most of these sites ranged between roughly 0.03 and 0.045 ppm; the observations at the South Pole were closer to 0.015 ppm, probably representing the contribution of ozone from the stratosphere.

Our best estimate is that the *total* natural background level of ozone is around 0.025 to 0.035 ppm. We need to break this total into the fraction due to emissions from local biogenic emissions of VOC and NO_X (which we account for separately), and the fraction due to stratospheric ozone. Based on the above evidence, a reasonable range for the constant stratospheric contribution is 0.01 to 0.015 ppm.

11.2.3.4 Particulate Matter -- Natural Level

Windblown soil, forest fires, salt spray and secondary particulates formed from ammonia, nitrogen oxide, sulfur oxide and reactive organic gases contribute to the natural ambient particulate concentration. We have emissions estimates for windblown soil, forest fires and natural emissions of nitrogen oxides and reactive organic gases, the latter two of which we use to estimate secondary particulate formation. However ,the inventory is not complete. Among other things, we do not have estimates of salt spray, natural sources of sulfur oxides, and lightning-

produced and stratospherically injected nitrogen oxides. Furthermore, the inventory for windblown soil does not include "dust devils", which are a potentially large source of emissions in the western states.

It is difficult to correct for these deficiencies. To account for missing natural emissions, we increase the estimates of wind erosion by 20% in our lower bound case and 10% in the upper bound. Furthermore, we account (to some extent) for missing emissions by restricting the maximum county PM_{10} reading to 200 $\mu g/m^3$ and the maximum TSP reading to 325 $\mu g/m^3$, because readings above this are most likely due to dust storms caused by wind erosion of agricultural and non-agricultural land.

TABLE 11.2-1. CALIFORNIA AND NATIONAL AMBIENT AIR QUALITY STANDARDS (NAAQS)

Pollutant	Averaging Time	California Standard	National Primary Standard
Carbon Monoxide (CO)	8 hour	9 ppm	9 ppm
	1 hour	20 ppm	35 ppm
Nitrogen Dioxide (NO_2)	Annual Average	n.a	0.053 ppm
	1 hour	0 25 ppm	n a
Ozone (O_3)	1 hour	0 09 ppm	0 12 ppm
Particulate Matter (PM_{10})	Annual Geometric Mean	30 $\mu g/m^3$	n a
	Annual Arithmetic Mean	n a	50 $\mu g/m^3$
	24 hour	50 $\mu g/m^3$	150 $\mu g/m^3$
Sulfur Dioxide (SO_2)	Annual Arithmetic Mean	n a	0 03 ppm
	24 hour	0 04 ppm	0.14 ppm
	1 hour	0 25 ppm	n a

Source California Air Resources Board (1991c)
n a =not applicable

TABLE 11.2-2. OZONE MONITORING SEASON BY STATE

EPA Region	State	Starting Month[a]	Ending Month[a]
4	Alabama	March	November
10	Alaska	April	October
9	Arizona	January	December
6	Arkansas	March	November
9	California	January	December
8	Colorado	March	September
1	Connecticut	April	October
3	Delaware	April	October
3	District of Columbia	April	October
4	Florida	January	December
4	Georgia	March	November
9	Hawaii	January	December
10	Idaho	April	October
5	Illinois	April	October
5	Indiana	April	September
7	Iowa	April	October
7	Kansas	April	October
4	Kentucky	April	October
6	Louisiana	January	December
1	Maine	April	October
3	Maryland	April	October
1	Massachusetts	April	October
5	Michigan	April	October
5	Minnesota	April	October
4	Mississippi	March	November
7	Missouri	April	October
8	Montana	June	September
7	Nebraska	April	October
9	Nevada	January	December
1	New Hampshire	April	October
2	New Jersey	April	October
6	New Mexico	January	December
2	New York	April	October
4	North Carolina	April	October
8	North Dakota	May	September
5	Ohio	April	October
6	Oklahoma	March	November
10	Oregon	April	October
3	Pennsylvania	April	October

(continued next page)

EPA Region	State	Starting Month [a]	Ending Month[a]
1	Rhode Island	April	October
4	South Carolina	April	October
8	South Dakota	June	September
4	Tennessee	April	October
6	Texas (AQCR 4, 5, 7, 10, 11)[b]	January	December
6	Texas (AQCR 1, 2, 3, 6, 8, 9, 12)	March	October
8	Utah	May	September
1	Vermont	April	October
3	Virginia	April	October
10	Washington	April	October
3	West Virginia	April	October
5	Wisconsin	April	October
8	Wyoming	April	October

Ozone season data is from "Protection of Environment" Title 40 *Code of Federal Regulations* Part 58, 1995 ed

AQCR = Air Quality Control Region (see "Protection of Environment" Title 40 *Code of Federal Regulations* Part 81, 1995 ed)

[a]The Code of Federal Regulations did not state the day that the ozone season starts or ends We assume that the entire month is included in the ozone season

[b]Texas has two ozone seasons

11.3 HEALTH EFFECTS CAUSED BY CRITERIA POLLUTANTS

We estimate the health effects caused by criteria pollutants using dose-response functions derived from epidemiological studies that link ambient air pollution levels people face in their everyday life and the adverse health effects that people also experience.[1] A dose-response function is simply an equation that estimates the change in the incidence of adverse health effects caused by air pollution. In this section, we discuss why we chose particular dose response functions, what these dose-response functions look like, and how they are derived.

There are a variety of health effects probably associated with motor vehicle air pollution. These effects are often broken down between acute and chronic effects. Acute effects include eye irritation, headaches, respiratory illness, hospitalization and relatively quick death, and chronic effects include asthma, chronic bronchitis, emphysema and cancer. We reviewed many studies that examine the link between air pollution and adverse health, but unfortunately found that most of them cannot be used to develop dose-response functions. This is especially true of studies of chronic morbidity. To be included in our analysis, a study must meet three criteria:

i). It must have a good statistical design, for example, we prefer that it estimate the effect of several pollutants simultaneously.

ii). It must produce coefficients that we can use to predict the effect of changing the level of pollution (many studies fail on this score).

iii). The health effect measured in the study must be economically evaluable. Thus, we cannot use studies that measure, say, lung functioning in terms of forced expiratory volume in one second (defined in Table 11.3-1), because we cannot estimate an economic value of this effect.

When quantifying adverse health effects, we chose not to use any of the numerous clinical or laboratory studies that have examined the link between air pollution and adverse health effects. Laboratory studies typically expose human subjects to low levels of a pollutant for short periods of time and estimate technical measurements of lung function such as forced expiratory volume in one second (FEV_1) (Table 11.3-1).[2] We chose not to use laboratory studies for a number of reasons. In order to use clinical studies to estimate health effects, one must replicate the conditions in the study, which requires that one model people's activities and personal exposure to pollution during the course of a day. This requires strong assumptions about people's activities or very large amounts of data. The measures of lung functioning that clinicians generally use are difficult to evaluate

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[1]When we use the term epidemiological study, we refer to studies that look at the effects of air pollution on people in their daily lives, as opposed to looking at the effects of air pollution in, say, a laboratory

[2]Laboratory studies have also looked at the effects of air pollution (sometimes very high levels) on animals Obviously extrapolating from effects on animals to humans is difficult, and we chose not to do so given the choice of using epidemiological studies using humans When quantifying the effects of toxics, we could not rely on epidemiological or laboratory studies so we used the results from animal studies, we discuss this further in Chapter 11 6

economically. What, for example, is the dollar cost of reduced FEV?[3] Laboratory studies do not account for the actual mix of pollutants that people face, and they allow for only short exposure periods (Spektor et al., 1991). Finally, clinical studies may be less sensitive than epidemiological studies in determining the effect of low levels of pollution (Ostro et al., 1991: 700; Spektor et al., 1988b). For these reasons, we chose not to use clinical studies and to rely instead on epidemiological studies.[4]

11.3.1 Some issues to consider when using epidemiological studies to quantify the health effects of air pollution

A number of issues arise when using epidemiological studies to quantify the health effects of air pollution. The literature on the health effects of air pollution is large and disjointed -- studies use different measures of pollution, different measures of health effects and different statistical procedures, and the results vary widely. The uncertainty makes our estimates only rough approximations of the "true" cost. In recognition of this uncertainty, we estimate plausible upper and lower bounds, rather than point estimates.

11.3.1.1 Health effects thresholds

The threshold is the point where air pollution ceases to have an economic cost; below the threshold we assume there is no cost. The evidence is limited regarding thresholds, but the more researchers look the more harm -- and less evidence of threshold -- they find. Oak Ridge National Laboratory and Resources for the Future (1992: 2-13) reviewed the evidence regarding thresholds and concluded that "as has already been experienced with respect to regulating cancer risks, we may find that there are no 'safe' exposure levels to ozone and other air pollutants." Dockery et al. (1993) found that in six U.S. cities, fine particulates were associated linearly with mortality, with no apparent "no effects" threshold. Pope et al. (1995a) observe that acute health effects have been associated with particulate levels well below the current National Ambient Air Quality Standards. (This is important, because particulates appear to be by far the most damaging pollutant.)

We assume there is no threshold for NO_2, ozone and particulates and estimate effects down to the natural (or background) pollution level (see Section 11.2.3). Similarly, when estimating cancer incidence, we assume that there is no threshold. However, we derive our dose-response function for CO from the work of

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[3]One perhaps can link clinical measures to understandable symptoms that are more easily valued For example, Ostro et al (1989) analyzed the results from ozone chamber studies and found that a 10% reduction in FEV_1 is linked to a 15% increase in the probability of a mild, moderate or severe lower respiratory symptom (which in turn can be valued economically) and a 6% increase in the probability of a moderate or severe symptom (which also can be valued economically) In our view, however, this tenuous linkage, stretches the already difficult task of valuation to the breaking point

[4]Not everyone shuns clinical studies Krupnick and Kopp (1988) reworked the results from a clinical study by McDonnell et al (1983) to estimate the health effects of ozone, and Hall et al (1992) used clinical studies to estimate the health effects of air pollution in Los Angeles Criticism of the exposure model (REHEX) that they used is discussed in Harrison and Nichol's (1990) work

Schwartz and Zeger (1990), who found a threshold for effects at 7 ppm. We assume that threshold here. We further discuss threshold levels below in the sections on each pollutant.

11.3.1.2 Interactions among pollutants

Pollutants may interact in ways that magnify or negate their individual effects. A mixture of pollutants -- which is what people are exposed to -- may be more or less harmful than is indicated by the simple sum of the effects of the pollutants measured in isolation.

The evidence for interactions is mixed. Krumm and Graves (1982) analyzed the causes of emergency cardiac and respiratory admissions to Cook County Hospital in Chicago and found a strong effect for SO_2 with little effect for coefficient of haze (COH) but significant interactions between SO_2 and COH. However, most studies have found little effect for SO_2 on hospital admissions and no interaction between SO_2 and particulates (Table 11.3-26). On the other hand, Krzyzanowski et al. (1992) found that in the presence of higher PM_{10} levels, ozone has a more detrimental effect on lung functioning. And researchers studying rats and guinea pigs have found interactions between various pollutants (Last et al., 1983; Warren and Last, 1987; Last, 1991).

In any event, we do not have dose-response functions that explicitly model interactions with separate coefficients that indicate the strength of any interaction. If interactions do occur, then we bias our results by excluding them, but we can not say the direction of the bias.

11.3.1.3 Proxy Pollutants

The pollutants that we do consider may be proxies for the truly pernicious (but overlooked) pollutants in the atmosphere. If the proxy is not perfectly correlated with the true pollutant, then we generally underestimate the effects of air pollution, and we may misallocate the estimated effects if the pollution sources (e.g., power plants versus cars) emit different ratios of the proxy (measured) and true (unmeasured) pollutant.[5]

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[5]Measurement error in the covariates can bias the estimated pollution coefficient downward or upward The direction of the bias depends on the amount of measurement and the correlation between the pollution variable and the other covariates Generally, we feel that the exposure measurement error will dominate as found by Schwartz (1994c 653, 1994d 372, 1994e 597)

Schwartz (1994a 653, citing Judge et al , 1980) notes "Error in exposure measurements can produce bias in either direction in the estimated regression coefficient in a multivariate model The total bias involves a sum of the term proportional to the ratio of the measurement error variance to the total variance in exposure, which always biases downward, and terms involving the correlation between exposure and covariates These can have different signs, and therefore can bias in either direction "

A similar point was noted by Klepper et al (1993 203) ". as long as measurement error in the pollution variables is classical, it will only cause the estimate of the pollution exposure coefficient to be biased asymptotically toward zero On the other hand, measurement error in the other variables can have far more pernicious effects It could cause the pollution variables to appear to have an effect on health when in fact they have no true effect or it could even cause them to appear to have an effect in the wrong direction "

11.3.1.4 Collinearity Among Pollutants

There is often a high degree of collinearity between pollutants, which makes it difficult to determine which pollutant is the culprit (Lipfert and Wyzga, 1995: 11). In studies of Los Angeles, Kinney and Ozkaynak (1991) and Shumway et al. (1988) reported that three pollutants predict mortality equally well. In studies of Steubenville, Ohio and Philadelphia, Moolgavkar et al (1995) linked O_3, SO_2 and TSP to mortality and concluded that there is not a single or dominant culprit such as particulates. Abbey et al. (1995) estimated associations between a variety of health effects and the pollutants TSP, PM_{10}, $PM_{2.5}$, SO_4, and ozone, but could not separate the effects of the different pollutants in part because of high correlations between them. Kinney et al. (1995) found PM_{10} correlated with ozone and CO in a study of the association between PM_{10} and mortality in Los Angeles.

We note, however, that researchers have found a link between particulates and mortality in places with very low SO_2 levels (Pope et al., 1992; Fairley, 1990), but have not found a link between SO_2 and mortality in places with very low particulate levels. This suggests at least that particulates in general and not SO_2 specifically are associated with mortality.

11.3.1.5 Not All Effects Considered

We do not include the personal cost of avoiding pollution because we know little about how much people try to avoid pollution or mitigate its effects. Evans et al. (1988) interviewed residents of Los Angeles and found that even though people are anxious about pollution, they do little to avoid air pollution. Other researchers, however, believe that avoidance behavior is important. In any case, we do not know the size of the cost and so, reluctantly, ignore it. This biases our estimates of the cost of air pollution downward by an unknown amount.

11.3.1.6 Unrepresentative Health Effects Studies

Some of our dose-response functions are derived from epidemiological studies of relatively small populations Nevertheless, we apply these functions to every county population group in the U.S.. To the extent that the pollution exposure and response of the measured population is not the same as the exposure and response of the [rest of the] populations in the U.S., our results might be inaccurate.

Moreover, some people are (exquisitely) sensitive to air pollution, and suffer effects of a different kind or to a different degree than does the rest of the population Asthmatics, children, the elderly, individuals with pre-existing respiratory infections (who suffer more from ozone pollution [see Ostro et al., 1993]), and individuals with heart disease (who are more susceptible to angina induced by carbon monoxide) are examples of sensitive populations. Because the effects of air pollution on these small but sensitive populations might not show up in studies of

large populations composed of mainly not-sensitive people, it is preferable in principle to identify these sensitive groups and estimate effects for them separately.

In practice however, it is very difficult to identify and determine the effect of air pollution on all possible groups. To keep our analysis manageable, we consider separately (to at least some extent) three reasonably well-studied groups: asthmatics, children and the elderly.

Asthmatics and Air Pollution

A number of studies have focused on the effects of air pollution on asthmatics particularly in regard to the incidence of asthma attacks. We use these studies (e.g., Whittemore and Korn, 1980) to estimate the increased incidence of asthma attacks. It is possible that asthmatics are more susceptible to other types of effects caused by air pollution, such as the effect of NO_2 on coughing which we discuss below, however we have no way at the moment to quantify some of the possible differences between asthmatics and the general public.

Children and Air Pollution

Although there is no doubt that air pollution affects children's health, the type of the effect is uncertain. Children reportedly do not suffer from symptoms such as coughing as much as adults do. Avol et al. (1985) found air pollution has roughly the same effect on technical measurements of lung functioning in children and adults, but children seem to suffer fewer symptoms from a given pollution level. Portney and Mullahy (1986) and Krupnick et al. (1990: Table 4) reported that children did not develop the ozone-related respiratory symptoms suffered by adults, and they found that particulates caused significantly fewer respiratory symptoms in children than in adults.

On the other hand Avol et al. (1985) reported that children might experience more lung damage from pollutants than adults because they are less likely to notice (i.e., have a higher tolerance to irritation). Furthermore because children are more likely than adults to be outside (where pollutant levels are higher) and exercising, they probably receive a larger dose of pollution (Hall et al., 1989). We further discuss the evidence for the effects on children below in the sections on each pollutant.

The Elderly and Air Pollution

People over 65 have 16% more restricted activity days due to acute respiratory symptoms than do those aged 45-64 (Table 11.3-2), suggesting that the elderly may also suffer greater morbidity due to air pollution.[6] In fact, many of the victims of air pollution do appear to be elderly, but until recently the epidemiological literature has not focused on elderly people. Schwartz and Dockery (1992a) reported a 10% increase in the mortality rate for people over the age of 65 and just 3% in people younger, due to a 100 $\mu g/m^3$ increase in ambient total suspended particulates.

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[6] Morris et al (1995) reported that carbon monoxide causes an increase in hospital admissions due to congestive heart failure Other recent studies examining the effect of air pollution on the elderly include Schwartz (1994a, 1994b) and Saldiva et al (1995)

Morris et al. (1995) reported that individuals over the age of 65 are more likely to enter the hospital for congestive heart failure because of CO.

We probably underestimate the effects of air pollution on the elderly because they usually are generally not well represented in epidemiological studies. Ostro (1989) confined their study of air pollution in Los Angeles to individuals under the age of 65, and Schwartz and Zeger (1990) examined the effects of air pollution on students nurses with a mean age of nineteen. The results of these studies probably should not be applied to the elderly. However for lack of more information we must treat the elderly similarly to other adults in most cases (an exception is our estimate of congestive heart failure caused by CO), and as a result we may underestimate the true effect of air pollution.

11.3.2 Carbon Monoxide

Carbon monoxide is dangerous because it binds with hemoglobin in the blood to form carboxyhemoglobin (COHb), thereby reducing the oxygen carrying capacity of the blood and limiting the release of oxygen from circulating hemoglobin (Allred et al., 1991: 90). CO adversely affects individuals with heart trouble (about seven million people in the U.S have heart disease) [EPA, 1991: 2-17]), and is linked to headaches (Schwartz and Zeger, 1990) (Tables 11.3-3 and 11.3-4). CO most strongly affects fetuses, infants, pregnant women, elderly people, people with anemia, and people with a history of cardiac, respiratory, or vascular disease (EPA 1991: 1-21).

11.3.2.1 Morbidity

CO affects the heart through the increase in the level of COHb in the blood. Unfortunately, we are unable to directly estimate the effect of COHb. There are two steps that we would have to perform: 1) use ambient CO data to estimate COHb blood levels, and 2) quantify the link between COHb and an "economically valuable" effect (i.e., an effect that has been valued by, say, estimated medical costs, a contingent valuation survey, etc.). Data and models are available for the first step, but, unfortunately, not for the second.

Johnson et al. (1992b) used a CO exposure model to track the CO exposure of individuals in Denver over the course of a day, and estimate the number of person-hours in which a Denver adult with ischemic heart trouble experienced various COHb levels.[7] We considered extrapolating these results so that Denver would have been the model for the rest of the urban areas of the country. We would have estimated person-hours of exposure in each city by scaling the Denver results by the ratio of the annual average CO exposure in each city to that in Denver, with an adjustment for differences in altitude.

At this point, we would have estimated person-hours of exposure. However, we could not have proceeded to estimate the effect of the exposure on people's health, because we are not aware of a dose-response function that links person-

[7]This model was adapted for use as the mobile-source hazardous-air-pollutant-exposure model, HAPEM-MS, we describe in detail how we use HAPEM-MS to estimate toxics exposure in Chapter 11 6 of this report

hours of COHb exposure to an economically valuable effect. The EPA (1991: 1-20) reported that COHb levels of 3% to 6% increase angina symptoms, but they did not specify the relationship between hours of elevated COHb, the level of COHb and the likelihood and strength of the effect on angina. Other studies (e.g., Allred et al., 1989) have linked COHb levels to the onset of angina in individuals that are exercising, but we do not know how to value this effect. However, we concluded that there is not enough information available to develop a useful dose-response function.

Instead, we skipped the intermediate step of estimating COHb and focused on epidemiological studies that estimate the linkage between CO and adverse health effects. We begin with a review of studies of CO levels and hospital admissions.

A number of studies (Table 11.3-4) have examined the possible link between CO and hospital admissions, especially for cardiovascular problems. Kurt et al. (1978) found more cardiorespiratory admissions in an emergency room in Denver on days of high CO levels compared to days of low CO levels. The levels of O_X, NO_X and sulfur compounds (a subset of PM_{10}) were low and uncorrelated with CO and thus unlikely to confound the results. Ponka (1991) and Sunyer et al. (1991) also found a correlation between CO and hospital admissions, but the authors did not control for other pollutants, and calculated only the correlation between pollutants and admissions. Morris et al. (1995) and Schwartz and Morris (1995) both found CO significantly linked to congestive heart failure (ICD-9 code 428); the Schwartz and Morris study is particularly important because it controlled for PM_{10}, an important possible confounder. Not all researchers have found an effect of CO: in a study of residents of Steubenville, Ohio, Samet et al. (1981) did not find CO linked to respiratory-related emergency room admissions. Nevertheless, the weight of the evidence in these studies suggests that CO does have an effect on hospital admissions for congestive heart failure. We use the results of Morris et al. to quantify the link.

We reviewed four epidemiological studies (aside from hospital admission studies) that tested the link between CO and morbidity (Table 11.3-3). Robertson and Lebowitz (1984) and Lebowitz et al. (1987) found CO correlated with cough and rhinitis but they did not report the coefficients that we need to develop dose response functions. In a diary study of student nurses in Los Angeles, Schwartz and Zeger (1990) found a significant association between CO and headaches. Such a link is not surprising given that CO is known to affect humans' neurological functioning and blood vessels in the eyes (EPA, 1991: 10-177 and Table 1-2). In another diary study of 24 Denver asthmatics, Perry et al. (1983) did not find CO linked to asthma attacks, although they did find a significant response for (particulate) nitrates. The lack of an observed effect might have been due in part to the small sample size and short data collection period (three months).

Morbidity and Carbon Monoxide: Conclusion

Carbon monoxide causes heart problems, headaches, and perhaps other illnesses. We are able to estimate the effects of CO on hospitalization for congestive heart failure in persons over 65 and on headaches for the general population, on the basis of the work by Morris et al. (1995) and Schwartz and Zeger (1990). We do not

estimate any effects of CO on heart problems in individuals below the age of 65 and thus undoubtedly underestimate the effects of CO.

The results of Morris et al. (1995: Figure 2) suggest that CO has effects down to very low levels; Schwartz and Zeger (1990) did not report a threshold for the effect of CO. On the basis of this, we assume that there is no threshold.

There is little evidence concerning whether children, or other age groups, are more or less susceptible to an increase in headaches caused by CO. When estimating headaches caused by CO, we treat children identically to adults in both the lower and upper bound scenarios.

Estimating Headaches Caused by Carbon Monoxide

Schwartz and Zeger (1990) used logistic regression to analyze the health symptoms reported in the diaries of 110 student nurses living in Los Angeles from 1961 to 1964. The highest one-hour daily measurements of CO, NO_2, SO_2 and ozone -- but not particulates -- were taken from a monitors located within 2.5 miles of the hospital where they lived and worked.

There are a number of weaknesses in the study. The omission of particulates, which are associated with adverse health effects in many epidemiological studies, will bias the results if particulates affect the incidence of headaches and particulates and CO are correlated. The young and healthy student nurses are *not* representative of the national population. The estimated coefficient probably is smaller than it would have been with a more representative national sample. On the other hand, student nurses are more likely to be exposed to debilitating agents which might make them more susceptible to getting headaches. Nevertheless, in spite of the weaknesses, we use the study.

Using logistic regression, Schwartz and Zeger (1990: 63) estimated the effect of CO on the incidence of headaches, where incidence was defined as the presence of a symptom when the previous day was symptom free. The median bout of headache lasted one day (Schwartz and Zeger, 1990: Table 2).

To use the results of Schwartz and Zeger, we start with the basic assumption of the logistic model that:

$$\ln\left(\frac{p}{1-p}\right) = X \cdot \beta$$

where:

p = the probability of a day with a headache

X = the matrix of covariates

β = the vector of coefficients in the model.

We solve for the probability of a day with headache:

$$p = \frac{1}{1+e^{-X\beta}}$$

We then use this equation twice: to calculate the probability of a day with a headache before and after a change in the ambient CO concentration. We calculate this change with the following equation:

$$\Delta\ Headache = \left[\frac{1}{1+e^{-\Omega-\beta_c\ PP}} - \frac{1}{1+e^{-\Omega-\beta_c\ PI}}\right]\ Population$$

where:

Δ Headache = change in the number of days with a headache

Ω = -2.107 (= the mean values of the other covariates multiplied by their coefficients)[8]

β_c = coefficient on CO, 0.0125 (Schwartz and Zeger, 1990: 63, Table 5)

PP = maximum one-hour CO level (ppm), after control

PI = maximum one-hour CO level (ppm), before control

Population = county population of all individuals, of all ages (U.S. Bureau of the Census, 1994).

Estimating Hospitalization for Congestive Heart Failure Caused by Carbon Monoxide

The work by Morris et al. (1995) quantifies the link between CO and hospitalization for congestive failure (ICD-9 code 428) in seven cities in the U.S. They report essentially a linear relationship between CO and hospitalization, although at very low CO levels (less than 2 ppm) the relationship is nonlinear and the effect of CO is stronger (Morris et al., 1995: Figure 2). Nevertheless, we assume that a linear approximation is reasonable (perhaps underestimating the true effect) and then estimate the average number of daily hospitalizations per 100,000 people over the age of 65 per ppm of CO in each city. We estimate a range of 0.05 to 0.12. Finally, we note that a certain fraction of the people that are admitted for congestive heart failure die, and their death should be valued much more highly than someone who is admitted for congestive heart failure and is then released. Based on the estimated number of cases of congestive heart failure reported in Morris et al. (1995) and the reported number of deaths from congestive heart failure (U.S Department of Health and Human Services, 1991), we find 6% of the admittances for congestive heart failure result in death.

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[8]Note that we assume that the other covariates do not change with a change in the CO level, and we set the covariates at their mean values The coefficients and the mean values of the covariates in the headache estimation are

Covariate	*Coefficient*	*Mean Value of Covariate*
Intercept	-2 218	1
CO	0 0125	16 71 ppm
Monday	0.386	0 143
Pollen Allergy	0 328	0 17 prevalence in sample

We estimate the change in congestive heart failure with the following equation:

$$\Delta \textit{Congestive Heart Failure Admits} = \beta\ (PP - PI)\ (1 - \textit{probability of death})\ \textit{Population Over 65}$$

where:

Δ *Congestive Heart Failure Admits* = change in the number of hospital admittances for congestive heart failure

probability of death = 6% of hospital admittances for congestive heart failure result in reported mortality for congestive heart failure

β = 0.05 (lower bound), 0.12 (upper bound)

PP = maximum one-hour CO level (ppm), after control

PI = maximum one-hour CO level (ppm), before control

Population Over 65 = county population of all individuals over the age of 65 (U.S. Bureau of the Census, 1994).

11.3.2.2 Mortality

Because of the high value of mortality and the high level of CO emissions from motor vehicles, it is important to establish if there is any relationship between CO emissions and mortality. Lipfert (1985: 765-766) charged that several studies have linked CO with increased mortality, but that "these findings have been largely overlooked." The EPA (1991: 1-12) concluded in the latest CO criteria document that the evidence is "suggestive but not conclusive" that CO may lead to sudden death in people with coronary artery disease. After examining a number of studies (Table 11.3-4), we also conclude that it is likely that CO is responsible for increased mortality, however most of the evidence does not allow us to distinguish between the effect of CO and the effect of particulates; the work of Morris et al. (1995) which we use to estimate the increased incidence of hospital admittances for congestive heart failure. As we noted, roughly 6% of the these cases result in death; we use this to estimate the effect of CO on mortality, recognizing that it is likely an underestimate of the true effect of CO on mortality. We present our review of the evidence regarding the link between CO and mortality:

- Hexter and Goldsmith (1971) reported that CO in Los Angeles caused increased mortality, however they measured only CO and O_3. CO may be capturing the mortality effect of other pollutants not included in the analysis, especially particulate matter. We believe that this study is not reliable.

- In an epidemiological study carried out in Baltimore, Kuller et al. (1975) found no association between ambient CO and myocardial infarction-caused mortality, although they did not rule out such an association.

- Mendelsohn and Orcutt (1979: 98-101) found that CO may cause between 7,000 and 35,000 deaths annually in the U.S., however the high standard

errors of the coefficients and the fact that NO_2 reportedly saved 63,936 lives per year makes us skeptical of the relationship between CO and mortality. The authors themselves state that sulfate is the dominant effect and that CO may have little, if any effect, on mortality.

- In another study of Los Angeles -- this one measuring several pollutants, including particulates (KM), hydrocarbons (HCs), and CO -- Shumway et al. (1988: 231) found a positive relation between mortality and three measures of pollution: KM, HC and CO.[9] However, the pollutant measures were so highly correlated that the authors could not attribute the mortality effects to any one pollutant. They concluded (p. 233) that future modeling efforts need use only one of these pollution measures. The evidence that we have seen indicates that particulates are the main cause of mortality.

- Kinney and Ozkaynak (1991), using the same data set as Shumway (1988), found a significant relationship between mortality and ozone and a group of pollutants: CO, NO_X and KM Due to collinearity, they could not distinguish whether CO, NO_X or KM was the responsible agent, so they concluded for predictive purposes that any one of the three is suitable.

- Finally, we note epidemiological studies by Stern et al. (1981), Edling and Axelson (1984) and Stern et al. (1988) that looked at the mortality rates of people in occupations exposed to high levels of automobile pollution -- motor vehicle examiners, garage workers and tunnel officers. All three studies found an abnormally high number of cardiovascular deaths, which is consistent with the hypothesis that CO causes cardiovascular problems. Moreover, Stern et al. (1981) found a higher incidence of cancer. However these studies did not control for other pollutants such as toxic gases and particulates.

- Kinney et al. (1995) estimated the risk of daily mortality as a function of pollution in Los Angeles from 1985 through 1990, and found that levels of PM_{10}, CO, and O_3 were, by themselves (in separate single-pollutant models) significantly associated with increased mortality risk. However, CO and O_3 levels were somewhat correlated with PM_{10} levels. When CO and PM_{10} were included simultaneously, the relative risk of both dropped and was no longer significant (at $p = 0.05$). When O_3 and PM_{10} were included simultaneously, PM_{10} was significantly associated with increased mortality risk, but O_3 was not. Kinney et al. (1995) do not draw any definitive conclusion about the relationship between CO or O_3 and mortality.

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[9]Describing KM, Shumway et al (1988 227) reported that "KM monitors [draw] ambient air through a segment of porous tape during two-hour intervals and then measured the amount of light transmitted through the tape "

Mortality and Carbon Monoxide: Conclusion

The available evidence *suggests* to us that an increase in the concentration of CO does increase the risk of death for some people. However, nobody has quantified this risk convincingly and in a way that we can use to establish a dose-response function that directly links CO with mortality. However, we estimate an effect of CO on mortality indirectly by using the work of Morris et al. (1995) and assuming that 6% of the estimated cases of hospital admittances for congestive heart failure result in mortality. We estimate this effect with the following equation:

$$\Delta \textit{Congestive Heart Failure Deaths} = \beta \cdot (PP - PI)\ (\textit{probability of death})\ \textit{Population Over 65}$$

where:

Δ *Congestive Heart Failure Deaths* = change in the number of hospital admittances for congestive heart failure resulting in death

probability of death = 6% of hospital admittances for congestive heart failure result in reported mortality for congestive heart failure

β = 0.05 (lower bound), 0.12 (upper bound)

PP= maximum one-hour CO level (ppm), after control

PI= maximum one-hour CO level (ppm), before control

Population Over 65 = county population of all individuals over the age of 65 (U.S. Bureau of the Census, 1994).

11.3.3 Nitrogen Dioxide

A number of laboratory and epidemiological studies suggest that NO_2 increases minor respiratory symptoms and eye irritation (Table 11.3-5). We did not find evidence linking NO_2 to more serious illnesses such as emphysema, chronic bronchitis and cancer. Of course it is possible that NO_2's contribution to more serious illness has simply escaped detection up until now. Populations most at risk include those people with preexisting respiratory disease, children and the elderly (EPA, 1993c: 1-23).

11.3.3.1 Morbidity

Minor Respiratory Symptoms

Schwartz and Zeger (1990) analyzed diary data collected from 110 student nurses living in Los Angeles, and found an association between NO_2 and the incidence of sore throat and phlegm attacks. A number of other studies have found similar results. Samet and Utell (1990) reported that NO_2 increases the susceptibility of people to respiratory infection and decreases lung functioning, and Goings et al. (1989: 1075) found NO_2 increases the susceptibility of adults to respiratory infections

Several studies have found NO_2 linked to cough, rhinitis and more general respiratory symptoms (Table 11.3-5), although they do not give the information necessary to determine a dose-response function. Robertson and Lebowitz (1984) and Lebowitz et al. (1987) examined symptoms reported by "normal" groups and an

asthmatic groups living in Tucson. Using spectral analysis, both studies linked NO_2 to coughing in both the normal and asthmatic groups, however spectral analysis is not useful for quantifying the effects of pollutants. Koo et al (1990), in a study of mothers and their primary school children in Hong Kong, found NO_2 linked to cough and chronic rhinitis in non-smoking mothers, but did not provide the information necessary to develop a dose-response function. Hasselblad et al. (1992) performed a meta-analysis (using the results from twelve studies) and found a significant relationship between respiratory effects in children under the age of twelve and a 30 $\mu g/m^3$ increase in NO_2 -- roughly the increase that would be expected with the use of a gas stove in one's home. The meta-analysis, however, only measured the effect of 30 $\mu g/m^3$ increase in NO_2 and did not allow for the interpretation of different changes in NO_2 levels, and thus we can not use it for this analysis.

Against these positive findings, three well-run epidemiological studies did not find that NO_2 increases respiratory symptoms (Table 11.3-5). Harrington and Krupnick (1985) reanalyzed the data base collected by Shy and Love (1980) in Chattanooga, Tennessee, and found that NO_2 did not increase respiratory disease in children. Instead, they found a "U" shaped dose-response curve, with the estimated illness rate at the highest observed two-week maximum concentration (384 $\mu g/m^3$) lower than that at the lowest observed concentration (27 $\mu g/m^3$). In a study of 5000 individuals living in four communities in southern California, Krupnick et al. (1990) found no relationship between NO_2 and acute respiratory disease. And Ostro et al. (1993), analyzing a subset of the data used by Krupnick et al. (1990), also did not find NO_2 linked to either upper or lower respiratory symptoms.

We did not find any evidence that NO_2 is associated with asthma attacks. Holguin et al. (1985), Dockery et al. (1989) and Roemer et al. (1993) all reported no link between NO_2 and asthma (Table 11.3-5).

Eye Irritation

Schwartz and Zeger (1990: 66) reported that NO_2 increases the incidence of eye irritation, probably because it is a precursor in the formation of peroxyacetyl nitrate. Lebowitz et al. (1987) also found NO_2 linked to eye irritation. Ostro et al. (1993), however, found ozone linked to eye irritation but not NO_2.

Severe Respiratory Symptoms

We found little evidence that NO_2 causes chronic respiratory problems or respiratory symptoms severe enough to require hospitalization (Table 11.3-5). Lafuma et al. (1987) did find evidence that rats exposed to NO_2 may develop more severe emphysema, but the rats in the study were exposed to levels of NO_2 higher than people commonly receive, which makes the study of doubtful usefulness in determining the effects of NO_2 on humans. In a study of Seventh-Day Adventists living in California, Euler et al. (1988) did not find any evidence of NO_2 increasing the incidence of COPD, and Dockery et al. (1989) did not see any link between NO_2 and bronchitis, chronic cough or persistent wheeze.

In Table 11.3-6 we review the effects of NO_2 on admissions to hospitals. Samet et al (1981), Bates and Sizto (1983), Sunyer et al. (1991) and Lipfert and Hammerstrom (1992) did not find NO_2 linked to hospital admissions. Richards et al. (1981), Bates et al. (1990) and Ponka (1991) did find NO_2 correlated with hospital admissions, but they did not control for the effects of other pollutants.

Morbidity Conclusion

It appears that NO_2 increases respiratory symptoms and eye irritation, but not chronic respiratory disease or hospital admissions. We use Schwartz and Zeger's (1990) work to estimate the increase in the number of days with sore throat, excess phlegm and eye irritation. We develop a dose-response function and apply it to all age groups -- including children, as explained next.

NO_2 adversely affects children. Although Roemer et al. (1993), Hoek et al. (1993), Dockery et al. (1989) and Harrington and Krupnick (1985) did not find an effect for children, the meta-analysis of 12 studies of children performed by Hasselblad et al. (1992) found that NO_2 causes respiratory problems in children.[10] The EPA (1993c: 1-17) also concluded that NO_2 adversely affects children 5-12 years old after it reviewed a number of indoor air epidemiology studies. The EPA found an insignificant (but directionally correct) effect for infants two years and younger [11]

We estimate the effects of NO_2 down to its background level. Schwartz (1989) reported reductions in pulmonary functioning below the NAAQS standard of 0.05 ppm, and Schwartz and Zeger (1990: 65, Figures 3 and 4) reported that even very small amounts of NO_2 increase sore throat and eye irritation. Both of these findings suggest that there is no safe level of NO_2.

Estimating Sore-Throat Days Caused by Nitrogen Dioxide

Using logistic regression, Schwartz and Zeger (1990) estimated the effect of NO_2 on the incidence of sore throat, where incidence was defined as the presence of a symptom when the previous day was symptom free. The median bout of sore throat lasted two days (Schwartz and Zeger, 1990: Table 2), so we multiply the estimated effect by two to account for the total number of days with a sore throat.

We calculate the change in the number of days with sore throat with the following equation:

$$\Delta \, Sore\ Throat = 2 \cdot \left[\frac{1}{1+e^{-\Omega-\beta_n PP}} - \frac{1}{1+e^{-\Omega-\beta_n PI}} \right] Population$$

where:

Δ Sore Throat = change in the number of days with sore throat

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[10]Meta-analysis is a more powerful test than individual studies and thus more likely to reject the null hypothesis (i e , NO_2 has no effect on children) when it is false

[11]In the infant analysis, the odds ratio was 1 09 with a 95% confidence interval of 0 95 to 1.26 (EPA, 1993c 1-18)

Ω = -3.782 (= the mean values of the other covariates multiplied by their coefficients)[12]

β_n = coefficient on NO_2, 2.571 (Schwartz and Zeger, 1990: 63, Table 5)

PP= maximum one-hour NO_2 level (ppm), after control

PI = maximum one-hour NO_2 level (ppm), before control

Population = county population of all individuals, of all ages (U.S. Bureau of the Census, 1994).

Estimating Excess-Phlegm Days Caused by Nitrogen Dioxide

Schwartz and Zeger (1990) estimated the effect of NO_2 on the incidence of excess phlegm, where incidence was defined as the presence of a symptom when the previous day was symptom free. The median bout of excess phlegm lasted two days (Schwartz and Zeger, 1990: Table 2); hence we multiplied the estimated effect by two, to account for the total number of days with a excess phlegm.

We calculate the change in the number of days with excess phlegm with the following equation:

$$\Delta \textit{ Excess Phlegm} = 2\left[\frac{1}{1+e^{-\Omega-\beta_n PP}} - \frac{1}{1+e^{-\Omega-\beta_n PI}}\right] \textit{Population}$$

where:

Δ Excess Phlegm = change in the number of days with excess phlegm

Ω = -3.386 (= the mean values of the other covariates multiplied by their coefficients)[13]

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[12]The coefficients and the mean values of the covariates in the sore throat estimation are

Covariate	*Coefficient*	*Mean Value of Covariate*
Intercept	-2 311	1
NO_2	2.571	0 13 ppm
Temperature	-0.0238	71.8 (degrees Fahrenheit)
Monday	0 4570	0.143
Sinusitis	0 7514	0 23 prevalence in sample

[13]The coefficients and the mean values of the covariates in the excess-phlegm day estimation are

Covariate	*Coefficient*	*Mean Value of Covariate*
Intercept	-2 379	1
NO_2	0.843	0 13 ppm
Temperature	-0 0169	71 8 (degrees Fahrenheit)
Monday	0 626	0.143
Smoking	0 207	0 564 [a]

[a] Smokers are categorized as 0=nonsmoker, 1=as much as 2 pack-years, and 2=more than 2 pack-years We do not know the percentage of the sample in each category We do know that 38 4% of the sample smoked and 18% of the sample smoked more than 15 cigarettes a day. We assume that 18% of the sample smoked more than 2 pack-years and the balance of the smokers (20 4% of the population) smoked less than 2 pack-years

β_n = coefficient on NO_2, 0.843 (Schwartz and Zeger, 1990: 63, Table 5)
PP = maximum one-hour NO_2 level (ppm), after control
PI = maximum one-hour NO_2 level (ppm), before control
Population = county population of all individuals, of all ages (U.S. Bureau of the Census, 1994).

Estimating Eye-Irritation Days Caused by Nitrogen Dioxide

Schwartz and Zeger (1990) estimated the effect of NO_2 on the incidence of eye irritation, where incidence was defined as the presence of a symptom when the previous day was symptom free. The median bout of eye irritation lasted one day (Schwartz and Zeger, 1990: Table 2).

The equation to estimate the change in the number of days with eye irritation is slightly more complicated than the other logistic equations because the NO_2 variable is the mean of the current and previous days' ambient levels. We use the daily one-hour maximum NO_2 level, however, rather than the two-day moving average because our procedure for filling in missing observations does not account for the exact day of the missing observation.

We calculate the change in the number of days with eye irritation with the following equation:

$$\Delta \textit{ Eye Irritation} = \left[\frac{1}{1+e^{-\Omega-\beta_n PP}} - \frac{1}{1+e^{-\Omega-\beta_n PI}} \right] \textit{Population}$$

where:

Δ Eye Irritation = change in the number of days with eye irritation
Ω = -3.463 (= the mean values of the other covariates multiplied by their coefficients)[14]
β_n = coefficient on NO_2, 1.604 (Schwartz and Zeger, 1990: 63, Table 5)
PP = maximum one-hour NO_2 level (ppm), after control
PI = maximum one-hour NO_2 level (ppm), before control
Population = county population of all individuals, of all ages (U.S. Bureau of the Census, 1994).

3.3 2 *Mortality*

The evidence in the literature linking NO_2 and mortality is weak (Table 11.3-6). In a time-series study of mortality records in St. Louis, Dockery et al. (1992) found

[14]The coefficients and the mean values of the covariates in the eye irritation estimation are

Covariate	*Coefficient*	*Mean Value of Covariate*
Intercept	-3 705	1
NO_2	1.604	0 13 ppm
Oxidant*Oxidant	0 000767	10 24 pphm
Monday	0 527	0 143
Pollen Allergy	0 5066	0 17 prevalence in sample

PM_{10} linked to mortality but not NO_2. Shumway et al. (1988), in a study of mortality in Los Angeles, found no link between NO_2 and mortality. Kinney and Ozkaynak (1991) used the same data as Shumway et al. (1988) and found an association between NO_2 and mortality, but high collinearity between the pollution variables prevented them from distinguishing between the effect of CO, NO_2 and KM (an indirect measure of particulates). Because the best evidence links particulates and mortality, we assume that KM, and not NO_2, is the best predictor of mortality in the Kinney and Ozkaynak (1991) work. And because we estimate mortality using particulate data, to also use NO_2 would invite double counting. Therefore, we conclude that there is as yet no satisfactory evidence of a link between NO_2 and mortality.[15]

11.3.4 Ozone

Ozone is a strong oxidant linked with a number of adverse health effects. It alters the mechanical functions of the lung, injures cells in the respiratory tract (Mehlman and Borek, 1987: 38), and reduces the lungs' ability to expel foreign (possibly carcinogenic) material (Pinkerton et al., 1989). It causes respiratory infection (Gilmour et al., 1993), inflammation in the respiratory tract (Koren et al., 1989) and acute respiratory symptoms, including asthma attacks (Holguin et al., 1985; Ostro et al., 1993). Moreover, Kinney and Ozkaynak (1991) and Moolgavkar (1995) reported that ozone is linked with mortality. All people are susceptible to the effects of ozone, but people with asthma, COPD, bronchitis and allergies are especially sensitive (Bresnitz and Rest, 1988: 395).

11.3.4.1 Acute Morbidity

Eye Irritation

In a review of the health effects of ozone Lippmann (1989c) noted that oxidants other than ozone such as peroxyacetyl nitrate and aldehydes are responsible for increased eye irritation. This is consistent with the laboratory results of Kulle et al. (1985), who did not find that ozone increases eye irritation. Since peroxyacetyl nitrate and aldehydes are generally found together with ozone, ozone may estimate their effects. If motor vehicles cause the same percentage of peroxyacetyl nitrate, aldehydes and ozone then we may use ozone as a proxy to estimate the effect of motor vehicles on eye irritation.[16]

Zagraniski et al. (1979), Schwartz and Zeger (1990) and Ostro et al. (1993) presented evidence linking ozone (and oxidants) to eye irritation, but only Schwartz and Zeger (1990) published coefficients for a dose-response function.

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[15]In analyses similar to ours, Schwartz et al (1985), Rowe et al (1986) and Hall et al (1989) also concluded that there is not enough evidence to link NO_2 and mortality

[16]Motor vehicles actually may contribute equally to ambient ozone and aldehyde concentrations Gasoline and diesel vehicles are responsible for roughly 40% of national emissions of VOCs (EPA, 1995a, 1995b), and motor vehicles are also responsible for roughly 40% of the ambient concentrations of formaldehyde and acetaldehyde (see Table 11 6-8)

Asthma Attacks

A number of studies have linked ozone and other oxidants to asthma attacks (Tables 11.3-7 to 11.3-9). Whittemore and Korn (1980) studied 443 asthmatics living in California and found both oxidants and TSP linked to asthma attacks. Dockery et al. (1989) found ozone significantly related to the asthma rates of grade school children. Holguin et al. (1985), in a careful study of Houston asthmatics, found ozone linked to asthma. Lebowitz et al. (1987), using spectral analysis, found ozone linked to wheeze, coughing and reduced pulmonary functioning in asthmatics. And Kulle et al. (1985) and Schwartz and Zeger (1990) found ozone related to chest discomfort, which is consistent with the hypothesis that ozone causes asthma attacks.

However, the evidence has not shown that ozone increases the number of *new* asthmatics. Portney and Mullahy (1990) and Abbey et al. (1991a) examined the long-term consequences of air pollution, and did not find that ozone increases the number of new asthmatics. Bates et al. (1990), Ponka (1991) and Cody et al. (1992) found that ozone causes asthma-related hospital admissions, but Richards et al. (1981) and Schwartz et al. (1993) have not reported this effect.

To estimate the effect of ozone on the incidence of asthma we use the results of Whittemore and Korn (1980) in our lower-bound case, and the results of Holguin et al. (1985) in our upper-bound case.

Acute Respiratory Symptoms Other than Asthma Attacks

Several studies have linked ozone to broad groups of respiratory symptoms. Portney and Mullahy (1986) used the 1979 Health Interview Survey and found ozone significantly related to minor respiratory-related restricted days (mRRADs) in adults. Ostro and Rothschild (1989) used six years of the Health Interview Survey (1976-1981) and found that ozone causes mRRADs, although the results were decidedly mixed -- some years of data yielded significant negative coefficients and other years yielded significant positive coefficients.[17] Finally, Ostro et al. (1993), in a re-analysis of data from a study of 290 families in Southern California (by Krupnick et al., 1990), found ozone linked to lower and upper respiratory symptoms.

In both the lower-bound and the upper-bound cases, we use the coefficients from Ostro et al. (1993) to estimate the effect of ozone on respiratory ailments. The work of Ostro et al. (1993) is preferable to that of Portney and Mullahy (1986) and Ostro and Rothschild (1989) because the latter studies relied on the number of incidents occurring over a two-week period rather than daily incidence and used a broadly defined dependent variable.

Because the lower respiratory illnesses counted by Ostro et al. (1993) include asthma attacks, which we estimate separately, we avoid double-counting respiratory ailments by subtracting the number of asthma attacks from the number of days with lower respiratory illness. This subtraction assumes that RRADs that include asthma

[17]Ostro and Rothschild's (1989) results for 1979 are close to Portney and Mullahy's (1986)

attacks include no other symptoms. To the extent that this is not true, we undercount symptoms and underestimate the effects of ozone.

Other Symptoms

In a study of 290 families in southern California, Krupnick et al. (1990) found ozone significantly related to a combined measure, termed ARD2, of any respiratory complaint, headache and eye irritation. This measure thus includes all of the effects already enumerated above -- eye irritation, asthma attacks, and upper and lower respiratory illnesses -- but also other effects, such as headaches.

In our upper-bound case, we use the coefficients from Krupnick et al. (1990) to estimate the effect of ozone on any symptom (ARD2) other than eye irritation, asthma attack, and upper and lower respiratory illness. Because ARD2 does include eye irritation, asthma, and lower and lower and upper respiratory illness, we must subtract the estimated number of cases of these from the estimated number of cases of ARD2[18].

We do not include any of these other [residual] symptoms in our lower-bound case.

Ozone and Morbidity: Conclusion

We found reasonably persuasive evidence linking ozone with eye irritation, asthma attacks, other acute lower and upper respiratory symptoms, and other symptoms (Table 11.3-10). We use Schwartz and Zeger's (1990) work to estimate the change in eye irritation associated with ozone, using ozone as an acceptable proxy for the oxidants that often appear together with ozone and directly cause eye irritation. We estimate the change in asthma attacks using the results of Whittemore and Korn (1980) in our lower-bound case, and the results of Holguin et al. (1985) in our upper-bound case[19]. We use the work of Ostro et al. (1993) to estimate the change in lower and upper respiratory symptoms other than asthma. Finally, we use the work of Krupnick et al. (1990) to estimate the change in all other symptoms (such as headaches), in our upper bound case only. Table 11.3-11 presents the health effects studies used by previous economic analyses.

In the upper-bound case, we treat children the same as adults when applying the dose-response functions for eye irritation, asthma, other lower and upper respiratory symptoms, and any other symptom, in the upper bound scenario. In the lower bound case, we do not estimate an effect for children for eye irritation, or for

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[18]We could use the ARD2 measure alone to estimate all symptoms associated with ozone, and not bother to estimate eye irritation, asthma, and respiratory illnesses separately However, we feel that it is more precise to add separate estimates of the individual effects than to use a broad, catch-all measure to count everything

[19]Because the number of cases of respiratory illness other than asthma equals the total number of cases of respiratory illness (Ostro et al , 1993) minus the number of asthma cases, the difference between the lower-bound (Whittemore and Korn, 1980) and the upper-bound (Holguin et al, 1985) number of asthma cases changes the number of asthma versus non-asthma cases of respiratory illness, but not the *total* number of cases of respiratory illnesses However, the change in the distribution of asthma versus non-asthma cases matters because the former are much more costly than are the latter (Table 11 4-4)

lower and upper respiratory symptoms. Although children suffer a decline in lung function due to ozone (Detels et al., 1991: 357), they are not as likely as adults to display symptoms such as coughing following ozone exposure.[20] The reason for this difference is not clear. However, even if children do not display symptoms it is possible that they still suffer damage from ozone exposure that will manifest itself when they are older.

We assume no threshold and estimate the effect of ozone down to its natural background level (0.015 ppm in the upper bound and 0.010 in the lower bound) because even very low levels of ozone cause adverse health effects.

Our assumptions regarding ozone are summarized below:

Symptom	Lower-bound case	*Children?*	Upper-bound case	*Children?*
Eye irritation	Schwartz and Zeger (1990)	No	Schwartz and Zeger (1990)	Yes
Asthma attacks	Whittemore and Korn (1980)	Yes	Holguin et al. (1985)	Yes
Respiratory illnesses except asthma attacks	Respiratory cases (Ostro et al. 1993) minus asthma cases	No	Respiratory cases (Ostro et al. 1993) minus asthma cases	Yes
All other symptoms	none	No	ARD2 cases (Krupnick et al., 1990) minus all of the above cases	Yes

Estimating Eye Irritation Caused By Ozone

Schwartz and Zeger (1990) analyzed data collected from 110 student nurses living in Los Angeles in the early 1960's and estimated the effects of CO, SO_2, NO_2, and oxidants on eye irritation, headache, chest discomfort, and other symptoms. Using logistic regression they found oxidants linked to the incidence of eye irritation. The median bout of eye irritation lasted one day.[21]

We calculate the change in the number of days with eye irritation with the following equation:

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[20]Avol et al (1985) and McDonnell et al (1985a) found that children suffer a decline in the amount of air that they can expel in one second (FEV1) but do not suffer from the coughing that afflicts adults following ozone exposure (Folinsbee et al , 1988, McDonnell et al , 1983) Krupnick et al (1990) and Portney and Mullahy (1986) found ozone linked to acute respiratory illness in adults but not in children

On the other hand Whittemore and Korn (1980) and Holguin et al (1985) found ozone provokes asthma attacks in both children and adults Berry et al (1991) found children suffering cough and runny nose due to ozone exposure, although the results of this study are weakened because other pollutants were not included in the analysis

[21]They define incidence as the presence of a symptom when the previous day was symptom free

$$\Delta \text{ Eye Irritation} = \left[\frac{1}{1+e^{-\Omega-\beta_o (PP^2)}} - \frac{1}{1+e^{-\Omega-\beta_o (PI^2)}} \right] \text{Population}$$

where:

Δ Eye Irritation = change in the number of incidences of days with eye irritation

Ω = -3.335 (= the mean values of the other covariates multiplied by their coefficients)[22]

β_O = coefficient on ozone, 7.67 (Schwartz and Zeger, 1990: 64, Table 5)[23]

PP = maximum one-hour oxidant level (ppm), after control

PI = maximum one-hour oxidant level (ppm), before control

Oxidant = Ozone/0.9 (Krupnick and Kopp, 1988: 2-22)

Population = county population of all individuals, of all ages in the upper bound case. In the lower bound case, the population includes only individuals above the age of 17 (U.S. Bureau of the Census, 1994).

Estimating Asthma Attacks Caused by Ozone -- Whittemore and Korn (1980)

Whittemore and Korn (1980) studied 443 physician-confirmed asthmatics from six communities in the Los Angeles. The participants lived within two miles of an air quality monitor and kept a daily diary regarding their health and any asthma medication used.

The dependent variable was the rate of asthma attacks per day among the respondents. Pollution variables were 24-hour average concentration ($\mu g/m^3$) of TSP and the daily maximum hourly average (ppm) of oxidants (including, but not limited to, ozone).

Following Krupnick and Kopp (1988: 2-37), we calculate the change in the number of days with asthma attacks with the following equation:

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[22]The coefficients and the mean values of the covariates in the eye irritation estimation are

Covariate	*Coefficient*	*Mean Value of Covariate*
Intercept	-3 705	1
NO_2	1 604	0.13 ppm
[Oxidant]^2	0 000767	10.24 pphm
Monday	0 4570	0 143
Pollen Allergy	0.5066	0 17 prevalence in sample

[23]Schwartz and Zeger (1990) used oxidants in parts per hundred million, so the published coefficient is 10^4 times smaller than shown here

$$\Delta \text{ Asthma Attacks} = \left(\frac{m}{1+m} - p \right) \text{ Asthmatic Population,}$$

$$m = \frac{p}{1-p} \, e^{[\beta_o (PP-PI)]}$$

where:

Δ Asthma Attacks = change in the daily number of asthma attacks

p = daily incidence rate for asthma = 0.0271 (Krupnick, 1988: 4-6).

β_O = coefficient on ozone, 1.66 (Whittemore and Korn, 1980: 691, Table 5)

PP = maximum one-hour O_X level (in ppm), after control

PI = maximum one-hour O_X level (in ppm), before control

Oxidant = Ozone/0.9 (Krupnick and Kopp, 1988: 2-22)

Asthmatic Population = 4.45% of the county population, based on the average of the asthma rate between 1988 and 1991 (Table 11.3-12); population data from the U.S. Bureau of the Census (1994).

As explained above, we use this equation in our lower bound.

Estimating Asthma Attacks Caused by Ozone -- Holguin et al. (1985)

Holguin et al. (1985) studied 51 non-smoking physician-diagnosed asthmatics from two Houston communities living within 2.5 miles of an ozone monitor. Using diaries kept by respondents, Holguin et al. (1985) determined the 12-hour asthma attack rates over a six month period.

Because it is impractical have air quality monitors at each person's home, Holguin et al. (1985) measured ozone inside and outside of the home over a relatively short period of time and regressed each set of observations on the ozone readings at a nearby outside monitor. Using the resulting regression coefficients, they estimated hourly exposure levels inside and outside of the home during the length of the study.[24]

To avoid overestimating exposure and following Holguin et al. (1985) as closely as possible, we adjust for the estimated time that people spend indoors and outdoors and for the difference in the ozone levels between the two. We use 57.5% of the ambient reading at fixed-site monitors to estimate asthma attacks between 7 am-7 pm and 52.5% of the ambient reading between 7 pm-7 am.[25]

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[24]Using entries from an hourly diary kept by the participants, Holguin et al (1985) estimated the exposure of each respondent for each hour in every 12-hour period (e g , 7 am-7 pm) A weighted average was used when respondents split an hour between indoors and outdoors Holguin et al (1985) used the highest hourly reading for a given 12-hour period to help predict asthma attacks

[25]Except for some ozone forming from the use of photocopiers and laser printers, ozone originates from outdoor sources, and because it is readily absorbed and destroyed on surfaces, indoor levels tend to be lower than outdoors (Graedel, 1988 148) Weschler et al (1989) reviewed the literature and found that the indoor/outdoor ratio most likely ranges roughly between 0.2 and 0 8 with the precise value depending on the air exchange rate between the two environments and whether air filters are used Since we do not know the indoor/outdoor ratio for the study's participants, we assume it equaled 0 5,

Following Krupnick and Kopp (1988: 2-37), we calculate the change in the number of days with asthma attacks with the following equation, applied twice (once for daytime, once for nighttime):

$$\Delta \textit{ Asthma Attacks} = \left(\frac{m}{1+m} - p \right) \textit{ Asthmatic Population},$$

$$m = \frac{p}{1-p} \cdot e^{[\beta_o (w\ PP - PI)]}$$

where:

Δ Asthma Attacks = change in the number of asthma attacks for the 7 am-7 pm or 7 pm-7 am period

p = daily incidence rate for asthma = 0.0271 (Krupnick, 1988: 4-6).

β_O = coefficient on ozone, 6.20 (Holguin et al., 1985: 276, Table 4)

PP = maximum one-hour ozone level (in ppm) for 7 am-7 pm, adjusted for indoor exposure, after control

PI = maximum one-hour ozone level (in ppm) for 7 am-7 pm, adjusted for indoor exposure, before control

w = weight used to estimate the maximum ozone concentration at night relative to the known maximum during the day; thus, when the equation is run for the daytime (7 am to 7 pm), the weight w on the daytime maximum ozone levels (X_1 and X_0) is 1.0, and when the equation is run for the nighttime (7 pm to 7 am), the weight w on the [same] daytime maximum ozone levels is 0.37, on the assumption that the nighttime maximum is 37% of the observed daytime maximum (Krupnick and Kopp, 1988: 2-37)

Asthmatic Population = 4.45% of the county population, based on the average of the asthma rate between 1988 and 1991 (Table 11.3-12); population data from the U.S. Bureau of the Census (1994).

We use this equation in our upper bound.

Estimating Lower and Upper Respiratory Symptoms Caused By Ozone

Ostro et al. (1993) examined the effect of COH, NO_2, ozone, SO_2 and SO_4 on lower and upper respiratory symptoms in 321 nonsmoking adults living in Azusa, California. Controlling for temperature, sex, day of study, gas stove use and the presence of chronic respiratory disease, they found ozone fairly closely linked to lower respiratory symptoms and upper respiratory symptoms. Although they considered the pollutants separately, the correlation between ozone and SO_4 is fairly low (r=0.24). No effect was found for the other pollutants.

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and using the results from time-activity studies, we assume that people spend roughly 85% of their time indoors between 7 am-7 pm and 95% between 7 pm-7 am (EPA, 1993a. 5-29) We use 57 5% (= 85%*0 5 + 15%*1 0) of the ambient reading at fixed-site monitors to estimate asthma attacks between 7 am-7 pm and 52 5% (=95%*0 5 + 5%*1 0) between 7 pm-7 am

Because Ostro et al. (1993) reported the odds ratio for a 0.1 ppm change in the ozone level, we estimate the change caused by ozone in lower and upper respiratory symptoms using a different type of approximation (derived below) than that used in the logistic models of Schwartz and Zeger (1990).

Lower Respiratory Illness

To calculate the change in the incidence of lower respiratory illness, we use the following equation (which we derive later):

$$\Delta \textit{Lower Respiratory Illness} = \left[p\ (1-p)\ \beta_o\ (PP - PI)\right]\ \textit{Population}$$

where:

Δ Lower Respiratory Illness = change in the number of days with lower respiratory illness

p = 0.039 = mean daily incidence rate (Ostro et al., 1993: 693)

β_O = 1.0436 = ozone coefficient calculated from the odds ratio (=1.11; Ostro et al., 1993: Table 5) estimated from a 0.10 ppm change in the ozone level

PP = maximum one-hour ozone level (ppm), after control

PI = maximum one-hour ozone level (ppm), before control

Population = county population of non-asthmatic individuals, of all ages in the upper bound case. In the lower bound case, the population includes only non-asthmatics above the age of 17 (U.S. Bureau of the Census, 1994).

Upper Respiratory Illness

To calculate the change in the incidence of upper respiratory illness, we use the following equation (which we derive later):

$$\Delta \textit{Upper Respiratory Illness} = \left[p\ (1-p)\ \beta_o\ (PP - PI)\right]\ \textit{Population}$$

where:

Δ Upper Respiratory Illness = change in the number of days with upper respiratory illness

p = 0.015 = mean daily incidence rate (Ostro et al., 1993: 693)

β_O = 0.7696 = ozone coefficient calculated from the odds ratio (=1.08; Ostro et al., 1993: Table 5) estimated from a 0.10 ppm change in the ozone level

PP = maximum one-hour ozone level (ppm), after control

PI = maximum one-hour ozone level (ppm), before control

Population = county population of all individuals, of all ages in the upper bound case. In the lower bound case, the population includes only individuals above the age of 17 (U.S. Bureau of the Census, 1994).

Deriving the Equation for Estimating Respiratory Illness

We start with the basic assumption of the logistic model, namely that the log of the odds is a linear function of the covariates in the model:

$$\ln\left(\frac{p}{1-p}\right) = X\ \beta \qquad (1)$$

where:
p = the probability of respiratory illness
X = the matrix of covariates
β = the logistic regression coefficients of the model.

We solve for the probability of respiratory illness

$$p = \frac{1}{1+e^{-X\beta}} \qquad (2).$$

When estimating the effect of ozone on eye irritation, we use equation (2); however Ostro et al. reported the odds ratio but not the estimated logistic regression coefficients (β), which forces us to use a different approach.

Taking the first derivative of equation (2) with respect to the concentration of ozone, holding the other covariates constant, we find:

$$\frac{\partial p}{\partial X_i} = (1+e^{-X\beta})^{-2} e^{-X\beta}\ \beta_i \qquad (3)$$

where:
X_i = the ozone concentration
β_i = the ozone coefficient.

Using equation (2), we solve for $e^{-X\beta}$ in terms of p:

$$p = \frac{1}{1+e^{-X\beta}} \quad \Rightarrow \quad 1+e^{-X\beta} = \frac{1}{p} \quad \Rightarrow \quad e^{-X\beta} = \frac{1-p}{p} \qquad (4).$$

We enter the solution from equation (4) into equation (3) and derive:

$$\frac{\partial p}{\partial X_i} = \left(1+\frac{1-p}{p}\right)^{-2} \cdot \left(\frac{1-p}{p}\right) \beta_i = p\ (1-p)\ \beta_i \qquad (5).$$

To make equation (5) useful for estimating health effects, we use a first order Taylor series approximation, equation (6), and then solve for Δp:

$$\frac{\partial p}{\partial X_i} \approx \frac{\Delta p}{\Delta X_i} \qquad (6)$$

$$\Delta p = p\ (1-p)\ \beta_i\ \Delta X_i \qquad (7)$$

We use equation (7) to estimate the effect of ozone on lower and upper respiratory illness. We discuss below the calculation of the ozone coefficient, β_i, using the odds ratio.

Calculating the Logistic Regression Coefficient from the Odds Ratio

Ostro et al. (1993) published the odds ratio for respiratory illness from a 0.1 ppm increase in the ozone level. We use this odds ratio and backtrack to estimate the logistic regression coefficient originally used to determine the odds ratio! With the coefficient we can then estimate the effect of any change in the ozone level, consistent with the ozone concentrations experienced by the sample in Ostro et al.'s (1993) study. We present the calculations used to estimate the logistic regression coefficient for lower respiratory illness; we did analogous calculations to determine the coefficient for upper respiratory illness.

We define the odds ratio with the following table, which shows the percentage of people that have lower respiratory illness given a high level and a baseline level of ozone exposure:

Percentage Of People With And Without Respiratory Illness High And Baseline Ozone

Ozone Level	Lower Respiratory Illness	No Illness
High Ozone (Baseline + 0.1 ppm)	A%	B%
Baseline Ozone	C%	D%

We calculate the odds of lower respiratory illness for each ozone level and the ratio of the two to get the "odds ratio:"

$$Odds\ of\ Lower\ Respiratory\ Illness\ High\ O_3 = \frac{A}{B}$$

$$Odds\ of\ Lower\ Respiratory\ Illness\ Baseline\ O_3 = \frac{C}{D}$$

$$Odds\ Ratio = \frac{\frac{A}{B}}{\frac{C}{D}}$$

The logistic model used by Ostro et al. (1993) assumed that the log of the odds is a linear function of the covariates in the model, so we can solve for the odds of lower respiratory illness at the baseline ozone level and when it is 0.1 ppm higher

$$\ln\left(\frac{A}{B}\right) = X_h \cdot \beta \quad \Rightarrow \quad \frac{A}{B} = e^{X_h \beta}$$

$$\ln\left(\frac{C}{D}\right) = X_b \ \beta \quad \Rightarrow \quad \frac{C}{D} = e^{X_b \beta}$$

where:
X_h = model covariates with high ozone level (baseline plus 0.1 ppm)
X_b = model covariates with baseline ozone level
β = model coefficients.

We determine an expression for the odds ratio (= 1.11) for lower respiratory illness in terms of the change in the ozone level and the ozone coefficient:

$$Odds\ Ratio = \frac{\frac{A}{B}}{\frac{C}{D}} = \frac{e^{X_h \beta}}{e^{X_b \beta}} = e^{X_h \beta - X_h \beta} = e^{\beta_i \left(X_{i,h} - X_{i,b}\right)} = 1\ 11$$

where:
β_i = ozone coefficient
$X_{i,h}$ = high ozone level
$X_{i,b}$ = baseline ozone level.

Finally we solve for the ozone coefficient, β_i, for lower respiratory illness:

$$\beta_i = \frac{\ln(1\ 11)}{X_{i,h} - X_{i,b}} = \frac{\ln(1\ 11)}{0.1} = 1\ 0436 \quad .$$

Estimating ARD2 (any symptom) Caused By Ozone

As mentioned above, Krupnick et al. (1990) studied 290 families in Southern California and found ozone significantly related to a combined measure of any respiratory complaint, headache and eye irritation (termed ARD2). In the upper bound case, we estimate the change in the number of ARD2 symptoms with the following equation:

$$\Delta ARD2 = \beta_o \ (PP - PI) \ Population$$

where:
β_O = 0.20 = ozone coefficient from Krupnick and Kopp (1988: 2-34)
PP = maximum one-hour ozone level (ppm), after control
PI = maximum one-hour ozone level (ppm), before control
population = people of all ages (U.S. Bureau of the Census, 1994)

The change in ARD2 includes cases of eye irritation, asthma attacks, and upper and lower respiratory illness, which we have counted already (above). Hence, we subtract these from the estimated change in ARD2, to end up with the number of cases of other symptoms (such as headaches). We include these other symptoms in our upper bound estimate only.

11.3 4 2 Chronic Morbidity

While scientists have linked ozone to less severe forms of chronic disease such as asthma, hay fever and sinusitis (Table 11.3-8), they have not yet found strong evidence that ozone increases the number of people suffering from chronic illness. Nevertheless it is likely that such a link exists. A recent series of papers by Balmes (1993), Bates (1993), Devlin (1993), Lippman (1993) and Ostro (1993a) have discussed the evidence for the link and suggested future avenues of research.

In a national study, Portney and Mullahy (1990) examined the effect of both ozone and TSP on hay fever, sinusitis, and a combined measure of chronic respiratory problems (asthma, chronic bronchitis and emphysema). Controlling for TSP, they found ozone significantly related to the sinusitis and hay fever. However, because they used only one year of health data, it is not clear if ozone increased the number of people who suffered from hay fever and sinusitis, increased the number of symptoms among existing sufferers, or both. In any event, given that we already use the work of Ostro et al. (1993) to estimate the effect of ozone on the incidence of upper respiratory symptoms (which includes both sinusitis and hay fever), it would be double counting to use Portney and Mullahy's (1990) work to estimate the increase in new cases.

In a study of Seventh-Day Adventists living within five miles of their current California residence for at least ten years, Abbey et al. (1991a; 1993) found an increase in the number of physician-confirmed asthmatics in areas with higher levels of ozone. However Abbey et al. included only one pollutant at a time and the significant effect for ozone could be due to other pollutants. TSP was more strongly linked to asthma than ozone, and in the same study TSP was linked to chronic bronchitis and all chronic respiratory problems. Since we already use PM_{10} (based on Abbey et al., 1995) to estimate the effect of chronic respiratory illness we choose not to use Abbey et al.'s (1991a; 1993) work to estimate a possible link between ozone and chronic respiratory illness. The foregoing suggests to us that ozone causes new cases of asthma, but we are not able to measure them due to the close correlation of ozone with TSP.

There is little evidence that ozone causes more severe symptoms such as emphysema and chronic bronchitis. Neither Euler et al. (1988) or Abbey et al (1991a; 1993) reported ozone causing chronic bronchitis or emphysema. Although Fujinaka et al. (1985) found that ozone caused significant long-term damage in the lungs of monkeys exposed to 0.64 ppm ozone for eight hours per day for a year, the high ozone levels and the usual problems with using the results of animal studies to estimate the effects in humans, persuade us not to use this study.

11.3 4.3 Mortality

Hexter and Goldsmith (1971), Shumway et al. (1988), Schwartz (1991) and Dockery et al. (1992) reported no significant correlation between ozone and mortality. However, Kinney and Ozkaynak (1991) found that ozone increased acute mortality in Los Angeles, Mills (1991) found that it may increase the incidence of cancer of Seventh-Day Adventists living in California, Moolgavkar (1995) found that ozone increased acute mortality in Philadelphia during the summer, and Ozkaynak et al. (1995) found that ozone and TSP or PM_{10} were both significantly associated with daily mortality in Toronto, Canada.

Recently, Kinney et al. (1995) estimated the risk of daily mortality as a function of pollution in Los Angeles from 1985 through 1990, and found that levels of PM_{10}, CO, and O_3 were, by themselves (in separate single-pollutant models) significantly associated with increased mortality risk. However, CO and O_3 levels were somewhat correlated with PM_{10} levels. When O_3 and PM_{10} were included simultaneously, PM_{10} was significantly associated with increased mortality risk, but O_3 was not. Kinney et al. (1995) believe that "definitive conclusions regarding a possible role of O_3 in daily mortality cannot be drawn from this small data set, nor from the existing literature" (p. 68).

To explain why ozone may be linked to mortality, Kinney and Ozkaynak (1991: 115) suggested that ozone is most deadly for people who have already serious health problems, and is acting as the proverbial last straw. Along similar lines, Cody et al. (1992: 193) found that ozone causes an increase in hospital admissions from asthma attacks and suggested that ozone-induced asthma attacks cause increased mortality.

Nevertheless, the evidence regarding an independent link between ozone and mortality is mixed, and one reasonably might doubt that ozone has any nontrivial effect apart from the effect of other pollutants. We already include the effects of particulates and CO on mortality. It is likely that we would be double counting the effects of air pollution by including a separate estimate for ozone. While we recognize that there could be a link between ozone and mortality, we do not include to avoid double counting the effects of air pollution.

11.3.5 Particulate Matter

Particulates have been linked to a variety of adverse health effects – reduced pulmonary functioning, asthma attacks, respiratory symptoms, hospital admissions for cardiac and respiratory problems, chronic respiratory disease and mortality. All people are affected by particulates, but those with previous respiratory symptoms and the elderly are particularly prone to its adverse effects. Tables 11.3-13 to 11.3-17 summarize the epidemiological evidence that we discuss further below.

Table 11.3-18 presents a variety of the particulate measures used in epidemiological studies and in setting air pollution standards, both in the U.S. and in Britain. Ideally whatever measure(s) we choose would capture all of the health effects associated with particulates. We use three particulate measures -- $PM_{2.5}$, PM_{10} and TSP -- to estimate health effects, because these measures and the

associated health effects studies cover the broadest range of effects. Health effects researchers have used a variety of particulate measures (e.g., H^+, sulfates, $PM_{2.5}$, PM_{10}, COH, TSP, and British Smoke), depending on the availability of air pollution and health data in a particular geographic area. A number of studies have used TSP to measure particulates, although the number of these studies has declined as the research focus has shifted to inhalable particulates. The current criteria pollutant is PM_{10}, and most recent studies link PM_{10} to morbidity (e.g., Pope, 1989) and mortality (e.g., Dockery et al., 1992). However, as discussed in Chapter 11.1, many researchers now believe that $PM_{2.5}$ or even finer particulates, or acidic particles specifically, will prove to be the most dangerous.

11.3.5.1 Are the effects associated with particulate matter a function of the size of the particles, the composition of the particles, or the number of particles?

Particulate matter is a heterogeneous mix of solid or liquid compounds, including organic aerosols, sulfates, nitrates, and metals, suspended in the atmosphere. It comprises a very wide range of chemical constituents, structures, and sizes, which in turn can have a wide range of physiological and biological effects.

The epidemiological studies that we use to quantify health effects relate the effects to an undifferentiated mass of particles (usually all particles less than 10 μm in diameter); they do not relate health effects to individual PM compounds, or to the absolute number of particles inhaled. However, because the size and chemical characteristics of PM mixes vary from one emissions source to the next (for example, PM from diesel engines is quite a bit different than PM from road dust), it is likely that some emissions sources contribute more to the estimated overall harm (from undifferentiated PM) than do others. Some sources of PM even might be harmless. Thus, in order for us to correctly attribute the estimated health effects to specific emissions sources, we must know what specific properties of PM are causing the health effects, and where the specifically harmful PM comes from.

Current research, reviewed below, indicates that smaller particles are more dangerous than larger particles, that acidic particles are more dangerous than dust particles, and that more particles (of any size or composition) are more dangerous than fewer particles.

The effect of particulate size.

It matters a lot whether health effects are related to the size of the PM, because PM from combustion generally is much smaller than PM from dust. If size does not matter, then most of the health effects might be attributed to fugitive dust, which accounts for the bulk of the airborne particulate matter to which people are exposed.

However, there is a near-consensus among researchers that fine particulates (less than 2.5 μm in diameter), which can penetrate deeply into the lungs, are more dangerous than coarser particulates, although exactly which are the more dangerous

sizes is not known.[26] Here is a sampling of some recent findings and reviews regarding the relationship between particle size and health effects:

- Pope et al. (1995: 669) single out particulates less 2.5 microns as being a larger public health concern than the coarser fraction of PM_{10}, because the smaller particles can be inhaled more deeply into the lungs.

- Dockery et al. (1995) aver that "an overall evaluation of the epidemiologic evidence suggests that fine particulates ($PM_{2.5}$), which are primarily from combustion sources, are more closely associated with human health effects than coarser particles" (p. 120).

- Marrack (1995a) offers a similar perspective, concluding that "particles less than 3.0 μm diameter have biological properties that make them much more significant than the larger components" (p. 8).

- The cross-sectional mortality study of Ozkaynak and Thurston (1987), and the hospitalization study of Thurston et al. (1994), found a stronger effect for fine than coarse particulates.

It is possible that the most harmful component of particulate matter is smaller still -- less than 1.0 μm:

- Bates (1995) reviews a recent colloquium on particulate air pollution and suggests that the harmful particles might be less than 1.0 μm in size, because in general very small particles can penetrate more easily into the lungs, and because some very small particles appear particularly dangerous.

- In laboratory studies of rats Oberdorster et al. (1992) found particulates less than 0.02 microns as having a much stronger effect than particulates less than 0.2 microns. In later work, Oberdorster et al. (1995) found that ultrafine particles of polytetrafluoroethylene were extremely toxic and caused acute mortality in rats at very low inhaled mass concentrations.

- Ostro (1990) found that sulfate particulates, which range from about 0.05 to 5.0 μm (Allen, 1995), have the strongest effect on respiratory effects, possibly through a link to acid aerosols.

- Miller et al. (1995) argue that a "reasonable argument can be made that, for some individuals, the inhalation of high concentrations of particles

[26]In recent years, ambient particulate data collection efforts have gradually focused on finer particulates, moving from TSP, to PM_{10} and $PM_{2.5}$ and even $PM_{1.0}$ Undoubtedly, more resources will be devoted to collecting data on fine particulates -- $PM_{2.5}$, PM_1 and even finer particulates

between about 0.1 and 0.3 μm may result in a localized overloading of the lung's clearance mechanisms that triggers a cascade of events leading to acute morbidity and/or mortality" (p. 630).

We believe, then, that it is likely that $PM_{2.5}$ or $PM_{1.0}$ is more dangerous than the coarse fraction of PM_{10}. Still, it is doubtful that the coarse fraction is altogether harmless. In the first place, many of the studies cited above state that the coarse particles are *less* harmful, not harmless. Furthermore, some studies have found that the coarse fraction of PM_{10} can have the same effect as the fine fraction. For example, Douglas Dockery et al. (1992) in a time-series study of mortality in St. Louis and Eastern Tennessee found roughly the same effect for $PM_{2.5}$ and the coarser fraction of PM_{10}. And Ozkaynak et al. (1995) report that in a study of daily mortality and pollution in Toronto, they "could not distinguish the estimated mortality effects of TSP from those associated with exposures to PM-10" (p. 812)[27]. Consequently, we feel that it is still premature to ignore the coarser fraction of PM_{10} altogether[28].

In sum, most epidemiological and toxicological research suggests that $PM_{2.5}$ is more dangerous than the coarser fraction of PM_{10}, but does not demonstrate that the coarser fraction of PM_{10} is completely harmless. Our own view is that qualitatively, fine PM is at least twice as dangerous as coarse PM, and perhaps an order of magnitude more dangerous. Therefore, when we apportion total particulate damages to individual sources (such as motor vehicles), we assume that $PM_{2.5}$ is from 2.0 (lower bound) to 10.0 (upper bound) times as potent (in terms of deaths per gram) as is the coarse fraction of PM_{10}. In defense of this range, we can say only that, on the basis of the evidence we reviewed, it seems reasonable to us. Obviously, one could make different assumptions.

The effect of particulate composition.

Are all particle types of a given size equally dangerous, or are, say, combustion particles of a given size generally more dangerous than dust particles of the same size? The answer is important because road dust is the largest single source of particulate matter in the U.S. emissions inventory, and one legitimately might wonder whether road-dust particles of a given size really are as harmful as diesel-engine PM of the same size.

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[27]Of course, this does not prove that all particle sizes were equally harmful It is possible that TSP and PM_{10} were so closely correlated that their effects simply were not statistically separable

[28]It is likely that the relationship between particle size and health effect is different for different health effects. For example, it might be that coarse particles affect asthma as much as do fine particles, but affect mortality much less than do fine particles Nevertheless, we assume one $PM_{2.5}/PM_{10}$ potency ratio for all health effects, we do not establish different $PM_{2.5}/PM_{10}$ potency ratios for different health effects

It appears that composition does matter. Two recent studies suggest that mineral-based and related PM from dust are not as dangerous as other types of particulates, of the same size:

> • Kleinman et al. (1995) tested the biological effects of road dust, nitrates, and sulfates. Road dust had some significant adverse effects on cells, but generally had fewer adverse effects than did nitrates and sulfates. All of the particles (of all three types) in their experiments were relatively large, 4 μm. The concentration of road dust administered was about 12 times greater than the concentration of sulfates, and 3 times greater than the concentration of nitrates. The experimenters conclude that "in terms of potency relative to the concentration of each component administered, the effects could be ordered as SO_4^{2-} > NO_3^- > road dust" (p. 600).
>
> • Koenig et al. (1995) studied the relationship between visits to the emergency room and levels of two different kinds of fine particulate matter: those from combustion sources, such as automobiles, and those from dust (mainly dust storms). They note that "at first glance, it appears that fine particles from the earth's crust are less likely to be associated with adverse health outcomes than fine particles from combustion sources," but warn that "the individual characteristics of each air shed make comparisons risky" (p. 806). (See also Heflin, 1994).
>
> • In a study of the relationship between PM_{10}, ozone, and respiratory-related hospital emissions, Schwartz (1996) tested to see if agricultural dust had less of an effect than did the "average" PM_{10}.

> Windblown dust from agricultural land is an important source of PM10 in the fall, after crops are harvested If this particulate is less toxic than average, a lower PM10 slope should be seen during the fall To test this possibility, I repeated the basic regression with an interaction term between PM10 and the fall season The interaction term was negative, indicating a lower slope, but it had a t-statistic less than one, and there was no improvement in model fit (p 23-24)

This perhaps does hint, barely, that agricultural dust is less harmful than average PM_{10}, but the lack of significance, and lack of improvement in model fit, make the finding weak at best.

Many other studies did not specifically control for size, but nevertheless suggest that all else equal, dust particles are not as dangerous as combustion particles:

> • Xu et al. (1994: 222) suggested that natural soil dust may be less dangerous than anthropogenic pollution, because soil is coarse and not readily inhalable and is more inert than, say, particulates from coal combustion.

• Cormier et al. (1990) found that organic dust increased the incidence of cough and sputum production but had little lasting effect on the respiratory health of peat moss factory workers.

• Yano (1990) found only a small increase in respiratory symptoms in an area with high levels of volcanic ash (which was relatively biologically inert).

• Ozkaynak and Thurston (1987) reported that coal particulates increased mortality rates, while soil and auto particulates did not.[29]

• Lewtas (1995) suggests that particulate organic matter might be the "causative agent" for human mortality and morbidity.

• Marrack (1995a) concludes that the principal health effects of particulate matter are due to acidic $PM_{2.5}$, to hazardous air pollutants absorbed onto carbonaceous PM, and to mutagenic organic matter, most of which apparently are derived from combustion sources. However, he does also identify adverse effects of mineral and vegetable dusts (see below).

• In a review of a recent colloquium on particulate air pollution and human health, Bates (1995) suggests that studies have shown that ash from residual fuel oil is more toxic than generic dust in Dusseldorf Germany, which in turn is more toxic than volcanic ash from Mount St. Helens.

• Many researchers believe that acid particles, which come from combustion sources but not fugitive dust, are the most dangerous component of particulate air pollution (Marrack, 1995a, 1995b; Samet et al., 1995; Schlesinger, 1995; Utell and Frampton, 1995; Waldman et al., 1995). These particles reportedly cause increased morbidity and mortality (Amdur, 1989; Lippmann, 1989a, 1989b; Ostro et al., 1991). For example, Samet et al. (1995) remark that "current concepts of particle toxicity emphasize the role of particle acidity and the induction of inflammation at sites of injury" (p. 5). And Thurston et al. (1994) report that in their research, "the acidity of an aerosol has been confirmed to be one important particulate matter attribute to be considered.." (p. 287)[30].

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[29]We do not attach much significance to the surprising result regarding auto particulates Ozkaynak and Thurston used observations from only 25 MSAs in the mid-west -- and their negative result contradicts a substantial body of work that shows that diesel and gas particulates are carcinogenic (EPA, 1993a, Mauderly, 1994, Schlesinger, 1995, Cohen and Higgins, 1995), and contradicts recent work by Saldiva et al (1995) that found a significant link between PM_{10} and daily mortality of elderly persons in Sao Paulo, Brazil, where the primary source of pollution comes from motor vehicles

[30]However, a number of studies have not found a significant effect for acidity Pope et al (1992) linked daily mortality with PM_{10} that turned out to have very low particle acidity Similarly, Dockery et al (1993) found that "mortality was more strongly associated with the levels of inhalable, fine, and

Still, not all researchers are convinced that one can distinguish particle types according to harm. Lipfert and Wyzga (1995: 7) reported "no evidence for a differential effect of particle chemistry on mortality". Dockery and Pope (1994) note that researchers have found that particulates affect people regardless of location, and that the magnitude of the effect is reasonably similar, which suggests that the composition of particulates is not very important. For example, the estimated logistic regression coefficients from Utah (Pope et al., 1992) and St. Louis and eastern Tennessee (Dockery et al., 1992) are remarkably close --0.00147 versus 0.00150 and 0.00160. Likewise, mortality studies in London have produced results similar to those in the U.S. (Schwartz and Dockery, 1992a: 602). In light of this, Dockery and Pope (1994), in their recent review of the effects of particulate air pollution, argue against distinguishing particles by potency:

> The mass concentration of PM_{10} includes a wide array of potentially toxic chemical species It is, therefore, presumptuous to assign these observed health effects solely to the mass concentration of particulates On the other hand, the consistency of these observed effects across so many communities suggests that, lacking an explicit hypothesis, these associations should be assigned to a nonspecific definition of inhalable or fine particulate concentrations common to urban areas .Until controlled animal- and human -exposure studies identify the active component(s) of these complex mixtures and can characterize their underlying mechanisms of toxicity, it is prudent to ascribe health effects observed by epidemiologists to the undifferentiated particle mass rather than to any specific component (1994 127)

Moreover, regardless of whether it is reasonable to distinguish particle potency by composition, it certainly is the case that fugitive dust, although perhaps less harmful than, say, sulfates, is not harmless. Marrack (1995a) points out that

> A number of "inert" mineral PM-10 when inhaled cause adverse tissue changes which may be recognized as disease These exposures may be at levels below the NAAQS The exposures do not have to be long term to result in tissue damage effects but the latent period prior to recognizable changes is usually years Oxides and salts of Beryllium, Manganese, Iron, Cadmium and Nickel on their own or as part of mixed chemical composition PM-10 have been implicated in such tissue damage A variety of crystalline silicon oxide (silica) containing minerals when inhaled as small particles can cause lung tissue damage which is usually progressive without additional silica exposure (p 4)

In the same vein, Miller et al. (1995) argue that a "tracheobronchial deposition of coarse mode particles should not be dismissed as potentially contributing to the acute morbidity seen in asthmatics" (p. 630). As mentioned above, Kleinman et al. (1995) and Koenig et al. (1995) found that dust does have adverse effects, albeit apparently not as serious as the effects of combustion particles and sulfates.

Finally, Fairley (1990) notes that re-entrained road dust contains "... in addition to soil particles, engine oil which contains various metals; tire particles; and sulfates" (p. 161) -- that is, some of the compounds that people suspect of being

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sulfate particles than with the levels of total suspended particles, the sulfur dioxide levels, the nitrogen oxide levels, or the acidity of the aerosol" (p 1755) Dockery et al (1992) have a similar finding, although they emphasize that they cannot rule out aerosols as a risk factor

particularly dangerous. Similarly, road dust is involved in the atmospheric chemistry that produces some of the putatively more harmful particulates, such a nitrates (Yang et al., 1994). And to the extent that, say, acidic sulfate particles would not exist in the absence of road dust, road dust in effect is as dangerous as is sulfate.

This evidence suggests that particulates from paved and unpaved roads, road construction and agricultural tillage are less harmful than other types of particulates, but not entirely harmless. Qualitatively, it appears to us that dust *of a given size class* could be anywhere from about half as potent as other (mainly combustion) particles, to an order of magnitude less potent. Thus, in our lower bound, we assume particulates from paved roads, unpaved roads, construction, agricultural tillage, and livestock are 10% as potent as other particles; in our upper bound, we assume that they are 50% as potent We do not pretend that this range has any real quantitative basis; we suggest only that it is not unreasonable given the evidence. One certainly could make different assumptions.

The effect of the number of particles.

Some researchers have suggested that health effects are related directly to the number-concentration of particles inhaled (number of particles per ml), regardless of size and composition. The greater the number concentration, the greater the irritation, and the more the immune system is overwhelmed locally (Chen et al., 1995). As noted above, Miller et al. (1995) argue that a high concentration of particles might overwhelm the lung's defenses and eventually cause morbidity and mortality.

Generally, however, the number of particles is a function of the size of the particles, because small particles can be inhaled more deeply into the lung. Thus, sources that emit smaller particles are more likely to cause a localized PM overload in the lungs and eventually adverse health effects. Consequently, if the number concentration of particles really is the determinant of health effects, we may as a reasonable approximation apportion health effects of PM on the basis of the size distribution of particles from emissions sources.

11.3.5. 2 Acute Morbidity

Table 11.3-13 summarizes the epidemiological work examining the link between particulates and pulmonary functioning. The bulk of the work suggests that particulates cause a decline in lung functioning (which, unfortunately, we cannot value in dollars). Tables 11.3-14 and 11.3-15 consider the effects of particulates on effects that we can value. We consider, in turn, the effects of particulates on asthma, general respiratory ailments and hospital admissions.

Asthma

Five studies found a significant effect between particulates and asthma:

- Cohen et al. (1972) studied 20 asthmatics living in West Virginia and found various particulate measures and SO_2 linked to asthma, although no single pollutant was found to be the cause of asthma attacks.

- In a study of Los Angeles asthmatics, Whittemore and Korn (1980) controlled for the effect of O_X and found TSP linked to asthma attacks.

- Perry et al. (1983) found particulate nitrates linked to asthma in a study of 24 Denver asthmatics. However, a later study by Ostro et al. (1991) (discussed below) did not support the results of this paper.

- In a study of 207 Denver asthmatics, Ostro et al. (1991) did not find an effect for nitrates but did find that $PM_{2.5}$ increased the incidence of asthma attacks. Because Ostro et al. did not publish the coefficient for $PM_{2.5}$, we can not use the study to develop a dose-response function.

- Finally, in a study of industrial towns in the Netherlands, Roemer et al. (1993) found SO_2 and particulates associated with asthma attacks. (The pollutants were considered separately.)

The available evidence, then, indicates that particulate air pollution causes asthma attacks. We use the Whittemore and Korn (1980) to develop a dose-response function, because theirs is sophisticated statistical analysis, is amenable to developing a dose-response function, and considers ozone and particulates simultaneously.

Respiratory Symptoms

In Table 11.3-14 we review a number of studies that examined a possible link between particulates and acute respiratory ailments other than asthma attacks.

- Portney and Mullahy (1986) used the 1979 national Health Interview Survey to study the effects of ozone and SO_4 on over 3000 adults 17 and older. They found that ozone increases significant minor respiratory symptoms but they found no effect for SO_4.

- Ostro and Rothschild (1989) used six years (1976-1981) of data from the Health Interview Survey and found $PM_{2.5}$ associated with both minor and more serious respiratory illness, which give rise to respiratory-related restricted activity days (RRADs). They found significant effects in most years, including 1979, the year that Portney and Mullahy (1986) analyzed

- In a study of Los Angeles residents, Krupnick et al. (1990) found that the coefficient of haze (COH) increases all types of respiratory symptoms, especially in adults.

- Using observations from 321 nonsmoking adults --a subset of Krupnick et al.'s (1990) data -- Ostro et al. (1993) did not find COH to be a significant predictor of lower respiratory illness ($p = 0.14$), but did find SO_4 significantly linked to lower respiratory illness.

Although the evidence is mixed, in part because a variety of particulate measures have been used, it does indicate that particulates are linked to respiratory problems. We use the study by Ostro and Rothschild (1989) to estimate the link because the study is well done, and because $PM_{2.5}$ can be reasonably approximated using PM_{10} data and probably is a better measure of particulate air pollution than are either SO_4 or COH.

Hospital Admissions

Eleven of the fourteen studies that we review, and all of the studies since 1983, found particulates significantly related to hospital admissions (Table 11.3-15). Hospital admissions, however, overlap with our other measures of morbidity (asthma attacks and RRADs) and acute mortality. To avoid double-counting we do not estimate the incidence of hospital admissions due to particulates.

Our Conclusion

We estimate the effect of particulates on asthma and RRADs. There is some overlap between RRAD and asthma attacks -- to avoid double-counting we estimate RRAD only for the nonasthmatic population. We do not estimate the incidence of hospital admissions because these are reasonably well captured by our estimates for asthma, RRADs and mortality. The health effects studies that we use are summarized in Table 11.3-19; the studies used by previous economic analyses are in Table 11.3-20.

Particulates definitely have a negative effect on pulmonary functioning and symptoms in children (Ostro, 1989; Pope, 1989; Krupnick et al., 1990; Roemer et al., 1993). Krupnick et al. (1990) compared the effects of particulates on children and adults and reported that the coefficient for COH was 59% smaller for children than it was for adults. In the lower bound, we use a coefficient that is 59% smaller for children. We do not adjust the number of asthma attacks, because the majority of participants in Whittemore and Korn's (1980) study were children, and asthma is prevalent among children (Table 11.3-12).

Although the evidence is mixed, we assume that there is no threshold level below which particulates are harmless. Chestnut et al. (1991) did not find reduced pulmonary functioning when the quarterly average TSP level fell below 60 $\mu g/m^3$ Similarly, Vedal et al. (1991) found no effect on respiratory symptoms when the annual average TSP and PM_{10} levels fell below 45-50 $\mu g/m^3$ and 35-40 $\mu g/m^3$. On the other hand, studies that link particulates with mortality have reported no threshold. Schwartz (1991), Dockery et al. (1992), Pope et al. (1992) and Schwartz and Dockery (1992b) reported an effect for particulates well below the NAAQS standard.

Estimating Asthma Attack-Days Caused by Particulates

Whittemore and Korn (1980) studies 443 physician-confirmed asthmatics from six communities in the Los Angeles, who kept daily diaries in the period 1972 to 1975. Each asthmatic lived with in two miles of an air monitor.

The dependent variable is the rate of asthma attacks per day among the respondents. The pollution variables included the 24-hour average concentration

($\mu g/m_3$) of TSP and the daily maximum hourly average (ppm) of oxidants (which include ozone).

Following Krupnick and Kopp (1988), we calculate the change in the number of days with asthma attacks with the following equation:

$$\Delta \, Asthma \;\; Attacks = \left(\frac{m}{1+m} - p \right) \; Asthmatic \; Population,$$

$$m = \frac{p}{1-p} \cdot e^{\left[\beta_{pm} \, (PP-PI)\right]}$$

where:

Δ Asthma Attacks = change in the daily number of asthma attacks

p = daily incidence rate for asthma = 0.0271 (Krupnick, 1988: 4-6).

β_{pm} = coefficient on TSP, 0.00079 (Whittemore and Korn, 1980: 691, Table 5)

PP = daily average TSP level ($\mu g/m^3$), after control

PI = TSP level ($\mu g/m^3$), before control

Asthmatic Population = 4.45% of the county population, based on the average of the asthma rate between 1988 and 1991; these values are reported in Table 11.3-12; population data from the U.S. Bureau of the Census (1994).

Estimating Respiratory-Related Restricted Activity Days (RRADs) Caused by Particulates

Using data from 68 MSAs collected by the Health Interview Study (HIS) for the years 1976-1981, Ostro and Rothschild (1989) examined the effect of ozone and $PM_{2.5}$ on working adults 18-65 years old. The $PM_{2.5}$ data was estimated from airport visibility data. The pollutants were considered simultaneously in a Poisson regression, and the correlation between the two pollutants was low over the six years of data (r = -0.03 to 0.25).

The dependent variable is the incidence of respiratory-related restricted activity days (RRADs) and minor RRADs over a two-week period. Ostro and Rothschild found the two-week daily-average $PM_{2.5}$, lagged one period, a significant predictor of both RRADs and mRRADs, although the best results were found for RRADs. The results for ozone were mixed and indicated that ozone is responsible for minor respiratory ailments.

We calculate the change in the daily (rather than bi-weekly) incidence of RRADs with the following equation (derived below):

$$\Delta RRAD = RRAD_0 \cdot \left[e^{(PP-PI)\,B_{pm}} - 1 \right] \; Population$$

where:

Δ RRAD = change in the number of RRADs in a day

$RRAD_0$ = 0.118/14, the average number of RRADs in a day (Ostro and Rothschild, 1989: 242) (Ostro and Rothschild estimated 0.118 RRADs over two weeks; we assume one-fourteenth this amount per day)[31]

PP = daily average $PM_{2.5}$ level ($\mu g/m^3$), after control

PI = daily average $PM_{2.5}$ level ($\mu g/m^3$), before control

B_{pm} = 0.0158 , the weighted average of the $PM_{2.5}$ coefficients, where each coefficient is weighted by the inverse of its variance (Ostro and Rothschild, 1989: 242)[32]

Population = county population of non-asthmatic individuals of all ages (U.S. Bureau of the Census, 1994).

Deriving the Equation for Estimating RRAD

To calculate the change in RRADs, we start with the basic assumption of the Poisson regression model used by Ostro and Rothschild (1989):

$$E(RRAD_0) = e^{X_0 \beta} \qquad (1)$$

where:

$E(RRAD_0)$ = the expected number of RRAD per day, given the baseline values for the covariates (where the baseline value is denoted by a subscript 'o')

X_0 = the matrix of covariates (including $PM_{2.5}$), at baseline values

B = vector of coefficients.

Changing only the $PM_{2.5}$ level, we calculate the expected number of RRAD per day:

$$E(RRAD_1) = e^{X_1 \beta} \qquad (2)$$

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[31]Ostro and Rothschild (1989) estimated the incidence of RRADs over a two-week period, using the average $PM_{2.5}$ pollution level over two weeks. Ideally, we would replicate their procedure exactly: we would estimate the average $PM_{2.5}$ pollution level over two weeks, calculate the change in RRADs over a two-week period, with respect to the two-week average incidence of RRADs, and do this calculation 26 times for each year. However, because we estimate $PM_{2.5}$ levels with respect to daily PM_{10} levels, it is easier for us to calculate the change in RRADs daily, with respect to a daily average incidence of RRADs which we assume to be one-fourteenth of the average incidence over two weeks, and run the equation 365 times per year. This method of using the daily average pollution level and the daily average incidence of RRADs will not necessarily yield the same result as will the preferred approach of using the two-week average incidence of RRADs and the two-week daily average pollution level, because as can be seen from the equation the change in RRADs is linear with respect to the average incidence but nonlinear with respect to pollution.

[32]Using the published standard deviations, we determine that the weighted average equals 0.0150. We assume the difference between this and Ostro and Rothschild's value of 0.0158 is attributable to rounding error, and that their calculations carry more significant figures and thus are more desirable.

Dividing equation (1) by equation (2), we find that the other covariates drop out, and the expression on the right-hand side of equation (3) is a function only of the change in the ambient $PM_{2.5}$ concentration and the $PM_{2.5}$ coefficient:

$$\frac{E(RRAD_1)}{E(RRAD_0)} = \frac{e^{X_1 \beta}}{e^{X_0 \beta}} = e^{(PP-PI)\beta_{pm}} \qquad (3)$$

where:
PP = the new $PM_{2.5}$ ambient concentration
PI = the baseline $PM_{2.5}$ ambient concentration
B_{pm} = the $PM_{2.5}$ coefficient.

Multiplying both sides of equation (3) by equation (1), we get:

$$E(RRAD_1) = E(RRAD_0) \cdot e^{(PP-PI)\beta_{pm}} \qquad (4).$$

Finally, subtracting equation (1) from both sides of equation (4), we get:

$$\Delta E(RRAD) = E(RRAD_0)\left[e^{(PP-PI)\beta_{pm}} - 1\right] \qquad (5)$$

We use equation (5) to estimate the effect of particulates on RRAD

11.3.5.3 Chronic Morbidity

A number of studies have found that particulates cause chronic respiratory problems in people of all ages (Table 11.3-16). Chapman et al. (1985), in a study of young adults, and Dockery et al. (1989) and Vedal et al. (1991), in studies of grade school children, found particulates linked to chronic cough, chronic phlegm, wheezing, chest illness, and bronchitis. In a study of two closely matched counties in the Utah Valley, Archer (1990) found more deaths from nonmalignant respiratory disease in the county with higher pollution levels. Finally, in a series of studies of adult Seventh Day Adventists living in California, Euler et al. (1987; 1988) and Abbey et al. (1991a; 1993; 1995) found TSP and PM_{10} significantly linked to airway obstructive disease (AOD), which includes asthma, chronic bronchitis and emphysema.

The evidence clearly points to a link between particulates and chronic disease. For several reasons, Abbey et al.'s (1995) study is the most useful: they used a panel design which allows us to determine the incidence of new cases of chronic disease, they reported statistics that allow us to develop dose response functions; and they measure ambient particulate levels using PM_{10} rather than TSP.

Estimating Chronic Respiratory Disease Caused by Particulates

Abbey et al. (1995) used multiple logistic regression in a panel study to link PM_{10} with asthma, chronic bronchitis, and emphysema. They based the analysis on health surveys completed by 3,914 Seventh Day Adventists over the age of 25 living within five miles of their current residence in California for at least ten years (as of 1977). Health surveys were conducted in 1977 and again in 1987.

Abbey et al. (1995: 140) classified individuals as definitely having asthma, chronic bronchitis or emphysema if the following conditions were met:

- *asthma*: having been told by their physician that they had asthma as well as having a history of wheezing, or
- *chronic bronchitis*: symptoms of cough and /or sputum production on most days, for at least three months per year, for two years or more, or
- *emphysema*: having been told by their physician they had emphysema as well as having shortness of breath when walking either normal paced or hurried.

Their method of classification appears to allow new cases of chronic disease to be classified in more than one group: 7.38% (N=3,237, cases=239) got chronic bronchitis, 2.17% (N=3,634, cases=79) got asthma, yet only 8.50% (N=3236, cases=275) got AOD. Although Abbey et al. did not specify why the sample sizes differ, the smaller percentage for AOD suggests overlapping definitions and a small percentage of people getting emphysema (roughly 0.7%). (Abbey et al. reported an insufficient number of cases to do a separate analysis on emphysema; they did not report the number of emphysema cases.)

The percentage of new cases of chronic bronchitis (7.38%) that occurred between 1977 and 1987 in Abbey et al.'s sample seems high compared to the national figures of chronic bronchitis prevalence (5.01%) we report in Table 11.3-12. Four possible explanations are:

- *A reversal rate of roughly 50%.* The reversal rate equals the number of cases that had definite symptoms in 1977 who did not have definite symptoms in 1987 divided by the number who had definite symptoms in 1977.
- *Different definitions of chronic bronchitis.* The National Center for Health Statistics (1992) -- the source of the national rate -- asked the respondent whether he or she has had "bronchitis," while Abbey et al. asked if the respondent had "cough and/or sputum production on most days, for at least three months per year." It seems likely that Abbey et al.'s would produce more positive responses.
- *Misreporting by respondents.* Regarding asthma, Abbey et al. (1993: 42), who used the same data set as Abbey et al. (1995), reported confirming 30

out of 49 cases of asthma by checking the respondents' medical records. A 61.2% confirmation rate is low for a serious disease like asthma. Obviously people either did not confide in their doctors or they misunderstood the health survey; the latter seems more likely.

- *California specific factors.* A brief review of the counties with non-attainment areas (EPA, 1992a) suggests that California has a disproportionate share. Higher pollution rates (or other factors) in California, relative to the rest of the U.S., may have caused a higher proportion of cases.

We assume that it is better to use our own best estimate of the annual incidence rate of new cases, rather than the original estimate of Abbey et al. (1995), even though we take our coefficient (beta) from Abbey et al. To account for the misreporting that apparently occurred in the Abbey et al study, we multiply their reported incidence rates by 61%, which as noted above, appears to be the ratio of the true (doctor-confirmed) incidence rate to the reported rate. Hence we assume the incidence of new cases over ten years is 5.185% (rather than 8.5%) for AOD, and to determine the annual rate we divide these percentages by ten.

We do not make any adjustment for the high reversal rate. An adjustment would be called for if the reversal rate in Abbey et al. (1995) differed from the reversal rate in Krupnick and Cropper (1992) and Viscusi et al. (1991) -- studies that we use to value chronic illness. We have no information regarding any difference between these studies.

Abbey et al. (1995) estimated the cumulative number of hours of PM_{10} exposure above thresholds of 40, 50, 60, 80 and 100 $\mu g/m^3$, from 1973-1977. They deemed these exposure levels representative of the study population's long-term exposure to PM_{10}; they picked the exposure variable that gave the best statistical fit. Little is known about the best way to estimate long-term exposure, so we accept their procedure .

Particulates emitted in any of the exposure periods may have been only partially responsible for the estimated increase in AOD. Particulates may quickly affect susceptible people or the effect may be more gradual, with many years of exposure necessary to contract chronic disease -- in which case no single year or episode of exposure would be responsible. We assume that the estimated new cases of AOD will occur over a 20-year period, with the effects distributed in a bell-shape over this period (Table 11.3-21). Clearly a different lag structure between exposure and disease could have been chosen, but until more is known about the etiology of AOD and its link to particulates, we consider a 20-year lag a reasonable approximation.

We use the following equation (derived in Section 11.3.4.1) to determine the number of new cases of AOD caused by PM_{10}:

$$\Delta AOD = p\ (1-p)\ \beta_{pm} \cdot (PP - PI)\ Population$$

where:

Δ AOD = change in the number of cases of airway obstructive disease (AOD)
p = 0.005185 = estimated annual incidence of new cases of AOD
β_{pm} = coefficient on PM_{10}, $5.401 \cdot 10^{-5}$ (40 $\mu g/m^3$ threshold); = $5.791 \cdot 10^{-5}$ (50 $\mu g/m^3$ threshold); = $7.402 \cdot 10^{-5}$ (60 $\mu g/m^3$ threshold); = $1.001 \cdot 10^{-4}$ (80 $\mu g/m^3$ threshold); = $1.699 \cdot 10^{-4}$ (100 $\mu g/m^3$ threshold) (Source: Table 11.3-22)
PP = one individual's annual hours of PM_{10} exposure above the threshold, after control
PI = one individual's annual hours of PM_{10} exposure above the threshold, before control
Population = county population of all individuals (U.S. Bureau of the Census, 1994).

It is not obvious which of the five coefficients we should use. To allow for the uncertainty in our choice, we use the mean estimated number of cases in our lower bound, and in our upper bound we use the maximum.

Calculating The Regression Coefficient From The Relative Risk Estimate

Abbey et al. (1995) published the relative risk but not the estimated coefficients for all of the exposure levels; they presented coefficients only for exposure exceeding 100 $\mu g/m^3$. The fact that particulates adversely affect people at much lower exposure levels and that 100 $\mu g/m^3$ is rarely exceeded in many communities in the United States suggests that we should estimate the coefficients for other exposure thresholds.

We use the relative risk estimates published by Abbey et al., summarized in Table 11.3-22, to find the "odds ratio," and then estimate the logistic regression coefficient. We present the calculations for the estimated coefficient for AOD and exposure in excess of 100 $\mu g/m^3$; we do exactly analogous calculations for other exposure thresholds.

The relative risk is the ratio of the risk with and without PM_{10} exposure, and can be formally defined with a table showing the percentage of people that have AOD, depending on their PM_{10} exposure.

Percentage Of People With AOD In High PM_{10} And Baseline PM_{10} Exposure Cases

PM_{10} Level	AOD	No AOD
High PM_{10} Exposure (Baseline + 1000 hours/year at > 100 $\mu g/m^3$)	A	B
Baseline PM_{10} Exposure	C	D

We can calculate the "risk" of AOD at the two exposure levels and then the "relative risk" (which is the ratio of the two risks):

$$Risk\ of\ AOD\ With\ High\ PM_{10}\ Exposure = \frac{A}{A+B}$$

$$Risk\ of\ AOD\ With\ Baseline\ PM_{10}\ Exposure = \frac{C}{C+D}$$

$$Relative\ Risk = \frac{\frac{A}{A+B}}{\frac{C}{C+D}} .$$

Abbey et al. (1995: Table 3) reported that the incidence rate new cases of AOD in their sample was 8.498%, which we assume equals the baseline incidence rate (C in the table above). Given the relative risk (= 1.17) of AOD from 1000 hours of PM_{10} above 100 $\mu g/m^3$, and the fact that the sums of A and B, and C and D, both equal 100%, we can then calculate A, B, C and D:

$$Relative\ Risk = \frac{\frac{A}{A+B}}{\frac{C}{C+D}} = \frac{A}{C} = 1\ 17$$

$$B = 100\% - A = 90.057\%$$

$$D = 100\% - C = 91.502\%$$

It is then easy to calculate the odds ratio:

$$Odds\ Ratio = \frac{\frac{A}{B}}{\frac{C}{D}} = 1\ 1888 .$$

Finally, using the formula developed in Section 11.3.4.1, we estimate the logistic coefficient for PM_{10}:

$$\beta_{PM_{10}} = \frac{\ln(Odds\ Ratio)}{X_h - X_b} = \frac{\ln(1\ 1888)}{1000} = 1\ 729\ \ 10^{-4}$$

where:

X_h = 1000 hours above 100 $\mu g/m^3$, over the course of a year

X_b = 0 hours above 100 $\mu g/m^3$, over the course of a year.

Our estimated coefficient ($\beta_{PM_{10}} = 1.729\ \ 10^{-4}$) is close to Abbey et al.'s (1995: Table 3) published coefficient ($\beta_{PM_{10}} = 1.699\ \ 10^{-4}$). The difference probably is due to

rounding error in the relative risk: a coefficient of $1.699 \cdot 10^{-4}$ implies a relative risk of 1.1668, which rounds to the published figure of 1.17[33]. In any event, our estimated coefficient of $1.729 \cdot 10^{-4}$ is close enough to the published estimate of $1.699 \cdot 10^{-4}$ that we may use the relative risk to estimate the (unpublished) coefficients for the exposures at other threshold levels (Table 11.3-22).

11.3.5.4 Particulates and mortality: "acute" versus "chronic" deaths, "harvest" versus "non harvest" deaths, and the relationship to times-series versus prospective cohort and cross-sectional studies

For years researchers have debated what (if any) effect particulates have on mortality. In 1985, Morgan et al (1985: 665) claimed "almost any answer is possible...depending on which expert is consulted."

Since their statement, a number of results have been published providing convincing evidence that particulates are positively associated with acute mortality, *and* that the size of the estimated effect is consistent across the U.S (see Dockery and Pope, 1994; Schwartz, 1994a, 1994b). A variety of particulate measures have been used, and yet all measures have found a significant effect: Ozkaynak and Thurston (1987) studied sulfates; Fairley (1990), coefficient of haze; Dockery et al. (1992) and Pope et al. (1992), PM_{10}; Schwartz, (1991), Schwartz and Dockery (1992a and 1992b), TSP; and Schwartz and Marcus (1990), British smoke Furthermore, two prospective cohort studies (Dockery et al., 1993; Pope et al., 1995) and a number of "ecologic" studies (e.g., Ozkaynak and Thurston, 1987) using annual pollution levels have found a significant link between mortality and a measure of chronic particulate exposure. Thus, there are two strands of evidence linking particulates to both "acute" and "chronic" deaths. As we discuss below, it appears that we should divide acute deaths into two groups: "harvest" deaths that would have occurred anyway, and "non-harvest" deaths that would have occurred significantly later in life.

Defining Acute and Chronic Deaths

The epidemiological evidence suggests that there are at least two and most likely three types of deaths that we need to distinguish when we value mortality: "acute harvest" deaths, "acute non-harvest" deaths, and "chronic" deaths.

Acute deaths are those that occur only a relatively short time -- say, less than a week -- after exposure to particulate air pollution. There are two kinds of acute deaths due to pollution: *harvest deaths* and *non-harvest deaths*. Acute harvest deaths are those that would have occurred in a few days anyway even if there had there been no particulate pollution. For example, if particulate air pollution hastens by a few days or weeks the death of an already moribund person, the death is called "acute harvest". An acute non-harvest death is one that would not have occurred

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[33]It also is possible, but in our view unlikely, that the difference is due to the baseline incidence rate (C in the calculation above) being different from 8 498% if the relative risk was exactly 1 17, then Abbey et al 's (1995) published coefficient of 1 699 10^{-4} implies a baseline incidence rate of 7 0% However, the 8 498% that we assume is equal to the number of new cases divided by the sample size, which is the definition of the incidence rate in the Abbey et al study

soon had there been no particulate air pollution. If particulate air pollution kills a seriously ill person who otherwise would have recovered and lived a long time afterwards, the death is called "acute non-harvest". We distinguish between harvest and non-harvest deaths because the former cost only a few days or weeks of life, whereas the latter cost years, and we believe that the value of the death is related at least crudely to the number of days or years lost (Chapter 11.4).

Chronic deaths are those that occur many years after the precipitating exposure to particulate air pollution. If exposure to air pollution initiates a cancer or cardiopulmonary disease that years later is fatal, the resulting death is called a "chronic" death. We distinguish between acute and chronic because the latter occur much later than do the former and hence have a lower present value, all else equal (Chapter 11.4).

It would be nice if the available epidemiological studies separately estimated acute harvest deaths, acute non-harvest deaths, and chronic deaths, but they do not -- quite. Instead, we have in general three different kinds of epidemiological studies: time-series studies, and prospective cohort and cross-sectional studies.[34] Time-series studies (e.g., Pope et al., 1992) link daily mortality with ambient particulate concentration. They estimate total acute deaths, both harvest and non-harvest, but do not necessarily distinguish between acute harvest and acute non-harvest deaths They cannot capture chronic deaths[35]. Prospective cohort studies (e.g., Pope et al., 1995) keep track of individuals over many years and link observed mortality with long-term average pollution levels. They are designed to control for important confounding factors such as smoking and are able to estimate acute non-harvest deaths and chronic deaths, but do not distinguish between the two[36]. Cross-sectional studies (e.g., Ozkaynak and Thurston, 1987), also called "ecologic" regressions, link (retrospectively) annual average pollution level with annual mortality rates in metropolitan regions. Although these regressions are common, so too is the criticism that they do not adequately control for important confounding variables, such as smoking, except by using city-wide averages.[37] Like prospective cohort studies, the cross-sectional studies estimate acute non-harvest deaths and chronic deaths.

To estimate acute harvest deaths, we must deduct from total time-series deaths an estimate of the number of acute non-harvest deaths therein. To estimate chronic deaths, we must deduct from total prospective cohort deaths (or cross-

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[34]Lipfert and Wyzga (1995) give a useful summary of different types of mortality studies

[35]Actually, time-series studies would capture chronic deaths if the day-by-day pollution pattern were the same every year, and if the time from exposure to long-term death was absolutely invariant Of course, these conditions never obtain

[36]And as discussed below, it also is possible, albeit not necessarily likely, that some chronic deaths are not captured by either type of study

[37] Criticisms of cross-sectional studies are considered in Evans et al (1984b), Lipfert et al (1988) and Lipfert and Wyzga (1995), among others

sectional deaths[38]) an estimate of the number of acute non-harvest deaths therein. We must estimate acute non-harvest deaths as some fraction of total time-series or total prospective cohort deaths. Given this, our approach is:

i) estimate the number of all acute deaths (time-series study);

ii) estimate (on the basis of the review below) the fraction of total time-series acute deaths that are non-harvest deaths;

iii) estimate the number of acute non-harvest deaths, and the number of acute harvest deaths (multiply time-series total of step i by fraction from step **ii)**

iv) assume that the number of acute non-harvest deaths estimated in **iii)**, from the time-series study, also is the number of acute non-harvest deaths captured by the prospective cohort study (or cross-sectional study);

v) estimate chronic deaths, by subtracting from total estimated prospective cohort and cross-sectional deaths the estimated number of acute non-harvest deaths.

We emphasize two points here. First, to estimate acute non-harvest deaths we separate harvest from non-harvest deaths in the time-series study, rather than separate chronic from non-harvest in the prospective cohort (or cross-sectional) study, because more time-series studies provide evidence bearing on the separation. Second, we *assume* (step **iv**) that the number of acute non-harvest deaths in the cross-sectional studies is the same as the number in the time-series studies. *Statistically* , this need not be so, simply because the time-series studies estimate differences due to daily pollution levels, and the cross-sectional studies estimate differences due to annual pollution levels. (At the extreme, time-series studies will not capture any acute non-harvest deaths (or any deaths at all) in places with the same pollution level everyday throughout the year, and cross-sectional studies will not capture any acute non-harvest deaths (or any deaths at all) in places with the same annual mean pollution level.) We make this assumption only to keep our effort manageable.

Separating acute non-harvest deaths from acute harvest deaths and chronic deaths.

How can we separate acute non-harvest deaths from acute harvest deaths (in time-series studies) or from chronic deaths (in prospective cohort or cross-sectional studies)? As discussed above, the issue is central to our estimation of the cost of mortality. If all acute deaths are harvest deaths -- i.e, if in the time-series studies the daily pollution simply had hastened (or "harvested") deaths by a few days -- then the

[38]To estimate non-harvest acute deaths and chronic deaths, we use a cross-sectional study (Ozkaynak and Thurston, 1987) in the lower bound and a prospective cohort study (Pope et al.) in the upper bound

cross-sectional studies estimate a completely different population of individuals, ones who had died from (chronic) long-term effects associated with air pollution.[39] In this case, we would multiply estimated time-series (acute-harvest) deaths by the cost of an acute death, multiply estimated cross-sectional (chronic) deaths by the present-value cost of a chronic death, and add the two together. On the other hand, if all acute deaths are non-harvest deaths, we would multiply estimated time-series deaths by the cost of an acute non-harvest death, subtract all time-series deaths from the total number of cross-sectional deaths in order to arrive at the number of chronic deaths, and multiply the resulting number of chronic deaths by the cost of a chronic death.

We have found three studies that bear (weakly) on the question of acute non-harvest versus acute harvest, and one that bears on the question of acute non-harvest versus chronic.

1). Spix et al. (1993) provide weak evidence that in the daily mortality studies, pollution is harvesting deaths. They estimated a pollution*prior-mortality interaction term with two different pollution variables to determine the amount of harvesting (i.e., hastening of death). After some search, they used the mortality level the previous two weeks in this interaction term and found a negative (but insignificant, p=.5 and p=.1 for SO_2 and suspended particulates) coefficient, which indicates that as mortality two weeks previously increases air pollution will have less of an effect. They found that the relative risk of air pollution rises 50% (RR=1.08 to 1.12 for SO_2 and RR=1.14 to 1.27) when going from high to low periods of previous mortality. If one interprets these results to mean that air pollution kills fewer people when there are fewer people near death, then one can infer that air pollution is killing those already near death. In their own assessment, Spix et al. (1993) wrote that "...suspended particulates do not cause deaths in the sense of acute toxicity, but they may in some cases lead to the extra stress that causes the death of a moribund person on a certain day, instead of slightly later [a harvest death], and in some cases lead to the death of a seriously ill person who would otherwise have recovered [an acute non-harvest death]" (p. 523; brackets added).

We note, though, that Spix et al.'s (1993) own assessment is merely a statement of the logical possibilities (time-series deaths either are acute harvest deaths or else acute non-harvest deaths), not a specific conclusion supported by their findings. If, as we said above, one believes their findings and interprets them to mean that air pollution kills fewer people when there are fewer people near death, then air pollution causes mainly or exclusively harvest deaths. To the extent that air pollution causes acute non-harvest rather than harvest deaths, one would not expect to find a negative interaction term. If one does not believe their findings at all, one cannot make any specific conclusion at all. The point is that this study either is weak evidence that in the daily mortality studies, pollution is harvesting deaths, otherwise it is silent on this issue.

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[39]If particulates hastened death *only* a few days, then virtually no effect would be found by the prospective cohort and cross-sectional studies

2). On the other hand, Utell and Frampton (1995) argue that the "harvesting effect...has not been evident in the epidemiology of particulate exposure" (p. 647).

3). Pope et al.'s (1992) study of particulate levels and mortality in the Utah Valley, where a steel mill is the dominant contributor to ambient particulate levels, also provides weak evidence that in the time-series studies, the deaths are non-harvest. On the basis of their estimated Poisson regression coefficient, they predicted a 2.3% drop in the mortality level when the steel mill shut down for a year. If time series studies are capturing a large proportion of deaths that are premature by only, say, a few days or weeks, then the actual drop in the annual mortality level should have been close to zero. In fact the actual drop was 3.2%[40]. This suggests that in the daily-mortality (time-series) studies, the deaths are acute non-harvest deaths.

4). In a study of six U.S. cities, Dockery et al. (1993) reported a significant association between long-term pollution exposure and lung cancer, as did Pope et al. (1995) in a study of 151 metropolitan statistical areas. This finding indicates that the prospective cohort studies (and presumably cross-sectional studies) are capturing chronic deaths, not acute non-harvest deaths.

What can we make of this evidence? It appears to us that there is little ground for assuming that in the time-series studies, pollution *mainly* is harvesting deaths. Rather, it appears to us that harvested deaths are in the minority. Thus, we assume that acute harvest deaths are 25% (upper-bound cost case) to 50% (lower-bound cost case) of total time-series-estimated acute deaths. Acute non-harvest deaths therefore are 75% to 50%. We subtract these estimated acute non-harvest deaths from total cross-sectional deaths, to obtain chronic deaths.

It turns out that nationally, and in almost every county in the U.S., the estimated number of cross-sectional deaths exceeds the number of acute non-harvest deaths estimated with respect to the time-series results. However, in a few counties, the reverse is true, and the number of acute-non harvest deaths estimated with respect to the time-series results exceeds the total number of cross-sectional deaths and hence the number of acute non-harvest deaths included in the cross-sectional studies.[41] In those few counties, we have two options as regards the number of acute non-harvest deaths: 1) assume that it is as estimated originally, with respect to the time-series results, or 2) assume that it is equal to the (lower) number of cross-sectional deaths. We have chosen the former: we always estimate the number of acute non-harvest deaths with respect to the time-series results, even if the result is more than the total number of cross-sectional deaths.

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[40]It is not clear why the actual was greater than the predicted drop Perhaps unusual weather or infectious disease contributed to some of the difference

[41]It is possible for acute non-harvest deaths estimated from the time-series studies to exceed cross-sectional deaths in one county, but for the reverse to be true in another county because the time-series equations -- used to estimate acute non-harvest deaths -- do not have the same structure as the lower-bound cross-sectional equation the time-series equations estimate deaths as a nonlinear function of PM_{10} and the background death rate, whereas the lower-bound cross-sectional equation estimates death as a linear function of $PM_{2.5}$ and the total population

Nonlinear Effect of Particulates on Mortality

It is possible that sudden jumps in the particulate level cause deaths directly, independent of the average annual pollution level. Cross-sectional studies, which relate differences in death rates to differences in average annual particulate levels, do not capture this possible effect of jumps, because by hypothesis the direct deaths due to jumps are independent of the average annual particulate level (i.e., are in addition to any deaths associated with the rise in the average annual particulate level caused by the jumps). Time-series studies capture any immediate deaths due to jumps, but of course do not capture any long-term deaths due to jumps. (A death due to a cancer initiated by a sudden rise in the particulate level might be an example of a long-term death due to a jump.) Thus, it is at least theoretically possible that not only might there be little overlap between, say, prospective cohort and time-series studies, there might even be a type of PM-related death not captured by either: long-term deaths due to jumps. However, we have not found any evidence in support of this hypothesis, and so have not accommodated it formally.

Beyond this, it is not clear if in general the relationship between particulate air pollution and mortality is essentially linear or significantly nonlinear. Samet et al. (1995), in a re-analysis of Schwartz and Dockery's (1992a) study of daily mortality in Philadelphia, find statistical indications that "strongly support the hypothesis that the effects of SO_2 and TSP are nonlinear" (p. 31). Lipfert and Wyzga (1995) also suggest that the best functional forms might be nonlinear. However, Pope et al. (1995b) conclude from their review of the epidemiological literature that "health effects increase monotonically with pollution levels, often with a near linear dose-response relationship" (p. 14).

We use non-linear functions to estimate short-term or "acute" deaths from particulate air pollution, and a linear function to estimate long-term or "chronic" deaths from air pollution.

11.3.5.5 Particulates and acute mortality

A number of time-series studies have been performed which, when taken together, present a coherent picture that particulates increase the daily mortality rate. Bates (1992) reported on a series of particularly persuasive studies in Utah:

> The recent analyses of the respiratory consequences of air pollution in Utah are unique Air monitoring has shown that in this location, oscillations occur in PM_{10} levels without any significant SO_2, NO_2, or acid aerosol H_2SO_4 accompaniments. About 40% of the particles originate from a single source An initial report related hospital admissions for respiratory disease to the PM_{10} levels (Pope, 1989), this was confirmed in a later analysis (Pope, 1991) A third report indicated an excess of respiratory mortality in the impacted region (Archer, 1990), and a fourth (Pope, 1991) has shown that PM_{10} levels are associated with reduction in PEFR [i e , lung functioning] in normal children and increased symptoms and medication use in a panel of adult asthmatics in the area of concern. Thus in one location, without exposure to multiple pollutants, four different adverse health indices have been found to be associated with variations in the PM_{10} levels below the present U S standard respiratory mortality, increased respiratory hospital admissions, reduced lung function, and increased symptoms and medication use This is a unique example therefore of remarkable coherence and is particularly valuable as multiple pollutants were not present (p 340)

The weight of the evidence, then, clearly indicates that particulate pollution causes mortality. Schwartz (1994a) sums up the case:

> The associations of particulates with daily mortality have now been reported at lower concentrations in locations with humid climates and air pollution peaking in cold weather. in locations with semiarid climates and air pollution peaking in cold weather. and in locations with humid climates and air pollution peaking in warm weather, suggesting that the possibility of confounding by weather and seasonal factors is unlikely Furthermore, the relative risks reported in the studies were quite similar, which also makes confounding less likely (p 34)

> The epidemiologic studies of particulate air pollution and daily mortality show consistency of finding, evidence of dose-dependent increases in risk, similarity in slopes, and exposure preceding effect These findings also are coherent with studies relating airborne particles to symptoms and pulmonary function and hospital attendance Overall, this pattern meets the generally accepted criteria for drawing causal inference in epidemiology In light of such a pattern, it would seem that the burden of proof has now shifted, and it is incumbent upon those who disbelieve the causality of the reported associations to provide evidence showing that they are confounded . In the absence of such evidence, it is only prudent to treat these associations as causal (pp 34-35)

Although some investigators have questioned the statistical association between daily mortality and particulate air pollution (Li and Roth, 1995; Moolgavkar et al., 1995), a recent independent and sophisticated re-analysis of six of the more prominent studies, including those questioned by Li and Roth (1995) and Moolgavkar et al. (1995), validated the original results. The independent re-analysis concluded that "the original findings cannot be explained by an arbitrary choice of statistical model, but appear to be robust to a variety of modeling procedures" (*Particulate Air Pollution and Daily Mortality*, 1995).

Two well-run studies allow us to quantify mortality. We use the results from Pope et al.'s (1992) study, however, rather than Dockery et al.'s (1992) because it allows us to separately estimate total, cardiovascular, respiratory, and all other deaths. For simplicity in our results we sum the estimated cardiovascular and respiratory deaths.

Using Poisson regression, Pope et al. (1992) found a significant association between the five-day moving average of PM_{10} and cardiovascular and respiratory deaths and no effect for PM_{10} on the incidence of "all other deaths." In both the lower and upper bound scenarios, we use the coefficients for cardiovascular and respiratory deaths. We assume that there is no effects threshold, and estimate the effects down to particulates' estimated natural background level.

Estimating Acute cardiovascular Deaths Caused By Particulates

As discussed earlier, we distinguish between "acute" mortality and "chronic" mortality. Acute mortality refers to deaths linked to current pollution levels. Chronic mortality refers to deaths caused by air pollution but not linked to current air pollution levels. In the case of particulate air pollution, we will distinguish between acute cardiovascular deaths and acute respiratory deaths because we have separate equations for them.

We estimate the number of acute cardiovascular deaths caused by PM_{10} with the following equation (derived in Section 11.2.4.1):

$$\Delta Cardiovascular\ Deaths = Cardiovascular\ Deaths_0 \cdot \left[e^{(PP-PI)\beta_{pm}} - 1 \right]$$

where:

Δ Cardiovascular Deaths = change in the daily number of cardiovascular deaths

Cardiovascular $Deaths_0$ = county daily average number of cardiovascular deaths (U.S. Department of Health and Human Services, 1991)

PI = daily average PM_{10} level ($\mu g/m^3$), after control[42]

PP= daily average PM_{10} level ($\mu g/m^3$), before control

B_{pm} = 0.00179, PM_{10} Poisson regression coefficient (Pope et al., 1992: 214).

Estimating Acute respiratory Deaths Caused By Particulates

We estimate the number of acute respiratory deaths caused by PM_{10} with the following equation:

$$\Delta Respiratory\ Deaths = Respiratory\ Deaths_0 \left[e^{(PP-PI)\beta_{pm}} - 1 \right]$$

where:

Δ Respiratory Deaths = change in the daily number of respiratory deaths

Respiratory $Deaths_0$ = county daily average number of respiratory deaths (U.S. Department of Health and Human Services, 1991)

PP = daily average PM_{10} level ($\mu g/m^3$), after control

PI = daily average PM_{10} level ($\mu g/m^3$), before control

B_{pm} = 0.00361, PM_{10} Poisson regression coefficient (Pope et al., 1992: 214).

11.3.5.6 Chronic Mortality

Air pollution might have a gradual or cumulative mortal effect, as well as an immediate mortal effect. We term the gradual, cumulative effect "chronic mortality.

The evidence indicates that air pollution causes chronic mortality. Detels et al. (1991), Jedrychowski and Krzyzanowski (1989), and van der Lende et al. (1980) found that long-term exposure to air pollution causes a significant decline in lung functioning, which is a significant predictor of chronic disease and early death (Anderson et al., 1988; Krzyzanowski and Wysocki, 1986; Cullen, 1983; Beaty et al., 1982; Higgins and Keller, 1970). Archer (1990) found higher mortality from non-

[42]When estimating cardiovascular deaths and respiratory deaths, we use the daily average PM_{10} level (rather than the five-day moving average used by Pope et al (1992)), because our procedure for filling in missing observations (Section 11.2.2) does not account for the exact day of the missing observation

malignant respiratory disease in the more polluted of two closely paired counties in the Utah Valley.

To estimate the upper bound of chronic mortality, we use the prospective cohort study of Pope et al. (1995a), which is perhaps the most comprehensive study to date. Using a proportional hazards model, Pope et al. (1995a) find that the number of annual cardiopulmonary deaths rises by 31% (i.e., the hazard ratio, or relative risk, = 1.31) when the annual average $PM_{2.5}$ pollution level increases from 9.0 to 33.5 $\mu g/m^3$. We can use Pope et al.'s relative risk to estimate the change in cardiopulmonary deaths as a function of a change in pollution.

The proportional hazards model assumes that the ratio of the pollution hazard, or risk, at pollution level PI to the risk at pollution level PP, is a nonlinear function of the difference between PI and PP.

$$RR \equiv \frac{h(t, PI, x_i)}{h(t, PP, x_i)} = e^{B'(PI-PP)}$$

where:

RR = relative risk (the hazard ratio)

$h(t, P, x_i)$ = the pollution risk as a function of time, the pollution level, and the other covariates x_i

t = time

x_i = the other covariates that affect the probability of dying

PI = the initial pollution level; in our analysis, the initial annual average $PM_{2.5}$ level ($\mu g/m^3$) (data from ambient air-quality monitors; see discussion in Chapter 11.2)

PP = the final pollution level (after the reduction in emissions); in our analysis, the annual average $PM_{2.5}$ level ($\mu g/m^3$), after the reduction in emissions (see discussion in Report #16 in the social-cost series listed at the beginning of this report)

B′ = the vector of coefficients of from the proportional hazards model (on the assumption that the covariates other than pollution remain the same, this vector becomes the coefficient on pollution, B_{PM})

The pollution risk at a given pollution level, $h(t, P, x_i)$, is defined as the ratio of the probability of dying at time t divided by the cumulative probability of having died by time t:

$$h(t, P, x_i) \equiv \frac{f(t, P, x_i)}{F(t, P, x_i)}$$

$$F(t, P, x_i) = \int^{t} f(t, P, x_i) dt$$

where:

$f(t, P, x_i)$ = the probability density (the probability of dying, as a function of the time t, the pollution level P, and the other covariates x_i)

$F(t, P, x_i)$ = the cumulative density function (the probability of *having* died, as a function of the time t, the pollution level P, and the other covariates x_i)

The function $h(t, P, x_i)$ thus expresses the death rate. However, to estimate this death rate, one need not actually specify the probability functions; instead, one can estimate the death rate as the ratio of the number of deaths in year to the total number of people dead or alive in the year. Thus, one can calculate the relative risk -- the ratio of the death rate at pollution level PI to the death rate at pollution level PP -- as:

$$\textit{Relative Risk } (RR) = \frac{\frac{A}{A+B}}{\frac{C}{C+D}}$$

$$\text{Risk of death at PP} = \frac{A}{A+B}$$

$$\text{Risk of death at PI} = \frac{C}{C+D}$$

where A, B, C, D, are the percentage of people who at the end of the year are:

	Dead	**Alive**
at PI	A	B
at PP	C	D

Pope et al. (1995) use this formula for the relative risk to estimate that the risk of death at 33.5 $\mu g/m^3$ (PP) is 1.31 times the risk at 9 $\mu g/m^3$ (PI). With this, we can estimate the coefficient B_{pm} in the proportional hazards model:

$$RR \equiv \frac{h(t, 33.5, x_i)}{h(t, 9, x_i)} = e^{B_{pm}(33.5-9)} = 1.31$$

$$B_{pm} = \frac{\ln(1.31)}{24.5} = 0.011022$$

Finally, we can derive the equation to estimate the change in cardiopulmonary deaths (Δ CPD), which is our ultimate objective:

$$\Delta CPD = CPD_{PI} - CPD_{PP}$$

$$CPD_{PI} = RR\ CPD_{PP}$$

$$\Rightarrow \Delta CPD = CPD_{PI} - \frac{CPD_{PI}}{RR}$$

$$\Rightarrow \Delta CPD = CPD_{PI}\ \left(1 - e^{-B_{pm}\,(PI-PP)}\right)$$

where:
ΔCPD = the change in cardiopulmonary deaths
CPD_{PP} = total cardiopulmonary deaths at pollution level PP
CPD_{PI} = total cardiopulmonary deaths at pollution level PI = county's annual number of cardiovascular and respiratory deaths (ICD-9 401-440 and 460-519) (U.S. Department of Health and Human Services, 1991).
B_{pm}, PI, and PP are as defined or derived above

We will use this equation to estimate deaths in our upper-bound case[43].

Example calculation To estimate the change in deaths due to, say, a decrease from 20 to 9 $\mu g/m^3$ of $PM_{2.5}$:

$$\Delta\ CPD = CPD_{20}\ \left(1 - e^{-0.011022\,(20-9)}\right) = 0.114 \times CPD_{20}$$

where:
CPD_{20} = cardio-pulmonary deaths at 20$\mu g/m^3$.

Pope et al. (1995a) estimated the relative risk of 1.31 from a Cox proportional hazard model. They also tried a simple regression model, and estimated an increase of 8.0 deaths per 100,000 people per year per μg/m3 increase of $PM_{2.5}$. We have used their Cox hazard model rather than their regression model because they controlled for more potentially confounding variables in the former.

In our lower bound, we estimate the change in deaths with an equation from Ozkaynak and Thurston (1987):

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[43]Pope et al (1995a) also tried a simple regression model, and estimated an increase of 8 0 deaths per 100,000 people per year per $\mu g/m^3$ increase of $PM_{2.5}$ We have used their Cox hazard model rather than their regression model because they controlled for more potentially confounding variables in the former

$$\Delta\ Deaths = B_{pm}\ (Annual\ \ Avg\ \ PM_{2.5} - Background)\ \ Population / 100{,}000$$

where.

B_{pm} = 2.2 deaths per 100,000 people per year per $\mu g/m^3$

Annual Avg $PM_{2.5}$ = annual average $PM_{2.5}$ level ($\mu g/m^3$), before control

Background= annual average $PM_{2.5}$ level ($\mu g/m^3$), after control

Population = county population of all individuals, of all ages (U.S. Bureau of the Census, 1994).

It turns out that the upper bound equation, from Pope et al. (1995a), estimates two times as many deaths as does the lower-bound equation at any given pollution level (see Chapter 11.7), and more deaths than does any other equation that we found. Consequently, one reasonably might question whether we should use it, even as an upper bound. We are uneasy with the both the magnitude of the damages that result from the use of the Pope et al. equation, and the sensitivity of the results to this magnitude. However, for three reasons, we are not so uneasy as to ignore the Pope et al study altogether. First, the Pope et al. study is comprehensive and well done. Second, previous work by Pope et al. recently has been validated (Samet et al., 1995). Third, Pope et al's regression model, which we do not use, actually estimates still more deaths than does their Cox proportional-hazard model, which we do use. As mentioned above, the Pope et al. regression model estimates 8.0 deaths per 100,000 people per year per $\mu g/m3$ increase of $PM_{2.5}$, which is 3.6 times higher than the lower-bound coefficient of 2.2 from Ozkaynak and Thurston whereas the Cox proportional-hazard model estimates two times more deaths than does the Ozkaynak and Thurston equation.

11.3.6 Sulfur Dioxide

SO_2 by itself appears to increase the breathing difficulty of asthmatics and may be linked to mortality (Tables 11.3-24 to 11.3-27; California Air Resources Board, 1991b). SO_2 has an indirect effect on morbidity and mortality through the formation of sulfate particulates. In this section, we concern ourselves with the direct effect of SO_2.

11.3.6.1 Morbidity

Two laboratory studies found that SO_2 increases bronchoconstriction in asthmatics down to 0.10 ppm (Sheppard et al., 1980; Sheppard et al., 1981). An epidemiological study by Schwartz (1992) found SO_2 linked to chest discomfort primarily in asthmatics.

It is not clear if SO_2 affects lung functioning in the general population. The epidemiological studies in Table 11.3-24 suggest that SO_2 does not have an effect on lung functioning in the general population; however, Xu et al. (1991) found SO_2 (considered separately from TSP) to be linked to reduced pulmonary functioning in Beijing, China residents. This suggests that high levels of SO_2 (found in Beijing) have a measurable impact on lung functioning.

Two epidemiological studies (Charpin, 1988; Schwartz et al., 1991) found that SO_2 increases various respiratory symptoms in children, but did not provide enough information for us to make a dose-response function. Most of the studies that we reviewed (Table 11.3-25) did not find a link between SO_2 and respiratory health. Also, there is no link to chronic illness.

A number of studies have examined the link between SO_2 and hospital admissions, with most finding no effect (Table 11.3-26). Three studies found a link:

- Fishelson and Graves (1978: 788-89) measured both SO_2 and coefficient of haze (a measure of particulates) in a study of admissions to a hospital emergency room in Chicago due to SO_2, finding a significant effect for SO_2 and none for particulates. Other researchers disagree. Mazumdar and Sussman (1983) performed an identical study in Pittsburgh and found the opposite result: a positive link between COH and hospital admissions and none between SO_2 and hospital admissions.

- Bates et al. (1990) studied the relationship between temperature and pollution and admissions to the emergency room in hospitals in Vancouver over a three period (1984-1986), finding a significant correlation between SO_2 and respiratory-related hospital admissions -- in some cases independent of other pollutants (coefficient of haze, NO_2, ozone and SO_4). Bates et al. (1990) presented only the correlation coefficients between hospital admissions and SO_2 which by themselves are not useful for a dose-response function because they give the direction of the effect but not the magnitude.

- Lipfert and Hammerstrom (1992) reported SO_2 linked to hospital admissions in southern Ontario, controlling for other pollutants. Because they did not publish the regression coefficients that they estimated, we cannot develop a dose-response function.

Most studies that control for the effects of other pollutants reject the linkage between SO_2 and hospital admissions. (Lipfert and Hammerstrom [1992] is the exception.) Richards et al. (1981), Goldstein and Weinstein (1986), Cody et al. (1992), Tseng et al. (1992), and Schwartz et al. (1993) all failed to find a link. Schwartz et al. (1991) found a significant effect for SO_2, but after controlling for TSP and NO_2, the effect disappeared. (And we discard the group of studies that found a significant effect for SO_2 but did not control for other pollutants [Samet et al., 1981; Bates and Sizto, 1983; Díaz-Caneja et al., 1991; Ponka 1991; and Sunyer et al., 1991].)

Morbidity and SO_2: Conclusion

SO_2 negatively affects asthmatics and may affect the general population. However, the evidence for an effect on the general population is mixed at best (most studies that controlled for other pollutants did not find an effect), and what positive evidence there is cannot be used to develop dose-response functions. We conclude that the current evidence does not support a quantifiable link between SO_2 and morbidity.

11.3.6.2 Mortality

Most of the studies that we reviewed (Table 11.3-27) found no link between SO_2 and mortality. However, two studies by Xu et al. (1994) and Moolgavkar et al. (1995) reported that SO_2 has a strong effect, independent of TSP levels. Examining mortality rates in Philadelphia, Moolgavkar et al. found a significant relationship between SO_2 levels and mortality in the fall, winter and spring, controlling for TSP and ozone. Xu et al. reported on mortality rates in Beijing, China, where pollution rates are quite high because of the extensive burning of coal. The results are particularly significant since SO_2 had a significant effect, both modeled separately and with TSP. TSP had a significant effect in the summer but not in the winter. Xu et al. (1994: 222) suggested that the dry north winds in the winter carrying natural soil dust may be less dangerous than anthropogenic pollution; soil is coarse and not readily inhalable and is more inert than, say, particulates from coal combustion. Since the winds contribute 40-60% of ambient TSP it would not be surprising that the TSP coefficient is insignificant. Future work should use PM_{10} measurements rather than TSP, since PM_{10} is more widely dispersed (and thus a better indicator of exposure) and is inhalable.

The work of Xu et al. (1994) and Moolgavkar suggests a link between SO_2 and mortality; however their conclusion is weakened because they used TSP rather than an inhalable particulate measure. Furthermore the bulk of the evidence we reviewed suggests that SO_2 has only an indirect effect through its effect on particulate formation. Researchers have found a link between particulates and mortality in places with very low SO_2 levels (Pope et al., 1992; Fairley, 1990), but have not found a link between SO_2 and mortality in places with very low particulate levels. We conclude that the current evidence does not allow us to quantify an direct link between SO_2 and mortality independent of the link between particulates and mortality.

ABBREVIATIONS USED IN CHAPTER 11.3 TABLES

Pollutants

British Smoke = particulate measure used in the United Kingdom
CO = carbon monoxide
COH = coefficient of haze (general particulate measure)
H^+ = hydrogen ion (measure of acidity)
HC = hydrocarbons
KM = measure of particulates (similar to the coefficient of haze)
NO = nitrogen oxide
NO_2 = nitrogen dioxide
NO_3 = particulate nitrate
NO_x = nitrogen oxides (including but not limited to NO_2)
NH_3 = ammonia
NH_4 = particulate ammonium
O_3 = ozone
Ox = oxidants,
PM = particulate matter
PM_{10} = particulate matter with a diameter of 10 microns or less
PM_{15} = particulate matter < 15 micrometers in diameter
$PM_{2.5}$ = particulate matter with a diameter of 2.5 microns or less
Coarse PM_{10} = particulate matter with a diameter between 2 5 and 10 microns
SO_2 = sulfur dioxide
SO_4 = particulate sulfate
SO_x = sulfur oxides
SOA = secondary organic aerosols
SPM = suspended particulate matter
TSP = total suspended particulates
VOCs = volatile organic compounds

Measures of pulmonary functioning

FEV_1 = forced expiratory volume in one second
FVC = forced vital capacity
MMEF = maximal midexpiratory flow
PEF = peak expiratory flow
RRAD = respiratory-related restricted activity day
Some measures of pulmonary functioning are defined in Table 3-1

TABLE 11.3-1. DEFINITIONS OF MORBIDITY AND PULMONARY FUNCTIONING MEASURES

Health Effect [a]	Definition
AOD	Airway obstructive disease This includes chronic bronchitis, emphysema and asthma Other names for this are COPD (chronic obstructive pulmonary disease) and CORD (chronic obstructive respiratory disease)
ARD2	Any respiratory symptom, headache, or eye irritation This symptom group was used by Krupnick et al (1990) to determine the effects of air pollution in Los Angeles
RAD	Restricted activity day This is a day during which a respondent is forced to alter his or her normal activity The RAD includes days of work loss or bed disability as well as more minor restrictions, due to both respiratory and nonrespiratory conditions
mRAD	Minor restricted activity day An mRAD is a restricted activity day that does not result in either work loss or bed disability and therefore involves more minor conditions and reductions in activity Both respiratory and nonrespiratory conditions are included in mRAD "
RRAD	Respiratory-related restricted activity day A respiratory-related restricted activity day is a combined measure of respiratory ailments that includes the common cold, upper respiratory infections, influenza, acute bronchitis, pneumonia, and other respiratory conditions, including asthma attacks It includes three types of conditions 1) bed disability days, 2) work or school loss days and 3) minor restricted activity days
mRRAD	Minor respiratory-related restricted activity day Involves more minor conditions and reductions in activity than does an RRAD.
Pulmonary Functioning [b]	**Definition**
FVC	Forced vital capacity The volume of air that can be expelled from fully inflated lungs by unassisted maximal subject effort
FEV_1	Forced expiratory volume in one second The volume of air expelled from the lungs during the first second of an FVC maneuver
FEF_{25-75}	Flow rate between 75 and 25% of vital capacity during the FVC maneuver, also known as maximal mid-expiratory flow rate
PEFR	Peak expiratory flow rate during an FVC maneuver

[a]Source National Center for Health Statistics (1992), Krupnick et al (1990), Ostro and Rothschild (1989), Ostro (1987)

[b]Source. Lippmann (1989c)

TABLE 11.3-2. NUMBER OF RESPIRATORY-RELATED AND OTHER RESTRICTED ACTIVITY DAYS BY AGE IN 1991 (100 PERSONS/YEAR)

Respiratory Conditions[a]	All Ages	<5	5-17	18-24	25-44	45-64	>65
All Restricted Activity Days	733.3	966 1	720 5	712 4	682 9	643 1	877 4
All Respiratory Conditions	341 6	526 3	407 2	297 7	285.8	309 4	358 7
Common Cold	70.8	150.7	77 5	82 0	54 5	51 9	73 4
Other Acute Upper Resp Infections	31 5	50.8	49 4	18 2	28.0	23.9	23 7
Influenza	184 5	236 9	235 2	169 1	166 2	181 6	139 3
Acute Bronchitis	22.5	51 4	24.0	15 7	17 0	25.1	18 1
Pneumonia	23 0	24 1	10 8	10 6	15.3	18 9	78.5
Other Respiratory Conditions	9 3	12.5	10.3	2 2	4.8	8 1	25 6
Eye Conditions	1 8	4 6	0.3	4 5	0 1	1 7	4 9
Headache, Excluding Migraine	5 2	--	7 6	4 9	5.2	3 3	8 0

Source National Center for Health Statistics (1992 Table 16)

[a]Some of these terms are defined in Table 11.3-1.

TABLE 11.3-3. SUMMARY OF EPIDEMIOLOGICAL STUDIES CONCERNING THE HEALTH EFFECTS OF CARBON MONOXIDE

Study	Population and Study Period	Pollutants	Results
Perry et al. (1983)	24 asthmatics living in Denver Data collected from January 9, 1979 through March 28, 1979.	CO, NO_3, O_3, $PM_{2.5}$, PM_{15}, SO_2, SO_4 and TSP considered independently	CO not linked to asthma Only NO_3 significantly linked to asthma
Robertson and Lebowitz (1984)	3800 whites living in Tucson Data collected from August 8, 1974 to May 4, 1977	CO, NO_2, O_3 and TSP considered jointly with stepwise regression	One pollutant at most after stepwise regression for a variety of symptoms, weather and pollen variables generally more important CO linked to cough and rhinitis
Lebowitz et al (1987)	204 people living in Tucson (45 asthmatics, 68 with airway obstructive disease, 62 with allergies and 29 individuals without a history of respiratory problems)	CO, NO_2, O_3 and TSP considered jointly	No effect of pollutants on individuals without a history of respiratory problems CO linked to daily peak flow and rhinitis in asthmatics, and cough in people with airway obstructive disease
Schwartz and Zeger (1990)	Approximately 100 student nurses in Los Angeles Data collected November 1961 to May 1964	CO, NO_2, O_x and SO_2 considered jointly.	Air pollutants linked to a variety of health effects CO linked to the incidence of headache

TABLE 11.3-4. SUMMARY OF HEALTH EFFECTS STUDIES EXAMINING EMERGENCY ROOM ADMISSIONS AND MORTALITY AND CARBON MONOXIDE

Study	Population and Study Period	Pollutants	Results
Hexter and Goldsmith (1971)	Mortality records for deaths from all causes in Los Angeles County from January 1, 1962 to December 31, 1965	CO and O_x considered independently	In a linear regression model, CO was found to be significantly linked to mortality No effect found for O_x
Kuller et al (1975)	Heart attack-caused mortality in adults, from 25-64 years of age, living in Baltimore, between June 1970 and June 1972	CO	Ambient CO not linked to mortality Heart attack victims had higher carboxyhemoglobin levels, however, the authors concluded the difference was probably due to cigarette smoking
Kurt et al (1978)	Cardio-respiratory-related emergency room admissions in Denver between November 1, 1975 and February 1, 1976	CO, NO_x, O_3, and sulfur compounds The analysis focused on CO alone, as the other pollutants had low levels and were not highly correlated with CO	CO correlated with emergency room admissions for cardiorespiratory complaints (i e , shortness of breath, difficulty in breathing, nontraumatic pain in the chest, asthmatic attack and increased cough)
Mendelsohn and Orcutt (1979)	Cross-sectional study of 408 counties across the U.S Demographic data (including mortality rate) are from 1970 Pollution data is from 1974	CO, nitrates, NO_2, O_3, sulfates, SO_2 and TSP considered jointly	In estimating the annual effects of air pollution, significant effects were found for CO (7,000 to 35,000 deaths), SO_2 (7,000 to 40,000 deaths), and sulfates (164,000 to 212,000 deaths) Significant negative effects were found for NO_2 No effect found for O_3, nitrates and TSP
Samet et al (1981)	All ages in Steubenville, Ohio Population = 31,000 Data collected for the months of March, April, October and November in 1974-1977	CO, NO_2, O_3, SO_2 and TSP considered independently in a regression analysis	Small, but significant link found between SO_2 and TSP and emergency room admissions for respiratory problems No effect for CO and other pollutants
Stern et al (1981)	1,558 white male motor vehicle examiners in employed in New Jersey for a minimum of six months between 1944 and 1973	CO measured although it was not used in the statistical analysis	Motor vehicle examiners had significantly more cardiovascular deaths within 10 years after employment, compared to national rates They also had higher cancer mortality found 30 years after employment

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Study	Population and Study Period	Pollutants	Results
Edling and Axelson (1984)	Cohort of workers (clerks, bus drivers, and garage workers) in a bus company, from 1951-1978	No measured pollutants	Garage workers suffered more than the expected number of cardiovascular-related deaths The authors suggest that the results are in accordance with the hypothesis that CO causes cardiovascular problems
Shumway et al. (1988)	All nonaccidental mortality records from Los Angeles County, with subcategories for respiratory-related deaths and cardiovascular-related deaths Data collected for 1970-1979	CO, HC, KM, NO_2, O_3, SO_2 considered independently , some pollutants (e g , CO, KM and HC) were highly corrected (r > 0 8)	CO, KM and HC were found to be approximately equal predictors of mortality No significant effect was found for NO_2, SO_2 and O_3
Stern et al. (1988)	5,529 New York City bridge and tunnel officers, employed at one of nine major water crossings, between January 1, 1952 and February 10, 1981.	CO	Tunnel officers suffered significantly more cardiovascular deaths than expected, based on New York City's population The relatively more-exposed tunnel officers also had a higher risk than bridge officers The risk for tunnel officers declined when switched to working at the less-exposed bridges.
Kinney and Ozkaynak (1991)	All nonaccidental mortality records from Los Angeles County, 1970-1979 The study also considered respiratory-related deaths and cardiovascular-related deaths	CO, KM, NO_2, O_3 and SO_2 considered jointly	CO, KM and NO_2 each significantly related to total mortality and cardiovascular-related mortality in models with O_3. It was not possible to determine which pollutant (besides O_3) caused mortality
Ponka (1991)	All ages living in Helsinki, Finland Data collected between 1987-1989	CO, NO, NO_2, O_3, SO_2 and TSP considered independently and in a step-wise regression	All of the pollutants were correlated with asthma-related hospital admissions Only NO_2 and O_3 linked to admissions for children Asthma-related emergency room admissions were more highly correlated with SO_2, TSP and O_3 All asthma-related hospital admissions (including emergency room) were more correlated with CO, NO and NO_2

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Study	Population and Study Period	Pollutants	Results
Sunyer et al. (1991)	All ages in Barcelona, Spain Data collected from 1985-1986	British Smoke, CO, NO_2, O_3 and SO_2 considered independently	CO a significant predictor of emergency room admissions for COPD British Smoke and SO_2 also linked to admissions Each pollutant was considered separately, so it is not possible to determine if CO would still be significant, controlling for other pollutants
Morris et al (1995)	Hospital admissions for congestive heart failure in persons over 65 in seven metropolitan areas of the U S	CO, NO_2, O_3 and SO_2 considered jointly	CO significantly linked to hospital admissions for congestive heart failure in both single-pollutant and multi-pollutant models
Schwartz and Morris (1995)	Hospital admissions for ischemic heart disease, dysrhythmias, and congestive heart failure in persons over 65 in Detroit, Michigan	CO, O_3, PM_{10} and SO_2 considered jointly	CO significantly linked to hospital admissions for congestive heart failure in both single pollutant and multi pollutant models No link to ischemic heart disease and dysrhythmias
Kinney et al (1995)	Daily counts of total deaths in Los Angeles County from January 1 1985 to December 31 1990, excluding accidents and suicides	PM_{10}, CO, and O_3 considered independently, plus PM_{10} + O_3, and PM_{10} + CO	In the single-pollutant models, each of the three pollutants had relative risks just significantly different from 1.0 (p value about equal to 0.05) In PM_{10} + O_3 model, PM_{10} risk was same as in PM_{10}-only model, but O_3 risk was 1 0 (no risk) In PM_{10} + CO model, risk of both was less than in single-pollutant models

TABLE 11.3-5. SUMMARY OF EPIDEMIOLOGICAL STUDIES CONCERNING THE HEALTH EFFECTS OF NITROGEN DIOXIDE

Study	Population and Study Period	Pollutants	Results
Robertson and Lebowitz (1984)	3800 whites living in Tucson Data collected from August 8, 1974 to May 4, 1977	CO, NO_2, O_3 and TSP considered jointly with stepwise regression	One pollutant at most included in the stepwise regression for a variety of symptoms, weather and pollen variables generally more important NO_2 linked to cough
Harrington and Krupnick (1985)	2928 children living in Chattanooga, Tennessee Data collected between Spring 1972 to Spring 1973	NO_2, SO_4 and TSP considered jointly in a pooled cross-sectional time series	A U-shaped relationship between acute respiratory disease and NO_2, no explanation was found for this result SO_4 was positively linked to acute respiratory disease
Holguin et al (1985)	51 asthmatics (aged 7-55) living in Houston Data collected between May-October 1981	CO, NO_2, O_3, PM_{15}, SO_2 and TSP CO and NO_2 considered jointly	NO_2 not significantly linked to asthma attacks, controlling for O_3 The effects of the other pollutants were not considered in the published results
Lebowitz et al (1987)	204 people living in Tucson (45 asthmatics, 68 with airway obstructive disease, 62 with allergies and 29 individuals without a history of respiratory problems)	CO, NO_2, O_3 and TSP considered jointly	No effect of pollutants on individuals without a history of respiratory problems NO_2 linked to wheeze and cough in asthmatics, and wheeze and eye irritation in people with airway obstructive disease
Euler et al (1988)	7,445 Seventh-Day Adventists 25 years and older living in California. Data collected from 1966-1976	NO_2, O_3, SO_2, and TSP considered independently and in two- and three-pollutant models	NO_2 not linked to chronic obstructive pulmonary disease (COPD) The authors concluded TSP is the best predictor of COPD
Dockery et al (1989)	Elementary school students, 10-12 years old, living in six cities in the U S Data collected during the 1980-1981 school year	NO_2, O_3, $PM_{2.5}$, PM_{15}, SO_2, SO_4 and TSP considered independently	NO_2 not linked to bronchitis, chronic cough, chest illness, persistent wheeze and asthma O_3 linked to asthma PM_{15} linked to bronchitis and chronic cough
Schwartz (1989)	National survey of people aged 6-24 years old, conducted between 1976-1980	Nitric acid, NO_2, O_3, SO_2, sulfuric acid and TSP considered independently	NO_2, O_3 and TSP significantly linked to pulmonary function (measured by FEV_1, FVC and peak flow)

(continued next page)

Study	Population and Study Period	Pollutants	Results
Koo et al (1990)	362 primary school children and 319 mothers in Hong Kong Data collected in May 1985.	NO_2	NO_2 linked to chronic cough and rhinitis in non-smoking mothers No effect found for children The authors concluded, other (unmeasured) pollutants may be the cause of the reported effects
Krupnick et al (1990)	290 families living in Azusa, California Data collected from September 1978 to March 1979	COH, NO_2, O_3 and SO_2 considered jointly	NO_2 had a significant, negative relationship with respiratory symptom in adults, and had an insignificant, negative effect on the incidence of respiratory symptoms in children COH was positively related to the incidence of respiratory symptoms in both adults and children O_3 significantly related to effects only in adults
Schwartz and Zeger (1990)	Approximately 100 student nurses in Los Angeles Data collected November 1961 to May 1964	CO, NO_2, O_x and SO_2 considered jointly	Air pollutants linked to a variety of health effects NO_2 linked to the incidence of eye irritation, phlegm and sore throat
Schwartz et al (1991)	Young children in five German cities Data collected from January 1983 to August 1985 in Duisberg, from September 1984 to April 1987 in Koln, from January 1986 to December 1987 in Stuttgart, Tubingen and Freudenstadt	NO_2, SO_2 and TSP considered jointly	NO_2, SO_2 and TSP were significant predictors of croup-related visits to doctors and hospitals, in single pollutant models In two pollutant models, NO_2 (t=1 06) and TSP (t=1 44) were both not significant NO_2 (t=1 83) was almost significant with SO_2 ($\|t\|<1$) TSP (t=2.80) was significant with SO_2 ($\|t\|<1$)
Braun-Fahrlander et al (1992)	Preschool children living in four cities in Switzerland Volunteers recruited collected between November 1985 and December 1986 to fill out six-week symptom diaries	NO_2, O_3, SO_2 and TSP considered jointly	NO_2 associated with the duration of respiratory symptom episodes, but the authors concluded that this effect may be due to confounding with TSP TSP linked to both the incidence and duration of respiratory symptoms No effect found for SO_2 or O_3
Hasselblad et al (1992)	Meta-analysis (synthesis) of 12 health effects studies looking at the effects of NO_2 on children under that age of 12	NO_2	Individually, the studies often do not show NO_2 having a significant effect Combined, the studies show that a 30 $\mu g/m^3$ increase in NO_2 will increase respiratory illness by 20 percent

(continued next page)

Study	Population and Study Period	Pollutants	Results
Hoek et al (1993)	Children from four years of age to seven years of age living in three nonindustrial towns in the Netherlands Data collected from March 1989 to July 1989	NO_2, O_3, PM_{10} and SO_2 considered jointly	NO_2 not significantly linked to pulmonary functioning after controlling for O_3 Daily O_3 levels were negatively correlated with lung functioning (measured by FEV_1, FVC, MMEF and PEF) A small effect was found for PM_{10}, independent of O_3
Ostro et al (1993)	321 adults (18 years and older) from Azusa, California A subset of the data used by Krupnick et al (1990) Data collected from September 1978 to March 1979	COH, NO_2, O_3, SO_2 and SO_4 considered independently	NO_2 not linked to lower respiratory symptoms, upper respiratory symptoms, or eye irritation SO_4 and O_3 had significant effects
Roemer et al (1993)	74 children with chronic respiratory problems from two, small industrial towns in the Netherlands Data collected from December 17, 1990 to March 17, 1991	British Smoke, NO_2, PM_{10} and SO_2 considered independently	NO_2 not linked to any adverse health effects SO_2, PM_{10} and British Smoke linked to asthma attacks, wheeze and runny nose

TABLE 11.3-6. SUMMARY OF HEALTH EFFECTS STUDIES EXAMINING EMERGENCY ROOM ADMISSIONS AND MORTALITY AND NITROGEN DIOXIDE

Study	Population and Study Period	Pollutants	Results
Richards et al (1981)	Children in Los Angeles Data collected from August 1, 1979 to January 31, 1980	COH, HC, NO, NO_2, O_3, SO_2 and SO_4 considered independently	NO, NO_2, COH and HC positively linked to asthma-related emergency room admissions SO_2 and O_3 negatively linked to asthma-related emergency room visits
Samet et al (1981)	All ages in Steubenville, Ohio Population = 31,000 Data collected for the months of March, April, October and November in 1974-1977	CO, NO_2, O_3, SO_2 and TSP considered independently in a regression analysis	NO_2 not linked to emergency room admissions for respiratory problems Small, but significant effects were found for SO_2 and TSP
Bates and Sizto (1983)	All ages in southern Ontario Data collected from the months of January, February, July and August 1974, 1976-1978	COH, NO_2, O_3 and SO_2 considered independently	NO_2 negatively correlated with respiratory-related admissions to hospitals Significant positive correlations found for SO_2 and O_3
Shumway et al (1988)	All nonaccidental mortality records from Los Angeles County (1970-1979), with subcategories for respiratory-related deaths and cardiovascular-related deaths	CO, HC, KM, NO_2, O_3 and SO_2 considered independently , some pollutants (e g., CO, KM and HC) were highly corrected ($r > 0.8$)	CO, KM and HC were found to be approximately equal predictors of mortality NO_2, SO_2 and O_3 not linked to mortality
Bates et al (1990)	All ages in Vancouver Data collected between July 1984 and October 1986	COH, NO_2, O_3, SO_2 and SO_4 considered independently	NO_2 related to respiratory-related admissions for adults (aged 61 years and over) during November and April SO_2 and SO_4 also had a significant effect on this group of people
Kinney and Ozkaynak (1991)	All nonaccidental mortality records from Los Angeles County, 1970-1979 The study also considered respiratory-related deaths and cardiovascular-related deaths	CO, KM, NO_2, O_3 and SO_2 considered jointly	CO, KM and NO_2 each significantly related to total mortality and cardiovascular-related mortality in models with O_3 It was not possible to determine which pollutant (besides O_3) caused mortality

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Study	Population and Study Period	Pollutants	Results
Ponka (1991)	All ages living in Helsinki, Finland Data collected between 1987-1989	CO, NO, NO_2, O_3, SO_2 and TSP considered independently and in a step-wise regression	All of the pollutants were correlated with asthma-related hospital admissions Only NO_2 and O_3 linked to admissions for children Asthma-related emergency room admissions were more highly correlated with SO_2, TSP and O_3 All asthma-related hospital admissions (including emergency room) were more correlated with CO, NO and NO_2
Sunyer et al (1991)	All ages in Barcelona, Spain Data collected from 1985-1986	British Smoke, CO, NO_2, O_3 and SO_2 considered independently	NO_2 not a significant predictor of emergency room admissions for COPD CO, British Smoke and SO_2 linked to admissions
Dockery et al (1992)	All nonaccidental mortality records from the St Louis metropolitan statistical area and eastern Tennessee from September 1985 to August 1986	H^+, NO_2, O_3, $PM_{2.5}$, PM_{10}, SO_2, SO_4 jointly	NO_2 not significantly linked to mortality A strong association was found between PM_{10} and mortality
Lipfert and Hammerstrom (1992)	Respiratory-related admissions to 79 acute-care hospitals in southern Ontario, between 1979 and 1985	COH, NO_2, O_3, SO_2, SO_4 and TSP.	O_3, SO_2, SO_4 and TSP were significantly associated with respiratory admissions No single pollutant was determined to be the cause There were no reported effects for COH and NO_2
Dockery et al (1993)	Health data collected over 14-16 years (study ended in 1991) from 8,111 white persons in six cities in the U.S -- Portage, WI, Topeka, KS, Watertown, MA, Kingston, TN, St Louis, MO, and Steubenville, OH	NO_2, O_3, $PM_{2.5}$, PM_{10}, PM_{15}, SO_2, SO_4, TSP and aerosol acidity considered independently	Mortality more strongly linked to $PM_{2.5}$, PM_{10}, PM_{15} and SO_4 than with NO_2, SO_2, TSP and aerosol acidity O_3 levels varied little and was not significant Air pollution linked to lung cancer and cardiopulmonary disease-related deaths

TABLE 11.3-7. SUMMARY OF STUDIES CONCERNING ACUTE MORBIDITY AND OZONE

Study	Population and Study Period	Pollutants	Results
Whittemore and Korn (1980)	443 asthmatics living in southern California between 1972 and 1975	NO_x, O_x, RSP, SO_x and TSP All except O_x were highly collinear In the analysis, TSP was used as a "surrogate" for all of these pollutants	O_x and TSP were both significantly related to asthma attacks, in multiple logistic regressions
Perry et al (1983)	24 asthmatics living in Denver Data collected from January 9, 1979 through March 28, 1979	CO, NO_3, O_3, $PM_{2.5}$, PM_{15}, SO_2, SO_4 and TSP considered independently	O_3 not linked to asthma Only NO_3 significantly linked to asthma
Robertson and Lebowitz (1984)	3800 whites living in Tucson Data collected from August 8, 1974 to May 4, 1977	CO, NO_2, O_3 and TSP considered jointly with stepwise regression	One pollutant at most after stepwise regression for a variety of symptoms; weather and pollen variables generally more important No reported effect for O_3
Holguin et al (1985)	51 asthmatics (aged 7-55) living in Houston Data collected between May-October 1981	CO, NO_2, O_3, PM_{15}, SO_2 and TSP CO and NO_2 considered jointly	O_3 significantly linked to asthma attacks, controlling for NO_2 The effects of the other pollutants were not shown in the published results
Portney and Mullahy (1986)	3,347 adults (aged 17 and older) from the 1979 national Health Interview Survey	O_3 and SO_4 considered independently and jointly.	The two-week average of the one-hour daily maximum of O_3 linked to minor RRADs over this same two-week interval O_3 not found linked to any acute illnesses in children No significant effects found for SO_4
Lebowitz et al (1987)	204 people living in Tucson (45 asthmatics, 68 with airway obstructive disease, 62 with allergies and 29 individuals without a history of respiratory problems)	CO, NO_2, O_3 and TSP considered jointly.	O_3 linked to wheeze, cough and reduced pulmonary functioning in asthmatics No effect of pollutants on individuals without a history of respiratory problems
Dockery et al (1989)	Elementary school students, 10-12 years old, living in six cities in the U S Data collected during the 1980-1981 school year	NO_2, O_3, $PM_{2.5}$, PM_{15}, SO_2, SO_4 and TSP considered independently	O_3 significantly related to asthma rates Particulate measures (especially PM_{15} and TSP) were associated with increased bronchitis, chronic cough and chest illness TSP was consistently associated with reduced pulmonary functioning

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Study	Population and Study Period	Pollutants	Results
Ostro and Rothschild (1989)	Six groups of roughly 8,000 adults (aged 18-65) from the 1986-1981 national Health Interview Survey	O_3 and $PM_{2.5}$ considered jointly	O_3 significantly linked to minor RRADs in three of the years (1976, 1979 and 1980), and negatively related in two of the years (1977 and 1981) $PM_{2.5}$ significantly related to RRADs in most years
Schwartz (1989)	National survey of people aged 6-24 years old, conducted between 1976-1980	Nitric acid, NO_2, O_3, SO_2, sulfuric acid and TSP considered independently	O_3 significantly linked to pulmonary function (measured by FEV_1, FVC and peak flow) Significant effects also found for TSP and NO_2
Krupnick et al (1990)	290 families living in Azusa, California Data collected from September 1978 to March 1979	COH, NO_2, O_3 and SO_2 considered jointly	O_3 significantly related to effects only in adults COH was positively related to the incidence of respiratory symptoms in both adults and children The pollutants were considered simultaneously Significant negative effects found for NO_2 and SO_2
Schwartz and Zeger (1990)	Approximately 100 student nurses in Los Angeles Data collected November 1961 to May 1964	CO, NO_2, O_x and SO_2 considered jointly	Air pollutants linked to a variety of health effects O_3 linked to the incidence of chest discomfort and eye irritation
Braun-Fahrlander et al (1992)	Preschool children living in four cities in Switzerland. Volunteers recruited collected between November 1985 and December 1986 to fill out six-week symptom diaries	NO_2, O_3, SO_2 and TSP considered jointly	No effect found for O_3 or SO_2 on respiratory symptoms suffered by preschool children NO_2 associated with the duration of respiratory symptom episodes, but the authors concluded that this effect may be due to confounding with TSP TSP linked to both the incidence and duration of respiratory symptoms
Castillejos et al (1992)	148 schoolchildren (aged 7-9 years old) in Mexico City Data collected between January 1 and June 30, 1988	O_3	O_3 linked to decreased lung functioning -- children with a history of chronic phlegm production are especially susceptible The results are somewhat weakened because no other pollutants were measured

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Study	Population and Study Period	Pollutants	Results
Schwartz (1992)	Approximately 100 student nurses in Los Angeles. Data collected November 1961 to May 1964	CO, NO_2, O_x and SO_2 considered jointly	O_x increased the duration of cough, phlegm and sore throat SO_2 increased the duration of chest discomfort, primarily in asthmatics.
Hoek et al (1993)	Children from four years of age to seven years of age living in three nonindustrial towns in the Netherlands Data collected from March 1989 to July 1989	NO_2, O_3, PM_{10} and SO_2 considered jointly	Daily O_3 levels were negatively correlated with lung functioning (measured by FEV_1, FVC, MMEF and PEF) A small effect was found for PM_{10}, independent of O_3 NO_2 not significantly linked to pulmonary functioning after controlling for O_3
Ostro et al (1993)	321 adults (18 years and older) from Azusa, California A subset of the data used by Krupnick et al (1990) Data collected from September 1978 to March 1979	COH, NO_2, O_3, SO_2 and SO_4 considered independently	Controlling for temperature, O_3 linked to lower respiratory symptoms ($p=0.07$), upper respiratory symptoms ($p=0.06$), and eye irritation ($p<0.0001$) SO_4 also had a significant effect on lower respiratory illness The pollutants were considered separately

TABLE 11.3-8. SUMMARY OF STUDIES CONCERNING CHRONIC MORBIDITY AND OZONE

Study	Population and Study Period	Pollutants	Results
Euler et al (1988)	7,445 Seventh-Day Adventists 25 years and older living in California Data collected from 1966-1976	NO_2, O_3, SO_2, and TSP considered independently and in two- and three-pollutant models	O_3 significantly linked to an increased risk of COPD In three pollutant models with TSP and SO_2, only TSP was significant
Portney and Mullahy (1990)	1,318 adults (over the age of 17) in a national survey in 1979	O_3 and TSP Both the annual average pollution level and six-year average (1974-1979) were used in this analysis	Marginally significant relationship found between TSP and emphysema, chronic bronchitis and asthma The six-year O_3 level was significantly related to the incidence of sinusitis and hay fever O_3 not related to a combined measure of more severe chronic disease (emphysema, chronic bronchitis and asthma)
Abbey et al (1991b)	6,303 nonsmoking Seventh-Day Adventists living in California in 1977, and who had resided within 5 miles of their current residence for 10 years Health data collected between 1977 and 1987. (Mortality and cancer analysis used full observation set, 3,914 observations for the respiratory symptom analysis)	O_3 and TSP considered independently and jointly The average pollution level from 1973-1977 was used to determine pollution exposure Estimated the number of hours of pollution exposure above four thresholds	O_3 linked to asthma and respiratory cancer No link found between O_3 and total mortality TSP significantly linked with all malignant neoplasms, airway obstructive disease and asthma The pollutants were considered separately
Abbey et al (1993)	3,914 nonsmoking Seventh-Day Adventists living in California in 1977, and who had resided within 5 miles of their current residence for 10 years Health data collected in 1977 and 1987	O_3, SO_2 and TSP considered independently and jointly The average pollution level from 1973-1977 was used to determine pollution exposure in published results Used the average annual number of hours of pollution exposure above five thresholds	O_3 linked to new cases of asthma and symptom severity of asthma When O_3 modeled with TSP the results were unstable, Abbey et al concluded both O_3 and TSP are significantly linked to new cases of asthma and symptom severity

TABLE 11.3-9. SUMMARY OF STUDIES CONCERNING HOSPITAL ADMISSIONS AND MORTALITY AND OZONE

Study	Population and Study Period	Pollutants	Results
Hexter and Goldsmith (1971)	Mortality records for deaths from all causes in Los Angeles County from January 1, 1962 to December 31, 1965	CO and O_x considered independently	In a linear regression model, CO was found to be significantly linked to mortality No effect found for O_x.
Richards et al (1981)	Children in Los Angeles. Data collected from August 1, 1979 to January 31, 1980.	COH, HC, NO, NO_2, O_3, SO_2 and SO_4 considered independently	NO, NO_2, COH and HC positively linked to asthma-related emergency room admissions SO_2 and O_3 negatively linked to asthma-related emergency room visits
Samet et al (1981)	All ages in Steubenville, Ohio Population = 31,000 Data collected for the months of March, April, October and November in 1974-1977	CO, NO_2, O_3, SO_2 and TSP considered independently in a regression analysis.	Small, but significant link found between SO_2 and TSP and emergency room admissions for respiratory problems No effect for CO and other pollutants
Shumway et al (1988)	All nonaccidental mortality records from Los Angeles County, with subcategories for respiratory-related deaths and cardiovascular-related deaths Data collected for 1970-1979	CO, HC, KM, NO_2, O_3 and SO_2 considered independently , some pollutants (e g , CO, KM and HC) were highly corrected (r > 0 8)	CO, KM and HC were found to be approximately equal predictors of mortality NO_2, SO_2 and O_3 not linked to mortality
Bates et al (1990)	All ages in Vancouver Data collected between July 1984 and October 1986.	COH, NO_2, O_3, SO_2 and SO_4 considered independently.	O_3 correlated with total emergency hospital admissions for all age groups (ages 1-4, 15-60, and 61+). No significant effect found for respiratory- and asthma-related emergency admissions Significant effects found for SO_2 and SO_4 on respiratory- and asthma-related emergency admissions

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Study	Population and Study Period	Pollutants	Results
Kinney and Ozkaynak (1991)	All nonaccidental mortality records from Los Angeles County, 1970-1979 The study also considered respiratory-related deaths and cardiovascular-related deaths	CO, KM, NO_2, O_3 and SO_2 considered jointly	CO, KM and NO_2 each significantly related to total mortality and cardiovascular-related mortality in models with O_3 It was not possible to determine which pollutant (besides O_3) caused mortality
Ponka (1991)	All ages living in Helsinki, Finland. Data collected between 1987-1989	CO, NO, NO_2, O_3, SO_2 and TSP considered independently and in a step-wise regression	All of the pollutants were correlated with asthma-related hospital admissions. Only NO_2 and O_3 linked to admissions for children Asthma-related emergency room admissions were more highly correlated with SO_2, TSP and O_3 All asthma-related hospital admissions (including emergency room) were more correlated with CO, NO and NO_2
Schwartz (1991)	All nonaccidental mortality records in Detroit, Michigan, from 1973 to 1982	O_3 SO_2 and TSP TSP predicted from daily observations of the visibility extinction coefficient	O_3 not significantly linked to mortality, controlling for TSP TSP strongly linked to mortality, the size of the coefficient was not significantly affected by the inclusion of SO_2 No link between SO_2 and mortality.
Sunyer et al (1991)	All ages in Barcelona, Spain Data collected from 1985-1986	British Smoke, CO, NO_2, O_3 and SO_2 considered independently	O_3 negatively and significantly correlated with emergency room admissions for COPD (This may have been caused by a high correlation between O_3 and temperature.) CO, British Smoke and SO_2 were linked to admissions
Cody et al. (1992)	All ages living in central and northern New Jersey Data collected from May through August in 1988 and 1989	O_3, PM_{10} and SO_2 and visibility (as a proxy for sulfate) considered independently	O_3 significantly associated with asthma-related emergency room admissions PM_{10} and SO_2 not significantly linked

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Study	Population and Study Period	Pollutants	Results
Dockery et al. (1992)	All nonaccidental mortality records from the St. Louis metropolitan statistical area and eastern Tennessee from September 1985 to August 1986	H^+, NO_2, O_3, $PM_{2.5}$, PM_{10}, SO_2, SO_4 considered jointly	O_3 not significantly linked to mortality A strong association was found between PM_{10} and mortality
Lipfert and Hammerstrom (1992)	Respiratory-related admissions to 79 acute-care hospitals in southern Ontario, between 1979 and 1985	COH, NO_2, O_3, SO_2, SO_4 and TSP	O_3, SO_2, SO_4 and TSP were significantly associated with respiratory admissions No single pollutant was determined to be the cause There were no reported effects for COH and NO_2
Dockery et al (1993)	Health data collected over 14-16 years (study ended in 1991) from 8,111 white persons in six cities in the U.S -- Portage, WI, Topeka, KS, Watertown, MA, Kingston, TN, St Louis, MO, and Steubenville, OH	NO_2, O_3, $PM_{2.5}$, PM_{10}, PM_{15}, SO_2, SO_4, TSP and aerosol acidity considered independently	Mortality more strongly linked to $PM_{2.5}$, PM_{10}, PM_{15} and SO_4 than with NO_2, SO_2, TSP and aerosol acidity. O_3 levels varied little and was not significant Air pollution linked to lung cancer and cardiopulmonary disease-related deaths
Schwartz et al (1993)	People under 65 Data collected from hospitals in Seattle from September 1, 1989 to September 30, 1990	O_3, PM_{10} and SO_2 considered independently	O_3 and SO_2 not linked to asthma-related emergency room admissions PM_{10} significantly linked to admissions
Kinney et al (1995)	Daily counts of total deaths in Los Angeles County from January 1 1985 to December 31 1990, excluding accidents and suicides	PM_{10}, CO, and O_3 independently, plus PM_{10} + O_3, and PM_{10} + CO	In the single-pollutant models, each of the three pollutants had relative risks just significantly different from 1.0 (p value about equal to 0.05) In PM_{10} + O_3 model, PM_{10} risk was same as in PM_{10}-only model, but O_3 risk was 1.0 (no risk) In PM_{10} + CO model, risk of both was less than in single-pollutant models
Moolgavkar et al (1995)	Philadelphia mortality data collected for the period 1973-1988.	O_3, TSP and SO_2 considered jointly	O_3 linked to summer time mortality SO_2 linked to mortality in the fall, winter and spring

TABLE 11.3-10. EPIDEMIOLOGICAL STUDIES USED TO ESTIMATE THE HEALTH EFFECTS OF OZONE IN THIS ANALYSIS

Health Effect	Studies Used To Estimate Health Effects
ARD2	Krupnick et al. (1990)
Asthma Attacks	Holguin et al (1985), Whittemore and Korn (1980)
Eye Irritation	Schwartz and Zeger (1990)
Upper and Lower Respiratory Illness	Ostro et al (1993)

TABLE 11.3-11. EPIDEMIOLOGICAL STUDIES USED IN PREVIOUS ANALYSES TO ESTIMATE THE COST OF THE HEALTH EFFECTS OF OZONE

Study Of Economic Value Of Health Effects	Health Effects Evaluated	Epidemiological Study Used To Estimate Health Effects
Hall et al., 1989[a]	MRAD[b]	Portney and Mullahy (1986)
Harrison and Nichols, 1990[a]	Asthma Attack	Holguin et al (1985)
	Cough, Eye Irritation	Schwartz et al (1988)
	ARD2	Krupnick et al (1990)
	MRAD[c]	Ostro and Rothschild (1989)
Krupnick and Kopp, 1988[a]	ARD2	Krupnick et al. (1990)
	Asthma Attack	Holguin et al (1985), Whittemore and Korn (1980)
	Cough, Eye Irritation	Schwartz et al (1988)
	MRAD	Portney and Mullahy (1986)
RER (1990, Phase II)	Asthma Attack	Whittemore and Korn (1980)
	Cough, Eye Irritation	Schwartz et al (1988)
	ARD2	Krupnick et al (1990)
	MRAD	Portney and Mullahy (1986), Ostro and Rothschild (1989)
Rowe et al., 1986	Asthma Attack	Whittemore and Korn (1980)
	MRAD	Portney and Mullahy (1986)

MRAD = minor restricted activity day, ARD2 = any respiratory illness MRAD and ARD2 are defined in Table 3-1.

[a]This study also estimated symptom-days, using results from clinical studies

[b]Portney and Mullahy (1986) actually measured RRAD's, although they felt (1986. 36) that in fact ozone only caused minor symptoms and not bed disability days or work loss days In effect, they measured respiratory-related MRAD's. Similarly, Ostro and Rothschild (1989 245) did not find an effect for ozone on RRAD's, although they did find an effect for MRAD's.

[c]Ostro and Rothschild (1989) estimated MRAD's that are related to both respiratory and nonrespiratory ailments

TABLE 11.3-12. REPORTED CHRONIC CONDITIONS PER 1,000 PERSONS, BY AGE (TOTAL U.S. 1988-1991)

Chronic Condition	1988	1989	1990	1991
Asthma				
ALL AGES	41.2	47 7	41 9	47.2
Under 18 Years	49 9	61 0	57.6	62.5
18-44 Years	38.7	41.3	35.2	43.4
45-64 Years	34.8	41.5	38 6	40 7
65-74 Years	43 6	57 3	32 5	38.0
Over 74 Years	38 0	42.3	42 4	35.9
Chronic Bronchitis				
ALL AGES	49.4	49 2	51 1	50.5
Under 18 Years	54 3	50.5	53 3	53 1
18-44 Years	39 0	44 5	41 5	46.7
45-64 Years	56 1	53.7	57 4	53 9
65-74 Years	65.6	54 2	76.3	56.2
Over 74 Years	63.5	57 6	61.4	46 7
Chronic Sinusitis				
ALL AGES	139 7	138 3	131 3	129.3
Under 18 Years	61 4	68.9	56 7	59.6
18-44 Years	157.5	161.1	149.0	151 0
45-64 Years	188.0	173.5	181 9	171 1
65-74 Years	176.2	151.8	154 1	156 4
Over 74 Years	167.8	155.8	148.1	113.7
Emphysema				
ALL AGES	7.9	8.2	8.2	6 6
Under 18 Years	*	0.2	*	*
18-44 Years	0 6	1.2	0 7	0.6
45-64 Years	16 8	17.2	12 8	12.8
65-74 Years	35.5	32 4	44.3	32.7
Over 74 Years	40.7	42 5	47 1	31 9
Heart Disease[a]				
ALL AGES	84.1	75 9	78.5	82 6
Under 18 Years	23.3	17 1	18 9	18 5
18-44 Years	39.8	36 1	38.1	38 4
45-64 Years	135 9	118 9	118 7	134 1
65-74 Years	271.8	231.6	257.1	256 4
Over 74 Years	333.6	353.0	333.9	354 3

Source. National Center For Health Statistics' *Vital and Health Statistics Current Estimates From the National Health Interview Survey,* for the years 1988-1991.

[a]Heart disease includes ischemic heart disease, heart rhythm disorders and other selected diseases of the heart, excluding hypertension

TABLE 11.3-13. SUMMARY OF HEALTH EFFECTS STUDIES EXAMINING PULMONARY FUNCTIONING AND PARTICULATES

Study	Population and Study Period	Pollutants and Correlations	Results
Dodge et al (1985)	678 children living in four towns in Arizona, two of the towns had copper smelters Data collected from 1979 to 1982	SO_2 and SO_4	No significant differences in lung functioning between children living in areas with different levels of SO_2 and SO_4
Dockery et al (1989)	Elementary school students, 10-12 years old, living in six cities in the U.S Data collected during the 1980-1981 school year	NO_2, O_3, $PM_{2.5}$, PM_{15}, SO_2, SO_4 and TSP considered independently	NO_2 not linked to bronchitis, chronic cough, chest illness, persistent wheeze and asthma O_3 linked to asthma PM_{15} linked to bronchitis and chronic cough
Schwartz (1989)	National survey of people aged 6-24 years old, conducted between 1976-1980	Nitric acid, NO_2, O_3, SO_2, sulfuric acid and TSP considered independently	NO_2, O_3 and TSP significantly linked to pulmonary function (measured by FEV_1, FVC and peak flow)
Chestnut et al (1991)	963 nonsmoking adults (aged 25-75) from the First National Health and Nutrition Examination Survey	TSP	TSP significantly related to reduced FEV_1 and FVC A threshold for the effects of TSP found at 60 $\mu g/m^3$.
Xu et al (1991)	1440 adults (40-69 years of age) living in three areas of Beijing, with different pollution levels Data collected in August 1986	SO_2 and TSP	SO_2 and TSP both linked to significantly reduced pulmonary functioning (measured by FEV_1 and FVC) Independent effects for each pollutant were not determined
Hoek et al (1993)	Children from four years of age to seven years of age living in three nonindustrial towns in the Netherlands Data collected from March 1989 to July 1989	NO_2, O_3, PM_{10} and SO_2 considered jointly	PM_{10} levels reduced lung functioning (measured by FEV_1, FVC, MMEF and PEF) They controlled for O_3, which also had a significant effect With O_3 controlled statistically, NO_2 and SO_2 were not significantly linked to pulmonary functioning
Pope and Kanner (1993)	624 adult (aged 35-60) smokers, with mild to moderate chronic lung disease, living in Salt Lake City, Utah	PM_{10}	PM_{10} significantly linked to lower pulmonary functioning, measured by FEV_1 and FVC

TABLE 11.3-14. SUMMARY OF HEALTH EFFECTS STUDIES EXAMINING ACUTE RESPIRATORY SYMPTOMS (EXCLUDING HOSPITAL ADMISSIONS) AND PARTICULATES

Study	Population and Study Period	Pollutants	Results
Cohen et al (1972)	Seven months of daily symptom reports kept by 20 asthmatics living in West Virginia	NO_3, SO_2, SO_4, soiling index (alternative particulate measure) and TSP considered independently	Individually all of the pollutants were significant contributors to asthma attacks No single pollutant was found to be the cause of asthma attacks
Whittemore and Korn (1980)	443 asthmatics living in southern California between 1972 and 1975	NO_x, O_x, RSP, SO_x and TSP. All except O_x were highly collinear In the analysis, TSP was used as a "surrogate" for all of these pollutants	O_x and TSP were both significantly related to asthma attacks, in multiple logistic regressions
Love et al (1981)	250 families from two polluted areas in New York City and one low pollution area in Long Island Data during the 1971-1972 school year.	SO_2 and TSP	Families in the communities with higher SO_2 and TSP levels had significantly more acute respiratory problems No single pollutant found to be the cause.
Perry et al. (1983)	24 asthmatics living in Denver Data collected from January 9, 1979 through March 28, 1979	CO, NO_3, O_3, $PM_{2.5}$, PM_{15}, SO_2, SO_4 and TSP considered independently	Most particulate measures not linked to asthma. Only NO_3 significantly linked to asthma
Robertson and Lebowitz (1984)	3800 whites living in Tucson Data collected from August 8, 1974 to May 4, 1977	CO, NO_2, O_3 and TSP considered jointly with stepwise regression	One pollutant at most after stepwise regression for a variety of symptoms, weather and pollen variables generally more important TSP linked to wheeze
Dodge et al (1985)	678 children living in four towns in Arizona, two of which had copper smelters Data collected from 1979 to 1982	SO_2 and SO_4	Children living in areas with higher SO_2 and SO_4 ambient concentrations had a higher incidence of cough
Portney and Mullahy (1986)	3,347 adults (aged 17 and older) from the 1979 national Health Interview Survey	O_3 and SO_4 considered independently and jointly	The two-week average of the one-hour daily maximum of O_3 linked to minor RRADs over this same two-week interval O_3 not found linked to any acute illnesses in children No significant effects found for SO_4

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Study	Population and Study Period	Pollutants	Results
Lebowitz et al (1987)	204 people living in Tucson (45 asthmatics, 68 with airway obstructive disease, 62 with allergies and 29 individuals without a history of respiratory problems)	CO, NO_2, O_3 and TSP considered jointly	O_3 linked to wheeze, cough and reduced pulmonary functioning in asthmatics No effect of pollutants on individuals without a history of respiratory problems
Charpin et al (1988)	450 children aged 9-11 from the Gardonne coal-basin, France Data collected between December 1983 and March 1984	NO_2, respirable particulates and SO_2 considered jointly	Respirable particulates not linked to symptoms SO_2 positively correlated with the incidence of cough, wheezing, runny nose and eye irritation, in communities with the highest pollution levels.
Ostro and Rothschild (1989)	Six groups of roughly 8,000 adults (aged 18-65) from the 1986-1981 national Health Interview Survey.	O_3 and $PM_{2.5}$ considered jointly	$PM_{2.5}$ significantly related to RRADs in most years O_3 significantly linked to minor RRADs in three of the years (1976, 1979 and 1980), and negatively related in two of the years (1977 and 1981).
Krupnick et al (1990)	290 families living in Azusa, California Data collected from September 1978 to March 1979.	COH, NO_2, O_3 and SO_2 considered jointly	COH was positively related to the incidence of respiratory symptoms in both adults and children O_3 significantly related to effects only in adults NO_2 and SO_2 not positively linked to health effects.
Ostro et al (1991)	207 asthmatics living in Denver Data collected from December 1987 through February 1988.	H^+, nitrates, nitric acid, $PM_{2.5}$, SO_2, and SO_4 considered independently	$PM_{2.5}$ linked to asthma H^+ linked to moderate cough, asthma and shortness of breath No effect found for nitrates, nitric acid or SO_2
Braun-Fahrlander et al (1992)	Preschool children living in four cities in Switzerland Volunteers recruited between November 1985 and December 1986 to fill out six-week symptom diaries	NO_2, O_3, SO_2 and TSP considered jointly	TSP linked to the incidence of coughing and upper respiratory symptoms, TSP also linked to the duration of respiratory symptoms NO_2 associated with the duration of respiratory symptom episodes, but the authors concluded that this effect may be due to confounding with TSP. No effect found for SO_2 or O_3

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Study	Population and Study Period	Pollutants	Results
Pope and Dockery (1992)	60 symptomatic (with a history of mild respiratory symptoms) and 60 asymptomatic children living in the Utah Valley, between December 6, 1990 and March 15, 1991	PM_{10}	PM_{10} linked to reduced pulmonary functioning and cough in both the symptomatic and asymptomatic groups. The effects on the symptomatic group were particularly strong.
Ostro et al (1993)	321 adults (18 years and older) from Azusa, California A subset of the data used by Krupnick et al (1990, discussed above) Data collected from September 1978 to March 1979	COH, NO_2, O_3, SO_2 and SO_4 considered independently.	SO_4 and O_3 had significant effects SO_2 not linked to adverse respiratory effects
Roemer et al (1993)	74 children with chronic respiratory problems from two small industrial towns in the Netherlands Data collected from 12/17/90 to 3/17/91.	British Smoke, NO_2, PM_{10} and SO_2 considered independently	SO_2, PM_{10} and British Smoke linked to asthma attacks, wheeze and runny nose However, the pollutants were considered independently, making it difficult to ascribe an independent effect to any pollutant.

TABLE 11.3-15. SUMMARY OF HEALTH EFFECTS STUDIES EXAMINING ADMISSIONS TO HOSPITALS AND PARTICULATES

Study	Population and Study Period	Pollutants	Results
Fishelson and Graves (1978)	All ages in Chicago. Data collected from September 1971 to March 1973	COH and SO_2 considered jointly	COH found in some regressions to be significantly and negatively related to hospital admissions SO_2 linked to cardiac-related emergency room admissions of people aged 40-59 and 60+.
Richards et al (1981)	Children in Los Angeles Data collected from August 1, 1979 to January 31, 1980	COH, HC, NO, NO_2, O_3, SO_2 and SO_4 considered independently	NO, NO_2, COH and HC positively linked to asthma-related emergency room admissions SO_2 and O_3 negatively linked to asthma-related emergency room visits
Samet et al (1981)	All ages in Steubenville, Ohio Population = 31,000 Data collected for the months of March, April, October and November in 1974-1977	CO, NO_2, O_3, SO_2 and TSP considered independently Correlation between TSP and SO_2 = 0.69.	SO_2 and TSP weakly linked to emergency room admissions for respiratory problems
Bates and Sizto (1983)	All ages in southern Ontario Data collected from the months of January, February, July and August 1974, 1976-1978	COH, NO_2, O_3 and SO_2 considered independently	No effect found for COH SO_2 and O_3 increased respiratory-related admissions to hospitals during July and August
Mazumdar and Sussman (1983)	All ages in Allegheny County, Pennsylvania (including the City of Pittsburgh) Data collected from 1972-1977	COH and SO_2 considered jointly	COH linked to both increased emergency room admissions and increased mortality SO_2 not consistently linked to hospital emergency admissions or mortality
Pope (1989)	Hospitals admissions for respiratory-related illnesses, between April 1985 and February 1988 in the Utah Valley	PM_{10}	PM_{10} strongly related to respiratory-related admissions, particularly for asthma and bronchitis PM_{10} had a stronger effect on children than adults
Díaz-Caneja et al (1991)	All ages living in the city of Santander, Spain. Data collected from 1979 to 1982	SO_2 and suspended particulate matter (SPM)	SPM found to be a better predictor than SO_2 of hospital admissions for chronic obstructive pulmonary disease (COPD) and heart failure Effects for SPM found down to at least 40 $\mu g/m^3$, and possibly lower

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Study	Population and Study Period	Pollutants	Results
Ponka (1991)	All ages living in Helsinki, Finland. Data collected between 1987-1989	CO, NO, NO_2, O_3, SO_2 and TSP independently and in a stepwise regression. Correlation between SO_2 and TSP = 0.19	All of the pollutants were correlated with asthma-related hospital admissions Asthma-related emergency room admissions were more highly correlated with SO_2, TSP and O_3 All asthma-related hospital admissions (including emergency room) were more highly correlated with CO, NO and NO_2
Pope (1991)	Comparison of hospital admission rates in three counties in Utah, between April 1985 and March 1989	PM_{10} The main contributor of PM_{10} pollution in Utah County is a steel mill Cache County has no mill, and has substantially lower PM_{10} levels	Respiratory admissions were substantially higher in Utah County than Cache County When the steel mill closed for a year, admissions dropped substantially in Utah County, and subsequently rose when the mill reopened.
Schwartz et al (1991)	Young children in five German cities Data collected from January 1983 to August 1985 in Duisberg, from September 1984 to April 1987 in Koln, from January 1986 to December 1987 in Stuttgart, Tubingen and Freudenstadt	NO_2, SO_2 and TSP considered jointly	Of the three pollutants, TSP is the strongest predictor of croup SO_2 a significant predictor of croup-related visits to doctors and hospitals, in single pollutant models SO_2 not significant when considered with either NO_2 or TSP.
Sunyer et al (1991)	All ages in Barcelona, Spain Data collected from 1985-1986	British Smoke, CO, NO_2, O_3 and SO_2 considered independently Correlation between pollutants (except ozone) ranged between 0.49 and 0.67 (ozone was lower)	British Smoke a significant predictor of emergency room admissions for COPD SO_2 and CO also linked to admissions
Lipfert and Hammerstrom (1992)	Respiratory-related admissions to 79 acute-care hospitals in southern Ontario, between 1979 and 1985.	COH, NO_2, O_3, SO_2, SO_4 and TSP.	O_3, SO_2, SO_4 and TSP were significantly associated with respiratory admissions. No single pollutant was determined to be the cause. There were no reported effects for COH and NO_2

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Study	Population and Study Period	Pollutants	Results
Tseng et al (1992)	Four age groups (0-1, 1-4, 5-14, and 15+) were examined in this study of the population in Hong Kong Data collected from 1983-1989.	NO_2, NO_x, O_3, respirable particulates, SO_2 and TSP	TSP positively linked to hospital admissions for asthma for ages 1-4 SO_2 found to be significantly and negatively correlated with hospital admissions for asthma for all age groups It is not clear why this results occurred, perhaps it was because of the use of highly aggregated (quarterly) data.
Schwartz et al (1993)	People under 65 Data collected from hospitals in Seattle from September 1, 1989 to September 30, 1990	O_3, PM_{10} and SO_2 considered independently	O_3 and SO_2 not linked to asthma-related emergency room admissions. PM_{10} significantly linked to admissions No threshold seen for PM_{10} down to 10 $\mu g/m^3$

TABLE 11.3-16. SUMMARY OF STUDIES CONCERNING CHRONIC MORBIDITY AND PARTICULATES

Study	Population and Study Period	Pollutants	Results
Chapman et al (1985)	5,623 young adults in four Utah communities, with varying pollutant levels. Health data collected by survey in 1976, pollution data collected between 1971-1975	Nitrates, SO_2, SO_4 and TSP Five-year mean pollution level used in the analysis	Communities with higher SO_2 and SO_4 ambient concentrations had a higher incidence of persistent cough and phlegm (i.e , cough and phlegm for at least three months per year)
Euler et al (1987)	7,445 Seventh-Day Adventists, aged 25 years and older, and who had resided within 5 miles of their current residence for 10 years Health data collected in 1977	SO_2 and TSP	TSP was significantly related to chronic obstructive pulmonary disease, significant effects also found for SO_2
Euler et al (1988)	7,445 Seventh-Day Adventists, aged 25 years and older, and who had resided within 5 miles of their current residence for 10 years Health data collected in 1977	NO_2, O_3, SO_2 and TSP	TSP was significantly related to chronic obstructive pulmonary disease, controlling for O_3 and SO_2. No effect found for NO_2
Dockery et al (1989)	Elementary school students, 10-12 years old, living in six cities in the U.S Data collected during the 1980-1981 school year	NO_2, O_3, $PM_{2.5}$, PM_{15}, SO_2, SO_4 and TSP considered independently	Particulate measures (especially PM_{15} and TSP) were associated with increased bronchitis, chronic cough and chest illness TSP was consistently associated with reduced pulmonary functioning O_3 significantly related to asthma rates
Archer (1990)	Mortality records for respiratory cancer and nonmalignant respiratory disease (NMRD) from three Utah counties Data collected from 1950-1987 for respiratory cancer and 1968-1987 for NMRD	Utah and Salt Lake counties had higher levels of CO, NO_2 O_3, SO_2 and TSP than Cache County.	Utah and Cache counties are closely matched demographically However, Utah County has higher pollution levels, due to a steel mill built in the early 1940s Starting in 1960, Utah County had a significantly higher rate of respiratory cancer and NMRD (compared to Cache County) This difference was attributed to air pollution from the steel mill

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Study	Population and Study Period	Pollutants	Results
Portney and Mullahy (1990)	1,318 adults (over the age of 17) in a national survey in 1979	O_3 and TSP Both the annual average pollution level and six-year average (1974-1979) were used in this analysis	Marginally significant relationship found between TSP and emphysema, chronic bronchitis and asthma. The six-year O_3 level was significantly related to the incidence of sinusitis and hay fever. O_3 not related to a combined measure of more severe chronic disease (emphysema, chronic bronchitis and asthma)
Abbey et al (1991)	6000 Seventh-Day Adventists living in California, and who had resided within 5 miles of their current residence for 10 years Health data collected in 1977 and 1987	O_3 and TSP considered independently. The average pollution level from 1973-1977 was used to determine pollution exposure The average between 1966-1977 was also tried and produced similar results. The later period was used because there are data from more monitoring stations	TSP significantly linked (95% CI) with all malignant neoplasms, airway obstructive disease and asthma O_3 linked to asthma, bronchitis and respiratory cancer at a 90% confidence interval No link found between O_3 and total mortality.
Vedal et al (1991)	2,199 students (grades 1-6) in Port Alberni, British Columbia, from January 1989 to April 1989	PM_{10}, "submicronic" particles and TSP	All particulate measures (annual mean levels) were associated with chronic cough, chronic phlegm, wheezing and congestion and hospitalization for chest illness. A threshold found for TSP (45-50 $\mu g/m^3$) and PM_{10} (35-40 $\mu g/m^3$)
Abbey et al (1993)	3,914 nonsmoking Seventh-Day Adventists living in California in 1977, and who had resided within 5 miles of their current residence for 10 years Health data collected in 1977 and 1987	O_3 and TSP considered jointly The average pollution level from 1973-1977 was used to determine pollution exposure in published results Estimated the average annual number of hours of pollution exposure above five thresholds	O_3 linked to new cases of asthma and symptom severity of asthma When O_3 modeled with TSP the results were unstable, Abbey et al concluded both O_3 and TSP are significantly linked to new cases of asthma and symptom severity

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Study	Population and Study Period	Pollutants	Results
Abbey et al (1995)	3,914 nonsmoking Seventh-Day Adventists living in California in 1977, and who had resided within 5 miles of their current residence for 10 years Health data collected in 1977 and 1987.	PM_{10} The average pollution level from 1973-1977 was used to determine pollution exposure in published results Estimated the average annual number of hours of pollution exposure above five thresholds	PM_{10} linked to new cases of airway obstructive disease (AOD)

TABLE 11.3-17. SUMMARY OF HEALTH EFFECTS STUDIES EXAMINING MORTALITY AND PARTICULATES

Study	Population and Study Period	Pollutants	Results
Mazumdar et al (1982)	Mortality records for all nontraumatic causes in London during the winters of 1958-1972	British Smoke and SO_2 considered jointly Correlation > 0.80 in all years	A strong association was found between British smoke and mortality, regardless of whether SO_2 was considered in the regression
Ozkaynak and Thurston (1987)	Total mortality data from 100 metropolitan areas in 1980	$PM_{2.5}$, PM_{15}, SO_4 and TSP	SO_4 was the best predictor of mortality, followed by $PM_{2.5}$ PM_{15} and TSP were generally not significant The strength of the effect declined with increasing particle size Particulates derived from coal and metals were found to be most potent
Fairley (1990)	Mortality data by cause of death from Santa Clara County between 1980 and 1986 (1983 missing)	COH	COH linked to respiratory, circulatory and all nonaccidental deaths There is a borderline significance between COH and cancer
Schwartz and Marcus (1990)	Mortality records for all nontraumatic causes in London during the winters of 1958-1972.	British Smoke and SO_2 Correlation > 0 80 in all years	A strong association was found between British smoke and mortality, regardless of whether SO_2 was considered in the regression
Kinney and Ozkaynak (1991)	All nonaccidental mortality records from Los Angeles County, 1970-1979 The study also considered respiratory-related deaths and cardiovascular-related deaths	CO, KM, NO_2, O_3 and SO_2 considered jointly	CO, KM and NO_2 each significantly related to total mortality and cardiovascular-related mortality in models with O_3 It was not possible to determine which pollutant (besides O_3) caused mortality SO_2 had no effect on mortality.
Schwartz (1991)	All nonaccidental mortality records in Detroit, Michigan, from 1973 to 1982.	O_3, SO_2 and TSP considered jointly TSP predicted from daily observations of the visibility extinction coefficient	TSP strongly linked to mortality, the size of the coefficient was not significantly affected by the inclusion of SO_2 SO_2 not significantly linked to mortality, controlling for TSP. No link between O_3 and mortality

Dockery et al (1992)	All nonaccidental mortality records from the St Louis metropolitan statistical area and eastern Tennessee from September 1985 to August 1986	H^+, NO_2, O_3, $PM_{2.5}$, PM_{10}, SO_2, SO_4 considered jointly	A strong association was found between PM_{10} and mortality SO_2 not significantly linked to mortality.

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Study	Population and Study Period	Pollutants	Results
Pope et al (1992)	Nonaccidental mortality in Utah County from 1985 to 1989	PM_{10} Levels of H^+, NO_2, O_3 and SO_2 were at low levels, except during the summer when O_3 approached the national standard of 0 12 ppm.	PM_{10} had the strongest effect on respiratory deaths, followed by cardiovascular and all other deaths.
Schwartz and Dockery (1992a)	All nonaccidental mortality records from Philadelphia, from 1973-1980. The mortality records were divided into decedents < 65 years old, and decedents 65 and older	SO_2 and TSP considered jointly	TSP strongly linked to mortality, the size of the coefficient was not significantly affected by the inclusion of SO_2. The effect of TSP was significantly higher on people older than 65 SO_2 not significantly linked to mortality, controlling for TSP No interaction found between TSP and SO_2
Schwartz and Dockery (1992b)	All nonaccidental mortality records from Stuebenville, Ohio metropolitan area Data collected from 1974-1984	SO_2 and TSP considered jointly	TSP strongly linked to mortality, the size of the coefficient was not significantly affected by the inclusion of SO_2 SO_2 not significantly linked to mortality, controlling for TSP
Dockery et al (1993)	Health data collected over 14-16 years (study ended in 1991) from 8,111 white persons in six cities in the U S -- Portage, WI, Topeka, KS, Watertown, MA; Kingston, TN, St Louis, MO, and Steubenville, OH.	NO_2, O_3, $PM_{2.5}$, PM_{10}, PM_{15}, SO_2, SO_4, TSP and aerosol acidity considered independently	Mortality more strongly linked to $PM_{2.5}$, PM_{10}, PM_{15} and SO_4 than with NO_2, SO_2, TSP and aerosol acidity O_3 levels varied little and were not significant Air pollution linked to lung cancer and cardiopulmonary disease-related deaths
Xu et al (1994)	All nonaccidental mortality records in two residential areas in Beijing, China, from 1989	SO_2 and TSP considered jointly	TSP significantly linked to mortality only in the summer, with and without the inclusion of SO_2 In the winter, TSP had a negative and insignificant coefficient (t=-1 54 with SO_2 included)

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Moolgavkar et al (1995)	Philadelphia mortality data collected for the period 1973-1988	O_3, TSP and SO_2 considered jointly	With all three pollutants in model, O_3 linked to summer time mortality and SO_2 linked to mortality in the fall, winter and spring
Pope et al (1995a)	Mortality and individual risk factors (e.g , smoking) data from 552,138 adults in 151 metropolitan statistical areas	SO_4 and $PM_{2.5}$	$PM_{2.5}$ significantly linked to cardiopulmonary deaths. SO_4 linked to cardiopulmonary and lung cancer deaths

TABLE 11.3-18. A VARIETY OF MEASURES FOR PARTICULATES

Particulate Measure	Description
TSP	Total suspended particulates, which are generally less than 60 micrometers (m) in diameter
British Smoke	A particulate measure typically used in Britain, similar to TSP
PM_{10}	Particulate matter less than 10 micrometers (m) in diameter This is the U.S criteria pollutant measure for particulates
COH	Coefficient of haze, a measure based on visibility
$PM_{2.5}$	Particulate matter less than 2.5 micrometers (m) in diameter
SO_4	Sulfates, which are typically 0.2 - 0.6 micrometers (m) in diameter
H^+	Hydrogen ion, the acidic component of particulates

Sources EPA (1982), Withey (1989 521), Krupnick et al. (1990 4), Ostro (1990: 422)

TABLE 11.3-19. EPIDEMIOLOGICAL STUDIES USED IN THIS ANALYSIS TO ESTIMATE THE HEALTH EFFECTS OF PARTICULATES

Health Effect Evaluated	Particulate Measure	Epidemiological Study Used To Estimate Health Effects
Asthma	TSP	Whittemore and Korn (1980)
Respiratory-Related Restricted Activity Day (RRAD)	$PM_{2.5}$	Ostro and Rothschild (1989)
Airway Obstructive Disease (AOD)	PM_{10}	Abbey et al (1995)
Acute Mortality	PM_{10}	Pope et al (1992)
Chronic Mortality	$PM_{2.5}$	Ozkaynak and Thurston (1987) [lower bound] Pope et al (1995a) [upper bound]

TABLE 11.3-20. EPIDEMIOLOGICAL STUDIES USED IN PREVIOUS ANALYSES TO ESTIMATE THE HEALTH EFFECTS OF PARTICULATES

Study Of Economic Value Of Health Effects	Health Effects Evaluated	Particulate Measure	Epidemiological Studies Used To Estimate Health Effects
Hall et al, 1992	RAD	PM_{10}[a]	Ostro (1987)
	Mortality	PM_{10}[b]	Evans et al (1984a)
Harrison and Nichols, 1990	RRAD	PM_{10}[a]	Ostro and Rothschild (1989)
	Mortality	PM_{10}	Evans et al (1984a)
Krupnick and Portney, 1991	Morbidity [b]		
	Mortality	SO_4	Ozkaynak and Thurston (1987)
RER (1990, Phase II)	Any Respiratory Symptom	COH	Krupnick et al (1990)
	MRAD, RRAD	$PM_{2.5}$	Ostro and Rothschild (1989)
	Mortality	TSP	Lave and Seskin (1970), Lipfert (1980)

[a]The original health effect studies (Ostro, 1987, Evans et al, 1984a) cited by Hall et al. (1992) used $PM_{2.5}$ and TSP data, respectively. To use these studies with PM_{10} data, Hall et al (1992) assumed that PM_{10} is 61% $PM_{2.5}$, and TSP is 55% PM_{10}

[b]Krupnick and Portney (1991) also estimated particulate-related morbidity, but they did not state on which paper(s) they based their estimate

TABLE 11.3-21. ASSUMED PERCENTAGE OF AOD ATTRIBUTABLE TO PM_{10} EACH YEAR

Year	Percentage of Effect
1	1
2	1
3	2
4	3
5	4
6	6
7	7
8	8
9	9
10	9
11	9
12	9
13	8
14	7
15	6
16	4
17	3
18	2
19	1
20	1

Source Our judgement

TABLE 11.3-22. RELATIVE RISK OF AOD FROM EXPOSURE TO PM_{10}

PM_{10} Threshold Level	Annual hours of exposure[a]	Relative Risk	Estimated Coefficient[b]	Arithmetic Average[c]	Standard Deviation[d]
40 g/m3	250	1.01	4 352 E-5	5 401 E-5	7.50 E-6
	500	1.03	6 470 E-5		
	1000	1.05	5.344 E-5		
	2500	1.13	5.375 E-5		
	5000	1.28	5 464 E-5		
50 g/m3	250	1 01	4.352 E-5	5.791 E-5	8 55 E-6
	500	1.03	6 470 E-5		
	1000	1.06	6.386 E-5		
	2500	1.14	5 765 E-5		
	5000	1.31	5.985 E-5		
60 g/m3	250	1 02	8.665 E-5	7 402 E-5	7.96 E-6
	500	1.03	6 470 E-5		
	1000	1 07	7 418 E-4		
	2500	1.18	7.295 E-4		
	5000	1.38	7 160 E-4		
80 g/m3	250	1.02	8 665 E-5	1.001 E-4	9 17 E-6
	500	1.05	1 069 E-4		
	1000	1.10	1.046 E-4		
	2500	1.26	1.022 E-4		
100 g/m3	250	1.04	1.718 E-4	1.712 E-4	2.10 E-6
	500	1.08	1.688 E-4		
	1000	1.17	1.729 E-4		

Source Abbey et al (1995).

[a]Annual hours of exposure above each threshold. Abbey et al. (1995 Table 3) used the average annual number of hours from 1973-1977

[b]The estimation of the estimated coefficients is explained in Section 11.2 4.2 of the text

[c]The arithmetic average of the estimated coefficients for each threshold level.

[d]The standard deviation of the estimated coefficients for each threshold level

TABLE 11.3-23. PERCENTAGE OF TOTAL NATIONAL MORTALITY BY CAUSE OF DEATH IN 1989 AND 1990

Cause of Death	1989[a]	1990
Major Cardiovascular Diseases	43.33	42.57
Malignancies	23.07	23 40
Accidents and Adverse Effects	4 42	4 33
Chronic Obstructive Pulmonary Diseases and Allied Conditions	3 92	4.12
Pneumonia and Influenza	3.56	3.64
Suicide	1 40	1 42
Other	20 29	20.52

Source. U.S Bureau of the Census (1992 Table 114)

[a]The percentages do not add up to 100 due to rounding error

TABLE 11.3-24. SUMMARY OF HEALTH EFFECTS STUDIES EXAMINING PULMONARY FUNCTIONING AND SULFUR DIOXIDE

Study	Population and Study Period	Pollutants	Results
Dodge et al (1985)	678 children living in four towns in Arizona; two of the towns had copper smelters Data collected from 1979 to 1982	SO_2 and SO_4	No significant differences in lung functioning between children living in areas with different levels of SO_2 and SO_4
Dockery et al (1989)	Elementary school students, 10-12 years old, living in six cities in the U.S. Data collected during the 1980-1981 school year.	NO_2, O_3, $PM_{2.5}$, PM_{15}, SO_2, SO_4 and TSP considered independently Annual mean pollutant levels used in the analysis	None of the pollutants were found to have an effect on pulmonary function (measured by FEV_1 and other measures).
Schwartz (1989)	National survey of people aged 6-24 years old, conducted between 1976-1980.	Nitric acid, NO_2, O_3, SO_2, sulfuric acid and TSP considered independently	SO_2 not significantly linked to pulmonary function (measured by FEV_1, FVC and peak flow) Significant effects found for TSP, O_3 and NO_2
Xu et al (1991)	1440 adults (40-69 years of age) living in three areas of Beijing, with different pollution levels Data collected in August 1986	SO_2 and TSP	SO_2 and TSP both linked to significantly reduced pulmonary functioning (measured by FEV_1 and FVC) Independent effects for each pollutant were not determined
Hoek et al (1993)	Children from four years of age to seven years of age living in three nonindustrial towns in the Netherlands. Data collected from March 1989 to July 1989.	NO_2, O_3, PM_{10} and SO_2 considered jointly	SO_2 not significantly linked to pulmonary functioning after controlling for O_3 Daily O_3 levels were negatively correlated with lung functioning (measured by FEV_1, FVC, MMEF and PEF) A small effect was found for PM_{10}, independent of O_3

TABLE 11.3-25. SUMMARY OF HEALTH EFFECTS STUDIES EXAMINING ACUTE AND CHRONIC RESPIRATORY SYMPTOMS (EXCLUDING HOSPITAL ADMISSIONS) AND SULFUR DIOXIDE

Study	Population and Study Period	Pollutants	Results
Acute effects			
Cohen et al (1972)	Seven months of daily symptom reports kept by 20 asthmatics living in West Virginia	NO_3, SO_2, SO_4, soiling index (alternative particulate measure) and TSP considered independently Pollutants moderately correlated TSP and SO_2 (r=0 537)	Individually all of the pollutants were significant contributors to asthma attacks No single pollutant was found to be the cause of asthma attacks.
Love et al (1981)	250 families from two polluted areas in New York City and one low-pollution area in Long Island Data during the 1971-1972 school year	SO_2 and TSP	Families in the communities with higher SO_2 and TSP levels had significantly more acute respiratory problems No single pollutant found to be the cause
Perry et al (1983)	24 asthmatics living in Denver Data collected from January 9, 1979 through March 28, 1979	CO, NO_3, O_3, $PM_{2.5}$, PM_{15}, SO_2, SO_4 and TSP considered independently	SO_2 not linked to asthma Only NO_3 significantly linked to asthma
Dodge et al. (1985)	678 children living in four towns in Arizona, two of the towns had copper smelters Data collected from 1979 to 1982.	SO_2, and SO_4	Children living in areas with higher SO_2 and SO_4 ambient concentrations had a higher incidence of cough
Charpin et al (1988)	450 children aged 9-11 from the Gardonne coal-basin, France Data collected between December 1983 and March 1984	NO_2, respirable particulates and SO_2 considered jointly	SO_2 positively correlated with the incidence of cough, wheezing, runny nose and eye irritation, in communities with the highest pollution levels. Respirable particulates not linked to symptoms
Dockery et al (1989)	Elementary school students, 10-12 years old, living in six cities in the U.S Data collected during the 1980-1981 school year	NO_2, O_3, $PM_{2.5}$, PM_{15}, SO_2, SO_4 and TSP considered independently	SO_2 not linked to bronchitis, chronic cough, chest illness, persistent wheeze and asthma O_3 linked to asthma PM_{15} linked to bronchitis and chronic cough

Krupnick et al (1990)	290 families living in Azusa, California Data collected from September 1978 to March 1979	COH, NO_2, O_3 and SO_2 considered jointly Correlation SO_2 and COH = 0 57	SO_2 not linked to respiratory symptom in adults, and even had a negative effect on the incidence of respiratory symptoms in children COH was positively related to the incidence of respiratory symptoms in both adults and children

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Study	Population and Study Period	Pollutants	Results
Schwartz and Zeger (1990)	Student nurses in Los Angeles Data collected November 1961 to May 1964	CO, NO_2, O_x and SO_2 considered jointly	SO_2 not linked to the incidence of cough, phlegm, sore throat, headache, chest and eye irritation The pollutants were considered simultaneously
Jaakkola et al (1991)	759 children under the age of six living in three cities in Finland Data collected from November to December 1982	SO_2 used as a proxy for all air pollution	Children in the more polluted city had a higher rate of respiratory infection
(Ostro et al (1991)	207 asthmatics living in Denver Data collected from December 1987 through February 1988	H^+, nitrates, nitric acid, $PM_{2.5}$, SO_2, and SO_4 considered independently Correlation between SO_2 and $PM_{2.5}$ = 0 64 Correlation between SO_2 and H^+ = 0.35	SO_2 not linked to moderate cough, asthma or shortness of breath H^+ linked to moderate cough, asthma and shortness of breath $PM_{2\,5}$ linked to asthma No effect found for nitrates or nitric acid
Schwartz et al (1991)	1800 children from six cities (Watertown, Kingston-Harriman, TN, St Louis, MO, Portage, WI, Stuebenville, OH, and Topeka, KS). Diary data collected from 1984-1988	SO_2 Other pollutants were not discussed in this methodological paper.	SO_2 linked to the incidence of cough. The units of measurement were not given, nor whether the pollutants were considered separately or simultaneously
Braun-Fahrlander et al (1992)	Preschool children living in four cities in Switzerland Volunteers recruited collected between November 1985 and December 1986 to fill out six-week symptom diaries	NO_2, O_3, SO_2 and TSP considered jointly	No effect found for SO_2 or O_3 NO_2 associated with the duration of respiratory symptom episodes, but the authors concluded that this effect may be due to confounding with TSP TSP linked to both the incidence and duration of respiratory symptoms
Schwartz (1992)	Student nurses in Los Angeles Data collected November 1961 to May 1964.	CO, NO_2, O_x, and SO_2 considered jointly	SO_2 increased the duration of chest discomfort, primarily in asthmatics

Ostro et al. (1993)	321 adults (18 years and older) from Azusa, California A subset of the data used by Krupnick et al (1990) Data collected from September 1978 to March 1979	COH, NO_2, O_3, SO_2 and SO_4 considered independently Correlation between SO_2 and COH = 0 57 Correlation between SO_2 and SO_4 not reported	SO_2 not linked to lower respiratory symptoms, upper respiratory symptoms, and eye irritation SO_4 and O_3 had significant effects

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Study	Population and Study Period	Pollutants	Results
Roemer et al (1993)	74 children with chronic respiratory problems from two, small industrial towns in the Netherlands Data collected from December 17, 1990 to March 17, 1991	British Smoke, NO_2, PM_{10} and SO_2 considered independently Correlation SO_2 and PM_{10} = 0 65 Correlation SO_2 and BS = 0.63	SO_2, PM_{10} and British Smoke linked to asthma attacks, wheeze and runny nose However, the pollutants were considered independently, making it difficult to ascribe an independent effect to any pollutant
		Chronic Effects	
Chapman et al (1985)	5,623 young adults in four Utah communities, with varying pollutant levels Health data collected by survey in 1976, pollution data collected between 1971-1975	nitrates, SO_2, SO_4 and TSP Five-year mean pollution level used in the analysis	Communities with higher SO_2 and SO_4 ambient concentrations had a higher incidence of persistent cough and phlegm (i e., cough and phlegm for at least three months per year)
Euler et al. (1988)	7,445 Seventh-Day Adventists 25 years and older living in California Data collected from 1966-1976	NO_2, O_3, SO_2 and TSP	Considered separately, SO_2 was significantly linked to an increased risk of COPD In models with three pollutants (O_3, SO_2 and TSP), only TSP was significant
Abbey et al (1993)	3, 914 nonsmoking Seventh-Day Adventists living in California in 1977, and who had resided within 5 miles of their current residence for 10 years Panel data collected in 1977 and 1987	O_3, SO_2 and TSP considered jointly. The average pollution level from 1973-1977 was used to determine pollution exposure in published results Estimated the average annual number of hours of pollution exposure above five thresholds	No link found between SO_2 and chronic respiratory illness -- emphysema, chronic bronchitis and asthma

TABLE 11.3-26. SUMMARY OF HEALTH EFFECTS STUDIES EXAMINING ADMISSIONS TO HOSPITALS AND SULFUR DIOXIDE

Study	Population and Study Period	Pollutants	Results
Fishelson and Graves (1978)	All ages in Chicago Data collected from September 1971 to March 1973	COH and SO_2 considered jointly Correlation between SO_2 and COH not reported	This study ran a large number of regressions testing for a link between SO_2 and COH and hospital emergency room admissions SO_2 linked to cardiac-related emergency room admissions of people aged 40-59 and 60+ COH found in some regressions to be significantly and negatively related to hospital admissions
Richards et al (1981)	Children in Los Angeles Data collected from August 1, 1979 to January 31, 1980	COH, HC, NO, NO_2, O_3, SO_2 and SO_4 considered independently	SO_2 and O_3 negatively (and significantly) linked to asthma-related emergency room visits. Positive correlation found between COH, HC, NO and NO_2
Samet et al (1981)	All ages in Steubenville, Ohio Population = 31,000 Data collected for the months of March, April, October and November in 1974-1977	CO, NO_2, O_3, SO_2 and TSP considered independently Correlation between TSP and SO_2 = 0 69	SO_2 and TSP weakly linked to emergency room admissions for respiratory problems
Bates and Sizto (1983)	All ages in southern Ontario Data collected from the months of January, February, July and August 1974, 1976-1978	COH, NO_2, O_3 and SO_2 considered independently	SO_2 and O_3 increased respiratory-related admissions to hospitals during July and August.
Mazumdar and Sussman (1983)	All ages in Allegheny County, Pennsylvania (including the City of Pittsburgh) Data collected from 1972-1977	COH and SO_2 considered jointly	SO_2 not consistently linked to either increased mortality or hospital emergency admissions COH linked to both increased mortality and increased emergency room admissions
Goldstein and Weinstein (1986)	All ages in New York City from 1969-1972	SO_2	SO_2 not linked to hospital emergency room visits for asthma.

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Study	Population and Study Period	Pollutants	Results
Bates et al (1990)	All ages in Vancouver. Data collected between July 1984 and October 1986	COH, NO_2, O_3, SO_2 and SO_4 considered separately Correlation SO_2 and SO_4 = 0 46 (May-October) and = 0.54 (November-April) Correlation SO_2 and COH = 0.341 (May-October) and = 0 64 (November-April)	SO_2 and SO_4 both correlated with asthma- and other respiratory-related hospital visits During November-April, only SO_2 correlated to respiratory-related admissions for patients 60 and younger -- no significant correlation reported between this group of people and other pollutants O_3 linked to total admissions (The results for COH were not reported)
Díaz-Caneja et al. (1991)	All ages living in the city of Santander, Spain Data collected from 1979 to 1982.	SO_2 and suspended particulate matter (SPM)	SPM found to be a better predictor than SO_2 of hospital admissions for chronic obstructive pulmonary disease (COPD) and heart failure
Ponka (1991)	All ages living in Helsinki, Finland Data collected between 1987-1989	CO, NO, NO_2, O_3, SO_2 and TSP independently and in a stepwise regression Correlation between SO_2 and TSP = 0.19	All of the pollutants were correlated with asthma-related hospital admissions Asthma-related emergency room admissions were more highly correlated with SO_2, TSP and O_3 All asthma-related hospital admissions (including emergency room) were more highly correlated with CO, NO and NO_2
Schwartz et al (1991)	Young children in five German cities Data collected from January 1983 to August 1985 in Duisberg, from September 1984 to April 1987 in Koln, from January 1986 to December 1987 in Stuttgart, Tubingen and Freudenstadt	NO_2, SO_2 and TSP considered jointly	SO_2 a significant predictor of croup-related visits to doctors and hospitals, in single-pollutant models. SO_2 not significant when considered with either NO_2 or TSP. Of the three pollutants, TSP is the strongest predictor of croup

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Study	Population and Study Period	Pollutants	Results
Sunyer et al (1991)	All ages in Barcelona, Spain Data collected from 1985-1986	British Smoke, CO, NO_2, O_3 and SO_2 considered independently Correlation between pollutants (except ozone) ranged between 0.49 and 0 67 (ozone was lower).	SO_2 a significant predictor of emergency room admissions for COPD British Smoke and CO also linked to admissions Each pollutant was considered separately, so it is not possible to determine if SO_2 would still be significant, controlling for other pollutants, particularly British Smoke
Cody et al (1992)	All ages living in central and northern New Jersey. Data collected from May through August in 1988 and 1989	O_3, PM_{10} and SO_2 and visibility (as a proxy for sulfate) considered independently	SO_2 not significantly linked to asthma-related emergency room visits A significant association found for O_3
Lipfert and Hammerstrom (1992)	Respiratory-related admissions to 79 acute-care hospitals in southern Ontario, between 1979 and 1985	COH, NO_2, O_3, SO_2, SO_4 and TSP.	O_3, SO_2, SO_4 and TSP were significantly associated with respiratory admissions No single pollutant was determined to be the cause There were no reported effects for COH and NO_2.
Tseng et al. (1992)	Four age groups (0-1, 1-4, 5-14, and 15+) were examined in this study of the population in Hong Kong Data collected from 1983-1989	NO_2, NO_x, O_3, respirable particulates, SO_2 and TSP	SO_2 found to be significantly and negatively correlated with hospital admissions for asthma for all age groups It is not clear why this result occurred, perhaps it was because of the use of highly aggregated (quarterly) data TSP positively linked to hospital admissions for asthma for ages 1-4
Schwartz et al (1993)	People under 65 Data collected from hospitals in Seattle from September 1, 1989 to September 30, 1990	O_3, PM_{10} and SO_2 considered independently	SO_2 not linked to asthma-related emergency room admissions (The SO_2 ambient data were from an industrial area and may poorly characterize population exposure, and thus reduce the likelihood of finding a significant effect.) PM_{10} significantly linked to admissions No effect found for O_3

TABLE 11.3-27. SUMMARY OF HEALTH EFFECTS STUDIES EXAMINING MORTALITY AND SULFUR DIOXIDE

Study	Population and Study Period	Pollutants	Results
Mazumdar et al (1982)	Mortality records for all nontraumatic causes in London during the winters of 1958-1972	British Smoke and SO_2 considered jointly Correlation > 0.80 in all years	SO_2 not significantly linked to mortality, controlling for British smoke. A strong association was found between British smoke and mortality, regardless of whether SO_2 was considered in the regression
Schwartz and Marcus (1990)	Mortality records for all nontraumatic causes in London during the winters of 1958-1972	British Smoke and SO_2 considered jointly Correlation > 0.80 in all years	SO_2 not significantly linked to mortality, controlling for British smoke A strong association was found between British smoke and mortality, regardless of whether SO_2 was considered in the regression
Kinney and Ozkaynak (1991)	All nonaccidental mortality records from Los Angeles County, 1970-1979. The study also considered respiratory-related deaths and cardiovascular-related deaths.	CO, KM, NO_2, O_x and SO_2 considered jointly.	No effect of SO_2 on the daily mortality rate O_3 most strongly related to mortality, followed by KM, CO and NO_2
Schwartz (1991)	All nonaccidental mortality records in Detroit, Michigan, from 1973 to 1982	O_3 SO_2 and TSP considered jointly TSP predicted from daily observations of the visibility extinction coefficient	SO_2 not significantly linked to mortality, controlling for TSP TSP strongly linked to mortality, the size of the coefficient was not significantly affected by the inclusion of SO_2 No link between O_3 and mortality
Dockery et al. (1992)	All nonaccidental mortality records from the St Louis metropolitan statistical area and eastern Tennessee from September 1985 to August 1986	H^+, NO_2, O_3, $PM_{2.5}$, PM_{10}, SO_2, SO_4 considered jointly	SO_2 not significantly linked to mortality A strong association was found between PM_{10} and mortality

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Study	Population and Study Period	Pollutants	Results
Schwartz and Dockery (1992a)	All nonaccidental mortality records from Philadelphia, from 1973-1980 The mortality records were divided into decedents < 65 years old, and decedents 65 and older	SO_2 and TSP considered jointly	SO_2 not significantly linked to mortality, controlling for TSP No interaction found between TSP and SO_2 TSP strongly linked to mortality, the size of the coefficient was not significantly affected by the inclusion of SO_2. The effect of TSP was significantly higher on people older than 65.
Schwartz and Dockery (1992b)	All nonaccidental mortality records from Stuebenville, Ohio metropolitan area, from 1974-1984	SO_2 and TSP considered jointly.	SO_2 not significantly linked to mortality, controlling for TSP TSP strongly linked to mortality, the size of the coefficient was not significantly affected by the inclusion of SO_2.
Dockery et al (1993)	Health data collected over 14-16 years (study ended in 1991) from 8,111 white persons in six cities in the U.S -- Portage, WI, Topeka, KS, Watertown, MA, Kingston, TN, St Louis, MO, and Steubenville, OH	NO_2, O_3, $PM_{2.5}$, PM_{10}, PM_{15}, SO_2, SO_4, TSP and aerosol acidity considered independently	Mortality more strongly linked to $PM_{2.5}$, PM_{10}, PM_{15} and SO_4 than to NO_2, SO_2, TSP and aerosol acidity. O_3 levels varied little and were not significant Air pollution linked to lung cancer and cardiopulmonary disease-related deaths
Xu et al (1994)	All nonaccidental mortality records in two residential areas in Beijing, China, from 1989	SO_2 and TSP considered jointly	SO_2 linked to mortality in both the summer and the winter The effect remained significant with and without the inclusion of TSP in the model TSP significant only in the summer
Moolgavkar et al (1995)	Philadelphia mortality data collected for the period 1973-1988	O_3, TSP and SO_2 considered jointly	With all three pollutants in model, O_3 linked to summer time mortality and SO_2 linked to mortality in the fall, winter and spring.

11.4 VALUING HEALTH EFFECTS

We first estimate the health effects caused by air pollution and then place a dollar value on the effects. An alternative procedure would be to use a hedonic approach (e.g., Brucato et al., 1990) and estimate the value of a reduction in air pollution. However, the hedonic approach estimates ill health, reduced visibility, property damage and other adverse effects of air pollution, and we are interested in valuing only the ill health. Furthermore the actual effects, or damages -- days of illness, lives lost, etc. -- are of interest in themselves, apart from their monetary value.

All of our dollar estimates are in 1991 $.

11.4.1 Acute Morbidity

Economists use several methods to estimate the cost of such things as the common cold, asthma and other illnesses which we group under the category, acute morbidity. In their review article Cropper and Freeman (1991: 166) suggested two broad approaches:

- The observed market approach. It includes "techniques that rely on demand and cost functions, market prices, and observed behavior and choices." Household production functions and cost-of-illness studies (which estimate the direct out of pocket expenses of illness) are examples.

- The hypothetical market approach. It includes techniques that directly ask people's "willingness to pay or accept compensation for a postulated change, how their behavior would change, or how they would rank alternative situations involving different combinations of health and income or consumption." Contingent valuation is an example.

Ideally, the morbidity valuation method should count:

- lost productivity due to missing work;

- lower productivity at work due to illness;

- the value of uncompensated activities, such as recreation or household chores, that must be given up because of the illness;

- the value of performing uncompensated activities less well, because of illness;

- medical expenditures for treatment of illness;

- the nonmarket costs of treating illnesses (air, water, and solid waste pollution from hospitals and from the pharmaceutical industry);

- the dollar equivalent of the physical and psychological pain and discomfort of the directly affected person;

- the dollar equivalent of the physical and psychological pain and discomfort of those who care about the directly affected person (if such concern is not included in the WTP of the directly affected person), and

- the cost of averting behavior (for example, the cost of extra preventative health care, or the value of activities that are changed or limited on account of pollution).

We briefly review the two groups of techniques.

11.4.1.1 Observed Market Approach to Estimating the Cost of Illness

In general, economists like to observe what people do rather than what they say would do. All else being equal, we obviously would prefer values derived from real markets ("revealed" preferences) to values derived from hypothetical markets and preferences. However, as we discuss next, all else never is equal, and there are significant shortcoming to using observed market transactions to value the health effects of air pollution.

Household Production Function Approach

Using the household production approach, an economist models the relationship between people's health, the level of air pollution and actions they take to avoid or cure ill health, such as visiting the doctor, staying indoors, or purchasing air conditioning (Freeman, 1993: Chapter 10). One can use this method to estimate the change in a pollution level, its effect on people and how much people value the change. It captures the direct monetary costs of illness, and the amount people spend on averting behavior.[1]

However, there are serious methodological drawbacks to this approach. If people's averting behavior produces a joint product, such as in the case of air conditioning, which removes particulates from the air *and* cools one's house, then one can not ascribe the full cost of the air conditioner to the health outcome of interest (Cropper and Freeman, 1991: 210). The approach assumes that the marginal benefit of a mitigating measure is equal to the marginal cost, which is true in principle for measures bought frequently and in small increments (such as aspirin), but not necessarily true for measures bought infrequently in large "chunks" (such as air conditioners). For the "typical" person that buys air conditioning, the marginal benefit will exceed marginal cost (i.e., there is consumer surplus).

There are other problems with this approach. It misses lost productivity from missed work when there are institutional structures that compensate people when they are sick, and it does not capture medical expenditures covered by free insurance

[1]Harrington and Portney (1987: 101) suggested including averting behavior can be "critical" when estimating the benefits of a pollution reduction program

such as Medicare and Medicaid. It is difficult to measure the cost of averting behavior. What, for example, is the cost of spending leisure time indoors rather than outdoors? (Cropper and Freeman, 1993: 201). It also does not cover nonmarket costs of illness including the pain and discomfort of those who care about the directly affected person. Furthermore, this approach excludes the nonmarket costs associated with medical care (e.g., pollution from hospitals and pharmaceutical companies). Finally, the method is costly to perform, because of the extensive data needed to properly model exposure to pollution.[2]

Cost of Illness Approach to Estimating the Cost of Illness

The cost of illness approach equates the cost of illness with lost productivity (measured by wages) and the medical costs associated with illness.[3] This approach obviously misses many cost categories, such as the loss of productivity that is not normally compensated (e.g., housework, work of retirees), pain and suffering, and averting behavior. The true cost of illness must exceed any cost estimated by this approach.

Hedonic Studies

An alternative to our approach of estimating damages and then valuing these damages is to look at the housing market and to estimate the value that people place on air pollution by looking at housing price differentials (e.g., Brucato et al., 1990; Graves et al., 1988). If for example, people are willing to pay $1,000 for a house in an area with low pollution levels versus an area with high pollution levels, then one might say that $1,000 is the upper bound that a household is willing to pay to avoid the health costs of air pollution. Air pollution also causes visibility loss, vegetation damage and other effects so, the reasoning goes, the health costs of air pollution may be significantly less than $1,000. One problem with this reasoning is that it assumes that people are aware of all of the health effects of air pollution and they have a good idea of the level of pollution that they are exposed to. This seems most unlikely as there is much that researchers do not know about the health effects of air pollution and, at best, most people only have a very rough idea of the air pollution that they are exposed to. With full information on the effects of air pollution, it is likely that the values implied by housing prices will be quite different.

Brucato et al. (1990) in a study of ozone pollution in the San Francisco area, suggest that the hedonic approach and the damage-function approach give comparable results. However, in our opinion, their conclusion is likely coincidental, and it is *unlikely* that the *full* costs of ozone (and other pollutants) are built into the price of homes.

11 4.1.2 Contingent Valuation Approach to Estimating the Cost of Illness

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[2]Lacking sufficient data, Dickie and Gerking (1991b) excluded particulates, an important contributor to ill health, from their analysis and therefore biased their result unacceptably.

[3]Previous studies include those by Brown (1990), Dixon (1985) and Rice et al (1985)

The contingent valuation approach uses a survey to directly ask people how much they are willing to pay to avoid illness. Its strength is that it can ask about any illness that people are familiar with and is a reasonably inclusive measure of the cost of illness. Contingent valuation includes all of the private costs that people incur when sick, including the potentially large category of pain and suffering. However, it underestimates or excludes costs covered by insurance, might not include the pain and suffering of those close to the [hypothetically] sick person (although there is no reason that this cannot be included in a survey), and definitely does not include the nonmarket costs associated with medical care (e.g., pollution from hospitals and pharmaceutical companies).

Some economists criticize the hypothetical nature of surveys, arguing that people might not consider carefully the opportunity cost of their money and hence might overestimate the amount they would actually be willing to pay to avoid illness. The critics also argue that respondents might not understand what they are valuing[4], and that the survey instrument might not properly emphasize that people should take into account the cost of the averting behavior and how they will feel after the averting behavior (such as taking aspirin to avoid a headache). However, surveys can be designed and administered to minimize these problems (Mitchell and Carson, 1989).

11.4.1.3 Estimates of the Cost of Acute Morbidity

Table 11.4-1 presents the results from studies (mostly contingent valuation) of the value of morbidity. Dickie and Gerking (1991a) is the only household production function study that estimated the cost of symptoms; most studies of this type valued a reduction in ambient air pollution per se. In the contingent valuation surveys there is a very large difference between the mean and median bids, which is the result of very large outlying bids. The median bids are more plausible, although they have a large variance -- Tolley et al. (1986) and Dickie et al.'s (1987) estimated WTP to reduce a day of coughing differs by an order of magnitude.

Table 11.4-3 presents the values of reduced morbidity used in previous studies of the social cost of air pollution. The cost of asthma is essentially the same in all of the studies, because researchers have based their estimates on the work of Rowe and Chestnut (1985) and Krupnick and Kopp (1988). The estimated values of RADs and RRADs have been taken from cost-of-illness studies because there are no relevant contingent valuation studies. All of the estimates for mRRADs reflect Krupnick and Kopp's (1988: 2-62) rationale that the WTP to avoid a mRRAD should exceed that for a single symptom, but not necessarily the WTP for a severe symptom or combination of symptoms. To value symptoms, such as coughing and eye irritation, researchers have used the results of contingent valuation studies. The data from these studies can be interpreted differently; hence the difference in the estimates.

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[4]For example, Loehman et al. (1979) mailed surveys to a cross section of the Tampa Bay population asking them to value the reduction of 90 days per year of severe symptoms -- probably more suffering than most people have experienced

We agree with Krupnick and Kopp (1988: 2-59), who concluded that the imprecision of the available estimates of morbidity costs preclude a definitive (point-estimate) of the cost. We review the available primary literature (Table 11.4-1), and the assumptions used in previous studies of health effects (Table 11.4-3), and decide on a plausible range for the cost of acute morbidity. Table 11.4-4 presents the values that we use for this study.

Lower Illness Cost for Children and Unemployed?

One might assume the cost of illness for children and the unemployed should be lower than the cost for working adults who are generally more productive. Hall et al. (1992), for example, valued non-working people's RAD's at half the value of working adults'. We did not because of the uncertainty in the estimated cost of illness, the lack of information in the literature addressing this problem, and the fact that we use widely different values for the lower and upper bound values.

Declining WTP

People may not value reducing the N^{th} symptom day as much as the first either because of income constraints, or simply because of declining marginal utility of "consumption" of health benefits Hall et al. (1989: 5-47) -- a common assumption in economics. Reviewing the available literature, Hall et al. (1989: 5-47) found that the average WTP to avoid each of N symptom days per year (WTP_N) equals the WTP to avoid one symptom day per year (WTP_1) multiplied by one over the square root of N:

$$WTP_N = WTP_1 \cdot N^{-0.5}.$$

The result, however, is based in part on a survey conducted by Loehman et al. (1979), the results of which suggest the respondents did not understand the survey. The respondents gave their willingness to pay to avoid one, seven and ninety symptom-days per year; the symptoms included shortness of breath, coughing/sneezing, and head congestion, at two severity levels -- mild and severe. They gave extremely low bids, valuing a reduction of 90 days of severe shortness of breath at a little over one dollar a day (median bid), and valuing the other symptoms even less. Few respondents probably understood what it would be like to experience 90 days per year with severe symptoms (virtually a chronic condition), and thus did not value the condition correctly[5]. Furthermore the survey had a very low response rate -- only 22%.

Nevertheless there probably *is* a decline in people's average WTP. Hall et al.'s equation gives plausible results, so we use it in deriving our results.

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[5]Thompson (1986) reported that people with chronic diseases were willing to pay a significant amount of money or undergo a nontrivial increase in the probability of mortality to be free of their chronic condition

Contiguous Symptom Days

We are not aware of any evidence regarding whether people value, say, two contiguous symptom days more or less than the sum of two separate symptom days. Furthermore we do not have any way of knowing whether the effects that we are estimating are contiguous or not. Therefore, we make the simplifying assumption that the utility of all symptom-days is independent on when the last symptom-day occurred.

Multiple Symptoms During a Single Day

Do people feel that multiple symptoms over the course of a day are more or less costly than experiencing the symptoms one at a time over the course of many days? Tolley et al. (1986) reported that the cost of individual symptoms is less than the cost of a combination of symptoms. However, we do not know the likelihood that air pollution-induced symptoms such as lower and upper respiratory illness occur together. Future work should account for this and adjust the cost of the symptoms using the work of Tolley et al or others.

Related to this, is the issue of double-counting effects when estimating individual symptoms such as chest discomfort and aggregated measures such as respiratory-related restricted activity days (RRAD). The double-counting arises because chest discomfort is often a symptom associated with an RRAD. To account for this, Krupnick (1988: Chapter 7) reduced the estimated number of respiratory symptoms such as chest discomfort by using the probability that a person experiences respiratory symptoms conditional on experiencing a mild respiratory-related restricted activity day -- an aggregated health measure that includes chest discomfort and other measures. We do not use Krupnick's (1988) result in the present study because for each pollutant that we consider we do not estimate an aggregated measure such as respiratory-related restricted activity day *in conjunction with* specific symptoms such as chest discomfort.

WTP Differing by Geographic Region

WTP measures may differ by geographic region, primarily because wage rates and hence the value of work differ. For example, Hall et al. (1989: 5.45) estimated different values for RAD's for different counties in the Los Angeles area. However, we do not account for any differences in the amount people from different parts of the country are willing to pay. Most regional values should fall within the relatively large range between our upper and lower bound estimates (Table 11.4-4).

Matching Problem

In valuing health effects, we merge the results from the epidemiological literature (which links air pollution to illness) and the economic literature (which places a value on illness). Ideally we would perfectly match the effect that we are estimating with the same effect from the economic literature and ensure that we appropriately value mild, moderate and severe effects. However, this is impossible to do, and the result is that we do not value the health effects that we estimate as precisely as we would like. This is the "matching problem" discussed by Krupnick (1988: 2-6).

For example, we estimate the number of respiratory-related restricted activity days (RRAD) caused by particulates, but we do not have a good measure of the cost of an RRAD, which is a broad category of effects. Hall et al. (1992) approximated its cost using assumptions about lost productivity and medical expenditures, but this does not capture all of the costs of RRAD nor does it capture the heterogeneity of effects associated with it (which includes both severe and mild illnesses).

11.4.2 Chronic Morbidity

Particulates cause asthma, chronic bronchitis and emphysema; we refer to this group as obstructive airway disease (AOD).[6] Krupnick and Cropper (1992) reported that people are willing to pay $0.46 million to $2.08 million to avoid a statistical case of chronic bronchitis, and Viscusi et al. (1991) reported $0.46 million to $2.29 million per statistical case of chronic bronchitis. We do not have estimates of people's WTP to completely avoid asthma or emphysema; we assume it is the same as WTP to avoid chronic bronchitis. In our lower bound case we use $0.5 million per case of COPD or AOD, and in the upper bound case we use $2.0 million.[7]

11.4.3 Mortality

Economists do not actually estimate the value of life per se; rather, they estimate either WTP to avoid an increase in the chance of dying, or willingness to accept compensation (WTA) for the increased risk. WTP usually is estimated by surveying people; WTA, by calculating the extra pay given to workers in risky jobs. In order to compare different estimates of the value of a change in the risk of dying -- that is, estimates based on different changes in the risk of dying -- the initially different estimates must all be normalized to the same risk level. In principle, risk values could be normalized to any level -- say, to a 10% chance of dying. But, unfortunately for the economists who have done this sort of work, it has seemed natural to express all estimates in terms of a 100% chance of dying -- "unfortunately," because the risk at the 100% chance-of-dying level usually is understood as the value of life, and lay people interpret this "valuation of life" as a hard-headed, cold-hearted calculation of the worth of a human being. But as noted above, economists value risk, not life per se; no WTP survey asks how much one would pay to avoid certain death. One therefore should not view "value of life" estimates as a measure of the worth of a human life; rather, one should view them as a way of standardizing estimates of the value of changes in risk. (Recently, Krupnick and Portney (1991: 525) expressed the value of risk reduction by assigning " a value of $1000 to each reduction of 0.001 in annual mortality risk", rather than using a $1 million dollar value of life.)

We considered two approaches to valuing a statistical life. The first assumes that the value of all lives is the same regardless of the number of years of living lost

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[6]Another common name is chronic obstructive pulmonary disease (COPD)

[7]Krupnick and Cropper (1992) and Viscusi et al (1991) do not report the year of their estimates Our figures are in 1991 $

In this approach, the value of a statistical life is estimated by contingent valuation studies, wage-risk studies and consumer-market studies. The second approach estimates the number of years lost and then places a value on those lost years (Fuchs and Zeckhauser, 1987). To estimate the value of deaths estimated by cross-sectional studies, we decided to use the former because it is difficult to estimate the number of years lost and the value that people place on those years. More generally we do not think that society's willingness to pay to reduce the risk of mortality is especially sensitive to the number of years saved, although it might be sensitive to the difference between one day and one year or longer.

There is some evidence that society places a less value on saving elderly people compared to younger individuals (Cropper et al., 1994). Since air pollution has the strongest effect on the elderly (Schwartz and Dockery, 1992a), we need to take notice of this when estimating the value of a statistical life. However, we do not formally account for this because we do not have separate dose-response functions for the elderly, so we do not know precisely what fraction of the deaths are of elderly individuals. Instead we simply lower our lower and upper bound estimates of the value of a statistical life.

11.4.3.1 Estimating the Value of Life: Wage Risk Studies

Wage-risk studies estimate the value-of-life by analyzing the wage differentials between occupations that are assumed equal in all regards except for the level of risk. However, for three reasons, wage-risk studies might underestimate the true cost of risk for most people. First, laborers might not be able to move freely between jobs, and hence might not be able to choose less risky occupations. Second, they might not fully understand the difference in risks of various occupations. Third, workers in risky occupations might be less averse to risk than are most people.

The quality of the estimates from these studies depends on the source of the data. Early wage/risk studies that used actuarial data (which includes all deaths, not just occupational deaths) reported relatively low estimates of the value of life -- less than $1 million (Table 11.4-5). Other early studies used occupational deaths by industry group (rather than actuarial data) and estimated that the value of life ranged between $4.4 to $9.5 million -- almost an order of magnitude higher than in the actuarial studies (Table 11.4-5). The industry groupings in these latter studies, however, were too broad; they did not account for differences in occupational risk within an industry or non-risk differences in wages between industries. Newer studies, correcting for these problems have found slightly lower values, ranging between $1.9 - 6.4 million (Table 11.4-5).

11 4.3.2 Estimating the Value of Life: Consumer Market Studies

Consumer market studies are similar to wage-risk studies, insofar as they examine revealed preferences. Consumer market studies look at the tradeoffs that consumers make in their consumption decisions, such as when deciding about the purchase of smoke detectors or wearing seat belts. In these studies, it is assumed that consumers equate the marginal benefits (i.e., risk reduction) with the marginal cost of the product (Fisher et al., 1989: 95). The estimated values of a statistical life are

relatively low (less than $1 million), probably because the benefits are underestimated: either the change in the risk is mis-estimated, or else on average the consumer benefits exceed the cost, which is possible because the goods are "lumpy" and bought infrequently (see Cropper and Freeman, 1991: 183).

11.4.3.3 Estimating the Value of Life: Contingent Valuation Studies

In the contingent valuation survey approach, researchers develop an hypothetical market and ask people's willingness to pay for alternative levels of safety with the received bid used to place a value on a statistical life. Contingent valuation studies are attractive because they include a broad range of people (not just a segment of the working population, as in wage-risk studies) and important attributes of risk, such as whether the risk is voluntary or involuntary, or the death quick (e.g., traffic accident) or slow and painful (e.g., cancer). However, some studies have been criticized because people may have difficulty understanding the risk they are asked to value, particularly if the risk is very small. The estimated values of a statistical life from contingent valuation surveys have ranged from $1.9 to $5.3 million – slightly lower than the estimates from the more recent wage risk studies.

11.4.3.4 Estimating the Value of Life: Conclusion

The literature presents a wide range of estimates for the value of a statistical life. We use a range of estimates that capture the variability of the estimates and still have some empirical support.[8] We estimate two classes of deaths and use two different sets of estimates of the value of a statistical life. We assume that deaths estimated from the time-series studies (acute harvest deaths) have been hastened a relatively short amount; for our lower bound estimate we use $10,000 and for the upper bound we use $50,000. The deaths estimated from the overlap of time-series and cross-sectional studies (acute non-harvest deaths) have been hastened a relatively longer time, and should be valued much more. The values from our literature review suggest a plausible range of $2 million to $5 million. However, taking into account the fact that a significant portion of the deaths that we are estimating are of the elderly or of individuals with compromised health, we use $1 million for our lower bound and $4 million for our upper bound.

When estimating chronic deaths, we assume that they will occur over a twenty-year period (see Table 11.3-21) and we value them at $1 million to $4 million at the time they occur. We then discount the value of these future deaths with an 8% and a 2% discount rate in the lower bound and upper bounds.

11.4.4 Cancer

Toxic pollutants such as benzene and diesel particulates increase the risk that people contract cancer. Cancers often have a long latency period, and are expensive and time-consuming to treat. The chance of recovery depends on many factors,

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[8]Most previous health-effects studies have assumed that the value of a statistical life ranges (roughly) between $1.8 to 9.2 million (Table 11 4-6)

including the age of the person and the type of cancer. Ideally our estimate of the cost of cancer would account for:

- the length of time between exposure to the toxic compound and the discovery of cancer;
- the amount of pain and suffering endured, medical costs incurred, and lost productivity between the discovery of cancer and the person's recovery or death;
- the probability of death; and
- the length of time between the discovery of cancer and death.

Unfortunately there is not enough information to address these issues satisfactorily, and as a result we must make simplifying assumptions about the cost of cancer. For *fatal* cancer cases, we assign the value of a statistical life at the point at which the cancer is discovered, and ignore, on the one hand, costs incurred between the time of discovery and death, and, on the other, the time between discovery and death. The omission of post-discovery costs understates the present value of the true total cost of cancer, but the failure to consider the time lag between discovery and death overstates the present value, so that these two simplifications tend to cancel.

We estimate the cost of non-fatal cancer cases on the basis of an estimate by Rae et al. (1991), and of estimates of the cost of chronic disease. Rae et al. (1991: 3-8) estimated that the sum of the direct cost of cancer (reflecting hospitalization, medication, treatment and administrative costs) and the indirect cost of cancer (i.e., foregone earnings[9]) ranges between $18, 246 and $602,048, with the higher figure reflecting lost income of the rich. The mean value, which they do not report, probably is closer to the lower figure. However, as Rae et al. (1991) note, theirs is a lower bound estimate, because it does not take into account pain and suffering and other personal costs of cancer. We have not found a comprehensive estimate of medical costs, lost productivity and pain and suffering costs of non-fatal cancer cases.

Presumably, people would pay at least as much to avoid non-fatal cancer as they would pay to avoid chronic bronchitis or arthritis. Krupnick and Cropper (1992) reported that people are willing to pay $0.46 million to $2.08 million to avoid a statistical case of chronic bronchitis; Viscusi et al. (1991) reported values of $0.46 million to $2.29 million per statistical case of chronic bronchitis; and Thompson (1986) reported that people with rheumatoid arthritis are willing to pay 22% of household income (or face a 27% increase in the risk of death) to be completely free of arthritis.

On the basis of these estimates, we choose $0.5 million as a lower bound estimate of the cost of non-fatal cancer, and $2 million for an upper bound. The

[9]The cost to society of cancer is not foregone earnings, as suggested by Rae et al (1991 3-8), because workers frequently receive some compensation when they are sick The relevant cost is lost productivity

lower and upper bound estimates include all costs of cancer, including medical costs, pain and suffering to both the patient and friends and lost production to society.

11.4.5 Discounting future deaths

The effect of pollution often appears many years after exposure. We discount these delayed effects back from the time of discovery of the chronic illness to the time of exposure, using a rate of 2% in the upper bound and 8% in the upper bound. We discuss our choice of discount rate in Report #2 of the social-cost series listed at the beginning of this report.

We assume that the incidence of chronic disease is approximately normally distributed (the shape of the distribution is based on our judgment), and estimate the percentage of cases that occur each year. Since the valuation procedure is a nonlinear function, one should not use the average latency period between exposure and incidence.

11.4.6 The value of life in the future

11 4.6.1 Background

The single biggest component of the social cost of motor-vehicle air pollution is the cost of mortality. The mortality cost is equal to the number of deaths due to motor-vehicle air pollution, multiplied by the value of life (VOL).

Some of the deaths due to motor-vehicle air pollution occur many years after exposure to the pollution: some motor-vehicle air pollution today kills people in, say, the year 2010. Our dose-response functions tell us the number of deaths in the future that result from exposure to pollution today. The economic literature on valuation tells us the VOL today. But what is the VOL in the future, in say the year 2010, when the life is actually lost? In this section, we argue that the VOL is related in some way to real wealth, and hence that the VOL in the future, given the VOL today, can be calculated on the basis of the annual increase in wealth.

11.4.6.2 Calculating the value of life

The VOL is calculated from either the willingness to pay (WTP) to reduce the probability of death, or the willingness-to-accept (WTA) compensation for an increase in the probability of death. As discussed above, the WTP or WTA is estimated in one of three ways: 1) by comparing the additional wages -- "the risk premium" -- demanded by workers in occupations with a known, relatively high risk of death; 2) by evaluating the actual tradeoffs that people make between money or time and the risk of dying (e.g., by comparing the "cost" of seat-belt use with the benefit of reduced risk of dying); or 3) by asking people about their WTP or WTA in hypothetical situations.

Wage/risk studies

The VOL calculated from wage/risk studies obviously is a function of real wage rates. If real wages in all occupations change by X% year, then the risk premium -- loosely put, the difference between wages in risky occupations and wages in similar but safe occupations -- will increase by X% per year as well, and hence the calculated VOL will increase by X%/year as well. (Of course, it is possible

that wages in risky occupations will change at different rates than will wages in safe occupations.)

One indication, then, of the future rate of change of the VOL is the historical rate of change of hourly full compensation. "Compensation" includes gross salary, overtime, incentives, and the money value of all benefits. (We are interested in the full compensation rate, rather than the just the hourly salary, because workers can be compensated for increased risk by higher benefits as well as by higher salary.) According to the Bureau of the Census (*Statistical Abstract of the United States, 1992*, 1992), the real hourly rate of compensation in the entire "business" sector increased 1.9%/year from 1960 to 1980, and 0.6%/year from 1970 to 1990. (Part of the difference between the 1960-to-1980 rate and the 1970-to-1990 rate is that real hourly compensation leveled off and declined after 1987.) It appears that the real hourly rate of compensation rate in all sectors increased by 0.6%/year as well: the real *annual* rate of compensation in all sectors increased by 0.6%/year from 1970 to 1990 (Table 11.4-7), and the average number of hours worked per week did not change between 1970 and 1990[10]. Thus, on the basis of these statistics, one might expect the VOL as calculated from wage/risk studies to increase by about 0.6%/year, in real terms.

However, the VOL calculated from a wage/risk study applies only to the types of workers studied. It does not necessarily apply to workers, in different fields, with different perceptions and valuations of risk, or to officially unemployed or retired persons. Thus, not only should one not rely exclusively on wage/risk studies in order to determine the VOL today, one should not presume that the real VOL necessarily increases at the rate of increase of real hourly compensation. To get a complete picture of the rate of change of the VOL, one must look at other measures as well.

Other measures of the value of life

We believe that the other measures of VOL -- the "shadow price" in actual markets, and the proffered WTP or WTA in hypothetical markets -- like the measure derived from wage/risk studies, are in some way related to personal wealth. As people get wealthier they have more to pay and more lose, in both real and hypothetical markets. Hence, another way to evaluate the rate of change of VOL over time is on the basis of the rate of change of measures of wealth (other than the hourly compensation rate).

Table 11.4-7 shows the change from 1970 to 1990 in several different measures of wealth. Wages and salaries are the gross annual paycheck earnings, including overtime but not benefits, of officially employed persons. Compensation is equal roughly to wages + benefits + employer-paid taxes, and official disposable income, is equal approximately to compensation + interest earnings - taxes. ("Official" means

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[10]According the Current Population Survey, people worked 39.1 hours per week in 1970, and 39.2 hours in 1990 (Bureau of the Census, *Statistical Abstract of the United States, 1992*, 1992). However, weekly hours by production and other non-supervisory ("blue-collar") workers actually declined significantly, from 37.1 to 34.5 (Bureau of Labor Statistics, *Employment, Hours, and Earnings, United States, 1909-94*, 1994)

that only the compensation of officially employed persons is counted.) The last row of the table, total implicit disposable income, is our creation, and is equal to official disposable income plus our estimate of the implicit value of the household labor of the officially unemployed. We have assumed that everyone who is over 16 and not employed and not in an institution (such as a prison) earns 25% of the average wages of officially employed persons.

Each of these different measures gives us some indication of the rate of change of wealth, and hence some indication of the rate of change of the VOL.

The first column of Table 11.4-7 shows each of these four measures on a per-capita basis (i.e., total wealth divided by the total population of the U.S. in 1970 or 1990). The data indicate that wealth per capita grew by approximately 1.5% per year between 1970 and 1990. This increase in per-capita income is explained by:

i) greater participation of women (especially married women) in the work force;

ii) increasing real disposable income per working person, in spite of declining real hourly compensation in the blue-collar sector[11] (as we will see, much of the increase in real disposable income per worker has come in the form of increased benefits and reduced taxes); and

iii) greater participation of unmarried individuals[12].

One can argue that an increase in per-capita wealth is not an accurate indication of the increase in VOL, because if the increase is due mainly to greater participation, then perhaps more people are working, but not getting wealthier. However, greater participation is in some sense equivalent to an increase in the real wage rate, because new workers must be earning more in the labor force than they do at home implicitly, or else they would not go into the labor force. If the accounts all along had been done by assigning an implicit wage to homemaking, we would see a greater growth in real income per-working capita then we see in the traditional statistics.

This is borne out by the data on wealth per working person. It is interesting to note that whereas wages have barely increased from 1970 to 1990, total implicit

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[11]Average hourly earnings for production and other non-supervisory ("blue-collar") workers declined from 8 03/hour in 1970 to 7 46/hour in 1990 (1982 dollars) (Bureau of Labor Statistics, *Employment, Hours, and Earnings, United States, 1909-94,* 1994)

[12]The participation rate of a participation group is equal to the number of people in that group who are in the civilian labor force divided by the total number of people in the group who are 16 and over and not in an institution The following are the salient statistics on the labor participation rate from 1970 to 1990.

- Old males (65 and over) participated quite a bit less in 1990, typically down from 25% to 15%.
- Married males participated less (which is something of a surprise): 86% down to 77% This is due mainly to lower participation by married males over 45
- Married females participated much, much more, in all age classes participation jumped from 41% to 58%
- unmarried persons of both sexes participated more (by about 10 percentage points), but the change was uneven across age groups and times

disposable income -- which counts the implicit earnings of the officially unemployed -- has increased substantially. This is because: a) the value of benefits has increased substantially (compare compensation to wages; compensation = wages + benefits); b) either non-wage income has gone up, or taxes have decreased, or both (compare official disposable income to compensation; official disposable income = compensation + non-wage income - taxes); and c) fewer people are remaining at home working at the relatively low implicit rate of the officially unemployed (compare total implicit disposable income to official disposable income; the former assumes that the officially unemployed implicitly earn 25% of the officially employed; when participation increases, as it did from 1970 to 1990 [see above], people move from the implicit low rate of the officially unemployed to the higher rate of the officially employed). These statistics suggest that people are becoming more productive, and hence, perhaps, more valuable.

But wealth per worker and wealth per capita still might not give a complete picture of the VOL. For example, one can argue that one also should examine wealth at the household level, on the grounds that wealth and expenses are shared within a household -- that a worker is working not just on his own behalf, but on behalf of a family or a household. Thus, Table 11.4-7 presents also wealth per household, as households are defined by the U.S. Census, and in the last columns, wealth per "related" household. In the Census, a household is any group of people living together, whether related or not. However, one might argue that wealth is not shared among unrelated people living in the same household, and hence that a better measure of the "unit" within which wealth and are expenses are shared is the number of "related" households: the number of family households plus the number of individuals in non-family households.

Wealth per Census household and wealth per related household increased from 1970 to 1990. However, the increase in wealth per official Census household generally was smaller than the increase per capita or per working person, and the increase in wealth per related household smaller still. Wealth per related household grew less than wealth per Census household because the number of people living with unrelated individuals grew faster than did the number of families -- loosely put, more people were "out on their own," spreading the total amount of wealth more thinly, and so reducing the increase per related household.

11.4.6.3 Summary

The illustrative statistics presented above, for the period 1970 to 1990, suggest that wealth and perhaps the VOL increased 0% to 1.8% per year. Note, though, that the annual rate of increase generally was higher from 1960 to 1980 than from 1970 to 1990, because many of the wealth measures presented in Table 11.4-7 actually declined a bit after 1987. This suggests that wealth, as it relates to the value of life, will increase at between 0.5% and 2.0% per year. In our formal analysis, we assume a narrower range of 1.0% to 1.5%.

TABLE 11.4-1. ESTIMATED COST OF ACUTE HEALTH EFFECTS (1991 $): SUMMARY OF THE LITERATURE

Health Effect	Median $/Day	Mean $/Day	Study Type	Population	Study
Minor Coughing/Sneezing	5.24	55.06	CV	404 respon-	Loehman et al
Severe Coughing/Sneezing	14 42	95.69		dents to a	(1979)
Minor Head Congestion	7.87	68.17		mailed ques-	
Severe Head Congestion	17.04	111 43		tionaire (22%	
Minor Shortness of Breath	10 48	102.25		response)	
Severe Shortness of Breath	23.59	166 49			
Cough	14.42	33.03	CV	40 respon-	Tolley et al
Eye Irritation	16.39	36 35		dents to mail	(1986)[a]
Sinus Problems	18.35	45.95		survey in	
Throat Congestion	17.04	37.97		Denver and	
3-Symptom Combination	39.98	n.a.		Chicago	
Can Not Breath Deeply	1 31	1494 47	CV	226 non-	Dickie et al
Pain on Deep Inspiration	4.59	1250.81		smoking	(1987)[a]
Shortness of Breath	0.00	10.33		adults in	
Wheezing	2.63	76 03		Glendora and	
Chest Tightness	6.55	1066 74		Burbank, CA	
Cough	1.31	465.52		in telephone	
Throat Irritation	3.93	19 66		survey.	
Sinus Congestion	4.59	313.97			
Headache	1.31	233.85			
Symptom (Normal Group)[b]	n.a	0.76	HPF	Same as	Dickie and
Symptom (Impaired Group)	n.a.	1.17		Dickie et al	Gerking (1991a)
				(1987)	
Health Effect	**Low $/Day**	**High $/Day**	**Study Type**	**Population**	**Study**
Asthma Attack	11 80	56.37	CV	64 adult	Rowe and Chest-
				asthmatics	nut (1985) [a]
				in Glendora,	
				California.	
Asthma Attack	1 69	47.32	COI	U S	Krupnick and
					Kopp (1988)
RAD	63.91	83 48	COI		Hall et al (1989 5-45)

CV = contingent valuation, HPF = household production function; COI = cost of illness, RAD=restricted activity day (see Table 11.3-1) n.a.=not available

[a]The original paper was not immediately available, so we used the values published in Krupnick and Kopp (1988) and Cropper and Freeman (1991. Table 6.3) We used the Consumer Price Index for all goods (Table 11 4-2) to update all of the estimates to 1991's $.

[b]The "symptom" was any one of 26 symptoms, such as chest and throat problems One hundred and twenty-six of the study group reported chronic respiratory problems and were placed in the "impaired" group, the remaining 100 respondents were placed in the "normal" group

TABLE 11.4-2. U.S. CONSUMER PRICE INDEX AND MEDICAL PRICE INDEX (1982-4=100)

Year	CPI[a]	Medical Care Price Index
1982	96.5	92.5
1983	99 6	100.6
1984	103.9	106 8
1985	107.6	113.5
1986	109.6	122 0
1987	113 6	130 1
1988	118.3	138.6
1989	124 0	149 3
1990	130 7	162 8
1991	136.2	177.0
1992	140 3	--

Source· U.S. Council of Economic Advisors (August 1992 23) and Small and Kazimi (1995)

[a]The Consumer Price Index includes all consumer items

TABLE 11.4-3. ESTIMATES OF THE COST OF ACUTE ILLNESS USED IN PREVIOUS STUDIES OF THE COST OF AIR POLLUTION (1991 $)[a]

Symptom	Low	High	Study
Asthma Attack	11.80	53 75	Krupnick and Kopp
Symptom-Day (Cough, Eye Irritation, Any Symptom [ARD2])	3.28	13.11	(1988· Table 2-6)
mRRAD	14.42	39 98	
Asthma Attack	11.80	56.37	Krupnick (1988 Table 6-9)
Cough	1 73	13.66	
Eye Irritation	6.55	14.22	
Lower Respiratory Illness	2 00	15.20	
mRRAD	13.06	40.30	
Nose/Throat Irritation	3.01	10.72	
Upper Respiratory Illness	5 07	8.93	
Asthma Attack	10 42	41.68	Krupnick and Portney
Symptom-Day (Cough, Eye Irritation, Any Symptom [ARD2])	3.13	10 42	(1991 526)
RAD	10 42	31.26	
Asthma Attack	11.77	53.62	Harrison and Nichols
Eye Irritation	3.25	13.08	(1990 Tables 6, 13)
mRAD	15.55	40.31	
RRAD	31.10	80.60	
Asthma Attack	11.54	54.92	RER (1990. Table 26)
Cough	3.29	14.28	
Eye Irritation	3.29	14.28	
Headache	3.29	14.28	
mRAD	14.28	40.09	
RRAD	23 06	73.04	
Cough	1.82	14.59	Hall et al (1992 14)
Eye Irritation	3.13	16.93	
Headache	3.13	22.93	
mRAD	15.11	38.82	
RAD	55.23	55 23	
Sore Throat	3.91	17 45	

mRRAD = minor respiratory-related restricted activity day, RAD = restricted activity day, mRAD = minor restricted activity day, RRAD = respiratory-related restricted activity day (see Table 11.3-1)

[a]We used the Consumer Price Index for all goods (Table 11 4-2) to update figures to 1991's $

TABLE 11.4-4. COST OF A DAY OF ACUTE HEALTH EFFECTS, IN THIS STUDY (1991 $)

Health Effect	Low $/Day [a]	High $/Day [a]
ARD2	3 00	14.00
Asthma Attack-Day [b]	10 00	50 00
Eye Irritation-Day [c]	3 00	14 00
Headache-Day [c]	3.00	14.00
Excess Phlegm-Day [c]	3.00	14 00
Lower and Upper Respiratory Illness [d]	3 00	14.00
RRAD	20.00	70.00
Sore Throat-Day [c]	3.00	14.00

[a]As we discuss in the text, these costs apply to the entire population We use judgmental values based in large part on the of Krupnick and Portney (1991); Krupnick (1988 Chapter 6) and Krupnick and Kopp (1988) discussed using judgemental estimates

[b]Holguin et al (1985 265) defined an asthma attack to contain three parts self-reported symptoms, an increase in asthma medication and a decrease in expiratory peak flow They then determined the probability of an asthma attack on any given day Since the dependent variable is the presence or absence each day of any asthma attack, the appropriate dollar value should be what society on average is willing to pay to avoid an asthma attack-day Not only asthmatics should be included in this WTP measure nonasthmatics may also value a reduction in the pain and suffering of asthmatics

[c]The incidence of eye irritation, headache, phlegm, and sore throat are measured in "symptom-days " What exactly are symptom-days? Schwartz and Zeger (1990), whose results we use to estimate air pollution-caused eye irritation, headache, phlegm, and sore throat, did not define a symptom-day In the original survey performed in the early 1960's, respondents stated whether they had a symptom on a given day and the severity of the symptom (mild, moderate or severe) (It is not reported in Hammer et al [1974] or Schwartz and Zeger [1990] what the respondents were instructed concerning the determination of symptom severity.) Hammer et al. (1974. 256), who analyzed the original diary data used by Schwartz and Zeger (1990), reported that virtually all symptoms were mild and subsequently ignored symptom severity when they calculated the incidence rate for each symptom We assume that Schwartz and Zeger (1990) did the same thing Thus the estimated symptom-days are days where people experience a generally mild disturbance

[d]Lower respiratory symptoms include dry cough, phlegm, shortness of breath, wheezing, chest discomfort or pain, chest cold, croup, asthma, and medically diagnosed bronchitis, influenza or pneumonia Upper respiratory symptoms include sinusitis, runny nose, dry, scratchy throat, sore throat, head cold and hay fever In this study, the values shown are applied to respiratory illnesses excluding asthma, which is valued separately

TABLE 11.4-5. ESTIMATES OF THE VALUE OF A STATISTICAL LIFE

Study	Mean Risk Level for the Sample (deaths/10^4 per.)[a]	Range of Estimates (10^6 1991$)[b]	Judgmental Best Estimate (10^6 1991$)[b]
Early Low-Range Wage Risk Studies[c]			
Arnould and Nichols (1983)	11.0	0 86	0.86
Thaler and Rosen (1975)	11.0	0 52 - 1 00	0.76
Early High-Range Wage Risk Studies[d]			
Olson (1981)	1.0	9.5	9 5
R Smith (1976)	1.0 & 1.5	4.3 - 4 7	4 4
V.K. Smith (1983)[e]	3.0	2.3 - 6 9	4 7
Viscusi (1978)	1.2	4 9 - 6 0	5 1
Recent Wage-Risk Studies [f]			
Dillingham (1985)	1 4 - 8.3	2.5 - 6 9	3 0
Gegax et al (1985)			
all union workers	8.2	2.3	
union blue-collar workers	10.1	1 9	1.9
Marin and Psacharopoulos (1982)[g]			
manual workers	2.0	3.2 - 3 7	3.5
nonmanual workers	2.0	10.7	
Moore and Viscusi (1988a)	0.79	6 0 - 7 8	6 4
Contingent Valuation Studies			
Gerking et al (1988)[h]	4.2 - 10 0	2 9 - 3 9	3 1
Jones-Lee et al. (1985)[i]	0 8 - 1.0	1 9 - 5 3	3.6
Averting Behavior Studies			
Blomquist (1979) [j]	3.0	0 45 - 1.67	0.73
Dardis (1980)[k]	0.9	0 43 - 0.67	0.55
Ippolito and Ippolito (1984)[l]	varied	0.29 - 1.50	0.62

Source Adapted from Fisher et al. (1989 Table 1) and Cropper and Freeman (1991 Table 6.1)

[a]Approximate annual deaths per 10,000 people

[b]We updated the figures to 1991's $ using the Consumer Price Index (Table 11 4-2)

[c]Based on actuarial data

[d]Based on industry accident data from the U S Bureau of Labor Statistics

[e]Assuming 0 4 percent of all injuries are fatal, as reported by Viscusi (1978) for the U.S Bureau of Labor Statistics injury statistics, and that the risk premium for fatal injuries is 33 to 100 percent of the premium for all risks

[f]This group of studies controlled for risk by occupation, but did not control for nonfatal occupational risks

[g]Study based on occupational data from the United Kingdom Their age-adjusted normalized risk variable is not directly comparable with the risk levels used in other studies However, the average risk of death for the entire sample was 2 in 10,000

[h]Respondents were asked how large a decrease in wages they would accept for a specified reduction in their job-related risk of death.

[i]Study examines people's WTP to reduce the risk of serious motor vehicle accidents in Great Britain

[j]Based on people's use of seatbelts

[k]Based on people's purchases of smoke detectors

[l]Based on people's change in smoking habits after publication of the Surgeon General's warning about the risks of smoking

TABLE 11.4-6. ESTIMATES OF THE VALUE OF A STATISTICAL LIFE USED IN HEALTH EFFECTS STUDIES (MILLION 1991 $)

Source [a]	Low	Mid	High
Small and Kazimi (1995)	2.0	4.7	11.0
Hall et al. (1992: 815)	1.8	4.0	9.2
Harrison et al. (1992: 33)[b]	–	2.1	4.2
Krupnick and Portney (1991: 525)[c]	–	1.0	–
Rae et al (1991: 3-9)	1.9	4.2	9.5
RER (1990: IV-13)	1.8	4.0	9.2
Rowe et al. (1986: 2-26)		2.6	
This study, slightly premature death[d]	0.01	–	0.05
This study, premature death[e]	1.0	–	4.0

[a]We use the Consumer Price Index (Table 11.4-2) to update the values in these studies to 1991$

[b]Harrison et al. (1992) first estimated the value of a year of lost life, by dividing the value of a statistical life as estimated in wage-risk studies ($4 to $8 million) by the number of remaining years of life at risk in wage-risk studies (estimated to be 40 years). They then multiplied the value per year by the estimated number of years lost to premature death due to particulate air pollution (21 years)

[c]Krupnick and Portney (1991) assumed that most of the mortality caused by air pollution occurs among the old and sick, and that these groups have a relatively low value of a statistical life.

[d]Refers to deaths that in the absence of air pollution would have occurred shortly after they actually did occur

[e]Refers to deaths that in the absence of air pollution would have occurred long after they actually did occur

TABLE 11.4-7. MEASURES OF PERSONAL WEALTH, 1970 TO 1990

	Wages and salaries[a]	Compensation of employees[b]	Official disposable income[c]	Total implicit disposable income[d]
1987$/capita[e]				
1970	7,615	8,525	9,960	11,336
1990	9,601	11,533	14,225	15,633
1970-1990	1.012	1.015	1.018	1.016
1987$/worker[f]				
1970	19,161	21,452	25,062	16,556
1990	19,974	23,992	29,593	20,497
1970-1990	1.002	1.006	1.008	1.011
1987$/official HH[g]				
1970	24,418	27,338	31,938	36,351
1990	25,581	30,727	37,900	41,652
1970-1990	1.002	1.006	1.009	1.007
1987$/related HH[h]				
1970	23,461	26,266	30,687	34,927
1990	23,391	28,096	34,655	38,086
1970-1990	1.000	1.003	1.006	1.004

From the U.S Bureau of the Census, *Statistical Abstract of the United States, 1992* (1992) HH = household See text for definition and discussion of measures

[a]Includes overtime, excludes benefits

[b]Equal roughly to wages plus benefits.

[c]Equal roughly to compensation plus non-wage income minus taxes

[d]Equal to official disposable income plus the implicit earnings of the officially unemployed, calculated at 25% of the wage rate of the officially employed

[e]The denominator is the total U.S population

[f]The denominator is either the total official labor force (in the case of wages and salaries, compensation, and official disposable income), or the total non-institutional population 16 years or older.

[g]The denominator is the number of households reported by the U.S Census

[h]The denominator is the number of family households plus individuals living in non-family households

11.5 THE CONTRIBUTION OF MOTOR-VEHICLE EMISSIONS TO AMBIENT POLLUTION AND THE HEALTH EFFECTS OF AMBIENT POLLUTION

11.5.1 Introduction

To estimate the health costs of emissions from motor-vehicles, we need to estimate the change in ambient air pollution due to motor vehicle emissions, because as shown in Chapter 11.3, our dose-response functions estimate changes in human health as a function of changes in ambient air pollution:

$$\Delta E = f(\Delta P, O) = f(PI, PP, O)$$

where:

ΔE = the change in the effect of interest (human health, crop production, or visibility)

ΔP = the change in ambient air pollution

O = other variables (such as population or incidence rate)

PI = actual ambient air quality in each county in the U.S

PP = the pollution level after the change in pollution -- in this analysis, the level had there been no motor-vehicle-related emissions from all motor vehicles or a class of motor vehicles.

In this chapter, we summarize how we estimate PP, the pollution level for three scenarios: removing all anthropogenic emissions, removing 100% of motor-vehicle-related emissions, and removing 10% of motor-vehicle-related emissions; we give a detailed explanation in Report #16 in the social-cost series listed at the beginning of this report. (The initial pollution level, PI, is the actual ambient air quality in each county in the U.S. These data, and the data for any of the other variables O, such as population, are discussed in other chapters of this report.)

The contribution of an emissions source to ambient pollution at an air-quality monitor depends on the strength and location of the source relative to other sources, and the atmospheric chemistry and physics intervening between the source and the point of exposure. In principle, one could estimate the contribution of various sources to ambient air pollution by modeling emissions, dispersion and atmospheric chemistry for all emission sources. However, this method requires an enormous amount of data and computer time, and often is accurate to within only 30%. We adopt a different, simpler approach that relies on a county-level emissions inventory (EPA, 1995a, 1995b) which we adjust to account for the location of emissions sources relative to people and, in the case of particulate, takes into account the relative potency of different particulate sources.

11.5.2 General modeling

In each county, we estimate PP, the pollution level without motor-vehicle-related emissions, on the assumption that the ratio of PP to PI (initial pollution in each AQCR or county) is equal to the ratio of the *modeled* PP to *modeled* PI:

$$\text{Assume: } \frac{PP}{PI} = \frac{PP^*}{PI^*} \qquad 1)$$

$$PP = PI \cdot \frac{PP^*}{PI^*}.$$

where:

PP = the estimated actual pollution level after the change in pollution (eliminate all anthropogenic emissions, or eliminate 10% or 100% of motor-vehicle-related emissions)

PI = the actual total ambient pollution level (data from air-quality monitors; discussed in Chapter 11.2)

PP* = the modeled level of pollution after the change in pollution

PI* = the modeled level of total ambient pollution.

Thus, in order to estimate PP, we must develop a model of ambient pollution, and estimate the ratio of PP* to PI* in each county.

In general, ambient air pollution at particular time and place is a function of the amount of pollutants emitted per unit time, the physical dispersion of the emissions from the emissions source to the site where the ambient pollution is being measured, and chemical transformations of pollutants. Dispersion and chemical transformations are a function of topography, meteorology, the mix of pollutants, and other factors. Formally:

$$PI_P^* = f\left(E_{P',i}; D_{P',i}(d,h,m,t...); C_{P'\rightarrow P}(s,m,t...)\right) \qquad 2)$$

$$PP_P^* = f\left(E_{P'\wedge,i}; D_{P',i}(d,h,m,t...); C_{P'\rightarrow P}(s,m,t...)\right)$$

where:

PI_P^* = the modeled initial level of ambient pollution P, at a particular time and place

PP_P^* = the modeled level of pollution P at a particular time and place, after the change in emissions

P = the ambient pollutant, measured at the ambient air-quality monitors and included in health, crop, or visibility damage functions: carbon monoxide (CO), ozone (O_3), nitrogen oxides (NO_X), total suspended particulate matter (TSP), particulate matter less than 10 microns in aerodynamic diameter (PM_{10}), and particulate matter less than 2.5 microns ($PM_{2.5}$)

$E_{p',i}$ = emissions of P' from source i, over some time period

p' = the emitted pollutant: CO' (--> CO), $PM_{2.5\text{-}10}$' (also called "coarse" PM_{10}) (--> PM_{10}), $PM_{2.5}$' (--> $PM_{2.5}$, PM_{10}), NO_X' (--> NO_2, O_3, PM_{10}, $PM_{2.5}$); volatile organic compounds (VOCs'; --> O_3, $PM_{2.5}$), SO_2' (--> PM_{10}, $PM_{2.5}$), ammonia (NH_3' --> PM_{10}, $PM_{2.5}$)

$D_{P',i}(d,h,m,t...)$ = the dispersion of emissions P' from source i, as a function of distance (d), height (h), meteorology (m; e.g., wind, temperature), topography (t), and other factors

$C_{P'-->P}(s,m,t...)$ = the chemical transformation of emissions of P' to ambient pollutant P, as a function of the mix of pollution (s), meteorology (m), topography (t), and other factors

$E_{P'\wedge,i}$ = emissions of P' from source i over some time period, *minus* the emissions that are presumed to be eliminated; in other words, the emissions of P' from source i that remain after the hypothetical change in emissions has occurred

Note that we distinguish between ambient air pollutants (P), measured at air-quality monitors, and emitted pollutants (P'), which disperse, and in some cases participate in chemical reactions, to become ambient, measured pollutants. Emitted pollutants can be the same chemical compounds as ambient pollutants (e.g., carbon monoxide [CO] is emitted, and also is an ambient pollutant), or can be involved in chemical reactions that produce ambient pollutants (e.g., volatile organic compounds [VOCs] are emitted, and are involved in the atmospheric formation of ozone).

To model the link between emissions and ambient air pollution we make several simplifications:

1). We assume that in each county c, the ambient pollution measured at the air-quality monitors is a function of:

i) emissions in county c, and
ii) emissions from other counties in the same Air Quality Control Region (AQCR)[1] as county c.

In essence, we model emissions from two source areas, or bands: the county of the monitor, and the band of counties around the county of the monitor. As explained next, we do this as a compromise between the impossible task of modeling emissions from every individual source and the oversimplification of having only one set of emission sources per air basin.

Recall that we estimate ambient air quality, as measured at EPA-ambient air-quality monitors, in each county. Ideally, we would model air quality in each county as a function of emissions from every source that contributes in any way to air quality in the county. This would require that we formally locate and characterize every individual emissions source, define air basins and pollution transport regions, and model air quality as a function of all effective emissions sources. Unfortunately, we do not have the data or resources to be able to do such detailed modeling for every county and air basin the U. S.

Rather than model the effect on air quality of every individual emissions source, one can define bands or regions of emissions, each with an effective "center"

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[1]Air quality control regions are defined in "Protection of Environment" Title 40 *Code of Federal Regulations* Part 81, 1995 ed

of emissions, and model the effect on air quality of emissions from these bands. The greater the number of bands or regions (as aggregations of emissions sources), the greater the precision, but the greater the data and analytical requirements. Our balance is to choose two emissions "bands," or areas: the county of the air-quality monitor in question, and the counties outside of this county but within the same AQCR. Within the county, we will estimate the actual effective location of different source categories (highway vehicles, power plants, off-road vehicles, construction, and so on). In the outside counties, we will assume a single effective location for all emission sources.

2). We ignore the transport of pollution from one AQCR to another, and assume that pollution within an AQCR is a function only of emissions within the AQCR. This assumption obviates the difficulties of analyzing long-range pollutant transport, and hence greatly simplifies our analysis.

3). We assume that emissions of precursor pollutants P′ disperse as P′ from the source to the receptor (the ambient air-quality monitor), and then at the receptor undergo any chemical transformations to produce ambient pollutant P. For example, we assume that VOC and NO_X emissions disperse as such from anywhere in the AQCR to the receptor in the county of interest, and at the receptor then are converted into ozone (O_3). We make this assumption because we cannot easily model chemical transformations as a function of the distance from the source.

4). In equation 1, we estimate the *ratio* PP*/PI*; we do not estimate PI* and PP* individually in units of concentration ($\mu g/m^3$). We do this because there is less uncertainty in modeling dispersion from one source *relative* to another than in modeling dispersion in absolute terms. Our model estimates the dispersion of emissions from non-motor-vehicle sources relative to dispersion of emissions from light-duty motor vehicles. With this relative model of dispersion, we can estimate the ratio PP*/PI*, but not PP* and PI* individually.

5). In the cases where we model the chemical transformation of precursor emissions to ambient pollutants (VOCs, NO_X --> O_3; NO_X, SO_X, NH_3, VOCs --> PM_{10}, $PM_{2.5}$), we ignore meteorology and topography and assume that the ambient pollution is a function only of the amount precursor emissions at the site of the monitor.

There are sophisticated models of emissions, dispersion, and atmospheric chemistry. However, it is time consuming and expensive to run all of the best models for every region in the U.S. To keep our task manageable, we will:

- use the results from the best available emissions models;
- treat dispersion very crudely;
- use an extremely simple nonlinear model of tropospheric ozone chemistry;
- greatly simplify tropospheric aerosol chemistry.

In the following sections, we discuss our simple models of ozone and aerosol chemistry. Details on these models, and on the treatment of dispersion and emissions, are given in Report #16 in the social-cost series listed at the beginning of this report.

11.5.3 Estimating the Contribution of Motor Vehicles to Ozone Formation

Ozone is not emitted as such by motor vehicles or any other source, but rather forms in the atmosphere from a series of photochemical reactions that involve NO_X, VOCs, and other compounds. The reaction rate and equilibrium depends on the relative abundance of the reactants, temperature, atmospheric mixing, and other factors. The reactions are complex and highly nonlinear, and there is no simple, universally accurate formula for determining the marginal contribution of each emission source or each precursor pollutant to ozone.

The most accurate way to estimate the contribution of each precursor or set of precursors to ozone -- i.e., to estimate $C_{p'->p}$ in equation 6 above -- is to run photochemical grid models with and without the precursor emissions from specific sources and estimate the change in the ozone level. But obviously this is very costly to do for the entire U.S. Instead, we assume a simple nonlinear relationship between VOCs (weighted according to their ozone-formation potential), NO_X, and ozone. Although this is a very crude basis for apportioning ozone damages, especially given the sophistication of regional ozone modeling, it almost certainly is not likely to be so much in error as to have a significant effect on our results.

We assume the following simple nonlinear relationship between ozone levels and VOC and NO_X emissions:

$$Oxidant = k \cdot (Hydrocarbons)^A \cdot (NO_x)^B \qquad (3)$$

This form has been used by others. For example, Schwing et al. (1980) used the following equation, taken from Merz et al. (1972), to estimate ozone formation in Los Angeles:

$$Oxidant = k \cdot (Hydrocarbons)^{0.15} \cdot (NO_x)^{0.54}$$

Schwing et al. (1980) assumed that the estimated functional form stayed constant over all pollution levels and that it was generalizable to the rest of the cities in the U.S.

We will use equation 3 to estimate the contribution of motor-vehicle VOC and NO_X emissions to ambient ozone. Like Schwing et al. (1980), we will use a single equation for all regions and conditions in the U.S. However, we doubt that Schwing et al.'s (1980) estimates of the exponents A and B (0.15 and 0.40), developed many years ago for Los Angeles, apply to all cities in the U.S. today. We chose A = 0.55, and B = 0.40, which results in an ozone sensitivity to VOC of around 0.6, and an ozone sensitivity to NO_X of slightly less. The final form of our equation is therefore:

$$Ozone = (VOCs)^{0.55} \ (NO_x)^{0.40}$$

Reactivity-weighted VOC emissions. The rate of ozone formation depends on the specific type of organic compound involved: some compounds, such as methane, react relatively slowly; others, such as some alkenes, react quite rapidly -- about two orders of magnitude more rapidly than does methane. Beyond this, the rates and equilibria of other reactions in the atmospheric chemistry of ozone also are determined by the specific mix of organic compounds involved. Thus, overall, the amount of ozone formed from VOC and NO_X emissions depends very much on the specific mix of individual organic compounds within the broad class "VOCs" (Nation Research Council, 1991).

Different emission-source categories emit very different mixes of organic compounds. For example, motor vehicles emit lots of relatively reactive alkenes, whereas natural-gas pipelines leak mainly unreactive alkanes. Because the mix of VOC emissions varies from source to source, and the ozone-creation potential of different VOC mixes varies widely, it is important to account for the different ozone-creation potential of different emission source categories.

In order to estimate the ozone-creation potential of different VOC-emission sources, one must: a) define a measure of ozone-creation potential; b) estimate the ozone formation potential of individual organic compounds; and c) estimate emissions of individual organic compounds from each source category. This can be a tall order, but fortunately for us, Derwent et al. (1996) have essentially done this already. They estimated the photochemical ozone-creation potential (POCP) of a large number of reactive hydrocarbons, under European conditions; estimated emissions of individual VOCs in each source category in the United Kingdom's emissions inventory; and then multiplied emissions of each compound by its POCP and summed over all VOC emissions within a source category, to produce an overall POCP-weighted VOC emission for each of the source category in the United Kingdom's emissions inventory.

The results of the Derwent et al. (1996) analysis, which we use here, are summarized in Table 11.5-1. We assume that POCPs estimated for European conditions are similar to POCPs for U. S. conditions, and that the mix of VOCs in each source category in the U. K. inventory is similar to the mix in the corresponding category in the U. S. emissions inventory.

11.5.4 Secondary Particulate Formation

Emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_X), and ammonia (NH_3) interact with water vapor, hydrocarbons, dust, and other carbons to form particles of ammonium sulfate and ammonium nitrate, emissions of VOC contribute to the formation of secondary organic aerosols. Because "secondary" particulate matter can constitute a sizable fraction of the total ambient particulate matter measured at air quality monitors, and because emissions of the precursors can vary substantially from source to source, it is important to have at least a simple model of the formation of secondary particulate matter from emissions of SO_2, NO_X, NH_3, and VOC.

Unfortunately, but not surprisingly, it is not easy to model secondary aerosol chemistry. According to Herrick and Kulp (1987):

> Reactions of the precursors with other chemical entities, often formed from photolysis, begin immediately on emission, and depending on emission rate, weather, and air concentration of all reactants may proceed at different rates Some reactions will take place in minutes, others in days In the meantime, the pollutants and their products are being transported, diluted, deposited, and augmented by new emissions along their path (p I-4).

Nevertheless, in Report #16 in the social-cost series listed at the beginning of this report, we develop a simple model of the formation of secondary particulates that we use to estimate the contribution of motor vehicles to particulates.

11.5.4.1 Estimating Effective PM10

As we noted in Chapter 11.3, the effect of particulates appears to depend on both its chemistry and its size. We assume that larger particles are less harmful than smaller particles, and that geologic particles are more inert and less biologically damaging than are combustion particles. We make these distinctions in order to more accurately estimate the contribution of each particulate emissions source (motor vehicles, road dust, etc.) to health effects of particulate air pollution.

Ideally, we would have a separate dose-response function for each particle size class ($PM_{2.5}$ and coarse PM_{10}), for each health effect. Then, we would treat each particle size class as a different pollutant: we would estimate the change in the concentration of each PM type, due to a change in emissions, and then use the PM-type-specific dose-response functions to estimate the changes in health effects.

However, as presented in Chapter 11.3, we do not have separate dose-response functions for each PM size class; rather, for each health effect we have one function that relates health effects to one measure of PM pollution. Because coarse and fine PM are so closely correlated, any single measure of PM pollution -- TSP, PM_{10}, or $PM_{2.5}$ -- almost certainly captures the effects all PM pollution, unless the original epidemiological analysis isolated the effect of size, perhaps by including different size classes in the model. Thus, regardless of the what the independent pollution variable in our dose-response function actually is, we can presume that it is influenced by emissions of all sizes of PM.

Our task, then, is to "apportion" the estimated PM health effects to individual PM emission sources according to the sizes (and types) of PM emitted from each source. A source that emits a kg of PM_{10} that consists mainly of large particles contributes less to the health effects, and hence should get less of a weight, than does a source that emits a kg of PM_{10} that consists mainly of fine particles, all else equal

These health-effect "weights" are applied to the contribution of each size class to the $\mu g/m^3$ concentration of all PM. Thus, if coarse PM and fine PM contribute equally to the $\mu g/m^3$ concentration, but fine PM is twice as potent -- that is, causes twice the effects per $\mu g/m^3$ -- then fine PM is responsible for 2/3 of the total PM health effects estimated with the PM dose-response function. The point here is that the weights -- the relative health-effects per $\mu g/m^3$ -- are applied to the contribution to the $\mu g/m^3$ concentration, not to the emissions. Thus, we must estimate the

contribution of each particle size class to the $\mu g/m^3$ concentration. This is accomplished by the simple dispersion modeling discussed above.

TABLE 11.5-1. EMISSIONS, POCP-WEIGHTED EMISSIONS, AND POCP- ADJUSTMENT FACTORS FOR VARIOUS VOC-EMISSION SOURCES

Source category in U. K. emissions inventory	Source category in U.S. emissions inventory	Emissions in U.K. *(kt/yr)*	POCP-weighted emissions in U. K. *(kt/yr)*	POCP adjustment factor[a]
Petrol exhaust	Gasoline vehicle exhaust[b]	652	506	0.78
Petroleum refining and distribution	Petroleum and related industries	134	83	0.62
Petrol evaporation	Gasoline vehicle exhaust[b]	143	87	0.61
Solvent usage	Solvents and storage	787	461	0.59
Stationary combustion	Fuel combustion by electric utilities; Fuel combustion by industry; Fuel combustion by other; Other combustion	56	27	0.49
Diesel exhaust	Diesel vehicles; Non-road engines	175	77	0.44
Industrial and residential waste	Waste disposal and recycling	3	1	0.28
Natural gas leakage	None	34	9	0.26
Chemical processes	Chemicals and allied products; Metals processing; Other industrial processes	200	43	0.21
Biogenic emissions[c]	Biogenic emissions	n.a.	n.a.	1.1

From Derwent et al (1996), except "Source category in U S emissions inventory," which is our matching POCP = photochemical ozone-creation potential

[a]Equal to the ratio of POCP-weighted emissions to unweighted emissions Derwent et al (1996) refer to this as the "sector-mean POCP"

[b]Our runs of EMFAC7F (California Air Resource Board's motor vehicle emission model), and the analysis by Ross et al (1995), suggest that vehicular evaporative emissions (including refueling emissions, but not further "upstream" emissions) are about 0 4, and vehicular exhaust emissions about 0 6, of total (exhaust + evaporative) VOC emissions from motor vehicles

[c]Based on POCP estimates of biogenic VOCs (e.g., terpene) from Derwent et al. (1996)

11.6 HEALTH EFFECTS CAUSED BY TOXICS

The effects of toxics from motor vehicles are difficult to estimate. There are many toxic compounds, and a large number of them are not well characterized. Toxics can have a variety of effects: they can be acute or chronic poisons, or cause cancer or birth defects or genetic mutations. It is difficult to model human exposure, and more difficult still to estimate defensible dose-response functions.

Ours, then, is not a complete estimate of all of the effects of all the toxic pollutants emitted by motor vehicles. Rather, we estimate the cancerous effect of only a fraction of the chemicals associated with motor vehicles. There are many other chemicals that may cause cancer that we do not consider, mainly because we can not estimate people's exposure or because the relevant studies have not been performed.[1] Furthermore, there may be chronic, acute, teratogenic or mutagenic effects that we do not consider.

Researchers have reported an increased risk of cancer in gasoline attendants, auto mechanics, truck drivers, and others exposed to motor vehicle-related pollutants. Grandjean and Andersen (1991) found a 12% higher rate of respiratory cancer in Danish gasoline station workers, compared to all employed males. Hayes et al. (1989) reported a higher incidence of lung cancer in occupations associated with motor vehicle exhaust (e.g., truck drivers), and Bender et al. (1989) reported higher rates of some types of cancer in Minnesota highway workers. Hoover and Fraumeni (1975), Blot et al. (1977), Blot and Fraumeni (1976), Gottlieb et al. (1982), Kaldor et al. (1984) reported a higher incidence of cancer mortality in counties with petroleum industries, and Theriault and Goulet (1979), Thomas et al. (1980), and Wong and Raabe (1989; 1990) reported higher cancer rates in petroleum workers.

Aside from increasing the risk of cancer, toxics and other chemicals adversely affect people by being unpleasant to smell, increasing morbidity (e.g., eye irritation, nausea),[2] and contributing to "environmental illness" or "multiple chemical sensitivity". Some people are extraordinarily sensitive to odorous chemicals, susceptible to effects at pollutant levels "orders of magnitude lower than levels known to cause symptoms by classical toxicologic or irritative mechanisms" (Shusterman, 1992: 81; see also Ziem and Davidoff, 1992). Goldsmith (1972; cited in Shusterman, 1992) reported a positive link between the intensity of odor exposure (validated by olfactometry) from petroleum refineries and self-reported cases of eye and nose irritation, dizziness, and nausea. Nevertheless, as we stated above, the data enable us to consider only the carcinogenic effects of toxics.

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[1]In a survey of the petrochemical industry, Cottle and Guidotti (1990) presented a long list of potentially dangerous chemicals The International Agency for Research on Cancer (1989) also presented a long list of potentially dangerous chemicals in its discussion of the processes and chemicals involved in petroleum refining

[2]The California Air Resources Board (1991a) and Altshuller (1993) reported formaldehyde causing eye irritation

11.6.1 Cancer Estimating Procedure

Paustenbach et al. (1990) and Freudenberg (1988) discussed the difficulties in quantifying the deleterious effects of toxics and other chemicals:

- scant data on ambient concentrations of toxics and resulting exposure;
- uncertainty regarding the size of the effect;
- uncertainty (particularly in the case of cancer) as to when the effects occur; and
- uncertainty about the appropriate dose-response function (particularly when multiple chemicals may combine to have more or less of an effect than when examined separately).

We use four steps to value the increased incidence of cancer caused by motor vehicles. First, we estimate toxics exposure from motor vehicles, using the results from a model (Hazardous Air Pollutant Exposure Model for Mobile Sources, or HAPEM-MS) developed for the EPA (1993a). Second, given estimates of exposure to six toxic pollutants (acetaldehyde, 1,3-butadiene, benzene, diesel particulates, formaldehyde and gasoline particulates), we apply the standard linear cancer development model to estimate new cases of cancer associated with these toxics. Third, we value these cases of cancer, taking into account our estimate of the types of cancers caused, when they occur and the probability that the victims will survive. Finally, we apportion these damages to six motor vehicle types. We discuss these four steps in more detail below.

11.6.1.1 Exposure To Toxic Air Pollutants

To estimate toxics exposure, we use the HAPEM-MS model. The EPA (1993a) used this model to estimate cancer cases caused by cars. We use the EPA's work and a companion work by Johnson et al. (1992a) to estimate the annual average per capita exposure to acetaldehyde, benzene, 1,3-butadiene, formaldehyde, diesel particulates, and gasoline particulates in a metropolitan statistical area (MSA). HAPEM-MS is desirable because it offers a method to generate county-level exposure estimates to specific toxics associated with motor vehicles. It accounts for people's movement each day between "microenvironments" of varying pollution levels. (For example, the inside of a car is a microenvironment, with relatively high levels of toxic air pollutants; office buildings and homes are another microenvironment, with relatively low levels of toxic air pollutants.) In this model the average exposure to pollution is the sum of the weighted daily micro-environment exposures, wherein the weights are proportional to the pollutant concentration and the length of time spent in each microenvironment.

The model requires a large amount of data. It divides an MSA into exposure districts -- one district for each CO monitor that operates in the MSA -- and the population into demographic groups based on age and working status (Table 11.6-1). Each demographic group may be broken down further based on residence and place

of work, increasing the number of groups beyond the nine given in Table 11.6-1. Based on studies of what people do each day, HAPEM-MS shuttles each group or cohort between five microenvironments and keeps track of the length and severity of CO exposure.[3] At the end of a day the model estimates the average exposure and at the end of the year estimates annual average exposure for each group. It then weights the average annual exposure of each group by its size and finds the average annual per capita CO exposure in the MSA.

To determine exposure to toxics, we assume (initially) that the emissions of toxics follow the same path as do CO emissions. That is, we assume that if the emission of one gram of CO results in an average exposure of 1 $\mu g/m^3$, then the emission of, say, half a gram of benzene results in an exposure of 0.5 $\mu g/m^3$. This assumption simplifies the analysis, but it may be inaccurate for toxic pollutants such as acetaldehyde and formaldehyde which break down quickly after emission and are created in secondary reactions from other gases in the atmosphere. Below we explain how we check the accuracy of this assumption and where necessary adjust the results to account for the destruction and secondary formation of toxic air pollutants.

Steps To Estimate Toxics Exposure

We estimate people's exposure to toxic air pollutants by dividing the U.S. into eleven urban regions and two rural regions, with the assumption that one subregion, or "model" area, in each region is representative of the rest of the region (This follows the procedure of the EPA [1993a] in estimating the effects of toxics.) Table 11.6-2 gives the population of each region we examine. Because we assume a homogeneous activity pattern within a region, we may apply the model-estimated toxics exposure in the "model" city to the other cities in the region.

Below, we review the four steps to estimate toxics exposure in all urban areas (i.e., MSAs). The same steps apply for rural areas which we define as counties outside MSAs.[4] Our review is brief; interested readers should consult EPA (1993a) and Johnson et al. (1992a) for more details.

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[3]The ambient CO level in each environment is assumed to be a fraction of the CO level measured at a fixed-site monitor These fractions were determined by estimating the relationship between measurements of monitors that people wear and the measurements made at CO monitors

The fraction of CO attributable to motor vehicles is higher inside motor vehicles and garages and alongside freeways than in office buildings Johnson et al. (1992a) do not account for this when using HAPEM-MS, they assume that motor vehicles contribute the same percentage in each microenvironment We can not amend this because we do not have access to HAPEM-MS and have relied on their results Future work with HAPEM-MS should determine the contribution of CO in each environment by source.

[4]The average annual per capita exposure is estimated for each model rural area with a similar procedure· we take the HAPEM-MS results for two model rural areas (Paducah, Kentucky and Farmington, New Mexico), and assume that each model rural area is a proxy for exposure in non-model rural areas Paducah is representative of the eastern half of the United States and Farmington is representative of the western half

1) Johnson et al. (1992a) used HAPEM-MS to estimate the average annual CO exposure in 1988 (Table 11.6-3) in model urban areas.

2) Given exposure in model urban areas, we estimate the exposure ($\mu g/m^3$) in "non-model" MSAs:

$$CO\ Exposure_{Non-Model\ MSA} = \frac{Ambient\ CO_{Non-Model\ MSA}}{Ambient\ CO_{Model\ MSA}}\ CO\ Exposure_{Model\ MSA}\ .^{5}$$

3) To determine the motor vehicle-related CO exposure in 1989-1991 -- years for which we do not have results from HAPEM-MS -- we adjust exposure from the base year (1988) to account for increased VMT (vehicle miles traveled)[6]:

$$CO\ Exposure_{1991,\ Model\ MSA} = \frac{Ambient\ CO_{1988,\ Model\ MSA}}{Ambient\ CO_{1991,\ Model\ MSA}}\ CO\ Exposure_{1988,\ Model\ MSA}\ VMT\ .$$

4) We then estimate exposure to toxics:

$$Toxics\ Exposure_{1988,\ Model\ MSA} = \frac{CO_{grams\ per\ mile}}{Toxics_{grams\ per\ mile}}\ CO\ Exposure_{1988,\ Model\ MSA}\ .$$

The gram per mile emission factors we use are in (Table 11.6-4).

Using Ambient Data to Check the HAPEM-MS Results, and to Adjust the Results for "Reactive" Toxics

We assume (initially) that toxic air emissions follow the same chemical and physical path from the tailpipe to air-quality monitor as does carbon monoxide (CO), which is relatively nonvolatile. However, if a significant amount of a toxic compound is destroyed en route -- or, conversely, if a significant amount is formed from other emissions -- then this assumed relationship between toxics emissions and its subsequent concentration may not hold. That is, some toxics actually might not follow the same path as the relatively nonvolatile CO. To check this, the EPA (1993a) used observations on the ambient concentration of acetaldehyde, 1,3-butadiene, benzene, and formaldehyde and determined an independent estimate of

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[5]When monitor readings are not available for a county in an MSA, we use the readings in the other counties in the MSA. When no readings at all are available for an MSA, we approximate the average exposure with the minimum estimated exposure of the MSAs in that urban region, on the assumption that MSAs without CO monitors have relatively low CO levels. We chose not to follow the EPA (1993a), which used the median estimated exposure in each region as a proxy for those MSAs without CO monitors, because we felt this might overestimate actual exposure.

[6]The EPA (1993a, 4-7) assumed that the VMT adjustment factor for 1990 equals 1.031, and for 1995 the adjustment factor equals 1.123, we determine the factors for 1989 (1.0155) and 1991 (1.0465) by linear interpolation.

toxics exposure. (They did not consider diesel and gasoline particulates because direct measurements of diesel and gasoline particulates are not available.) EPA compared the new estimates of exposure with the HAPEM-MS results. Which estimates are better? The EPA assumed that the ambient-based estimates take precedence over HAPEM-MS, perhaps because the ambient observations seem more grounded in reality. In our view, though, both estimates have problems.

To obtain an ambient-based exposure estimate, the EPA first calculated the annual average for each monitoring site and the overall average of monitors in each of four separate groups of monitors (Table 11.6-6). The network averages include all toxics sources. The EPA removed the contribution of other (non-motor-vehicle) sources of toxics (Table 11.6-7), and adjusted for a population's movement through microenvironments using what EPA calls the "integrated exposure adjustment constant", which is a simplified version of the HAPEM-MS model that they want to check.

The "integrated exposure adjustment constant" combines the amount of time that people spend in each microenvironment with the pollution concentration in the environment. The EPA (1993a: 5-29) estimated that people spend 5.9% of their time outdoors, 61.9% indoors at home, 24.6% at work and 7.6% during some form of transport, and then weighted the percentages by CO level in each place or microenvironment. The CO level in each microenvironment equals the ratio of the CO concentration in the microenvironment to the CO concentration at a fixed outdoor monitor site: outdoors = 0.758, indoors residence = 0.495, indoors other = 0.619, and inside a motor vehicle = 1.554 (Table 11.6-9). With these data, the constant is calculated as:

$$5.9\% \cdot 0.758 \frac{CO\ outdoor}{CO\ monitor} + 61.9\%\ 0.495 \frac{CO\ home}{CO\ monitor} + 24.6\%\ 0.619 \frac{CO\ work}{CO\ monitor} + 7.6\%\ 1.554 \frac{CO\ auto}{CO\ monitor} = 0.622$$

The EPA calculated an ambient-based estimate for each pollutant for each network and for each year. For example one network of benzene monitors for benzene had an average reading of 6.80 $\mu g/m^3$ in 1987 (Table 11.6-6). Attributing 59.5% of ambient benzene to motor vehicles and multiplying the results by the integrated exposure adjustment constant (0.622), the EPA estimated the annual exposure to benzene is 2.52 $\mu g/m^3$.[7]

After comparing the adjusted ambient data with the HAPEM-MS results, the EPA decreased the HAPEM-MS results for formaldehyde by a factor of 1.18, decreased the HAPEM-MS results for 1,3-butadiene by a factor of 1.37 and increased the HAPEM-MS results for acetaldehyde by a factor of 2.09; they did not change the

[7]Note that our reported exposure (2.52 $\mu g/m^3$) differs slightly from those of EPA (1993a) for reasons we discuss in Table 11.6-6

benzene estimate.[8] The EPA apparently used its best judgment in determining these factors.

Problems Comparing Ambient-Based Exposure Estimates And HAPEM-MS Exposure Estimates

Several problems encumber the EPA's (1993a) analysis. First the EPA determined national estimates of toxics exposure using monitor networks with as few as six observations: Bakersfield, Concord, Fremont, Richmond, San Jose and Stockton California comprise one network of monitors (EPA, 1993a: Appendix C, p.13); the HAPEM-MS results used CO monitors in 163 MSAs. There is little reason to expect the sets of results to agree. Second the EPA's method of comparing the HAPEM-MS and ambient-based national exposure estimates is not clear. Third when calculating their ambient-based exposure estimates, they used relatively simple assumptions about the length of time spent in microenvironments, and, furthermore, they calculated the integrated exposure adjustment constant for the nation as a whole, rather than for each of the eleven urban regions in the U.S.

An Alternative Comparison of HAPEM-MS and Ambient Toxics Data

Because of these shortcomings, we opted to redo the EPA's (1993a) calculations. For each MSA that has sufficient ambient toxics data, we compare our own ambient-based estimates with the HAPEM-MS results (Tables 11.6-10 to 11.6-13). We compare *individual cities*, and thereby avoid the problem of using data from a handful of cities to determine a national average. Second, we estimate the relationship between CO monitor observations and people's exposure for thirteen regions in the U.S. using HAPEM-MS rather using the integrated exposure adjustment constant as a proxy for the nation (Table 11.6-14).[9] Third, we use

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[8]The EPA (1993a: 5-29) did not change the HAPEM-MS benzene estimate "since the unit-risk estimate for benzene is an upper bound estimate, and the HAPEM-MS 1990 base control number [2 67 $\mu g/m^3$] matches the upper end of the range [2.68 $\mu g/m^3$] " However, the EPA is incorrect for three reasons.

1) the benzene unit-risk number is <u>not</u> an "upper bound" estimate In fact, the EPA (p. 5-39) reported that the benzene unit-risk number is the geometric mean of 21 maximum likelihood estimates;

2) the EPA (p. 5-28) incorrectly reported that the "overall average of the averages from the 31 cities was 7 18 $\mu g/m3$" in the NAVOC data Inadvertently, they reported the average of all 564 samples (weighted equally) from all 31 cities The overall average is 6.83 $\mu g/m^3$, which in turn causes the exposure estimate to decline below the HAPEM-MS estimate, and

3) the EPA (Table 5-1) incorrectly reported that 1 ppm of benzene equals 3.25 $\mu g/m^3$ at 25° C, the correct figure is 3.19 $\mu g/m^3$

The effect of the last two errors is to reduce the exposure estimate based on the ambient toxics data, in Table 11 6-6 the adjusted ambient data range from 1.50 $\mu g/m^3$ to 2.53 $\mu g/m^3$ -- well below the HAPEM-MS estimate of 2 67 $\mu g/m^3$ To be consistent with their adjustments to the other HAPEM-MS estimates of toxic exposure, the EPA (1993a) should have reduced the HAPEM-MS benzene estimate to conform with the ambient data

[9]Nevertheless, their constant is a reasonably good approximation -- most of our regional adjustment factors are close to the EPA's 0 622 constant (Table 11 6-14), and hence the EPA's adjusted ambient estimates are close to the HAPEM-MS estimates (Table 11 6-15).

ordinary least squares to determine if the ambient-based estimates are significantly different from HAPEM-MS results.

HAPEM-MS Exposure Estimate

We estimate toxics exposure in an MSA by taking the CO exposure estimate generated by HAPEM-MS (Johnson et al., 1992a) and multiplying it by the ratio of toxics and CO emissions:

$$Toxics\ Exposure_{1988,\ MSA} = \frac{CO_{grams\ per\ mile}}{Toxics_{grams\ per\ mile}}\ CO\ Exposure_{1988,\ MSA}$$

Ambient-Based Exposure Estimate

Because there is a shortage of ambient toxics observations, we combine data from several years in order to determine average ambient levels. To obtain an exposure estimate based on the overall average of the ambient data, we adjust the ambient toxics data by the proportion that is attributable to motor vehicles, and multiply by the regional exposure adjustment factor:

$$Toxics\ Exposure = Ambient\ Toxics\ \%\ Toxics\ Emissions_{motor\ vehicles}\ Regional\ Exposure\ Factor$$

where:

Toxics Exposure = ambient-based toxics exposure level ($\mu g/m^3$)

Ambient Toxic = average ambient toxic level ($\mu g/m^3$)[10]

Toxics $Emissions_{motor\ vehicles}$ = the % of toxics attributable to motor vehicles (Table 11.6-7)

Regional Exposure Factor = the HAPEM-MS average CO exposure divided by the actual annual average ambient CO level for the model city in the region (Table 11.6-14).

Results Of Our Comparison Between HAPEM-MS And Ambient Data

Tables 11.6-10 to 11.6-13 give the ambient-based exposure and HAPEM-MS exposure estimates for acetaldehyde, 1,3-butadiene, benzene and formaldehyde. For each pollutant, we regress the ambient-based estimates on those from HAPEM-MS. We interpret the regression coefficients as the factor with which to multiply the HAPEM-MS estimates of toxic exposure so that they conform with the ambient-based estimates of toxic exposure. If the coefficient is not different from one, then the HAPEM-MS estimates should not be changed; Table 11.6-16 gives the results.

Our regional factor equals the average per capita exposure estimate from HAPEM-MS, divided by the average ambient CO levels

$$\text{Exposure Factor in Region}_i = \frac{\text{Average CO Exposure in Model MSA}_i,\ \text{HAPEM-MS}}{\text{Average Ambient CO in Model MSA}_i,\ \text{National Air Data Bank}}$$

[10]We take a weighted average of all annual averages in an MSA (1987-1990), with the weighting determined by the number of observations in each average We make the assumption that the ambient level of toxic pollution should not differ between 1987 and 1990.

The coefficient for benzene, acetaldehyde and 1,3-butadiene differ significantly from one at the 95% confidence level, so it is appropriate to use the estimated coefficients to adjust the HAPEM-MS results. Thus, we multiply the HAPEM-MS acetaldehyde estimate by 2.53, the benzene estimate by 0.81 and the 1,3-butadiene estimate by 0.48. However, we do not change the formaldehyde exposure estimate.

Our revisions differ from the EPA's (1993a). They multiplied the HAPEM-MS acetaldehyde estimate by 2.09, the 1,3 butadiene estimate by 0.73, and the formaldehyde estimate by 0.85; they did not change the benzene estimate. We believe that our method is an improvement, and consequently use our own results[11]

11.6.1.2 Linear Cancer Model

The second step in valuing the damages caused by motor vehicle toxics, is to translate toxics exposure into estimated cancer cases. We use the linear cancer model. The linear cancer model, also termed the "one-hit" model since even very small amounts of toxics cause cancer, assumes that the risk of getting cancer is linearly related to the dose. Thus, this model assumes that the per unit effect of toxics at high and low doses is the same -- not an assumption unanimously accepted with equanimity. At very low doses, no one knows for sure whether the effect is truly linear, or even if toxics have any effect at all (Cohrssen and Covello, 1989: 95).[12] Nevertheless, the common presumption in most studies, and in ours, is that the "one-hit" (linear down to zero dose) model is correct for estimating the incidence of cancer following exposure to potential carcinogens.[13]

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[11]We recognize that, for several reasons, our method is still imperfect

First, it is doubtful that the placement of the toxics monitors is comparable to the placement of the CO monitors To the extent that the monitors are placed in different areas (e.g., residential versus central city), we expect the ambient-based and HAPEM-MS estimates to differ

Second, the estimated exposure level, based on the toxics monitoring data, is sensitive to the assumed contribution of motor vehicles to the ambient toxic concentration In reality, the precise portion of the ambient toxics levels attributable to motor vehicles is unknown

[12]Very large experiments would help resolve whether low doses are harmful (Rall, 1978, Land, 1981), but the scale of the experiments would have to be prohibitively large to explore the effects of very low doses.

[13]An alternative to the use of the linear cancer model, at least for particulates, would have been to use epidemiological studies, which correlate people's estimated exposure to, say, particulates and reported cases of cancer, or cancer deaths. This method is desirable because it relies on *reported* cases of cancer However, we did not find any studies that could provide useful dose-response functions We consider, here, some of the better studies that we reviewed

Cupitt et al (1994) used diaries of 43 residents of Boise, Idaho to estimate exposure to extractable organic matter (EOM) from residential wood smoke and motor sources They then estimated the risk to this exposure using the comparative potency method (Albert et al., 1983; Lewtas, 1991) They (p 82) found "an individual lifetime risk" of 4.7×10^{-4} from exposure to 4 7 ug/m^3 of EOM Of this risk, 0.92×10^{-4} is attributable to residential wood smoke, meaning that the remainder, roughly 3.8×10^{-4}, is from mobile sources However, we do not use Cupitt et al 's results they are based on a relatively small sample of diaries and the measured extractable organic matter is specific to Boise, Idaho.

In the linear model, the unit-risk number is the key to estimating the incidence of cancer.[14] A unit-risk number estimates the excess risk of cancer, to one individual, from 70 years (a lifetime) of continuous exposure to 1 $\mu g/m^3$.

$$Unit\ Risk_{Toxic_j} = \frac{Cancer\ Risk_{Individual_i}}{70\ Years'\ Exposure\ to\ Toxic_j\ at\ 1\ \mu g\ /\ m^3}$$

We should note that cancer unit-risk numbers are very imprecise: estimates of the unit risk for a particular compound can differ by an order of magnitude or more. For example, the EPA's official unit-risk estimate for formaldehyde differs by more than an order of magnitude from their updated (unofficial) estimate. The high degree of variability arises from the difficulty in measuring the effect of very small doses and using animals to estimate the effects on humans. Paustenbach et al. (1990) and Schneiderman (1981) discuss the difficulties.[15]

In a study of Seventh-Day Adventists who lived in the same residence in California for at least ten years, Abbey et al (1991) found that TSP caused an elevated risk of cancer in females However, it is not clear why women would have a higher risk than men

Archer (1991) compared three counties in Utah and found an elevated cancer risk in the county with a steel mill that generates 45% of the ambient particulates in the county Archer assumed that smoking rates are the same in these counties However, using smoking data, Blindauer et al (1993) reported that Archer's result can be explained by differences in smoking rates between the counties.

Buffler et al. (1988) found that TSP (their assumed proxy for toxics) was responsible for 1 5% of the lung cancer rate for white males aged 30-79 in Harris County, Texas -- equivalent to 1.9 extra lung cancer deaths per 100,000 people in Harris County However, TSP is not a particularly good proxy for toxics because it is not a "well-dispersed" pollutant (Detels et al., 1981), and the coarser fraction of TSP in not normally inhaled. Moreover, some toxics, such as benzene are not necessarily attached to particulates These factors lead to an underestimation of the true effect

Doll and Peto (1981 1248) estimated that at most 1% of lung cancer is attributable to air pollution, and Speizer (1983) reviewed the literature and estimated that at most 2% of lung cancer may be attributable to air pollution The Doll and Peto study and Speizer's work simply review a literature that is no better (and often worse) than the Buffler study Also, they do not estimate the effects of specific pollutants

In a prospective cohort study of 151 metropolitan areas, Pope et al. (1995a) reported a link between lung cancer and sulfate particulates They found a relative risk of 1.26 for sulfates (with a 95% confidence interval of 1 11-1 66) between the most and least polluted metropolitan areas, no significant effect was found for $PM_{2\,5}$ This would be a useful study but for the fact that we do not have much ambient sulfate data

[14]The EPA (1993a) gives more details on the evidence linking particular toxics to cancer, and the development of unit-risk numbers (both the EPA's own estimates and estimates by others)

[15]Concerning the numerous difficulties with using animal studies to estimate the risk of toxics to humans, Schneiderman (1981. 33) noted the sharp contrast between humans and lab animals Lab animals are genetically homogeneous, live in a much less complicated environment than humans, are exposed to relatively few potential carcinogens, have a different metabolism and immune system than do humans, and typically are given doses orders of magnitude higher than what people and animals normally encounter

To estimate the number of excess cancers to a population from exposure to a toxic air pollutant in a given year, we determine the number of "exposure-years" at an exposure level of 1 $\mu g/m^3$. (For example, the exposure of seventy people to 1 $\mu g/m^3$ for a year is equal to 70 exposure-years.) Multiplying the number of exposure-years by the unit-risk number then tells the number of cancer cases that will arise from exposure to motor vehicles. We calculate the number of excess cancers arising in a population from a year's exposure to a toxic pollutant by:

$$Excess\ Cancers_{Year_t} = \frac{Unit\ Risk\ Number \cdot Average\ Population\ Exposure_{Year_t} \cdot Population}{70\ Years},$$

where:

Excess Cancers$_{Year_t}$ = increase in cancer caused by annual automotive toxics emissions

Unit-Risk Number = unit-risk number of toxic (EPA, 1993a)

Average Population Exposure$_{Year_t}$ = annual per capita exposure estimated by HAPEM-MS

Population = county population of all individuals, of all ages (U.S. Bureau of the Census, 1992).

Given the estimated increased incidence of cancer, we still need to determine: (a) the latency period (the period between exposure and cancer development), (b) the type of cancer caused, (c) the recovery rate and the cost of treatment, (d) how to apportion the estimated damages among different vehicle types.

11.6.1.3 Latency Period, Type of Cancer and Recovery Rate

Latency Period

The development and diagnosis of cancer does not occur concurrently with the emission of toxics. There is a lag or latency period, which we assume may extend anywhere from one to fifty years. Unfortunately, there are no reliable estimates of the mean length of time between exposure and diagnosis of cancer, nor of the shape of the distribution of cancer cases over time. Concerning the mean of the distribution, Buffler et al. (1988) assumed a ten-year latency period when regressing lung cancer in year $_t$ on the TSP level in year $_{t-10}$, and found a small positive relationship between lung cancer and TSP. Friberg and Cederlof (1978: 51) reported that the latency period between cigarette smoking and cancer may be as long as three to five decades, and added that there is little reason to expect the latency period for air pollution to be less than this. Speizer (1983: 36), reporting results from a study on roofers (who are exposed to fumes from burning fossil fuels), stated that "there is a suggestion of an exposure-response relationship with a lag of 20 years and then a doubling of the risk of lung cancer over the next 20 years." These reports suggest that most cancers do not occur quickly after exposure. For lack of definitive estimates of the latency period, we assume that, on average, cancer is discovered 25 years after exposure, and that the incidence of cases follows, roughly, a normal distribution

(Table 11.6-17). We feel that this reflects the notions currently in the literature tolerably well.

Discount Rate

When the cancer occurs is important in our analysis because of the well-accepted economic practice of discounting future costs. We use real discount rates of 2% and 8%, which bracket most estimates in the literature (e.g., Hartman, 1990; Lind, 1990). We discuss our choice of discount rate in Report #3 of the social-cost series listed at the beginning of this report.

Type of Cancer and Recovery Rate

For each toxic, we estimate the type of cancer formed and the associated probability of recovery -- both are important factors in determining the cost of cancer. If a cancer victim dies we assume the cost is the value of a statistical life; if one recovers the cost of cancer equals the cost of treatment, lost productivity, and pain and suffering.

We estimate the type of cancer caused by each toxic, using the epidemiological and laboratory results cited by the EPA (1993a) in its estimates of the unit-risk (Table 11.6-18 to 6-20). Benzene is linked to an increased incidence of leukemia in studies of workers in rubber factories; hence, we estimate the mortality rate with the assumption that benzene causes leukemia. The other toxics are based on animal studies, and we assume that the types of cancer formed in rodents and humans are identical.[16] The unit-risk number for gasoline is *not* directly based on laboratory studies, instead it uses the "comparative potency method", which groups an unknown chemical with chemicals of a known carcinogenicity (Albert, 1983; Lewtas et al., 1991). We assume that gasoline particulates cause lung cancer.

We estimate the recovery rate for each type of cancer from statistics provided by the American Cancer Institute. Tables 11.6-21 and 11.6-22 show that, in general, recovery rates have increased over time, but that the recovery rate for African-Americans is lower than for whites, perhaps because of later diagnoses or less effective treatment. In addition the incidence of cancer is higher for African-Americans. We weight our estimated recovery rates by the relative populations of whites and African-Americans, and by the higher incidence rate for African-Americans. Although there may be regional differences, we assume for simplicity that a single recovery rate holds across the U.S. (Tables 11.6-23 and 11.6-24).

11 6.1.4 Apportioning Toxics Damages to Vehicle Type

The EPA (1993a) estimates the contribution of all motor-vehicles to exposure to toxic air pollutants, but not the contribution of individual classes of motor-vehicles (light-duty gasoline vehicles, heavy-duty diesel vehicles, etc.) We estimate the separate contribution of each motor vehicle class as follows. For benzene, we

[16]Of course, it is possible that a particular toxic might cause a different cancer in humans than it does in rodents However, it seems to us that any such assumption about different effects would be entirely ad hoc

first assume that all diesel vehicles are responsible for 3% of the total motor-vehicle contribution to benzene, because according to Carey (1987: 43), diesel vehicles emit about 3% of the benzene emitted by all motor vehicles. We then distribute this 3% to each of the three classes of diesel vehicles (light-duty auto, light-duty truck, heavy-duty truck) in proportion to VOC emissions from each of the three classes. We do the same for the remaining 97% of total motor-vehicle benzene that is attributed to gasoline vehicles. We do this for each county in the U.S.

For all other toxic air pollutants, we distribute the total motor-vehicle share (estimated by EPA, 1993a) to each of the six vehicle classes in proportion to VOC emissions from each of the six classes, with no initial distinction between gasoline and diesel vehicles.

Adjusting HAPEM-MS to Reflect Upstream Sources of Toxics

Ideally, our estimate of the carcinogenic effects of toxics would take into account the many sources of toxic emissions associated with the use of motor vehicles:

- releases from oil production fields and petroleum refineries;
- the distribution and marketing of gasoline and diesel;
- combustion of gasoline and diesel fuel in motor vehicles;
- evaporation of gasoline and diesel from vehicles;
- evaporation of gasoline and diesel from service stations;
- materials used in the interior of vehicles;
- fluids, such as oil, used in vehicles; and
- the production of motor vehicles.

However, the HAPEM-MS model (EPA, 1993a) considers only the contribution of fuel combustion and motor vehicle evaporative losses; it does not include the above "upstream" emissions. Consequently, we do not include the cost of upstream motor-vehicle related toxics in our analysis.[17]

11.6.2 Acetaldehyde

Motor vehicles are an important source of acetaldehyde, accounting for roughly 40% of ambient acetaldehyde (Table 11.6-7). Acetaldehyde is a probable

[17]We considered adjusting the estimated number of cancer cases by the ratio of (motor vehicle VOC + upstream VOC)/(motor-vehicle VOC) However, for two reasons, we decided against this upstream VOCs probably comprise different toxic fractions than do motor-vehicle VOCs, and upstream emissions sources probably are not as close to people as our motor-vehicles

human carcinogen (class B2; see Table 11.6-19) with an inhalation unit-risk value of $2.2 \cdot 10^{-6}/\mu g/m^3$.

The epidemiological evidence linking acetaldehyde to cancer in humans is weak. Bittersohl (1974) found an increase in the incidence of all types of cancer, but the sample size was small and the study did not control for smoking and exposure to other chemicals. However, a significant increase in cancer has been found in animals exposed to acetaldehyde. Woutersen et al. (1986) found an increased incidence of nasal and laryngeal tumors in rats, from which we assume that acetaldehyde causes cancers of the oral cavity and pharynx in humans (Tables 11.6-18 and 11.6-20).

11.6.3 Benzene

Motor vehicles contribute evaporative and exhaust benzene emissions, and account for approximately 60% of ambient benzene concentrations (Table 11.6-7).

Benzene is harmful to human health in several ways: 1) it causes leukemia; 2) it can cross the placenta, and thereby affect the health of the fetus; 3) it can disturb menstruation; and 4) it may be associated with aplastic anemia and chromosomal aberrations (IARC, 1982: 116-7, 127; National Research Council, 1985: 53). The young, the old, and other people that have immune systems that are not functioning properly, may be most susceptible to benzene's effects (Round et al., 1989: 11-39). It is not possible to quantify and value all these effects. In this analysis, we assess the increased risk of leukemia from exposure to benzene.

Benzene is a class A human carcinogen. The unit-risk number is $8.3 \cdot 10^{-6}/\mu g/m^3$. Unlike the other unit-risk numbers used in this study, which are based on an upper 95% confidence interval estimate, the unit-risk number for benzene is a maximum likelihood estimate unlike . It is based on epidemiological studies of workers, in rubber manufacturing plants, who suffer from increased nonlymphocytic leukemia, and is supported by an increased incidence of tumors in mice and rats.

11.6.4 1,3-Butadiene

Motor vehicles are responsible for about 55% of the ambient concentration of 1,3-butadiene. A recent study 1,3-butadiene production workers by Ward et al. (1995) found an increased risk or lymph cancer, and there are laboratory studies of mice and rats showing air-borne 1,3-butadiene causes cancer. It is a probable human carcinogen (class B2), with a unit-risk number of $2.8 \cdot 10^{-5}/\mu g/m^3$.

11.6.5 Diesel Particulates (as a cause of lung cancer)

Diesel particulates are dangerous because they absorb toxic, mutagenic and carcinogenic organic molecules that are emitted in the combustion process (National Research Council, 1981: 14). These particulates are less than a micron in diameter and lodge deep in the lung, for up to several hundred days; they may reach other parts of the body through the lymphatic and blood circulatory systems and cause additional damage (National Research Council, 1981: 55; Cuddihy et al., 1984: 17A).

Diesel particulates reportedly increase the incidence of lung cancer (Cuddihy et al., 1984: 18A), stomach cancer (Winkelstein, 1969) and more generalized types of cancer (Mills et al., 1991). For a recent review of diesel emissions and their effects, see *Diesel Exhaust: A Critical Analysis of Emissions, Exposure, and Health Effects* (Health Effects Institute, 1995). We assume diesel particulates cause lung cancer. The unit-risk number, based on a rat study, is $1.7 \cdot 10^{-5}/\mu g/m^3$ (EPA, 1993a: 9-34).

Note that this lung-cancer effect of diesel particulates does not double-count any of the other mortality effects of particulate matter estimated in Chapter 11.3. In Chapter 11.3, we use epidemiological studies to estimate acute respiratory deaths, acute cardiovascular deaths, and chronic cardiopulmonary deaths.

11.6.6 Formaldehyde

Motor vehicles account for roughly 35% of ambient concentrations of formaldehyde. Formaldehyde increases eye irritation and is a probable human carcinogen (class B1). The official EPA unit-risk number is $1.3 \cdot 10^{-5}/\mu g/m^3$; however, an updated, unofficial unit-risk number is 6.0×10^{-7} -- significantly lower than the official estimate. We use the updated unit-risk number.

The unit-risk number is based on the increased formation of squamous cell carcinoma in male rats that have inhaled formaldehyde. There is supporting evidence from epidemiological studies, and laboratory studies on viruses, yeast and other organisms. The epidemiological studies are considered limited primarily because they did not adequately control for exposure to other possible or known carcinogens. Still, these studies do point to an increase in lung and nasopharyngeal cancers. Furthermore, there is a possible link to leukemia and neoplasms in the brain and colon (EPA, 1992c). And, the fact that acetaldehyde, the closest aldehyde to formaldehyde, causes tumors in rats and hamsters further implicates formaldehyde as a carcinogen (EPA, 1992c).

11.6.7 Gasoline Particulates (as a cause of lung cancer)

Currently, there is no official unit-risk estimate for gasoline particulates. The EPA (1993a) relied on the comparative potency method to determine the unit-risk of $5.1 \cdot 10^{-5}$ $\mu g/m^3$ for cars with catalysts and $1.6 \cdot 10^{-5}$ $\mu g/m^3$ for cars without catalysts (Lewtas, 1991). The comparative potency method compares the results from mouse skin tumor initiation assays for carcinogens with known unit-risk numbers (i.e., coke oven emissions, roofing tar emissions and cigarette smoke) and gasoline particulates (Lewtas, 1991). The relative ranking found in the tumor assays is then assumed to apply to the unit-risk estimates. We assume that gasoline particulates cause lung cancer, since cove oven and roofing tar emissions and cigarette smoke are associated with lung cancer.

Whether or not a gasoline-powered car uses a catalytic converter affects the estimated toxicity of its emitted particulates. Consequently, we have separate unit risk estimates for cars with and without catalytic converters. We assume that 3% of gasoline powered vehicles do not use catalytic converters.

Note that this lung-cancer effect of gasoline particulates does not double-count any of the other mortality effects of particulate matter estimated in Chapter

11.3. In Chapter 11.33, we use epidemiological studies to estimate acute respiratory deaths, acute cardiovascular deaths, and chronic cardiopulmonary deaths.

11.6.8 Reporting the results

The cost of all six toxic air pollutants is included in Table 11.7-6, under the "toxics" column, and in Table 11.7-9, in the "toxics" row. (In these tables, gasoline and diesel particulates, as lung-cancer causing "toxic" air pollutants, are included under "toxics" rather than under "PM_{10}"). Toxic air pollutants also are included in all of the tables of the Appendix. In the Appendix tables, formaldehyde, acetaldehyde, benzene, and 1,3-butadiene are listed explicitly as ambient pollutants associated with VOC emissions. Gasoline and diesel particulates are represented by the line for the effect "lung cancer" associated with PM_{10} emissions.

Because we do not estimate the cost of toxic emissions from any source other than motor vehicles, we do not include toxics in the tables that estimate the cost of all anthropogenic air pollution (Tables 11.7-3 and 11.7-4). Also, as mentioned above, we do not actually estimate toxic air emissions from any of the "upstream" sources, such as petroleum refineries, associated with motor-vehicle use (Tables 11.7-6, 11.7-9, and all tables in the Appendix). This omission slightly underestimates the total cost of toxic air pollution attributable to motor-vehicle use.

TABLE 11.6-1. DEMOGRAPHIC GROUPS USED IN HAPEM-MS

Demographic Groups
Children 0 to 5
Children 6 to 13
Children 14 to 18
Workers with a Low Probability of Outdoor Work
Workers with a Moderate Probability of Outdoor Work
Workers with a High Probability of Outdoor Work
Nonworking Adults Under 35
Nonworking Adults 35 to 54
Nonworking Adults 55+

Source Johnson et al. (1992a Table 4)

TABLE 11.6-2. POPULATION OF THE ELEVEN "MODEL" URBAN AND TWO "MODEL" RURAL REGIONS USED TO ESTIMATE THE CANCEROUS EFFECTS OF TOXICS BY YEAR (MILLIONS)

Model MSA[a]	Urbanized Population of Associated Region			
	1988	1989	1990	1991
Boston	14 015	14.135	14.256	14 377
Denver	4.385	4.398	4.411	4 424
Houston	38 188	38 491	38 794	39.097
Los Angeles	27.930	28.700	29 330	30 030
Minn./St. Paul	19.756	19.775	19 794	19 813
New York City	17 168	17 147	17.126	17 105
Philadelphia	12 145	12 104	12 063	12.022
Phoenix	4 713	4.838	4 962	5 086
St Louis	29 059	29.100	29 142	29.183
Spokane	7.547	7.703	7.859	8.015
Washington, DC	14 961	15 169	15.377	15.585
Subtotal Urban	**189.867**	**191.491**	**193.115**	**194.738**
Farmington, NM	21.598	21.529	21 460	21.391
Paducah, KY	34.338	34.237	34 136	34.034
Total U.S.	**245.803**	**247.257**	**248.710**	**250.163**

Source U.S Bureau of the Census (1994).

[a]As discussed in the text, we estimate exposure to toxic air pollutants on the basis of exposure to CO Ideally, we would model CO pollution levels and exposure to CO in every city or county of the U.S We do have data on CO levels by county, but we cannot model exposure to CO in every city or county Instead, we use a "model" (or "representative") MSA to represent a *group* of MSAs that presumably have similar population characteristics For example, the movement of people and the subsequent pattern of CO exposure in Anchorage, Alaska, Portland, Oregon and other MSAs in the northwestern United States is assumed to be the same as that in Spokane, Washington

Because we assume the a population's movement and exposure pattern is the same within a given region represented by a model city, it follows that the difference between the annual average CO exposure in a model MSA and the annual average CO exposure in any other MSA that is represented by the model MSA, is determined using the ratio of the annual average ambient CO concentrations The equations that we are use are given in the text

TABLE 11.6-3. AVERAGE ANNUAL PER CAPITA CO EXPOSURE IN THE ELEVEN MODEL METROPOLITAN STATISTICAL AREAS (MSA) AND TWO MODEL RURAL AREAS USED IN HAPEM-MS (1988)

Model MSA	Per Capita CO Exposure ($\mu g/m^3$) [a]
Boston	972.73
Denver	1,060.61
Houston	633.33
Los Angeles	1,409.09
Minneapolis	1,221.21
New York City	1,269.70
Philadelphia	766.67
Phoenix	951.52
St Louis	606.06
Spokane	1,666.67
Washington D.C.	815 15
Model Rural Area	
Farmington, New Mexico	496.97
Paducah, Kentucky	439.39

[a]These estimates of CO exposure are derived simply by reversing the calculation of Johnson et al. (1992a), who calculated benzene exposure by multiplying estimated CO exposure by 0.0033, which according to work by the American Petroleum Institute (1988) is the median ratio of benzene to CO in the exhaust from 61 late-model automobiles. Johnson et al (1992a) presented the calculated benzene exposures, but not the original detailed estimates of CO exposure with respect to which they calculated benzene exposure Therefore, we simply divided the benzene-exposure estimates by 0.0033 to obtain the original underlying (but not presented) CO-exposure estimates used in Johnson et al (1992a)

We use the 0.0033 benzene/CO ratio only to retrieve to the original detailed CO exposure estimates of Johnson et al (1992a) We develop our own conversion factor to estimate exposure to toxics.

TABLE 11.6-4. GRAM PER MILE EMISSIONS OF CO AND TOXICS

Pollutant	Gram Per Mile Emissions
Acetaldehyde	0 0119
1,3-Butadiene	0 0156
Benzene	0 0882
Carbon Monoxide	29.6
Diesel Particulates	0 0669
Formaldehyde	0 0412
Gasoline Particulates	0 0198

Source EPA (1993a) The gram per mile emission factors are the average of emissions from gasoline and diesel vehicles weighted by the VMT of gasoline and diesel vehicles (EPA, 1993a Chapter 3)

TABLE 11.6-5. CONVERSION BETWEEN PARTS PER BILLION (PPB) AND MICROGRAMS PER METER CUBED ($\mu G/M^3$) FOR ALL POLLUTANTS (EXCEPT PARTICULATES) CONSIDERED IN THIS STUDY[a]

Pollutant	Converting 1 ppb to $\mu g/m^3$
Acetaldehyde (CH_3CHO)	1 ppb = 1.802 $\mu g/m^3$
Benzene (C_6H_6)	1 ppb = 3.194 $\mu g/m^3$
1,3-Butadiene (C_4H_6)	1 ppb = 2.212 $\mu g/m^3$
Carbon Monoxide (CO)	1 ppb = 1 145 $\mu g/m^3$
Formaldehyde (HCHO)	1 ppb = 1.228 $\mu g/m^3$
Nitrogen Dioxide (NO_2)	1 ppb = 1.881 $\mu g/m^3$
Ozone (O_3)	1 ppb = 1.963 $\mu g/m^3$
Sulfur Dioxide (SO_2)	1 ppb = 2.620 $\mu g/m^3$

[a]To make the conversions, we use the ideal gas law (PV = nRT) We assume that P = 1 atmosphere, and T = 298 Kelvin (= 25° Celsius) R = 082058(Liter Atmosphere) / (Kelvin Mole) V = 1000Liters(= $1m^3$)
Note that particulates is a class of compounds that have many different molecular weights; hence, it is not possible to determine parts per billion (ppb)

TABLE 11.6-6. AVERAGE AMBIENT CONCENTRATION OF TOXIC AIR POLLUTANTS AT MONITORING SITES, AND ESTIMATED EXPOSURE TO MOTOR-VEHICLE DERIVED TOXICS

Pollutant and Monitoring Network	Year	Average Ambient Toxic Level at Monitors ($\mu g/m^3$) [a]	EPA Estimate of Exposure to Motor-Vehicle Toxics, based on ambient data ($\mu g/m^3$) [b]	HAPEM-MS Estimate of National Exposure to Motor-Vehicle Toxics, in 1990 ($\mu g/m^3$)
Acetaldehyde [c]				
UATMP	1990	2 93	0.71	0 36
1,3-Butadiene				
AIRS [d]	1988	1 01	0.35	0 48
	1989	0 47	0 16	
	1990	0.22	0.08	
UATMP [e]	1989	0 46	0 16	
	1990	0 32	0.27	
NAVOC	1987	0.81	0.44	
Benzene				
AIRS	1987	6 80	2.52	2 67
	1988	4 06	1 50	
	1989	4 09	1.51	
UATMP	1989	6 01	2.22	
	1990	4.70	1.74	
TAMS	1987-1989	4 18	1.55	
NAVOC	1987	6.83	2.53	
Formaldehyde [c]				
UATMP	1990	5 14	1 05	1 25

Source. EPA (1993a)

AIRS = Aerometric Information Retrieval System, UATMP = Urban Air Toxics Monitoring Program, TAMS = Toxic Air Monitoring System, NAVOC = National Ambient Volatile Organic Carbon Database

[a]The ambient toxics levels for each year are the overall averages of the average ambient level found at each monitoring site

The EPA (1993a Appendix C) reported the observation in parts per billion (ppb) We convert from ppb to $\mu g/m^3$ using the factors in Table 11.6-5. Note that the conversion factor for benzene (1 ppb = 3 25 $\mu g/m^3$ at 25 ° C) reported by the EPA (1993a Table 5-1) is incorrect, the correct figure is 1 ppb = 3.194 $\mu g/m^3$ at 25 ° C

The EPA (1993a) unintentionally used two procedures to estimate the average toxics levels The EPA used the overall average of the averages from all sites in the AIRS and TAMS data and

unintentionally used the average of all observations from all sites for the UATMP and NAVOC data We report the overall average for all sites, as this appears to have been EPA's intention EPA (1993a 5-28) reported using the "overall average of the averages for each site" when considering the UATMP data, yet in EPA (1993a Appendix C-8) all observations from all sties were averaged together.

[b]The EPA (1993a) adjusts the ambient data to account for the percentage of emissions directly attributable to motor vehicles, and the percentage of each day that people spend in the microenvironments The percentage of ambient toxics levels attributable to motor vehicles is reported in Table 11.6-7, and the "integrated exposure adjustment constant" is 0.622 See the text for further discussion

[c]We report only the 1990 UATMP data because only it accounts for the scavenging of formaldehyde and acetaldehyde by ozone (EPA, 1993a 6-19, 8-15), which biases down the estimated formaldehyde and acetaldehyde levels

[d]We excluded samples collected from Houston because the EPA (1993a 7-14) reported that the monitor was close to a point source(s) of 1,3-Butadiene, and thus unrepresentative of typical exposure in Houston

[e]We exclude samples collected from Port Neches, Texas because the EPA (1993a 7-17) reported that the monitor was close to a point source(s) of 1,3-Butadiene, and thus unrepresentative of typical exposure in Port Neches, Texas

TABLE 11.6-7. THE ESTIMATED PERCENTAGE OF TOXICS EMISSIONS ATTRIBUTABLE TO MOTOR VEHICLES

Toxic Pollutant	EPA (1993a)	Ligocki (1993)
Acetaldehyde	39 [a]	42 [e]
Benzene	59.5 [b]	
1,3-Butadiene	55.5 [c]	
Formaldehyde	33 [d]	37.5 [e]

[a]The EPA (1993a 8-15) based its estimate of the contribution of motor vehicles to ambient acetaldehyde on a study by Ligocki and Whitten (1991 Table 3-2), who estimated emissions of ALD2 (acetaldehydes and other aldehydes) for a weekday in the Summer of 1990 in St Louis However, the EPA's (1993a) estimate is weak for several reasons

Acetaldehyde and other aldehydes are considered together, which may significantly overestimate the contribution of primary emissions of acetaldehyde to ambient acetaldehyde levels; a later study by Ligocki (1993) found that primary emissions of acetaldehyde account for between only 2% and 13% of ambient acetaldehyde in Baltimore (Table 11 6-8 here)

On the other hand, Ligocki and Whitten (1991) did not account for the secondary formation of ALD2 attributable to motor vehicles As it turns out, Ligocki (1993) reports that the secondary formation of acetaldehyde from motor vehicles is very important -- contributing 30% to overall ambient acetaldehyde levels in Baltimore and Washington D C in 1988

The EPA (1993a) estimate does not account for the contribution of upstream emissions, such as from refineries and gas stations, the contribution from these upstream sources is unknown

Finally, the EPA (1993a) extrapolates the results from one city (St Louis) to all of the U.S There are probably significant differences across the U.S , making it impossible to know what the true average should be

[b]EPA (1993a· 5-8) estimated that 85% of all benzene emissions are attributable to mobile sources, and that on-road vehicles account for 70% of mobile source emissions (59.5% of total emissions).

[c]EPA (1993a 7-4) estimated that mobile sources account for 94% of all 1,3-Butadiene emissions, and that on-road mobile sources account for 59% of mobile source emissions (55.5% of total emissions)

[d]EPA (1993a 6-21) cited a variety of studies in deriving this estimate EPA concluded that 30% of ambient formaldehyde is due to primary emissions, and that 70% is formed in secondary reactions It assumes that motor vehicles contribute 28% of primary formaldehyde (8 4% of the total), and 35% of secondary formaldehyde (24.5% of the total)

$$\%\text{Formaldehyde}_{\text{motor vehicles}} = (0.28\ \ 0.30 + 0\ 35\ \ 0\ 70)\ \ 100\% = 33\%$$

[e]The estimated mobile source contributions to ambient formaldehyde and acetaldehyde equal the average of the summer and winter contributions to simulated formaldehyde and acetaldehyde concentrations reported in Table 11 6-8, below

TABLE 11.6-8. PERCENTAGE OF PRIMARY/SECONDARY AND MOTOR VEHICLE/NON-MOTOR VEHICLE CONTRIBUTIONS TO SIMULATED FORMALDEHYDE AND ACETALDEHYDE CONCENTRATIONS IN BALTIMORE/WASHINGTON IN 1988

Pollutant And Source	Summer	Winter
Formaldehyde		
Motor Vehicle -Primary Emissions	7	30
Motor Vehicle -Secondary Emissions	28	10
Motor Vehicle - TOTAL	35	40
Non-Motor Vehicle - Primary Emissions	13	40
Non-Motor Vehicle - Secondary Emissions	52	20
Non-Motor Vehicle TOTAL	65	60
Acetaldehyde		
Motor Vehicle -Primary Emissions	2	13
Motor Vehicle - Secondary Emissions	30	29
Motor Vehicle - TOTAL	32	52
Non-Motor Vehicle - Primary Emissions	3	17
Non-Motor Vehicle - Secondary Emissions	65	31
Non-Motor Vehicle - TOTAL	68	48

Source Ligocki (1993), written personal communication with Donald R McCubbin.

TABLE 11.6-9. FIVE MICROENVIRONMENTS USED IN HAPEM-MS AND CO CONCENTRATION AS A FRACTION OF AMBIENT CO READINGS AT FIXED-SITE MONITORS

Microenvironment	Fraction of Fixed-Site Monitor
Indoors - Residence	0 495
Indoors - Other Location	0 619
Outdoors - Near Road	1 001
Outdoors - Other Locations	0.758
Inside Motor Vehicle[a]	1.554

Source Johnson et al. (1992a Table 6)

[a]The figure for inside motor vehicles is relatively low. Flachsbart et al (1987: Tables 5 and 6) found the ratio between in-vehicle ambient CO to be over four in some cases, depending upon the time and the speed of travel. We rely on the results of EPA (1993a) and can not use a higher figure for the present analysis

TABLE 11.6-10. COMPARING THE ADJUSTED AMBIENT ACETALDEHYDE MEASUREMENTS WITH THE HAPEM-MS ESTIMATE OF ACETALDEHYDE EXPOSURE

Region[a]	Metropolitan Statistical Area	Adjusted Ambient (ppb)[b]	HAPEM-MS (ppb)[c]
4	Chicago	0 47	0 14
9	Washington D C.	0.57	0.18
10	Houston	0.16	0.14
	Baton Rouge	0 45	0 11
	Pensacola	0 19	0 15
11	Wichita	0 43	0 16

Source. Johnson et al. (1992a) and EPA (1993a).

[a]Following the EPA (1993a), we divide metropolitan statistical areas (MSAs) into regions on the basis of geography and to a lesser extent industrial activity and use of transportation All MSAs in a region are assumed to have activity patterns identical to those of the "model" MSA of the region

[b]This estimate is based on the average of all annual averages (weighted by the number of observations in each average) for data from AIRS, UATMP and NAVOC We have adjusted the ambient data to account for the proportion of time that people spend in each microenvironment, using a different adjustment factor for each of the eleven urban regions in the U.S (Table 11.6-14)

[c]This is the average annual exposure to motor-vehicle derived acetaldehyde in 1988 estimated by HAPEM-MS.

TABLE 11.6-11. COMPARING THE ADJUSTED AMBIENT 1,3-BUTADIENE MEASUREMENTS WITH THE HAPEM-MS ESTIMATE OF 1,3-BUTADIENE EXPOSURE

Region[a]	Metropolitan Statistical Area	Adjusted Ambient (ppb)[b]	HAPEM-MS (ppb)[c]
3	Bakersfield	0.11	0.19
	San Jose	0 10	0.24
	Stockton	0.11	0 16
4	Chicago	0 05	0 15
5	Burlington	0.16	0 21
9	Washington D.C.	0.06	0 19
10	Houston	0.20	0.15
	Baton Rouge	0 13	0 12
	Dallas	0.03	0 11
	Fort Lauderdale	0.07	0.16
	Miami	0.04	0 21
	Pensacola	0 02	0.16
11	St Louis	0 03	0 14
	Detroit	0.06	0 12
	Louisville	0 14	0.25
	Wichita	0.03	0.17

Source Johnson et al (1992a) and EPA (1993a)

[a]Following the EPA (1993a), we divide metropolitan statistical areas (MSAs) into regions on the basis of geography and to a lesser extent industrial activity and use of transportation All MSAs in a region are assumed to have activity patterns identical to those of the "model" MSA of the region

[b]This estimate is based on the average of all annual averages (weighted by the number of observations in each average) for data from AIRS, UATMP and NAVOC We have adjusted the ambient data to account for the proportion of time that people spend in each microenvironment, using a different adjustment factor for each of the eleven urban regions in the U.S (Table 11.6-14)

[c]This is the average annual exposure to 1,3-butadiene in 1988 estimated by HAPEM-MS

TABLE 11.6-12. COMPARING THE ADJUSTED AMBIENT BENZENE MEASUREMENTS WITH THE HAPEM-MS ESTIMATE OF BENZENE EXPOSURE

Region[a]	Metropolitan Statistical Area	Adjusted Ambient (ppb)[b]	HAPEM-MS (ppb)[c]
1	Tacoma	0 49	1.29
2	New York	0 31	1.18
3	Los Angeles	1.35	1.31
	Bakersfield	0.83	0.75
	Fresno	1 44	0.72
	Merced	0.53	0.75
	Modesto	0 56	0.70
	Oakland	0 72	0.79
	Oxnard	0 81	0.70
	Riverside	1 09	0.99
	Sacramento	0.79	0.97
	San Diego	0.71	1.01
	San Francisco	0.54	1.17
	San Jose	0.83	0 95
	Santa Barbara	1.18	0.50
	Santa Rosa	0.82	0 93
	Stockton	0.77	0.62
	Vallejo	0 90	0 85
4	Cleveland	0.84	0 99
	Chicago	0 60	0 59
5	Boston	0 40	0 91
	Burlington	0 40	0 82
	Lowell	0.35	0.91
8	Philadelphia	0 95	0.72
9	Washington D.C.	0 67	0.77
10	Houston	0.66	0.59
	Atlanta	0 34	0.50
	Baton Rouge	0 76	0 48
	Birmingham	0.71	0.83
	Dallas	0 29	0 43
	Fort Lauderdale	0 66	0.61
	Jacksonville	0 25	0 68
	Miami	0 43	0 81
	Pensacola	0 42	0.63
11	St Louis	1 47	0.57
	Detroit	0.63	0 47
	Lansing/East Lansing	0.21	0 66
	Louisville	0.55	0 97
	Wichita	0 37	0 67

Source: Johnson et al (1992a) and EPA (1993a)

[a]Following the EPA (1993a), we divide metropolitan statistical areas (MSAs) into regions on the basis of geography and to a lesser extent industrial activity and use of transportation. All MSAs in a region are assumed to have activity patterns identical to those of the "model" MSA of the region

[b]This estimate is based on the average of all annual averages (weighted by the number of observations in each average) for data from AIRS, UATMP and NAVOC. (The TAMS data was excluded because it did not report the number of observations in a yearly average. The TAMS data set is small it has benzene observations for four cities and formaldehyde observations for two cities. We have observations for all of these cities in the other three data sets.) We have adjusted the ambient data to account for the proportion of time that people spend in each microenvironment, using a different adjustment factor for each of the eleven urban regions in the U.S (Table 11.6-14)

[c]This is the average annual exposure to benzene in 1988 estimated by HAPEM-MS

TABLE 11.6-13. COMPARING THE ADJUSTED AMBIENT FORMALDEHYDE MEASUREMENTS WITH THE HAPEM-MS ESTIMATE OF FORMALDEHYDE EXPOSURE

Region [a]	Metropolitan Statistical Area	Adjusted Ambient (ppb) [b]	HAPEM-MS (ppb) [c]
4	Chicago	0.93	0.72
9	Washington D.C	1.47	0.92
10	Houston	0.29	0 72
	Baton Rouge	1 00	0.58
	Pensacola	0.50	0.77
11	Wichita	0.92	0 81

Source Johnson et al (1992a) and EPA (1993a)

[a]Following the EPA (1993a), we divide metropolitan statistical areas (MSAs) into regions on the basis of geography and to a lesser extent industrial activity and use of transportation All MSAs in a region are assumed to have activity patterns identical to those of the "model" MSA of the region.

[b]This estimate is based on the average of all annual averages (weighted by the number of observations in each average) for data from AIRS, UATMP and NAVOC (The TAMS data was excluded because it did not report the number of observations in a yearly average The TAMS data set is small it has benzene observations for four cities, and formaldehyde observations for two cities We have observations for all of these cities in the other three data sets.) We have adjusted the ambient data to account for the proportion of time that people spend in each microenvironment, using a different adjustment factor for each of the eleven urban regions in the U.S (Table 11.6-14)

[c]This is the average annual exposure to formaldehyde in 1988 estimated by HAPEM-MS

TABLE 11.6-14. URBAN REGIONAL EXPOSURE ADJUSTMENT FACTORS

Model Area	HAPEM-MS Average CO Exposure (ppm)[a]	Average Annual Ambient CO Level (ppm)[b]	Regional Exposure Adjustment Factor[c]
Boston	0.85	1.36	0.63
Denver	0 93	1.35	0.69
Houston	0 55	0 91	0.60
Los Angeles	1.23	1 79	0.69
Minn /St. Paul	1.07	1 79	0 60
New York	1 11	2 44	0 45
Philadelphia	0.67	1.09	0.61
Phoenix	0 83	1.28	0.65
St. Louis	0 53	0 90	0.59
Spokane	1 46	2 50	0.58
Washington D C	0 71	1.02	0 70

[a]We convert the per capita CO exposure levels ($\mu g/m^3$) in Table 11.6-5 to ppm using the conversion factor of 1 ppm = 1145 $\mu g/m^3$

[b]Source Johnson et al (1992a Table B1)

[c]The regional exposure adjustment factor equals the HAPEM-MS average CO exposure divided by the actual annual ambient CO level (i e., column 1 divided by column 2)

TABLE 11.6-15. COMPARISON OF THE CO EXPOSURE ESTIMATES OF HAPEM-MS WITH EPA'S ADJUSTED AMBIENT EXPOSURE ESTIMATES, BY MODEL CITY

Model Area	HAPEM-MS Average CO Exposure (ppm)[a]	Average Annual Ambient CO Level, Adjusted for Micro-Environmental Exposure (ppm)[b]	Percent Difference
Boston	0.85	0.85	0 4 %
Denver	0.93	0.84	9.3
Houston	0.55	0.57	-2 4
Los Angeles	1.23	1.11	9.5
Mınn /St Paul	1 07	1 11	-4.4
New York	1 11	1.52	-36 9
Phıladelphıa	0 67	0.68	-1.3
Phoenıx	0.83	0 80	4 2
St Louıs	0.53	0.56	-5 8
Spokane	1 46	1.56	-6 9
Washıngton D C	0.71	0.63	10 9

[a]We convert the per capita CO exposure levels ($\mu g/m^3$) ın Table 11.6-5 to ppm usıng the conversıon factor of 1 ppm = 1145 $\mu g/m^3$.

[b]The adjusted average annual CO concentratıon ıs equal to the average annual CO level reported ın Johnson et al (1992a Table B1) multıplıed by 0 622, the EPA's (1993a) ıntegrated exposure constant (see text) We do not adjust for the contrıbutıon of motor vehıcles to CO exposure because the EPA's HAPEM-MS results dıd not account for the contrıbutıon of motor vehıcles to CO exposure

TABLE 11.6-16. RESULTS FROM REGRESSING THE AMBIENT-BASED ESTIMATE OF TOXICS EXPOSURE ON THE HAPEM-MS ESTIMATE[a]

Pollutant	Coefficient	t-Statistic	Lower 95%	Upper 95%
Benzene	0.81	11 7	0 67	0.95
Formaldehyde	1.14	5 6	0.61	1 66
Acetaldehyde	2.53	5.9	1.43	3.64
1,3-Butadiene	0 48	6.5	0.33	0.64

[a]We use the data from Tables 6-10 through 6-13 to run the regressions Note that we constrain the intercept to pass through zero The coefficient should be interpreted as the factor with which to multiply the HAPEM-MS estimates of toxic exposure so that they conform with the estimates of toxic exposure determined from our observations of ambient toxics levels

TABLE 11.6-17. FIFTY YEAR LATENCY PERIOD -- PERCENTAGE OF CANCER CASES ATTRIBUTABLE TO EACH YEAR[a]

Year s After Exposure to Carcinogen	Percentage of Total Number of Cancer Cases Each Year
1	0 1
2	0.1
3	0.2
4	0 2
5	0.3
6	0 4
7	0.5
8	0.6
9	0.7
10	0.9
11	1 1
12	1 3
13	1 5
14	1.8
15	2 1
16	2 4
17	2.7
18	3.0
19	3.3
20	3.6
21	4.0
22	4.3
23	4.7
24	5 0
25	5.2

a We assume that the cancer cases that we estimate will occur, will appear between 1 and 50 years after exposure, with a probability of one. The last half of this period is symmetrical with the first, so we only give the probability for each year in the first twenty-five years

TABLE 11.6-18. UNIT-RISK NUMBERS FOR TOXICS RELEASED FROM THE COMBUSTION OF GASOLINE AND DIESEL FUELS

Pollutant	Unit Risk [a]	Study Type	Cancer Found	Classification [b]
Acetaldehyde[c]	2.2×10^{-6}	rats, hamsters	nasal, nasal, trachea	B2
Benzene[d]	8.3×10^{-6}	humans	leukemia	A
1,3-Butadiene[e]	2.8×10^{-5}	mouse, rat	multiple tumors	B2
Diesel Particulates[f]	1.7×10^{-5}	rat	lung	B1
Formaldehyde[g]	1.3×10^{-5} (6.0×10^{-7})	rats, humans	squamous cell carcinoma, lung, buccal, nasopharyngeal	B1
Gasoline Particulates[h]	5.1×10^{-5} (1.6×10^{-5})	comparative potency	lung	[i]

[a]Unit Risk = Cancer Rate/70 ppm*years/one individual/µg/m3

[b]Carcinogenic classifications are described in Table 11.6-19

[c]The EPA (1993a 8-25) used an upper 95% confidence interval estimate, meaning that there is only a 5% chance the "true" unit risk is greater than this, they did not report a maximum likelihood estimate (MLE)

[d]The benzene unit risk estimate is a MLE (EPA, 1993a 5-39)

[e]We use the MLE for 1,3-Butadiene The 95% confidence interval estimate is an order of magnitude higher (2.8×10^{-4}) (EPA, 1993a 7-27).

[f]This is a 95% confidence interval estimate The EPA (1993a 9-34) did not report a MLE

[g]The formaldehyde unit risk number is under review, the updated (but unofficial) unit risk number is in parenthesis It is substantially lower than the official unit risk number The uncertainty in the estimated unit-risk for formaldehyde is caused, in large part, by a highly nonlinear relationship between dose and response a 2.5-fold increase in the dose of formaldehyde caused a fifty-fold increase in the number of tumors (EPA, 1993a 6-30) We use the unofficial (lower) unit-risk number

[h]The unit risk number for gasoline particulates applies to vehicles with a catalytic converter, the number in parentheses applies to vehicles without catalytic converters (EPA, 1993a 10-5) This is a 95% confidence interval estimate. The EPA did not report a MLE for gasoline particulates

[i]Gasoline particulates do not have a classification

TABLE 11.6-19. U.S. ENVIRONMENTAL PROTECTION AGENCY CANCER CLASSIFICATION SYSTEM

Classification	Description
A	Human carcinogen, with sufficient evidence from epidemiological studies
B1	Probable human carcinogen, with limited evidence from epidemiological studies
B2	Probable human carcinogen, with sufficient evidence from animal studies and inadequate evidence or no data from epidemiological studies
C	Possible human carcinogen, with limited evidence from animal studies in the absence of human data
D	Not classifiable as to human carcinogenicity, owing to inadequate human and animal evidence
E	Evidence of noncarcinogenicity for humans, with no evidence of carcinogenicity in at least two adequate animal tests in different species, or in both adequate animal and epidemiological studies

Source Cohrssen and Covello (1989 pp 49-50).

TABLE 11.6-20. TYPE OF CANCER ASSOCIATED WITH TOXICS RELEASED FROM THE COMBUSTION OF GASOLINE AND DIESEL FUELS BY MOTOR VEHICLES IN FUTURE YEARS

Pollutant	Cancer Type[a]
Acetaldehyde	Oral Cavity and Pharynx
Benzene	Leukemia
1,3-Butadiene	All Sites
Diesel Particulates	Lung
Formaldehyde	Oral Cavity and Pharynx
Gasoline Particulates	Lung

[a]The type of cancer depends on the studies on which the unit risk estimates are based

TABLE 11.6-21. TRENDS IN THE FIVE-YEAR RECOVERY RATE FOR CANCERS CAUSED BY TOXICS ASSOCIATED WITH MOTOR VEHICLES (WHITES)[a]

Cancer Type	1960-63	1970-73	1974-76	1977-80	1981-87
All Sites	39	43	50	51	53
Lung and Bronchus	8	10	12	13	13
Leukemia	14	22	34	36	36
Oral Cavity and Pharynx	45	43	55	54	54

Source: American Cancer Society (1992)

[a]The five-year recovery rate is the percentage of people that are still alive five years after diagnosis, taking into account normal life expectancy (e g , correcting for factors such as heart disease, accidents and diseases of old age)

TABLE 11.6-22. TRENDS IN THE FIVE-YEAR RECOVERY RATE FOR CANCERS CAUSED BY TOXICS ASSOCIATED WITH MOTOR VEHICLES (AFRICAN-AMERICANS)[a]

Cancer Type	1960-63	1970-73	1974-76	1977-80	1981-87
All Sites [b]	27	31	39	39	38
Lung and Bronchus	5	7	11	12	11
Leukemia	--	--	31	30	29
Oral Cavity and Pharynx	--	--	35	34	31

Source American Cancer Society (1992)

[a] The five-year recovery rate is the percentage of people that are still alive five years after diagnosis, taking into account normal life expectancy (e.g , correcting for factors such as heart disease, accidents and diseases of old age)

[b] The five-year survival rate for all cancer sites is lower for African-Americans (38%) than for whites (53%) In part this is due to later diagnosis Also African-Americans have a 7% higher incidence of cancer

TABLE 11.6-23. FIVE-YEAR CANCER RECOVERY RATE ASSOCIATED WITH TOXICS RELEASED FROM THE COMBUSTION OF GASOLINE AND DIESEL FUELS BY MOTOR VEHICLES, AFRICAN-AMERICANS AND WHITES (1988-1992)[a]

Cancer	1988	1989	1990	1991	1992
All Sites	49	49	50	50	51
Lung and Bronchus	13	13	13	13	13
Leukemia	33	33	34	35	35
Oral Cavity and Pharynx	51	51	52	52	51

Source American Cancer Society (various years)

[a]The five-year recovery rate is the percentage of people that are still alive five years after diagnosis, taking into account normal life expectancy (e.g., correcting for factors such as heart disease, accidents and diseases of old age)

TABLE 11.6-24. ESTIMATED FIVE-YEAR RECOVERY RATE OF CANCERS ASSOCIATED WITH TOXICS RELEASED FROM THE COMBUSTION OF GASOLINE AND DIESEL FUELS BY MOTOR VEHICLES IN FUTURE YEARS[a]

Cancer	2000 [b]	2010	2020	2030	2040
All Sites	56	63	69	76	82
Lung and Bronchus	16	18	21	23	26
Leukemia	43	53	63	73	83
Oral Cavity and Pharynx	54	57	61	65	68

[a]The five-year recovery rate is the percentage of people that are still alive five years after diagnosis, taking into account normal life expectancy (e g., correcting for factors such as heart disease, accidents and diseases of old age)

[b]To estimate recovery rates in future years, we regressed (linear OLS) the recovery rates on time We use the recovery rates in Tables 6-21 and 6-22, weighted by population (12% African-Americans) and the fact that the cancer incidence is 7% higher for African-Americans than whites, we assume other minorities have incidence and recovery rates the same as whites The estimated coefficients (and r-squared in parentheses) in the linear regression are: all sites = 0.65 (0.91), lung and bronchus = 0 25, leukemia = 1.01 (0.88), and oral cavity and pharynx = 0.36 (0.59)

Note that the data of Tables 11.6-21, 11.6-22, and 11.6-23 suggest that the recovery rate has leveled off in recent years If so, and if this leveling off actually continues, then our linear extrapolation (via regression) overestimates recovery rates in the outer years, and hence underestimates costs To check this, we re-estimated leukemia and lung-cancer costs assuming that recovery rates remain at their 1990 levels. The cost of each toxic increased by less than 20%, and the total social cost of air pollution changed by less than 0.01%

11.7 RESULTS

Most of the results that we present are based on a 10% reduction in motor vehicle emissions. However, for points of reference, we also estimate the health effects associated with a 100% reduction in motor vehicle emissions and a 100% reduction in all anthropogenic emissions. We focus on a 10% reduction because pollution formation and the associated health effects are the products of nonlinear functions, and we feel that it is more useful for policy makers to consider the effect of a relatively small reduction in emissions. As it turns out, the relationship between emissions and health effects is reasonably linear, and we mostly present the effects of a 10% reduction in emissions.

The results are presented in a number of ways. We estimate the human-health cost in the entire U.S., in urban areas of the U.S., in rural areas of the U.S., and in 11 major metropolitan statistical areas (MSAs): Boston, Denver, Houston, Los Angeles, Minneapolis, New York, Philadelphia, Phoenix, St. Louis, Spokane, and Washington D. C. We estimate the total dollar costs, dollar costs per vehicle-mile of travel, and dollar costs per kg of pollutant emitted. We also estimate costs due to direct emissions from motor vehicles, emissions of road-dust particulate matter, and emissions from "upstream" fuelcycle processes.

Table 11.7-1 presents "background" statistics for the MSAs: population, vehicle miles traveled (VMT), and the annual average pollution level; it also gives population and VMT for urban and rural areas and for the nation.

Table 11.7-2 summarizes the assumptions that we use in the lower and upper bounds. These tables are especially important because they help to explain the difference between the lower-bound cost and the upper-bound cost estimates; further differences between the lower and upper bound are described in Report #16 in the social-cost series listed at the beginning of this report.

Tables 11.7-3 and 11.7-4 presents national estimates of the number of cases of adverse health and their economic cost caused by all anthropogenic pollution between 1988 and 1991.

Tables 11.4-5 and 11.4-6 give the gram-per-mile emission estimates and the cost per VMT by vehicle class and pollutant, based on a 10% reduction in motor vehicle emissions.

Table 11.7-7 gives the cost per kilogram of emission by pollutant, emissions source and geographic region, again based on a 10% reduction in motor vehicle emissions. This table is useful because it allows one to calculate the cost of emissions from sources other than motor vehicles, such as petroleum refineries, or from motor-vehicles that have emission rates different from the national-average rates used in this study (for example, future low-emitting gasoline vehicles, or alternative-fuel vehicles). A nice feature of the $/kg estimates is that, unlike the total $ or $/VMT estimates, they are not affected by the uncertainty in the emissions inventory, because they are expressed per kilogram emitted. (They are, however, affected by uncertainty in the estimates of the exposure factors.) Furthermore, using the population figures in Table 11.7-1, one can use the fact that damages are

proportional to the number of people and calculate $/kg/person. We discuss this table more below.

Finally, in the Appendix, Tables 11.A-1 through 11.A-4 give the lower and upper-bound benefit estimates of a 100% reduction of motor vehicle emissions, in dollars per one thousand VMT, for urban areas, and the nation as a whole. Tables 11.A-5 through 11.A-60 give the lower and upper-bound benefit estimates of a 10% reduction of motor vehicle emissions, in millions of dollars and in dollars per one thousand VMT, for eleven metropolitan areas, urban areas, rural areas, and the nation as a whole. In each of these tables, we show costs by pollutant, by vehicle class, and by emissions source. The 60 tables are arranged as follows:

	Millions of dollars		**Dollars/1000 VMT**	
Region	*Lower bound*	*Upper bound*	*Lower bound*	*Upper bound*
100% emission reduction				
All United States	Table 11.A-1	Table 11.A-2		
All urban areas	Table 11.A-3	Table 11.A-4		
10% emission reduction				
All United States	Table 11.A-5	Table 11.A-6	Table 11.A-33	Table 11.A-34
All urban areas	Table 11.A-7	Table 11.A-8	Table 11.A-35	Table 11.A-36
All rural areas	Table 11.A-9	Table 11.A-10	Table 11.A-37	Table 11.A-38
Boston	Table 11.A-11	Table 11.A-12	Table 11.A-39	Table 11.A-40
Denver	Table 11.A-13	Table 11.A-14	Table 11.A-41	Table 11.A-42
Houston	Table 11.A-15	Table 11.A-16	Table 11.A-43	Table 11.A-44
Los Angeles	Table 11.A-17	Table 11.A-18	Table 11.A-45	Table 11.A-46
Minneapolis	Table 11.A-19	Table 11.A-20	Table 11.A-47	Table 11.A-48
New York	Table 11.A-21	Table 11.A-22	Table 11.A-49	Table 11.A-50
Philadelphia	Table 11.A-23	Table 11.A-24	Table 11.A-51	Table 11.A-52
Phoenix	Table 11.A-25	Table 11.A-26	Table 11.A-53	Table 11.A-54
St. Louis	Table 11.A-27	Table 11.A-28	Table 11.A-55	Table 11.A-56
Spokane	Table 11.A-29	Table 11.A-30	Table 11.A-57	Table 11.A-58
Washington D. C.	Table 11.A-31	Table 11.A-32	Table 11.A-59	Table 11.A-60

11.7.1 Discussion of results

Our summary tables, we hope, are self explanatory. Rather than simply review the results, we emphasize five points.

I). Our upper-bound estimate of the health cost of motor-vehicle air pollution is enormous: $450 billion dollars annually in the U.S. (Table 11.A-2). However, we are uneasy with this result, even as an upper bound.

Virtually all of the upper-bound cost -- 96% of it -- is damage from particulate air pollution. Most of the damage from particulates is mortality and chronic illness. In the upper bound, mortality from particulate air pollution accounts for 69% of total damages from all the pollutants -- $312 billion annually. Of this $312 billion, about $235 billion are due to long-term or "chronic" deaths, as opposed to short-term or "acute" deaths.

In our upper bound, we use a recent prospective cohort study by Pope et al. (1995a; see our Chapter 11.4 here). However, as shown in Table 11.7-8 and mentioned in Chapter 11.4, the Pope et al. study estimates many more chronic deaths than does our lower-bound study, by Ozkaynak and Thurston (O&T) (1987). (Recall from Chapter 11.4, and see below, that chronic deaths are equal to total estimated deaths less acute non-harvest deaths). As shown in Table 11.7-8, had we used our lower-bound estimate of the change in the long-term mortality rate per change in particulate pollution, with all of our other upper-bound assumptions, our upper bound estimate of damages from particulate-related mortality would have been almost 50% ($234 billion) lower (line 15A versus 15B). This dramatic dependency of the total damages on a single study is unsettling. One certainly could argue that the Pope et al. study gives implausibly large results, even as an upper bound, and should not be used pending corroboration.

We distinguish between "acute harvest" deaths (deaths that occur immediately after exposure to air pollution and would have occurred very soon anyway even if there had been no particulate air pollution) and "acute non-harvest" deaths (immediate deaths that would not have occurred soon had there been no particulate pollution) because we value the former much less than the latter (see Chapter 11.4). We distinguish between acute non-harvest deaths and "chronic" (greatly delayed) deaths because the latter occur in the future and so have a lower present value than (although the same nominal value as) the former. We assume that the number of chronic deaths is equal to the total number of cross-sectional deaths (Pope et al., 1995a, or O&T, 1987) less the amount of acute non harvest deaths.

II). The difference between our lower and our upper-bound estimates of particulates is considerable -- typically a factor of ten to twenty. This is the product of three factors: the estimated number of health effects, the value attached to the health effects, and (when comparing the lower and upper bounds for motor vehicles) the share of the damages attributable to motor vehicles. There is more uncertainty when considering motor vehicles' damages than when examining the damages of all particulates because the share of damages attributable to motor vehicles is uncertain. When considering the mortality damages of motor vehicle particulates (Table 11.7-8, lines 16A and 16B), we see the lower and upper bounds differ by a factor of almost 19. The reason for this large difference is roughly as

follows: the number of deaths differs by a factor of a little over two, the value of deaths by a factor of four to seven, and the share of motor vehicles by about 1.4.[1]

Chronic illness contributes $115.4 billion in our upper bound case, while in the lower bound it contributes only $4.4 billion. This (factor of 26.2!) uncertainty has three sources: 1) the estimated number of health effects differs by roughly a factor of about 2.4 between the lower and upper bounds; 2) the value attached to the health effects differs by a factor of 7.4; and 3) the share of the damages attributable to motor vehicles by a factor of about 1.5. This great uncertainty, while unsettling, simply reflects the current lack of knowledge about quantifying the link between air pollution and chronic illness.

III). Ozone is the least damaging pollutant emitted directly from motor vehicles -- less damaging even than CO and NO_X. Even in Los Angeles, the lower-bound ozone damages from motor-vehicles (see Table 11.7-9) amount to only a few dollars per person per year -- an evidently trivial amount. In the upper-bound case, damages from ozone are much higher than in the lower bound case, but still far less than PM damages from any source, including again the heretofore overlooked road dust[2]. We may conclude then, that unless ozone causes mortality (which most researchers apparently doubt) or is associated with chronic illness (which seems a more likely possibility), the dollar health damages from ozone are minor except during the most polluted times in the most polluted places.

IV). Note that the $ and $/VMT results apply to the per-mile emission levels of circa 1990. The Clean Air Act Amendments of 1990 mandated significant reductions in emissions from many sources, and as a result, vehicles and upstream emissions sources in the future will emit less per mile of travel and have a lower $/VMT cost than they did in 1990. To estimate the $/VMT cost of future, cleaner vehicles and upstream emissions sources, multiply the pertinent $/kg factors of Table 11.7-7 by the associated estimated future kg/mi emission rates.

The $/kg factors of Table 11.7-7 are independent of the kg/mi emission rate, and so can be applied to any future emission rate. They are, however, proportional to the *exposed* population: if you expect the exposed population to increase by 10% over 1990 levels, then you should increase the pertinent $/kg values by 10%.

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[1]Table 11 7-13 suggests that difference between the motor vehicle share (including road dust and upstream sources) in the lower and upper bounds differs by a factor of 1 4 Indeed, the average motor vehicle share for the nation differs by a factor of 1 4 (In the lower bound the average share is 20% and in the upper bound it is 28%)

[2]We point out that this perhaps surprising prominence of road dust over ozone most definitely is not due to us having made liberal assumptions regarding road-dust damages and conservative assumptions regarding ozone damages To the contrary, we have made a number of adjustments that significantly reduce the impact of road-dust. we have reduced the EPA's official estimate of road-dust emissions, we have assumed that road-dust particles are significantly less potent than are other particles, and we have down-weighted the impact of particles greater than 2.5 microns in diameter, which most road-dust particles are

Similarly, the $/kg estimates are proportional to the assumed value of health effects. The $/kg estimates also depend somewhat on the total change in pollution or emissions being considered, because some health effects are non-linearly related to pollution levels. However, the dependency is not strong: most of the major costs either vary linearly with pollution levels (in which case the $/kg cost is independent of the pollution level), or else nearly linearly.

The $/kg factors for different emissions sources (e.g., road dust versus motor-vehicle tailpipes) incorporate differences in the size of the population exposed, the ratio of effective exposure to emissions, the potency of particles by size class, and the potency of particles by composition. Thus, we see in Table 11.7-7 that the $/kg cost of particulate emissions directly from motor vehicles vastly exceeds the $/kg cost of particulates from road dust, because motor vehicle PM is more potent than is road-dust PM, and because more people are exposed to motor-vehicle PM than to road-dust PM.

V). A comparison of Tables 11.7-4, 11.7-9 and 11.7.10 reveals that, in the Los Angeles MSA, motor vehicles contribute 59% percent of anthropogenic damages in the lower bound and a rather high 86% in the upper bound. The national average is somewhat lower: 42% in the lower bound and 64% in the upper bound. These are surprisingly high figures, and are explained by the relative proximity of motor vehicles to people, particularly in urban areas, and the uncertainty regarding the emissions and potency of road dust.

VI). Two other results are worth highlighting: the nontrivial damages from upstream emissions (higher than damages from ozone attributable to direct motor-vehicle emissions), and the trivial damages from air toxics.

11.7.2. Implications of the results.

Our findings have interesting implications. Most regulations and analyses have focused on emissions of ozone precursors from motor vehicles. Yet, as we mentioned above, in our lower-bound case, ozone is the least damaging pollutant emitted directly from motor vehicles -- less damaging even than CO and NO_X -- and in fact is about an order of magnitude less damaging than road-dust, which no-one has even considered regulating. Ozone damages are much higher in the upper bound case, but still less far less than damages from particulates, including road dust.

Even though there is considerable uncertainty in our analysis, it is clear that, over a wide range of assumptions, damages from particulates dominate the total cost of the health effects of motor-vehicle air pollution. The summary of the damages (million $) in Table 11.7-9 shows this dramatically. Particulates dominate mainly because they are strongly associated with mortality, which is so costly.

We do not imply that the considerable resources that have been devoted to regulating and analyzing ozone air pollution have been wasted utterly. We do suggest, however, that regulatory and analytical efforts be broadened and redirected. (This in fact is starting to happen.) Certainly, we find no basis for the presumption, too common among many analysts, that the carbon-monoxide problem now can be

considered to be "solved" (even if CO levels come down by a factor of two, CO damages still will be of the same order of magnitude as ozone damages), or that fugitive dust can continue to be ignored.

11.7.3. Comparison with Studies of Air Pollution Costs in the South Coast Air Basin

Several well-done studies have estimated the economic benefits derived from reducing air pollution in the South Coast Air Basin. We focus our comparison of results here.

11.7.3.1. Small and Kazimi (1995), Krupnick and Portney (1991) , and Hall et al. (1992): the cost of air pollution in the Los Angeles Region

Krupnick and Portney (1991), Hall et al. (1992) and Small and Kazimi (1995) have estimated the health cost of ozone and particulate pollution in the South Coast Air Quality Management District. In Table 11.7-10, we compare their estimates with our estimates for the Los Angeles region.[3]

The four estimates differ widely, mainly on account of differences in particulate mortality and morbidity costs. Our estimates of mortality costs are higher than those of Krupnick and Portney (1991) and Hall et al. (1992) because we estimate a larger number of deaths, and, in comparison with Krupnick and Portney (1990), a higher value of life (see Table 11.4-6). Hall et al. (1992) and Krupnick and Portney (1991) reported that reducing pollution levels to the ambient air quality standard would save 1600-2000 lives in the South Coast Air Quality Management District; we estimate that removing anthropogenic particulate pollution would save 9,700-13,100 lives in Los Angeles. Our estimate comes closest to Small and Kazimi's as they estimate that 4,000-9,000 lives are lost annually and they use a slightly higher value of life than we do (see Table 11.7-10, note "d").

There are several reasons that our estimate of the number of deaths is higher than the previous studies.

1) We estimate the effects of all anthropogenic pollution, whereas Krupnick and Portney and Hall et al. estimate the effects of the reductions necessary to achieve ambient air quality standards in the year 2010. We estimate the effects of all anthropogenic pollution because it appears that there are health effects at concentrations below the ambient air quality standard.

2) We include deaths estimated from both time-series studies and cross-sectional studies, whereas Hall et al., Krupnick and Portney, and Small and Kazimi used only cross-sectional studies. Most importantly, in our upper bound case we use a recent study (Pope et al. 1995a) that estimates more cross-sectional deaths per unit change in PM pollution.

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[3] The Los Angeles region that we estimate includes four counties Los Angeles, Orange, Riverside, and San Bernadino The South Coast Air Quality District includes Orange County and portions of Los Angeles, Riverside and San Bernadino counties

3) Our estimates include all of Riverside, Los Angeles, and San Bernadino Counties, whereas the other's estimate include only portions.

We estimate a higher cost of morbidity due to particulates primarily because we include an estimate of the cost of chronic illness, and the others do not. Our estimate of the cost of ozone morbidity is lower than the estimate of Hall et al. (1992) because they use laboratory studies to estimate acute morbidity damages, and in general, the laboratory results give higher estimates than do epidemiological studies.

11.7.3.2. Small and Kazimi (1995): the cost of motor-vehicle air pollution in the Los Angeles Region

Small and Kazimi (1995) estimated the cost of motor-vehicle particulate and ozone air pollution in the South Coast Air Quality Management District. We can compare their estimates with our estimates of the cost of motor-vehicle ozone and particulate air pollution in Los Angeles.

To estimate the impact of particulates on mortality, Small and Kazimi started by estimating motor vehicles' contribution to ambient PM_{10} levels from *direct* PM_{10} emissions and the atmospheric transformation of VOC, NO_x and SO_x to secondary particulates. They then estimated the health impact of these different sources, by using the fraction of the annual average ambient PM_{10} level attributable to each source and a dose-response function by Ozkaynak and Thurston (1987). They use the results of Krupnick and Portney (1991) and Hall et al. (1992) to estimate ozone and particulate morbidity. Their cost estimates for the 1992 fleet are shown in Table 11.7-11. The results shown in Table 11.7-11 do not include the cost of upstream emissions, which they did not estimate, or the cost of road dust, which they estimated but excluded from their baseline results on account of the uncertainty in the road-dust emissions inventory. They calculated that dust from paved roads would have added 4.3 cents per mile to the cost of light-duty vehicles (Table 11.7-11). This would have resulted in a total cost of 7.6 cents per mile for light-duty gasoline vehicles, compared to 2.4 to 36.5 cents per mile in our analysis.

The estimates of Small and Kazimi (1995) fall within our ranges, but at the low end. There are two reasons that our upper-bound estimates are so much larger than Small and Kazimi's baseline estimates. First, as shown in Table 11.7-10, our upper bound estimate of the total cost of all anthropogenic ozone and particulate pollution in Los Angeles is larger than Small and Kazimi's estimate of same, mainly because we include more effects than they do: we include chronic illness from particulates and time-series as well as cross-sectional deaths from particulates. Second, in our upper bound (and on average) we attribute to motor vehicles a larger fraction of the total ozone and particulate damages (Table 11.7-12). Small and Kazimi apportion particulate damages on the basis of the contribution of particulates sources to the downtown Los Angeles monitoring station, and apportion ozone damages on the basis of the emission shares of ozone precursors. By contrast, we use exposure-weighted emission shares to apportion particulate damages, in each county in the Los Angeles region. The resulting contribution of motor vehicle

tailpipe emissions to total PM are shown in Table 11.7-12; Table 11.7-12 also presents the contribution of tailpipe emissions plus road dust and upstream sources.

Thus, in our high-cost case, we estimate greater total pollution damages, and attribute a greater fraction of this [greater] total to motor vehicles, than do Small and Kazimi (1995). Consequently, our upper-bound estimate of motor-vehicle pollution damages is quite a bit higher than Small and Kazimi's estimate. (Small and Kazimi's baseline estimate of motor-vehicle damages is higher than our lower-bound estimate of motor-vehicle damages primarily because their baseline estimate of total air pollution damages is higher than our lower-bound estimate.)

Note that we also estimate the cost of CO, NO_X, and toxic air pollution from motor vehicles, as well as the cost of O_3 and PM_{10} pollution from vehicles. In Table 11.7-11 we have included only O_3 and PM_{10} so that our estimates may be compared properly with those of Small and Kazimi (1995).

11.7.4. Summary of Sources of Uncertainty and Future Work Needed

The estimation of the social-cost of motor-vehicle emissions has three steps: estimating exposure to pollution, determining damages caused by exposure, and valuing the damages. Each of these steps is uncertain. In the following paragraphs we briefly summarize the key uncertainties. Most of these are discussed in more detail elsewhere in this report or other reports.

11.7.4.1 Exposure to pollution: general methodological issues

A). There are two general approaches to estimating exposure to air pollution: 1) model the movement and exposure of individuals in many micro-environments, over the course of the day, or 2) use readings from outdoor ambient air-quality monitors to represent the "average" exposure of large groups of people over wide areas and relatively long periods of time. In the first approach, the health effects of the micro-modeled exposure are estimated using dose-response functions derived from studies of the effects of exposure to air pollution in the laboratory. In the second approach, the health effects are estimated from dose-response functions derived from epidemiological studies of large populations and ambient air quality. The advantage of the first approach is that it uses a detailed, micro-model of actual individual exposure; the disadvantage is the weaknesses of the clinical studies that one must use to estimate health effects of micro-modeled exposure. The clinical studies are much less robust than are the epidemiological studies, because they apply to specific individuals under specific circumstances. Also, the endpoints of clinical studies generally are more difficult to value than are the endpoints of epidemiological studies.

In any event, the micro-exposure/clinical-study approach appears to estimate significantly higher damages than does the ambient-air-quality/epidemiological approach. Future research should aim to better understand and reduce this difference.

B). Most if not all epidemiological analyses and analyses of health costs done to date have (implicitly) weighted the readings from all monitors equally; that is, they have not tried to weight readings from monitors in proportion to the amount of human exposure associated with the pollution measured by the monitor. Future

analyses perhaps should attempt to weight monitors by exposure. We note, though, that an analysis of the health effects of ambient air pollution ought to treat monitor readings in the same way that they are treated in the epidemiological studies used to estimate dose-response functions.

11.7.4.2 Exposure to pollution: modeling the contribution of motor vehicles to ambient air pollution

We use a detailed emissions inventory, and a relatively crude air-quality model, to estimate the motor-vehicle contribution to ambient air pollution (see Report #16 in the social-cost series listed at the beginning of this report). There are several problems with this method.

A). For many pollutants, the emission inventory is uncertain, primarily because the underlying emission factors (in grams/unit of activity) are not well characterized. The emissions inventory for fugitive dust, and for many natural sources, is particularly uncertain. For example, one natural source, "dust devils" (arising in the desert) is not included in the inventory. (This makes it particularly difficult to determine the anthropogenic portion of total pollution.) The uncertainty in the emissions inventory is reflected in the span between our low and high emission "correction" factors -- the factors that we applied to the "official" EPA emissions inventory in order to produce a more accurate and properly characterized emissions inventory.

B). To estimate the contribution of motor vehicles and other sources to ambient air pollution, we use a relatively simple Gaussian plume dispersion model, in which pollutant concentration is a function of the rate of emissions, the velocity of the wind, distance from emissions source to receptor, the height of the emissions source, the height of the atmospheric region in which pollutants can mix (called the "mixing layer); the deposition or settling of pollutants; turbulent diffusion, and many other factors. Most of these parameters are uncertain. (The parameters that characterize atmospheric turbulence, and the source-receptor distance, are especially uncertain.) Moreover, the model itself is relatively crude: it assumes that the earth's surface is a plane, the atmosphere is homogenous, vertical wind speed is zero, particles are perfectly reflected from the surface and the underside of the inversion layer, emission sources are constant over time, and the effects of turbulent diffusion in the direction of the wind are negligible in comparison to the effects of transport by the wind.

The uncertainty in the parameter values and the crudity of the model structure result in considerable uncertainty in our estimate of the contribution of one source *relative* to that of another. (We do emphasize, though, that we use the model to estimate the *relative* contribution, and that this should be much less uncertain than an estimate of the absolute concentration.) The use of more sophisticated air-quality models, and better data on source locations, can go a long way towards reducing this uncertainty.

C). Our modeling of ozone is particularly weak, especially in light of the sophisticated modeling of regional ozone levels. Still, our simplistic model probably is not a relatively large source of uncertainty, because it is unlikely that the actual contribution of motor vehicles to ambient ozone differs from the modeled

contribution by more than 50%. This potential error actually is fairly small compared to the ranges of uncertainties shown in Table 11.7-2. Moreover, if total ozone damages are closer to our lower than our upper bound, then the total damages are so low both absolutely and relative to damages from other pollutants that it matters not how the damages are apportioned. Thus, it is likely (and somewhat ironic) that, in a social-cost analysis anyway, it probably is not worthwhile to do a detailed analysis of the one problem -- contribution to ozone levels -- for which the available tools are far more sophisticated than we have used here.

D). We do account for the formation of particulates in the atmosphere from NO_X, SO_X, VOC, and NH_3 emissions, but the methods and assumptions underlying the data that we use are quite simplified. Much more work needs to be done to adequately characterize the formation of the so-called "secondary" particulates.

E). We do not address the long-range transport of pollution. A rigorous, if expensive, approach would be to perform a chemical mass balance study or tracer study in each region of interest to determine the sources of ambient pollution.

11.7.4.3 Damage Estimation

A). In some of the instances in which there are two or more epidemiological studies of a particular pollutant and health effect, the damage coefficient -- the estimated change in the incidence rate per unit change in pollution -- differs greatly among the studies. Unless there is a compelling reason for choosing or weighting one study over another, these differences should be acknowledged and incorporated into the analysis. This can introduce considerable uncertainty.

B). Most studies have assumed that the health effects associated with a particular pollutant depend on that pollutant only, and not on interactions between pollutants. Recent studies suggest that a suite of pollutants may interact among themselves and with environmental variables (e.g., pollen, weather) to cause adverse effects. More research and more sophisticated models are needed to address this question.

C). Particulates cause most of the estimated damages, and are the source of the greatest uncertainty in the analysis. Research on particulates has lagged research on other pollutants, and as a result several important questions still need to be answered:

1) To what extent do time-series studies and cross-sectional (including prospective cohort) studies measure the same deaths due to air pollution? The scant available evidence suggests that there is only a partial overlap between the two types of studies, and thus that the results are, to some extent, additive rather than duplicative. However, a wide range of assumptions about the degree of overlap is reasonable (it even is theoretically possible that there are types of particulate-related deaths not captured by either type of study, although there is little evidence that this is so), and this wide range of course results in a wide range of estimated costs.

2) What is the mortality coefficient -- the change in the death rate per unit change in particulate pollution? Two recent, prospective cohort studies -- probably the best studies available -- have relatively large mortality coefficients, two to four times larger than those from previous studies. We use the coefficient from one of these studies (Pope et al., 1995a), in our upper bound estimate of cross-sectional and

chronic deaths. This makes our upper-bound estimates of the total cost quite a bit higher than the estimates in other similar studies.

3). What is the effect of particulate air pollution on chronic illness? Our estimate of chronic illness is especially uncertain. Although recent work indicates that air pollution harms the growth, development and health of the respiratory system, it is difficult to quantify this effect in a way that is useful for cost analyses. More work needs to be done to determine the size of this effect and the best way to estimate people's exposure.

4). To what extent does the effect of PM depend on the size of the particle? Many researchers believe that "fine" particulate matter -- that with a diameter of 2.5 microns or less -- is more dangerous than larger particulate matter, but the functional relationship between particle size and health effects has not been quantified. On the basis of recent findings, and discussions with epidemiologists, we assume that $PM_{2.5}$ is considerably more potent than the coarse fraction of PM_{10}, that particles larger than PM_{10} have no effect on human health at all, and that all particles (of a given type) smaller than $PM_{2.5}$ have the same effect. However, these are little more than our judgments, and probably wrong in detail. For example, it is possible that very fine particles ($PM_{1.0}$, or even smaller), cause more damage than do the particles in the $PM_{1.0}$ to $PM_{2.5}$ range. Ideally, one would know the continuous size distribution of particles from each emissions source, and the damages as a continuous function of size.

5). To what extent does the effect of PM depend on the chemical composition of the particles? Unfortunately, this dependence on chemistry is less well understood than is even the relatively poorly understood dependence on size. There is some indication that road dust and other soil- and mineral-based particulate matter is less damaging than is sulfate particulate matter from combustion, but the evidence is only suggestive, and certainly does not yet demonstrate that mineral-based particulates such as road dust have no adverse health effects at all. We assume in our analysis that fugitive dust PM is less dangerous than other kinds of PM, but not completely harmless.

Generally, there are many, many uncertainties regarding the characterization of, exposure to, and health effects of particulate air pollution. The July 1995 issue of the journal *Inhalation Toxicology* provides a good summary of research needs.

D). Air pollution probably has different effects on different age groups, but the differences have not been well-quantified. These differences might be important because society might wish to attach different values to damages to different age groups. Future work should determine damage coefficients by age group.

11.7.4.4 Valuing Damages

All of the values that we use to monetize air pollution damages are uncertain. As shown in Table 11.7-2, the difference between the lower and upper bounds varies by a factor of roughly two to four.[4] Certainly more work would be helpful to further refine our estimates, particularly in regard to our estimates of morbidity and the value of life. With regards to the latter, there are at least three issues:

1) are the available estimates of the value of life (actually, value of risk) pertinent to the risks posed by air pollution specifically?;

2) is the value of life a function of the age of the individual?; and

3) is the value of life a function of the number of years lost?

Although further research will help answer these and other questions, and reduce the uncertainty in the valuation step, it is unlikely that society ever will agree on point estimates for damage values, and that we always will have to choose plausible lower and upper bounds.

11.7.4.5 Seasonality

Our work does little to consider the seasonal aspects of the pollution problem. Some epidemiological work has found that the effects of pollutants differ by season, perhaps because of temperature, pollen or other factors. In addition, some pollution emission sources vary by the season: fugitive dust from agricultural sources occurs primarily in the summer, and wood smoke in the winter. A more careful study will estimate damages as they occur in each season, by each pollutant (or a mix of pollutants) and then apportion the damages to the appropriate sources.

In sum, there is much that we have yet to learn about what exactly are the damages that are caused by pollution and what are the prime contributors of those damages. If nothing else, our work illustrates the considerable uncertainties in this exercise, and highlights the need for further research.

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[4]We should point out that our upper bound estimate of the value of the life is much less than some values reported in the literature and assumed in other studies of health effects (see Tables 11.4-5 and 11 4-6) Consequently, we could argue that our treatment of uncertainty actually is conservative, and that the overall gap between the lower and the upper bound damages is even greater than estimated here

ABBREVIATIONS USED IN TABLES IN CHAPTER 7

Vehicles
LDGV = light-duty gasoline vehicle
LDGT = light-duty gasoline truck
HDGT = heavy-duty gasoline truck
LDDV = light-duty diesel vehicle
LDDT = light-duty diesel truck
HDDT = heavy-duty diesel truck
VMT = vehicle miles traveled
V = all motor vehicles
U = upstream emission sources associated with motor vehicles
RD = paved road dust
RE = unpaved road dust

Pollutants
CO = carbon monoxide
NO_2 = nitrogen dioxide
NO_X = nitrogen oxides (including but not limited to NO_2)
NH_3 = ammonia
O_3 = ozone
PM = particulate matter
PM_{10} = particulate matter of 10 microns or less aerodynamic diameter
$PM_{2.5}$ = particulate matter of 2.5 microns or less aerodynamic diameter
Coarse PM_{10} = particulate matter between 2.5 and 10 microns aerodynamic diameter
SO_2 = sulfur dioxide
SO_X = sulfur oxides
SOA = secondary organic aerosols
TSP = total suspended particulates
VOCs = volatile organic compounds

Health effects
AOD = airway obstructive disease (chronic illness)
ARD2 = presence of any symptom or condition
RRAD = respiratory restricted activity day

Geography
L. A. = Los Angeles
SCAQMD = South Coast Air Quality Management District (Orange County, and portions of Los Angeles, Riverside, and San Bernadino counties).
U.S. = United States

Note: all dollars are 1991 $.

TABLE 11.7-1. POPULATION, VMT, AND POPULATION-WEIGHTED AVERAGE AIR POLLUTION FOR THE NATION, URBAN AND RURAL AREAS, AND ELEVEN METROPOLITAN STATISTICAL AREAS (1990)

Area	Population (10^6)	VMT (10^9)	CO (ppm)	NO_2 (ppm)	O_3 (ppm)	PM_{10}[a] ($\mu g/m^3$)
Nation	248.7	2,148.0	n.e.	n.e.	n.e.	n.e.
Urban	197.6	1,596.4	n.e.	n.e.	n.e.	n.e.
Rural	51.2	551.6	n.e.	n.e.	n.e.	n.e.
MSAs						
Boston	3.8	28.3	2.5	0.026	0.013	21.0
Denver	1.8	12.8	3.2	0.021	0.024	25.0
Houston	3.7	35.1	2.2	0.032	0.049	32.1
Los Angeles	14.5	118.2	3.5	0.063	0.064	47.1
Minneapolis	2.5	19.5	3.2	0.030	0.013	26.9
New York	17.1	93.0	3.2	0.037	0.017	27.5
Philadelphia	5.9	39.4	2.2	0.033	0.018	28.6
Phoenix	2.1	17.1	3.4	0.042	0.050	40.9
St. Louis	2.4	22.2	2.0	0.030	0.016	28.9
Spokane	0.4	2.8	4.9	0.034	0.014	41.3
Washington D. C.	3.9	29.5	2.7	0.028	0.021	26.8

The values for ozone include readings from the non-ozone season (see Table 11.2-2) Also, in all cases, where there was no monitor reading in a County, we chose the minimum of the readings from the larger EPA region (see Section 11.2). For these reasons, the values in this table might seem relatively low.

n c = not estimated

[a]Includes particulate sulfates, particulates nitrates, and organic particulates

TABLE 11.7-2. DIFFERENCES BETWEEN THE LOWER AND UPPER BOUND SCENARIOS

	Lower Bound	Upper Bound
CO natural (background) level	0.4 ppm	0.1ppm
NO_2 natural (background) level	0.1 ppb	0.005 ppb
O_3 natural (background) level	0.015 ppm	0.01 ppm
O_3 effect on asthma	Whittemore & Korn (1980)	Holguin et al. (1985) (~ 3.7 times higher than in lower bound)
O_3 effect on symptoms other than eye irritation, asthma, respiratory illness	None	Krupnick et al. (1990) (ARD2)
O_3 effect on children's morbidity	None	Same as on adults
PM effect on children's RRAD	59% less than adults'	Same as on adults
PM effect on mortality (cross-sectional studies)	Ozkaynak and Thurston (1987)	Pope et al. (1995) (~ 2 times higher than in lower bound)
Value of morbidity (1991 $)		
headache (CO)	$3	$14
sore throat (NO_2)	$3	$14
excess phlegm (NO_2)	$3	$14
eye irritation (NO_2, O_3)	$3	$14
resp. illness excl. asthma (O_3)	$3	$14
any other symptom ARD2 (O_3)	$3	$14
asthma attack (O_3, PM)	$10	$50
RRAD (PM)	$20	$70
AOD, or chronic illness (PM)	$0.5 million	$2 million
Value of mortality (1991 $)		
Cancer from toxics	$0.5 million	$2 million
Harvest death[a]	$10,000	$50,000
Non-harvest death[a]	$1 million	$4 million
Value of health: rate of increase/yr.	1%	1.5%
Discount rate	8%	2%
Estimated AOD[b] (PM)	Median of 5 estimates	Max. of 5 estimates

(continued next page)

Emission correction factors[c]		
CO from LDGVs	1.5	1.8
NO_X from LDGVs	1.2	1.4
VOCs from LDGVs	1.1	1.3
PM_{10} from all vehicles	1.5	2.0
PM_{10} paved road dust	0.3	0.8
$PM_{2.5}$ paved road dust	0.07	0.57
PM_{10} unpaved road dust	1.0	1.0
$PM_{2.5}$ unpaved road dust	0.3	0.95
PM_{10} construction (except road)	0.5	0.1
$PM_{2.5}$ construction (except road)	5.0	1.0
PM_{10} road construction	0.1	0.5
$PM_{2.5}$ road construction	1.0	5.0
PM_{10} wind erosion	1.2	1.1
The effect of PM size and composition[d]		
Composition effect: potency of dust from paved roads and construction relative to potency of other PM.	0.1	0.5
Composition effect: potency of dust from unpaved roads, agricultural tillage, and livestock relative to potency of other PM.	0.1	0.5
Size effect: potency of $PM_{2.5}$ relative to potency of coarse PM_{10}	2.0	10.0

[a]We assume that the time-series studies measure two groups of deaths – people that probably would have died anyway very shortly after they actually did die (harvest deaths) and people that would have lived much longer but for particulates (non-harvest deaths) In the lower bound we assume that 50% of the estimated time-series deaths are harvest deaths, and in the upper bound we assume 25%.

[b]Abbey et al. (1995) estimated five different models of AOD, corresponding to five different exposure thresholds We estimate all five models in each county, and use the highest of the resulting estimates as our upper bound, and the median as our lower bound.

[c]These factors adjust the EPA's official county-level emission estimates to what we believe are better estimates of actual emissions See Report #16 of the social-cost series listed at the beginning of this report for details

[d]Potency refers to change in health effects per change in unit concentration of the PM. As shown, we assume that fugitive-dust PM is less potent than is other PM, in any size class, and that the coarse fraction of PM_{10} ($PM_{2.5}$ to PM_{10}) is less potent than is $PM_{2.5}$, for any given particle composition.

Keep in mind that the "Low" and "High" refer to low total motor-vehicle-related damages and high total motor-vehicle-related damages Our assumptions about the potency of $PM_{2.5}$ relative to the potency of the coarse fraction of PM_{10} affect both the magnitude of the total damages due to motor vehicles, and the distribution of that damage between road dust PM, which is mainly but not exclusively larger than $PM_{2.5}$, and tailpipe PM, which is less than $PM_{2.5}$

Notes to Tables 11.7-3 and 11.7-4.

Shown here are the number of cases and the monetary value of the health effects of all anthropogenic CO, NO_X, O_3, and PM_{10} air pollution. "All anthropogenic" pollution is all pollution down to natural background levels, not just pollution from motor vehicles

These tables do *not* include the health effects of so-called "toxic" air pollutants acetaldehyde, formaldehyde, benzene, 1,3-butadiene, gasoline particulates as a cause of lung cancer, and diesel particulates as a cause of lung cancer. We call these "toxic" air pollutants, and distinguish them from the other pollutants, because we estimate the health effects on the basis of unit-risk numbers (which measure cancer risk, or toxicity) and exposure to pollution in micro-environments (Chapter 11.6). By contrast, we estimate the health effects of all of the other air pollutants on the basis of human epidemiological studies and exposure to ambient air pollution (Chapters 11.2 and 11.3).

Note that in the case of particulate matter only, we estimate both toxic (lung cancer) and "non-toxic" (other mortality and morbidity) effects We did not include in these tables the "toxic" lung-cancer affects of gasoline and diesel particulates because we did not analyze *all* sources and ambient levels of toxics However, all of the non-lung-cancer effects of particulate matter, including other mortality effects, are included under ambient PM_{10} in these tables. (All of the toxic air pollutants are included in Tables 11.7-6 and 11.7-9, and in the tables in the Appendix.)

TABLE 11.7-3A. SUMMARY OF THE NUMBER OF CASES OF ADVERSE HEALTH EFFECTS CAUSED BY ALL ANTHROPOGENIC POLLUTION, 1988 AND 1989 (THOUSANDS OF CASES)

Emission	Ambient pollutant	Health effect	1988		1989	
			low	*high*	*low*	*high*
CO	CO	headache	193,547	225,508	181,241	213,709
		hospitalization	9	25	8	24
		mortality	0.6	1.6	0.5	1.5
NO_X	NO_X	sore throat	306,511	311,479	287,253	291,937
		excess phlegm	140,000	142,350	131,418	133,636
		eye irritation	126,215	128,303	118,396	120,365
$VOC+NO_X$	O_3	asthma attacks	3,877	11,824	3,655	11,334
		eye irritation	41,550	44,971	35,416	38,749
		lower respiratory illness	51,999	84,480	48,777	80,376
		upper respiratory illness	15,821	25,704	14,841	24,455
		ARD2	0	251,762	0	257,523
PM_{10}, SO_2, NO_X, VOC	PM_{10}[a]	asthma attacks	3,276	3,458	3,211	3,388
		RRAD	105,809	123,180	103,373	120,529
		chronic illness	52	111	50	112
		mortality	85	150	83	140

[a]Includes particulate sulfates, particulates nitrates, and organic particulates, as well as direct or primary particulate emissions

TABLE 11.7-3B. SUMMARY OF THE NUMBER OF CASES OF ADVERSE HEALTH EFFECTS CAUSED BY ALL ANTHROPOGENIC POLLUTION, 1990 AND 1991 (THOUSANDS OF CASES)

Emission	Ambient pollutant	Health effect	1990[b]		1991	
			low	*high*	*low*	*high*
CO	CO	headache	170,385	202,416	160,020	193,213
		hospitalization	8	23	7	22
		mortality	0.5	1.5	0.5	1.4
NO_X	NO_X	sore throat	265,577	269,583	269,741	273,510
		excess phlegm	121,800	123,700	132,156	133,929
		eye irritation	109,618	111,303	112,793	114,370
VOC+NO_X	O_3	asthma attacks	3,652	11,482	3,800	11,897
		eye irritation	33,852	37,383	36,219	39,818
		lower respiratory illness	48,584	81,089	50,680	84,220
		upper respiratory illness	14,782	24,672	15,420	25,624
		ARD2	0	276,144	0	268,403
PM_{10},	PM_{10}[(a)]	asthma attacks	3,003	3,172	2,848	3,008
SO_2, NO_X,		RRAD	88,673	120,133	100,636	117,459
VOC		chronic illness	39	93	39	91
		mortality	80	137	79	132

[a]Includes particulate sulfates, particulates nitrates, and organic particulates, as well as direct or primary particulate emissions

[b]In the text we calculate an alternative upper bound for 1990, using our lower-bound estimate of long-term deaths from PM with all of the other original upper-bound assumptions The alternative upper-bound estimate is quite a bit lower than the upper bound shown here.

TABLE 11.7-4A. SUMMARY OF HEALTH COSTS OF ALL ANTHROPOGENIC POLLUTION, 1988-1989 (1991$ BILLION)

Emission	Ambient pollutant	Health effect	1988		1989	
			low	*high*	*low*	*high*
CO	CO	headache	0.5	2.8	0.5	2.7
		hospitalization	0.1	0.3	0.1	0.2
		mortality	0.6	6.5	0.5	6.1
		All	1.2	9.5	1.1	9.0
NO_X	NO_X	sore throat	0.7	3.4	0.7	3.2
		excess phlegm	0.4	1.9	0.4	1.8
		eye irritation	0.4	1.8	0.3	1.7
		All	1.5	7.1	1.4	6.7
VOC+NO_X	O_3	asthma attacks	0.04	0.5	0.04	0.5
		eye irritation	0.1	0.6	0.1	0.5
		lower respiratory illness	0.2	1.2	0.1	1.1
		upper respiratory illness	0.05	0.4	0.04	0.3
		ARD2	0.0	2.8	0.0	3.1
		All	0.4	5.5	0.3	5.6
PM_{10}, SO_2, NO_X, VOC	PM_{10}[a]	asthma attacks	0.03	0.2	0.03	0.2
		RRAD	2.1	8.6	2.1	8.4
		chronic illness	13.3	210.3	12.8	213.3
		mortality	43.1	536.4	42.1	499.5
		All	58.6	755.5	57.0	721.4
All	*All*	*All*	61.7	777.7	59.8	742.7

[a]Includes particulate sulfates, particulates nitrates, and organic particulates, as well as direct or primary particulate emissions

TABLE 11.7-4B. SUMMARY OF HEALTH COSTS OF ALL ANTHROPOGENIC POLLUTION, 1990-1991 (1991$ BILLION)

Emission	Ambient pollutant	Health effect	1990		1991	
			low	*high*	*low*	*high*
CO	CO	headache	0.5	2.6	0.4	2.5
		hospitalization	0.1	0.2	0.1	0.2
		mortality	0.5	5.8	0.5	5.5
		All	1.1	8.6	1.0	8.2
NO_X	NO_X	sore throat	0.6	3.0	0.6	3.0
		excess phlegm	0.4	1.7	0.4	1.7
		eye irritation	0.3	1.5	0.3	1.5
		All	1.3	6.3	1.3	6.1
VOC+NO_X	O_3	asthma attacks	0.04	0.5	0.04	0.5
		eye irritation	0.1	0.5	0.1	0.6
		lower respiratory illness	0.1	1.1	0.2	1.2
		upper respiratory illness	0.04	0.3	0.05	0.4
		ARD2	0.0	3.3	0.0	3.2
		All	0.3	5.8	0.3	5.8
PM_{10}, SO_2, NO_X, VOC	PM_{10}[a]	asthma attacks	0.03	0.2	0.03	0.2
		RRAD	1.8	8.4	2.0	8.2
		chronic illness	10.1	177.1	10.0	173.8
		mortality	40.9	489.0	40.1	470.0
		All	52.8	674.7	52.1	652.1
All	*All*	*All*	55.5	695.4	54.7	672.3

[a]Includes particulate sulfates, particulates nitrates, and organic particulates, as well as direct or primary particulate emissions

[b]In the text we calculate an alternative upper bound for 1990, using our lower-bound estimate of long-term deaths from PM with all of the other original upper-bound assumptions. The alternative upper-bound estimate is quite a bit lower than the upper bound shown here.

TABLE 11.7-5. MOTOR VEHICLE POLLUTION: LOWER AND UPPER BOUND EMISSION ESTIMATES, BY MOTOR VEHICLE CLASS AND POLLUTANT (GRAM/MILE) (U.S. TOTAL, 1990)

Vehicle	Source	PM		VOC		CO		NO_x		SO_2	SOA
		low	*high*	*low*	*high*	*low*	*high*	*low*	*high*		
LDGV	V	0.06	0 07	2.7	3.2	35.3	42 3	2 4	2.8	0 1	0 02
	V+U	0.1	0.1	3.9	4 4	35.5	42.5	2 6	3 0	0.5	0 03
	V+U+RD	0 6	1.4	3 9	4 4	35.5	42.5	2.6	3 0	0.5	0 03
	V+U+RD+RE	3 9	4.7	3 9	4 4	35.5	42.5	2 6	3 0	0.5	0 03
LDGT	V	0.1	0 1	4 5	5 3	52 4	62 9	3.7	4.3	0 1	0.02
	V+U	0.2	0 2	6 5	7 3	52.9	63 4	4 1	4 8	1 1	0.05
	V+U+RD	0.8	2 0	6 5	7 3	52 9	63 4	4 1	4 8	1 1	0.05
	V+U+RD+RE	5.3	6 4	6.5	7.3	52 9	63 4	4 1	4.8	1 1	0 05
HDGT	V	0 6	0.8	16 7	16.7	211.3	211 3	11 9	11.9	0 4	0 12
	V+U	0 6	0.9	22.1	22.1	211 9	211.9	12.5	12.5	1 6	0 16
	V+U+RD	2.2	5.0	22.1	22.1	211.9	211.9	12.5	12.5	1 6	0 16
	V+U+RD+RE	13 0	15 8	22.1	22 1	211 9	211.9	12 5	12.5	1 6	0 16
Gasoline	V	0.1	0.1	3 3	3.8	40 9	48 6	2 8	3.2	0.1	0.02
Subtotal	V+U	0.1	0.2	4.7	5.2	41.2	48 9	3.0	3 5	0 7	0.03
	V+U+RD	0 6	1.6	4 7	5.2	41.2	48 9	3 0	3.5	0.7	0.03
	V+U+RD+RE	4 3	5 2	4 7	5.2	41.2	48 9	3 0	3 5	0.7	0.03

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Vehicle	Source	PM		VOC		CO		NO_x		SO_2	SOA
		low	*high*	*low*	*high*	*low*	*high*	*low*	*high*		
LDDV	V	0.5	0 7	0 4	0 4	1 1	1 1	1 3	1.3	0 5	0 003
	V+U	0.5	0.7	0 8	0 8	1 1	1 1	1 4	1 4	0 6	0.007
	V+U+RD	0 9	1.7	0 8	0.8	1.1	1 1	1 4	1 4	0 6	0.007
	V+U+RD+RE	3.5	4.3	0 8	0 8	1 1	1.1	1.4	1.4	0 6	0.007
LDDT	V	0.2	0 2	0 2	0.2	0 4	0 4	0.5	0 5	0.2	0.001
	V+U	0.2	0.2	0 8	0.8	0 5	0 5	0.6	0.6	0 5	0 008
	V+U+RD	0 7	1 7	0.8	0.8	0.5	0.5	0 6	0.6	0.5	0 008
	V+U+RD+RE	4 6	5.6	0.8	0.8	0 5	0.5	0.6	0 6	0.5	0 008
HDDT	V	2.5	3.3	2 2	2.2	9.0	9.0	16.0	16.0	2 3	0.05
	V+U	2.6	3 4	4 6	4.6	9 7	9 7	16.7	16.7	3 9	0.09
	V+U+RD	6.8	14.6	4.6	4 6	9.7	9.7	16.7	16.7	3 9	0 09
	V+U+RD+RE	35 7	43.6	4 6	4 6	9.7	9 7	16.7	16 7	3 9	0 09
Diesel	V	2.0	2 7	1.8	1 8	7.1	7 1	12 6	12 6	1 9	0 04
Subtotal	V+U	2.1	2 7	3 7	3.7	7.7	7 7	13 1	13 1	3 2	0.07
	V+U+RD	5 4	11 7	3.7	3 7	7.7	7.7	13 1	13.1	3.2	0 07
	V+U+RD+RE	28 5	34.7	3 7	3.7	7.7	7 7	13 1	13 1	3.2	0.07
ALL	V	0.2	0.3	3.1	3.7	38.2	45.3	3.6	4.0	0.2	0 02
M.V.s	V+U	0.3	0 4	4.6	5 1	38.6	45.6	3 8	4.3	0 9	0.04
	V+U+RD	1.0	2.4	4.6	5 1	38 6	45.6	3 8	4 3	0 9	0.04
	V+U+RD+RE	6.2	7 6	4 6	5 1	38 6	45 6	3.8	4.3	0 9	0 04

Note that the emission source category is cumulative: V includes just motor vehicle emissions, V+U includes V plus upstream emissions, V+U+RD includes V+U plus paved road dust emissions, and V+U+RD+RE includes V+U+RD plus unpaved road dust emissions. M V. = motor vehicle

TABLE 11.7-6. COST PER MILE OF MOTOR VEHICLE TRAVEL, BASED ON A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS : LOWER AND UPPER BOUND EMISSION ESTIMATES, BY MOTOR VEHICLE CLASS AND AMBIENT POLLUTANT (CENTS/VMT) (NATION, 1990)

Vehicle	Source	PM		O_3		CO		NO_2		Toxics[a]		Total	
		low	*high*	*low*	*high*	*low*	*high*	*low*	*high*	*low*	*high*	*low*	*high*
LDGV	V	0.48	7 02	0.01	0.07	0 04	0 37	0 04	0 22	0.00	0 05	0.58	7.71
	V+U	0 56	7.50	0.01	0 07	0.04	0.37	0 04	0.22	n.e.	n e.	0.66	8.20
	V+U+RD	0.60	10.90	0 01	0 07	0 04	0.37	0 04	0 22	n.e	n e	0 69	11 60
	V+U+RD+RE	0.65	12.18	0 01	0.07	0 04	0 37	0.04	0.22	n.e.	n e	0 75	12 88
LDGT	V	0.74	10 70	0.01	0 11	0 06	0.53	0 06	0.32	0 00	0 09	0 88	11.72
	V+U	0.90	11.54	0.01	0.11	0.06	0.53	0.06	0.32	n.e	n e.	1 04	12 56
	V+U+RD	0 94	16.09	0 01	0 11	0 06	0.53	0.06	0 32	n.e.	n e	1 09	17 11
	V+U+RD+RE	1 02	17 80	0.01	0 11	0 06	0 53	0 06	0 32	n e	n e	1 16	18 82
HDGT	V	1 56	30.28	0.03	0 28	0.15	1.63	0 12	0 76	0 01	0 29	1 86	33.12
	V+U	1.78	31.53	0.03	0.29	0 15	1.63	0.12	0.77	n.e.	n.e.	2 09	34 38
	V+U+RD	1.90	42.55	0.03	0.29	0.15	1 63	0 12	0 77	n.e.	n e	2 20	45.40
	V+U+RD+RE	2 07	46 69	0 03	0 29	0 15	1 63	0 12	0 77	n e.	n e.	2 37	49 54
Gasoline Subtotal	V	0.55	8 04	0 01	0 08	0 05	0.42	0 05	0 25	0.00	0.06	0 65	8 83
	V+U	0 64	8 61	0 01	0 08	0 05	0.42	0 05	0 25	n e	n.e.	0.75	9.40
	V+U+RD	0 68	12.33	0 01	0.08	0 05	0.42	0.05	0.25	n.e	n e	0 79	13.12
	V+U+RD+RE	0.74	13 74	0 01	0.08	0 05	0 42	0 05	0 25	n e	n e	0.85	14 53

(continued next page)

Vehicle	Source	PM		O_3		CO		NO_2		Toxics		Total	
		low	*high*	*low*	*high*	*low*	*high*	*low*	*high*	*low*	*high*	*low*	*high*
LDDV	V	1 47	18 49	0 00	0 02	0.00	0.01	0.02	0 11	0.01	0 08	1.50	18 64
	V+U	1.50	18.70	0.00	0.02	0.00	0 01	0.02	0 11	n.e	n e.	1 53	18 84
	V+U+RD	1 53	21.34	0.00	0.02	0.00	0.01	0 02	0.11	n e	n e	1 55	21 49
	V+U+RD+RE	1 57	22 34	0.00	0 02	0.00	0.01	0.02	0 11	n.e.	n e.	1.60	22 48
LDDT	V	0 47	5 77	0.00	0.01	0.00	0 00	0.01	0 04	0 00	0 03	0.48	5 82
	V+U	0.52	6 14	0 00	0.01	0.00	0 00	0 01	0.04	n.e.	n.e.	0.53	6.19
	V+U+RD	0.57	10.09	0.00	0.01	0.00	0.00	0 01	0.04	n.e.	n e.	0.58	10 14
	V+U+RD+RE	0.63	11.58	0.00	0.01	0.00	0 00	0.01	0 04	n.e.	n.e	0 64	11 63
HDDT	V	4.18	79 93	0 02	0 19	0 01	0 07	0.15	0.98	0 02	0.33	4 35	81 19
	V+U	4.43	81 37	0.02	0 20	0.01	0.07	0.15	0 99	n.e.	n.e.	4 61	82 63
	V+U+RD	4.75	110.91	0.02	0.20	0.01	0 07	0.15	0.99	n.e.	n e.	4 92	112 17
	V+U+RD+RE	5 21	122.01	0.02	0 20	0.01	0 07	0.15	0 99	n.e.	n e	5 38	123.27
Diesel Subtotal	V	3.48	64.86	0.01	0.15	0 00	0 05	0.12	0.78	0.01	0.27	3.62	65 85
	V+U	3 68	66.03	0 02	0.16	0 01	0 05	0 12	0 78	n.e.	n.e.	3 83	67 03
	V+U+RD	3.93	89 55	0 02	0.16	0.01	0 05	0 12	0 78	n.e.	n e.	4 07	90 55
	V+U+RD+RE	4.30	98.39	0.02	0 16	0 01	0 05	0.12	0 78	n e.	n.e.	4 44	99 39
ALL VEHICLES	V	0.78	12 57	0 01	0.09	0.04	0 39	0.05	0 29	0 00	0.08	0.89	13 37
	V+U	0.89	13 17	0.01	0 09	0.04	0 39	0.05	0 29	n.e.	n e.	1.00	13 98
	V+U+RD	0.94	18 47	0.01	0 09	0 04	0 39	0.05	0 29	n.e	n.e.	1 05	19 28
	V+U+RD+RE	1 02	20 46	0 01	0.09	0 04	0.39	0 05	0.29	n e.	n.e.	1 14	21 27

TABLE 11.7-7A. COST PER KG OF MOTOR VEHICLE EMISSIONS, BASED ON A 10% REDUCTION IN DIRECT MOTOR-VEHICLE EMISSIONS (1991 $, 1990 EMISSIONS)

Emission	Ambient pollutant	United States		All urban areas		Los Angeles	
		low	*high*	*low*	*high*	*low*	*high*
CO	CO	0.01	0.09	0.01	0.10	0.03	0.18
NO_X	nitrate PM_{10}	1.02	16.56	1.39	22.38	6.05	75.83
	NO_2	0.15	0.73	0.19	0.96	0.52	2.64
Total for NOx		1.17	17.29	1.59	23.34	6.58	78.47
$PM_{2.5}$	$PM_{2.5}$	10.42	159.19	14.81	225.36	63.98	779.13
PM_{10}	PM_{10}	6.70	17.68	9.09	23.89	38.12	78.34
Total for PM_{10}		9.75	133.78	13.74	187.48	58.79	638.33
SO_X	sulfate PM_{10}	6.90	65.52	9.62	90.94	34.98	226.89
VOC	organic PM_{10}	0.10	1.15	0.13	1.45	0.51	4.34
VOC+NO_X	ozone	0.01	0.11	0.02	0.14	0.05	0.40

Each $/kg value is equal to the total calculated health damages attributable to the pollutant and source, divided by emissions of the pollutant from the source.

TABLE 11.7-7B. COST PER KG OF MOTOR VEHICLE EMISSIONS, BASED ON A 10% REDUCTION IN DIRECT MOTOR-VEHICLE EMISSIONS AND RELATED UPSTREAM EMISSIONS (1991 $, 1990 EMISSIONS)

Emission	Ambient pollutant	United States		All urban areas		Los Angeles	
		low	*high*	*low*	*high*	*low*	*high*
CO	CO	0.01	0.09	0.01	0.10	0.03	0.18
NO_X	nitrate PM_{10}	0.96	15.53	1.31	21.17	6.02	75.11
	NO_2	0.14	0.68	0.18	0.91	0.52	2.62
Total for NOx		1.10	16.21	1.50	22.08	6.54	77.73
$PM_{2.5}$	$PM_{2.5}$	9.71	147.24	13.63	205.44	62.57	737.36
PM_{10}	PM_{10}	5.30	14.25	7.20	18.34	30.04	47.87
Total for PM10		8.78	116.01	12.23	158.23	54.68	509.18
SO_X	sulfate PM_{10}	2.80	22.60	4.40	35.28	33.53	209.88
VOC	organic PM_{10}	0.10	0.99	0.13	1.25	0.52	4.29
VOC+NO_X	ozone	0.01	0.10	0.02	0.12	0.05	0.39

Each $/kg value is equal to the total calculated health damages attributable to the pollutant and source, divided by emissions of the pollutant from the source.

TABLE 11.7-7C. COST PER KG OF MOTOR VEHICLE EMISSIONS, BASED ON A 10% REDUCTION IN DIRECT MOTOR-VEHICLE EMISSIONS, RELATED UPSTREAM EMISSIONS, AND PAVED-ROAD-DUST EMISSIONS (1991 $, 1990 EMISSIONS)

Emission	Ambient pollutant	United States		All urban areas		Los Angeles	
		low	*high*	*low*	*high*	*low*	*high*
CO	CO	0.01	0.09	0.01	0.10	0.03	0.18
NO_X	nitrate PM_{10}	0.96	15.53	1.31	21.17	6.02	75.11
	NO_2	0.14	0.68	0.18	0.91	0.52	2.62
Total for NOx		1.10	16.21	1.50	22.08	6.54	77.73
$PM_{2.5}$	$PM_{2.5}$	7.48	94.45	10.47	130.89	45.44	430.10
PM_{10}	PM_{10}	1.03	7.58	1.42	10.34	5.62	32.26
Total for PM10		2.84	39.87	3.92	54.64	15.20	169.45
SO_X	sulfate PM_{10}	2.80	22.60	4.40	35.28	33.53	209.88
VOC	organic PM_{10}	0.10	0.99	0.13	1.25	0.52	4.29
VOC+NO_X	ozone	0.01	0.10	0.02	0.12	0.05	0.39

Each $/kg value is equal to the total calculated health damages attributable to the pollutant and source, divided by emissions of the pollutant from the source

TABLE 11.7-7D. COST PER KG OF MOTOR VEHICLE EMISSIONS, BASED ON A 10% REDUCTION IN DIRECT MOTOR-VEHICLE EMISSIONS, RELATED UPSTREAM EMISSIONS, PAVED-ROAD-DUST EMISSIONS, AND UNPAVED-ROAD-DUST EMISSIONS (1991 $, 1990 EMISSIONS)

Emission	Ambient pollutant	United States		All urban areas		Los Angeles	
		low	*high*	*low*	*high*	*low*	*high*
CO	CO	0.01	0.09	0.01	0.10	0.03	0.18
NO_X	nitrate PM_{10}	0.96	15.53	1.31	21.17	6.02	75.11
	NO_2	0.14	0.68	0.18	0.91	0.52	2.62
Total for NOx		1.10	16.21	1.50	22.08	6.54	77.73
$PM_{2.5}$	$PM_{2.5}$	3.22	45.22	6.53	88.79	41.93	405.29
PM_{10}	PM_{10}	0.27	2.95	0.63	6.20	4.69	29.77
Total for PM10		0.60	15.13	1.45	31.69	12.35	155.58
SO_X	sulfate PM_{10}	2.80	22.60	4.40	35.28	33.53	209.88
VOC	organic PM_{10}	0.10	0.99	0.13	1.25	0.52	4.29
VOC+NO_X	ozone	0.01	0.10	0.02	0.12	0.05	0.39

Each $/kg value is equal to the total calculated health damages attributable to the pollutant and source, divided by emissions of the pollutant from the source.

TABLE 11.7-8. ESTIMATED MORTALITY CAUSED BY PARTICULATES: COMPARISON OF UPPER AND LOWER BOUND ESTIMATES IN 1990

	Estimated number of deaths due to 1990 anthropogenic particulate air pollution	Lower bound	Upper bound
2	Acute respiratory and cardiovascular deaths (Pope et al., 1992)	37,250	39,503
3	Fraction of acute deaths that are "harvest" deaths	0.5	0.25
4	Acute harvest deaths (3 * 2)	18,625	9,876
5	Acute non-harvest deaths (2 -4)	18,625	29,627
6A	Total cross-sectional deaths, by Ozkaynak and Thurston (O & T) (1987)	61,775	65,463
6B	Total cross-sectional deaths, by Pope et al. (1995)	119,660	126,995
7A	Chronic deaths: cross-sectional by O & T (1987) less acute non-harvest deaths (Chapter 1) (7A - 5)	43,150	35,836
7B	Chronic deaths: cross-sectional by Pope et al. (1995) less acute non-harvest deaths (Chapter 1) (7B - 5)	101,035	97,368
8A	All particulate deaths (acute plus chronic), using O & T (1987) (4+ 5 + 7A)	80,400	75,339
8B	All particulate deaths (acute plus chronic), using Pope et al. (1995) (4 + 5 + 7B)	138,285	136,871
	Value per estimated death (1991$)		
9	Acute harvest deaths	10,000	50,000
10	Acute death non-harvest deaths	1,000,000	4,000,000
11	Chronic death (present value)	513,000	3,800,000
	Total present value in 1990 of deaths due to all anthropogenic particulate air pollution (billion 1991$)		
12	Acute harvest deaths (4 * 9/1000000000)	0.19	0.49
13	Acute non-harvest deaths (5 * 10/1000000000)	18.63	118.51
14A	Chronic deaths, using O&T (1987) (7A * 11/1000000000)	22.14	136.18
14B	Chronic deaths, using Pope et al. (1995) (7B*11/1000000000)	161.47	370.00
15A	All particulate deaths, using O & T (1987) (12 + 13 + 14A) (lower bound here same as in Table 11.7-4)	**40.96**	255.18
15B	All particulate deaths, using Pope et al. (1995) (12 + 13 + 14B) (upper bound here same as in Table 11.7-4)	180.29	**489.00**

(continued next page)

Total present value in 1990 of deaths due to motor-vehicle particulate air pollution (billion 1991$)		Lower bound	Upper bound
16A	All deaths due to motor-vehicle particulate pollution (including road dust and upstream sources), using O & T (1987) (calculated by our model) (lower bound here same as in Table 11.A-1)	**16.7**	n.e.
16B	All deaths due to motor-vehicle particulate air pollution (including road dust and upstream sources), using Pope et al. (1995) (upper bound here same as in Table 11.A-2)	n.e.	**311.6**

n c = not estimated.

TABLE 11.7-9. COST OF MOTOR-VEHICLE AIR POLLUTION IN THE NATION, URBAN AREAS AND LOS ANGELES MSA, BASED ON A 100% REDUCTION IN MOTOR VEHICLE EMISSIONS IN 1990 (MILLIONS OF 1991$)

	Motor vehicles		Motor Vehicles + Upstream		Motor Vehicles + Upstream + Road Dust[a]	
	lower	*upper*	*lower*	*upper*	*lower*	*upper*
Nation						
PM_{10}[(b)]	16,727	266,391	18,961	279,354	21,943	432,829
O_3	214	1,899	228	1,945	228	1,945
NO_x	1,038	5,483	1,048	5,509	1,048	5,509
CO	919	8,085	921	8,092	921	8,092
toxics	87	1,622	n.e.	n.e.	n.e.	n.e.
Total	18,985	283,481	21,246	296,522	24,227	449,997
Urban						
PM_{10}[(b)]	15,954	253,126	18,059	265,228	20,599	401,037
O_3	196	1,730	209	1,771	209	1,771
NO_x	955	5,072	964	5,093	964	5,093
CO	829	7,089	831	7,094	831	7,094
toxics	76	1,411	n.e.	n.e.	n.e.	n.e.
Total	18,010	268,428	20,139	280,599	22,679	416,408
Los Angeles MSA						
PM_{10}[(b)]	4,203	51,869	4,291	52,564	4,633	76,260
O_3	33	265	34	266	34	266
NO_x	137	713	137	714	137	714
CO	99	746	100	746	100	746
toxics	3	63	n.e.	n.e.	n.e.	n.e.
Total[c]	4,476	53,656	4,565	54,353	4,968	79,033

n.e = not estimated.

[a]Includes both paved and unpaved road dust.

[b]Includes particulate sulfates, particulate nitrates, and organic particulates

TABLE 11.7-10. ESTIMATES OF AIR POLLUTION DAMAGES IN THE LOS ANGELES REGION (MILLIONS OF 1992 $)

	This Study[a]		Hall et al. (1992)[b]		Krupnick and Portney (1991)[b]	Small and Kazimi (1985)
	All anthropogenic emissions in Los Angeles[c] in 1990		Emissions reductions required to achieve air quality standards in SCAQMD 2010			All emissions including biogenic in 1990
Damage	*Low*	*High*	*Low*	*High*	*Best*	*Baseline*
particulate						
mortality	5,093	48,062	3,439	17,668	2,372	30,168[d]
morbidity	2,727	39,924	919	919	830	(e)
ozone						
morbidity	52	655	1,423	6,878	356	(e)
Total	7,872	88,642[f]	*5,781*	*25,465*	*3,557*	(e)

SCAQMD = South Coast Air Quality Management District (Orange County, and portions of Los Angeles, Riverside, and San Bernadino Counties).

[a]Our original 1991 $ estimates scaled by the 1992/1991 CPI (1.03), for comparison with the 1992 $ estimates of Small and Kazimi (1995)

[b]Hall et al (1992) and Krupnick and Portney (1991) report their results in 1988 $ We have scaled their results to 1992 $, for comparison with the results of Small and Kazimi (1995) In their own comparison, Small and Kazimi (1995) use the 1992/1988 CPI (1.186, in their analysis) to scale the results of Hall et al. (1990) and Krupnick and Portney (1991) We do the same

[c]All of Los Angeles, Orange, San Bernadino, and Riverside Counties.

[d]The geometric mean two mortality estimates based on mortality coefficients from Ozkaynak and Thurston (1987) and Evans et al. (1984), annual average PM_{10} of 57.8 $\mu g/m^3$, and a value of life of $4.87 million (see Small and Kazimi, 1995: footnotes 11 and 12)

Note that Small and Kazimi underestimate the lower bound coefficient (Evans et al) when they note (p. 18) "Based on the consensus that PM_{10} rather than TSP causes health damages, we assume that among the constituents of TSP, only PM_{10} causes mortality, then the same coefficient (0.338) applies to changes in PM_{10} " Actually, they needed to correct for the PM_{10} fraction of TSP, which we assume is 55%, as noted by Hall et al (1989· 4-20). The coefficient should be 0.615 (=0.338/0.55).

Finally, we estimate that anthropogenic sources contribute, on average, roughly 90% of ambient particulates. To make this estimate more comparable to our own, one should subtract 10% of their estimate to account for natural emissions

[e]Small and Kazimi (1995: 20) used the results of Hall et al. (1992) and Krupnick and Portney (1991) to estimate morbidity costs of ozone and particulates. We did not attempt to use Small and Kazimi's results to estimate the morbidity costs of all anthropogenic ozone and particulates.

TABLE 11.7-11. TWO ESTIMATES OF THE COST OF OZONE AND PARTICULATE AIR POLLUTION FROM MOTOR-VEHICLE S IN THE LOS ANGELES REGION (1992 CENTS/VMT)[A]

	This Study (PM and O3 damages only)[b]				**Small and Kazimi (1995)**
	Direct Emissions		Direct + Upstream + Road Dust		Direct Emissions
Vehicle	*Low*	*High*	*Low*	*High*	*Baseline*
Light-Duty Gasoline	2.1	23.2	2.4	36.5	3.3
Light-Duty Diesel	6.7	64.4	6.9	74.7	7.8
Heavy-Duty Diesel	20.5	324.0	22.9	462.8	52.7

[a]Small and Kazimi's (1995) estimates apply to the SCAQMD. Our estimates apply to the Los Angeles Metropolitan Statistical Area (MSA), which consists of Los Angeles, Riverside, Orange, San Bernadino, and Ventura Counties Note that because here we compare cents/VMT, and not total dollar damages, the difference between the SCAQMD and the Los Angeles MSA is relatively unimportant.

[b]We have converted our estimates from 1991 $ to 1992 $ by multiplying by the 1992/1991 CPI of 1 03 The estimates of Small and Kazimi (1995) are in 1992 dollars.

TABLE 11.7-12. THE CONTRIBUTION OF MOTOR VEHICLE EMISSIONS TO TOTAL DAMAGES FROM PARTICULATE AIR POLLUTION IN THE COUNTIES OF THE SOUTH COAST AIR BASIN

County	The fraction of ambient PM that is from motor-vehicle tailpipe emissions of: (tailpipe plus road dust and upstream in parentheses)					
	direct PM		*Precursors of secondary ambient PM*			
	Coarse[a] PM_{10}	$PM_{2.5}$	NO_x	SOx	Organic	*all sources*
Our upper bound						
Los Angeles	0.5%	19.2%	30.5%	5.8%	1.9%	57.8%
	(5.7%)	(40.8%)	(30.6%)	(5.9%)	(1.9%)	(84.9%)
Orange	0.4%	16.4%	27.3%	5.0%	1.7%	51.0%
	(5.5%)	(37.1%)	(27.4%)	(5.1%)	(1.8%)	(76.9%)
Riverside	0.3%	14.5%	21.9%	4.3%	1.3%	42.2%
	(5.1%)	(34.1%)	(21.9%)	(4.3%)	(1.3%)	(66.8%)
San Bernadino	0.3%	13.5%	21.1%	4.0%	1.2%	40.3%
	(5.6%)	(33.8%)	(21.2%)	(4.1%)	(1.3%)	(65.9%)
Our lower bound						
Los Angeles	2.1%	13.7%	25.5%	10.4%	2.2%	53.8%
	(6.0%)	(14.6%)	(25.7%)	(10.9%)	(2.4%)	(59.6%)
Orange	1.9%	12.7%	23.6%	9.6%	2.1%	50.0%
	(6.1%)	(13.7%)	(23.8%)	(10.0%)	(2.3%)	(55.8%)
Riverside	1.6%	11.5%	19.9%	8.4%	1.7%	43.1%
	(5.8%)	(12.4%)	(20.0%)	(8.6%)	(1.8%)	(48.6%)
San Bernadino	1.5%	10.5%	18.6%	7.7%	1.6%	39.9%
	(5.7%)	(11.4%)	(18.7%)	(7.9%)	(1.7%)	(45.5%)
Small & Kazimi (1995)	10.6%[b]		10.5%	5.3%	4.4%	30.8%

The percentages shown are the dispersion- and potency-weighted shares of particulate pollution, the calculation of the shares is discussed in Section 11.5. In the case of Small and Kazimi (1995), this ratio also is the same as the ratio of the concentration of the particular motor-vehicle pollutant to the concentration of all particulate matter, because they weight all PM10 equally.

[a]Small and Kazimi report the contribution of PM_{10}, combining coarse PM_{10} and $PM_{2.5}$.

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APPENDIX TABLES

In this Appendix, Tables 11.A-1 through 11.A-4 give the lower and upper-bound benefit estimates of a 100% reduction of motor vehicle emissions, in dollars per one thousand VMT, for urban areas, and the nation as a whole. Tables 11.A-5 through 11.A-60 give the lower and upper-bound benefit estimates of a 10% reduction of motor vehicle emissions, in millions of dollars and in dollars per one thousand VMT, for eleven metropolitan areas, urban areas, rural areas, and the nation as a whole. In each of these tables, we show costs by pollutant, by vehicle class, and by emissions source. The 60 tables are arranged as follows:

	Millions of dollars		**Dollars/1000 VMT**	
Region	*Lower bound*	*Upper bound*	*Lower bound*	*Upper bound*
100% emission reduction				
All United States	Table 11.A-1	Table 11.A-2		
All urban areas	Table 11.A-3	Table 11.A-4		
10% emission reduction				
All United States	Table 11.A-5	Table 11.A-6	Table 11.A-33	Table 11.A-34
All urban areas	Table 11.A-7	Table 11.A-8	Table 11.A-35	Table 11.A-36
All rural areas	Table 11.A-9	Table 11.A-10	Table 11.A-37	Table 11.A-38
Boston	Table 11.A-11	Table 11.A-12	Table 11.A-39	Table 11.A-40
Denver	Table 11.A-13	Table 11.A-14	Table 11.A-41	Table 11.A-42
Houston	Table 11.A-15	Table 11.A-16	Table 11.A-43	Table 11.A-44
Los Angeles	Table 11.A-17	Table 11.A-18	Table 11.A-45	Table 11.A-46
Minneapolis	Table 11.A-19	Table 11.A-20	Table 11.A-47	Table 11.A-48
New York	Table 11.A-21	Table 11.A-22	Table 11.A-49	Table 11.A-50
Philadelphia	Table 11.A-23	Table 11.A-24	Table 11.A-51	Table 11.A-52
Phoenix	Table 11.A-25	Table 11.A-26	Table 11.A-53	Table 11.A-54
St. Louis	Table 11.A-27	Table 11.A-28	Table 11.A-55	Table 11.A-56
Spokane	Table 11.A-29	Table 11.A-30	Table 11.A-57	Table 11.A-58
Washington D. C.	Table 11.A-31	Table 11.A-32	Table 11.A-59	Table 11.A-60

TABLE 11-A 1 COST OF AIR POLLUTION ATTRIBUTABLE TO A 100% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (U S TOTAL 1990) (LOWER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	302	303	303	109	109	109	17	17	17	428	429	429	0	0	0	0	0	0	4	4	4	4	4	4	432	433	433
		hospitalization	48	48	48	17	17	17	3	3	3	68	68	68	0	0	0	0	0	0	1	1	1	1	1	1	68	69	69
		headaches	306	307	307	112	112	112	18	18	18	415	416	416	0	0	0	0	0	0	4	4	4	4	4	4	418	419	419
NOx	NO2	sore throat	341	344	344	129	131	131	16	16	16	453	458	458	3	3	3	1	1	1	107	108	108	111	112	112	526	530	530
		excess phlegm	157	159	159	58	58	58	7	7	7	220	223	223	1	1	1	0	0	0	48	48	48	49	50	50	269	272	272
		eye irritation	142	144	144	52	53	53	7	7	7	200	202	202	1	1	1	0	0	0	44	44	44	45	45	45	243	246	246
NOx, NH3	nitrate PM10	mortality	3,433	3,466	3,466	1,245	1,259	1,259	154	156	156	4,831	4,879	4,879	31	31	31	6	6	6	1,027	1,035	1,035	1,064	1,073	1,073	5,892	5 949	5,949
		chronic illness	958	968	968	343	347	347	43	44	44	1,344	1,358	1,358	9	9	9	2	2	2	284	287	287	295	297	297	1,639	1 655	1,655
		asthma attacks	3	3	3	1	1	1	0	0	0	4	4	4	0	0	0	0	0	0	1	1	1	1	1	1	5	5	5
		RRAD	169	171	171	62	63	63	8	8	8	236	239	239	2	2	2	0	0	0	51	52	52	53	54	54	287	290	290
Total for NOxand NH3emissions			5,203	5,253	5,253	1,890	1,912	1,912	235	238	238	7,288	7,362	7,362	47	48	48	9	9	9	1,562	1,575	1,575	1,619	1,632	1,632	8,861	8,946	8,946
PM2.5	PM2 5	mortality	680	768	942	344	389	447	64	68	77	1,089	1,225	1,467	138	139	141	24	25	27	1,834	1,861	1,989	1 997	2,024	2,156	3,084	3 249	3,622
		chronic illness	197	221	261	99	111	124	18	19	21	314	351	407	40	40	41	7	7	8	503	510	540	550	557	588	864	908	994
		asthma attacks	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	1	2	2	2	2	2	3	3
		RRAD	34	38	47	17	19	22	3	3	4	54	61	73	7	7	7	1	1	1	92	93	100	100	101	108	153	161	180
		lung cancer	12	12	12	7	7	7	1	1	1	20	20	20	1	1	1	0	0	0	22	22	22	23	23	23	44	44	44
Coarse PM10	coarse PM10	mortality	222	246	1 156	93	103	409	17	18	66	332	367	1,631	9	9	20	2	2	11	96	102	771	106	113	803	437	479	2,436
		chronic illness	64	71	277	27	29	98	5	5	16	95	105	391	3	3	5	0	0	3	26	28	179	29	31	187	125	136	578
		asthma attacks	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	2
		RRAD	11	12	60	5	5	21	1	1	3	17	18	84	0	0	1	0	0	1	5	5	40	5	6	42	22	24	126
Total for direct PM10emissions			1,222	1,370	2,758	591	664	1,130	109	115	189	1,921	2,149	4,076	199	200	217	35	36	51	2,579	2,622	3,642	2,812	2,857	3,909	4,731	5,003	7,985
SOx, NH3	sulfate PM10	mortality	1,020	1,689	1,689	386	722	722	40	71	71	1,446	2,481	2,481	90	94	94	18	23	23	1,157	1,345	1,345	1,266	1,463	1,463	2,710	3,943	3,943
		chronic illness	280	443	443	104	189	189	11	18	18	395	651	651	25	26	26	5	6	6	298	344	344	328	376	376	723	1,026	1,026
		asthma attacks	1	1	1	0	1	1	0	0	0	1	2	2	0	0	0	0	0	0	1	1	1	1	1	1	2	3	3
		RRAD	51	84	84	19	36	36	2	4	4	72	122	122	5	5	5	1	1	1	58	67	67	63	73	73	134	194	194
Total for SOxand NH3emissions			1,351	2,217	2,217	510	948	948	52	93	93	1,913	3,256	3,256	120	125	125	24	30	30	1,514	1,757	1,757	1,658	1,913	1,913	3,570	5,166	5,166
VOCs	organic PM10 (SOA)	mortality	300	431	431	117	174	174	22	29	29	439	634	634	1	1	1	0	1	1	44	77	77	45	79	79	485	713	713
		chronic illness	85	114	114	33	46	46	6	8	8	124	168	168	0	0	0	0	0	0	12	19	19	13	20	20	137	188	188
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
		RRAD	15	22	22	6	9	9	1	1	1	22	32	32	0	0	0	0	0	0	2	4	4	2	4	4	24	36	36
	acetaldehyde	oral cancer	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
	benzene	leukemia	6	6	6	3	3	3	0	0	0	9	9	9	0	0	0	0	0	0	0	0	0	0	0	0	10	10	10
	1,3-butadiene	cancer all sites	22	22	22	9	9	9	1	1	1	32	32	32	0	0	0	0	0	0	1	1	1	1	1	1	32	32	32
	fomaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			430	597	597	168	240	240	32	39	39	629	877	877	1	2	2	0	1	1	60	101	101	61	104	104	690	981	981
VOCs, NOx	O3	asthma attacks	13	14	14	5	5	5	1	1	1	19	21	21	0	0	0	0	0	0	3	3	3	3	3	3	23	24	24
		lower resp illness	52	56	56	19	21	21	3	3	3	76	82	82	0	0	0	0	0	0	10	11	11	10	11	11	90	96	96
		upper resp illness	16	17	17	6	6	6	1	1	1	23	25	25	0	0	0	0	0	0	3	3	3	3	3	3	27	29	29
		eye irritation	48	51	51	19	21	21	3	3	3	65	69	69	0	0	0	0	0	0	10	11	11	10	11	11	74	78	78
Subtotal mortality effects			5,958	6,903	7,988	2,294	2,757	3,120	315	359	416	8,564	10,016	11,521	270	275	288	50	57	68	4,162	4,424	5,221	4,482	4 756	5 578	13,042	14,766	17 096
Subtotal cancer effects			42	42	42	18	18	18	3	3	3	63	63	63	2	2	2	0	0	0	22	22	22	24	24	24	87	87	87
Subtotal chronic morbidity effects			1,585	1,817	2,063	605	721	804	83	93	106	2,272	2,632	2,974	76	78	81	14	16	18	1,124	1,188	1,369	1,214	1,281	1,468	3,487	3,913	4,441
Subtotal acute morbidity effects			1,406	1,471	1,529	529	560	580	72	76	79	1,946	2,043	2,123	21	21	22	4	4	5	439	456	499	463	481	525	2,369	2,479	2,602
Subtotal ambient PM10			7,537	8,761	10,150	2,907	3,509	3 975	397	454	527	10,836	12,718	14,645	361	368	385	67	75	90	5 516	5,854	6,874	5,943	6,297	7,349	16,770	19,005	21,986
Subtotal ambient O3			129	139	139	50	54	54	7	7	7	183	197	197	1	1	1	0	0	0	25	27	27	26	28	28	214	228	228
Subtotal ambient NO2			640	647	647	239	242	242	30	30	30	873	883	883	6	6	6	1	1	1	198	200	200	205	207	207	1,038	1,048	1 048
Subtotal ambient CO			656	657	657	238	238	238	38	38	38	911	913	913	0	0	0	0	0	0	8	8	8	8	9	9	919	921	921
Total all emissions, pollutants, effects			8,991	10,233	11,622	3,445	4,056	4,522	473	531	604	12,846	14,754	16,681	368	375	392	69	77	92	5,748	6,090	7,111	6,184	6,542	7,595	18,985	21,246	24,227

TABLE 11-A 2. COST OF AIR POLLUTION ATTRIBUTABLE TO A 100% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (U S. TOTAI 1990) (UPPER BOUND)

	Ambient		LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
Emission	pollutant	Health effect	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	3,743	3,746	3,746	1,353	1,355	1,355	270	270	270	5,366	5,370	5 370	2	2	2	0	0	0	57	58	58	59	60	60	5 425	5,430	5,430
		hospitalization	148	148	148	54	54	54	11	11	11	212	212	212	0	0	0	0	0	0	2	2	2	2	2	2	215	215	215
		headaches	1,805	1,806	1,806	669	669	669	135	135	135	2,425	2,427	2,427	1	1	1	0	0	0	28	29	29	29	30	30	2,445	2,447	2,447
NOx	NO2	sore throat	1,749	1,758	1 758	671	676	676	105	106	106	2,299	2,310	2,310	14	14	14	3	3	3	697	699	699	713	716	716	2,716	2,727	2,727
		excess phlegm	817	822	822	299	301	301	47	47	47	1,157	1,164	1,164	6	6	6	1	1	1	310	311	311	318	319	319	1 451	1 459	1,459
		eye irritation	742	746	746	272	274	274	43	43	43	1,046	1,053	1,053	6	6	6	1	1	1	283	284	284	290	291	291	1,316	1,323	1,323
NOx, NH3	nitrate PM10	mortality	55 603	55,873	55,873	20,262	20 383	20 383	3,153	3,166	3,166	78,466	78,865	78,865	435	436	436	83	85	85	20,869	20 933	20,933	21,382	21 450	21,450	99 176	99 639	99,639
		chronic illness	21,252	21,349	21,349	7,573	7,616	7,616	1,208	1,213	1,213	30,034	30 178	30,178	166	167	167	31	32	32	7,954	7,977	7,977	8,151	8,175	8,175	38 184	38 353	38,353
		asthma attacks	18	18	18	6	7	7	1		1	25	26	26	0	0	0	0	0	0	7	7	7	7	7	7	32	32	32
		RRAD	1,033	1,038	1,038	378	380	380	59	60	60	1 452	1,459	1,459	8	8	8	2	2	2	392	393	393	401	402	402	1,830	1,839	1,839
Total for NOxand NH3emissions			81,215	81,604	81,604	29,462	29,637	29,637	4,616	4,634	4,634	114,480	115,054	115,054	636	638	638	121	123	123	30,510	30,604	30,604	31,262	31,360	31,360	144,707	145,371	145,371
PM2.5	PM2 5	mortality	10,154	11,132	53 493	5 143	5,514	19,819	1,430	1,460	3,719	16,694	18,069	76,572	2,071	2,079	2,603	365	372	832	40,388	40,574	71,458	42,783	42 985	74,801	59,184	60 734	149,386
		chronic illness	3,985	4,433	19,207	1,985	2,144	7,099	547	559	1,339	6 517	7,136	27,646	810	814	995	141	144	303	15,273	15,348	26,207	16,224	16,307	27,504	22,741	23,443	55 150
		asthma attacks	3	4	17	2	2	6	0	0	1	5	6	24	1	1	1	0	0	0	13	13	23	14	14	24	19	20	48
		RRAD	191	211	993	97	104	370	27	27	70	313	341	1,416	39	39	49	7	7	16	752	755	1 321	796	800	1,383	1 100	1,130	2,732
		lung cancer	227	227	227	119	119	119	35	35	35	381	381	381	20	20	20	4	4	4	415	415	415	438	438	438	819	819	819
Coarse PM10	coarse PM10	mortality	661	892	11,703	276	346	3,977	74	78	650	1,010	1,316	16,311	26	29	161	5	6	123	424	452	8,403	455	487	8,686	1 464	1,803	24,950
		chronic illness	257	380	4,062	106	142	1,378	28	30	225	392	553	5,665	10	12	57	2	3	42	159	173	2,879	171	187	2,978	563	740	8 643
		asthma attacks	0	0	4	0	0	1	0	0	0	0	0	5	0	0	0	0	0	0	0	0	3	0	0	3	0	1	8
		RRAD	12	18	218	5	7	74	1	1	12	19	26	304	0	1	3	0	0	2	8	9	156	9	9	162	28	35	464
Total for direct PM10emissions			15,491	17,296	89,924	7,732	8,379	32,844	2,143	2,192	6,051	25,332	27,828	128,324	2,977	2,994	3,888	522	536	1,321	57,431	57,739	110,865	60,888	61,227	115,978	85,917	88,724	242,199
SOx, NH3	sulfate PM10	mortality	7,724	10 910	10,910	2 920	4,416	4,416	446	597	597	11,079	15,897	15,897	685	704	704	139	162	162	12,834	13,759	13 759	13 654	14,621	14,621	24,677	30 433	30,433
		chronic illness	2,783	3,813	3,813	1 036	1,516	1,516	157	205	205	3,975	5,535	5,535	246	253	253	49	57	57	4,422	4,714	4,714	4,717	5,024	5,024	8,693	10 558	10,558
		asthma attacks	2	3	3	1	1	1	0	0	0	3	5	5	0	0	0	0	0	0	4	4	4	4	4	4	8	9	9
		RRAD	141	197	197	53	79	79	8	11	11	202	287	287	13	13	13	3	3	3	233	250	250	248	265	265	449	549	549
Total for SOxand NH3emissions			10,650	14,924	14,924	4,010	6,013	6,013	611	814	814	15,260	21,723	21,723	944	970	970	191	222	222	17,494	18 727	18,727	18,624	19,915	19,915	33,826	41,550	41,550
VOCs	organic PM10	mortality	3,420	4,196	4,196	1,335	1,672	1,672	379	415	415	5,131	6,280	6,280	10	13	13	2	6	6	744	941	941	755	961	961	5,884	7,239	7,239
	(SOA)	chronic illness	1,309	1,547	1,547	504	607	607	147	158	158	1,960	2,312	2,312	4	5	5	1	2	2	283	342	342	287	349	349	2,247	2,661	2,661
		asthma attacks	1	1	1	0	1	1	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
		RRAD	64	78	78	25	31	31	7	8	8	96	117	117	0	0	0	0	0	0	14	18	18	14	18	18	110	134	134
	acetaldehyde	oral cancer	13	13	13	5	5	5	1	1	1	19	19	19	0	0	0	0	0	0	0	0	0	0	0	0	20	20	20
	benzene	leukemia	117	117	117	47	47	47	9	9	9	173	173	173	0	0	0	0	0	0	5	5	5	5	6	6	178	179	179
	1 3-butadiene	cancer all sites	397	397	397	160	160	160	29	29	29	586	586	586	1	1	1	0	1	1	11	11	11	12	13	13	598	599	599
	fomaldehyde	oral cancer	5	5	5	2	2	2	0	0	0	7	7	7	0	0	0	0	0	0	0	0	0	0	0	0	7	7	7
Sub-total for VOC emissions			5,326	6,355	6,355	2,079	2,526	2,526	572	620	620	7,974	9,496	9,496	14	19	19	3	9	9	1,058	1,318	1,318	1,075	1,346	1,346	9,047	10,841	10,841
VOCs, NOx	O3	asthma attacks	231	239	239	88	92	92	15	15	15	330	341	341	1	1	1	0	0	0	54	56	56	56	57	57	399	408	408
		lower resp illness	446	461	461	166	173	173	28	29	29	658	681	681	2	2	2	0	0	0	102	105	105	105	108	108	816	839	839
		upper resp illness	136	140	140	51	53	53	8	9	9	200	207	207	1	1	1	0	0	0	31	32	32	32	33	33	248	255	255
		eye irritation	281	288	288	117	122	122	21	22	22	377	385	385	2	2	2	0	0	0	72	74	74	74	76	76	436	443	443
Subtotal mortality effects			81,304	86,749	139,921	31,288	33,687	51 623	5,751	5,986	8,817	117,746	125 798	199,296	3 228	3,264	3,920	594	632	1,208	75,316	76,718	115,552	79 088	80,564	120 578	195,811	205,277	317,075
Subtotal cancer effects			759	759	759	334	334	334	74	74	74	1,167	1 167	1,167	20	20	20	4	4	4	432	432	432	456	457	457	1 622	1,623	1,623
Subtotal chronic morbidity effects			29 586	31,521	49 978	11,204	12,026	18 217	2,087	2,166	3 140	42,878	45,714	71,335	1,236	1,250	1,476	223	237	435	28 090	28,554	42,119	29,550	30,041	44,030	72,427	75 755	115,365
Subtotal acute morbidity effects			7,821	7,977	8,977	2,953	3,024	3,362	517	525	578	10,823	11,048	12,424	94	95	108	18	19	30	3,003	3,040	3,767	3,113	3,152	3,900	13,620	13,867	15,934
Subtotal ambient PM10			108,841	116,319	188,947	41,826	45,090	69,555	7,708	8,026	11,885	157,757	168,790	269,285	4,543	4,594	5,488	832	885	1,669	105,186	107,077	160,202	110 510	112,504	167,255	267,210	280,173	433,647
Subtotal ambient O3			1 093	1,128	1,128	422	439	439	72	75	75	1,565	1,614	1,614	5	6	6	1	1	1	260	267	267	267	274	274	1,899	1 945	1,945
Subtotal ambient NO2			3 308	3 326	3 326	1 242	1 250	1,250	195	195	195	4 503	4 526	4 526	27	27	27	5	5	5	1,290	1 294	1 294	1,321	1,326	1,326	5,483	5 509	5,509
Subtotal ambient CO			5 696	5,700	5,700	2,075	2,077	2,077	415	415	415	8,004	8,010	8,010	3	3	3	0	0	0	88	89	89	91	92	92	8,085	8,092	8,092
Total all emissions, pollutants, effects			119,471	127,007	199,635	45 780	49,071	73,535	8,429	8,750	12,609	172,614	183,726	284,221	4,579	4,629	5,524	838	893	1,677	106,841	108,744	161,869	112,207	114,214	168,965	283,481	296,522	449,997

TABLE 11-A 3 COST OF AIR POLLUTION ATTRIBUTABLE TO A 100% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLI UTANT PATHWAY AND HEALTH EFFECT, $ MILLION (U S URBAN 1990) (LOWER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	271	272	272	97	97	97	15	15	15	384	384	384	0	0	0	0	0	0	3	3	3	3	4	4	387	388	388
		hospitalization	43	43	43	15	15	15	2	2	2	61	61	61	0	0	0	0	0	0	1	1	1	1	1	1	61	61	61
		headaches	281	281	281	102	102	102	16	16	16	378	379	379	0	0	0	0	0	0	3	4	4	4	4	4	381	382	382
NOx	NO2	sore throat	318	321	321	120	121	121	15	15	15	420	424	424	3	3	3	1	1	1	97	98	98	101	102	102	482	486	486
		excess phlegm	146	148	148	53	54	54	6	7	7	205	207	207	1	1	1	0	0	0	43	43	43	45	45	45	248	251	251
		eye irritation	133	134	134	48	49	49	6	6	6	186	188	188	1	1	1	0	0	0	39	40	40	41	41	41	225	227	227
NOx, NH3	nitrate PM10	mortality	3 281	3,312	3,312	1,181	1,194	1,194	145	147	147	4,605	4,650	4,650	30	30	30	6	6	6	961	969	969	997	1,005	1,005	5 599	5,652	5 652
		chronic illness	942	951	951	336	339	339	42	43	43	1,319	1,333	1,333	9	9	9	2	2	2	277	279	279	287	290	290	1 607	1,622	1 622
		asthma attacks	3	3	3	1	1	1	0	0	0	4	4	4	0	0	0	0	0	0	1	1	1	1	1	1	4	4	4
		RRAD	160	161	161	58	59	59	7	7	7	223	225	225	1	1	1	0	0	0	47	48	48	49	50	50	270	272	272
Total for NOxand NH3emissions			4,982	5,029	5,029	1,797	1,818	1,818	222	224	224	6,961	7,030	7,030	45	46	46	9	9	9	1,466	1,478	1,478	1,520	1,532	1,532	8,435	8,516	8,516
PM2.5	PM2 5	mortality	654	737	885	329	371	421	60	64	72	1,043	1,172	1 377	133	133	135	23	24	25	1,711	1 736	1,845	1,867	1,893	2 005	2,909	3 064	3,382
		chronic illness	194	218	255	97	109	121	18	19	21	309	345	396	39	40	40	7	7	7	489	496	523	536	543	571	844	887	967
		asthma attacks	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	1	1	1	1	2	2	2	3
		RRAD	32	36	44	16	18	21	3	3	4	51	58	68	7	7	7	1	1	1	84	85	91	92	93	99	142	150	165
		lung cancer	11	11	11	6	6	6	1	1	1	18	18	18	1	1	1	0	0	0	19	19	19	20	20	20	38	38	38
Coarse PM10	coarse PM10	mortality	214	236	1,001	89	98	355	16	17	57	318	351	1,413	8	9	18	1	2	10	89	95	657	99	105	685	417	456	2,098
		chronic illness	63	70	258	26	29	92	5	5	15	94	103	364	3	3	5	0	0	2	25	27	165	28	30	173	122	133	537
		asthma attacks	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	2
		RRAD	11	12	50	4	5	18	1	1	3	16	17	70	0	0	1	0	0	0	4	5	33	5	5	34	21	23	104
Total for direct PM10emissions			1,179	1,320	2,504	567	636	1,033	103	109	172	1,849	2,065	3,708	192	193	207	33	34	47	2,424	2,465	3,335	2,649	2,691	3,589	4,496	4,754	7,294
SOx, NH3	sulfate PM10	mortality	978	1 606	1,606	367	680	680	37	67	67	1,383	2,352	2,352	87	90	90	17	22	22	1 074	1,250	1,250	1 178	1,362	1 362	2,560	3,713	3,713
		chronic illness	276	432	432	103	182	182	10	18	18	388	631	631	24	25	25	5	6	6	290	333	333	319	365	365	707	996	996
		asthma attacks	1	1	1	0	1	1	0	0	0	1	2	2	0	0	0	0	0	0	1	1	1	1	1	1	2	3	3
		RRAD	48	79	79	18	33	33	2	3	3	68	115	115	4	4	4	1	1	1	53	62	62	58	67	67	126	180	180
Total for SOxand NH3emissions			1,303	2,117	2,117	488	896	896	50	88	88	1,840	3,100	3,100	115	120	120	23	29	29	1,418	1,646	1,646	1,556	1,795	1,795	3,395	4,892	4,892
VOCs	organic PM10	mortality	288	413	413	112	166	166	21	27	27	422	606	606	1	1	1	0	1	1	42	73	73	43	75	75	464	681	681
	(SOA)	chronic illness	84	112	112	32	45	45	6	8	8	122	165	165	0	0	0	0	0	0	12	19	19	12	19	19	134	184	184
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
		RRAD	14	20	20	6	8	8	1	1	1	21	30	30	0	0	0	0	0	0	2	4	4	2	4	4	23	34	34
	acetaldehyde	oral cancer	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
	benzene	leukemia	6	6	6	2	2	2	0	0	0	8	8	8	0	0	0	0	0	0	0	0	0	0	0	0	9	9	9
	1,3-butadiene	cancer all sites	19	19	19	8	8	8	1	1	1	28	28	28	0	0	0	0	0	0	0	0	0	0	0	0	28	28	28
	fomaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			412	572	572	160	229	229	30	38	38	602	838	838	1	2	2	0	1	1	57	96	96	58	99	99	660	937	937
VOCs, NOx	O3	asthma attacks	12	13	13	5	5	5	1	1	1	18	19	19	0	0	0	0	0	0	2	2	2	2	2	2	21	22	22
		lower resp illness	48	52	52	18	19	19	2	3	3	69	75	75	0	0	0	0	0	0	8	9	9	9	10	10	81	87	87
		upper resp illness	15	16	16	5	6	6	1	1	1	21	23	23	0	0	0	0	0	0	3	3	3	3	3	3	25	27	27
		eye irritation	45	48	48	18	20	20	3	3	3	61	65	65	0	0	0	0	0	0	9	10	10	9	10	10	69	73	73
Subtotal mortality effects			5 686	6,576	7,489	2,174	2 607	2,913	295	337	385	8,153	9,516	10,783	259	264	275	48	54	64	3,881	4,126	4,797	4,187	4,444	5 136	12,335	13,955	15,914
Subtotal cancer effects			37	37	37	16	16	16	3	3	3	55	55	55	1	1	1	0	0	0	19	19	19	21	21	21	76	76	76
Subtotal chronic morbidity effects			1,559	1 782	2,007	593	704	779	81	91	103	2,233	2,576	2,889	75	77	79	14	15	18	1,093	1,155	1 320	1 182	1,246	1,417	3,415	3,823	4,306
Subtotal acute morbidity effects			1,309	1,369	1,416	488	517	533	66	69	72	1,803	1,892	1,956	19	20	20	4	4	5	400	416	450	423	439	474	2,183	2,285	2,383
Subtotal ambient PM10			7,254	8,410	9,594	2,780	3 345	3,742	376	430	492	10,405	12,177	13,821	348	355	369	64	72	85	5,184	5,502	6,373	5,596	5,929	6,827	15 992	18 097	20,637
Subtotal ambient O3			120	129	129	46	50	50	6	7	7	169	182	182	1	1	1	0	0	0	22	24	24	23	25	25	196	209	209
Subtotal ambient NO2			597	603	603	221	224	224	27	27	27	810	819	819	6	6	6	1	1	1	179	181	181	186	188	188	955	964	964
Subtotal ambient CO			595	596	596	214	214	214	34	34	34	822	824	824	0	0	0	0	0	0	7	7	7	7	8	8	829	831	831
Total all emissions, pollutants, effects			8,591	9,763	10,948	3,271	3,844	4,241	445	500	562	12,243	14,039	15,683	355	362	376	66	74	86	5,393	5,715	6,586	5,813	6,151	7,048	18,010	20,139	22,679

TABLE 11-A 4. COST OF AIR POLLUTION ATTRIBUTABLE TO A 100% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (U S. URBAN 1990) (UPPER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	3,278	3,280	3,280	1,170	1,171	1,171	234	234	234	4,682	4,686	4,686	1	2	2	0	0	0	48	49	49	50	51	51	4,733	4,736	4,736
		hospitalization	130	130	130	46	46	46	9	9	9	185	185	185	0	0	0	0	0	0	2	2	2	2	2	2	187	187	187
		headaches	1,618	1,619	1,619	594	595	595	120	120	120	2,152	2,154	2,154	1	1	1	0	0	0	25	25	25	26	26	26	2,169	2,170	2,170
NOx	NO2	sore throat	1,640	1,648	1,648	624	628	628	97	98	98	2,136	2,146	2,146	14	14	14	3	3	3	640	642	642	656	658	658	2,497	2,506	2,506
		excess phlegm	767	771	771	277	279	279	43	43	43	1,081	1,087	1,087	6	6	6	1	1	1	284	285	285	291	292	292	1,349	1,356	1,356
		eye irritation	696	700	700	253	255	255	39	40	40	979	984	984	6	6	6	1	1	1	259	260	260	266	267	267	1,225	1,231	1,231
NOx, NH3	nitrate PM10	mortality	52,745	52,991	52,991	19,048	19,159	19,159	2,948	2,959	2,959	74,195	74,559	74,559	414	416	416	79	80	80	19,410	19,469	19,469	19,898	19,960	19,960	93,431	93,853	93,853
		chronic illness	20,903	20,997	20,997	7,425	7,467	7,467	1,182	1,186	1,186	29,510	29,650	29,650	164	164	164	30	31	31	7 766	7,789	7,789	7,960	7 984	7,984	37,470	37,633	37 633
		asthma attacks	17	17	17	6	6	6	1	1	1	24	25	25	0	0	0	0	0	0	6	6	6	7	7	7	31	31	31
		RRAD	990	995	995	360	362	362	56	57	57	1 388	1,395	1,395	8	8	8	1	2	2	370	371	371	379	380	380	1 745	1,753	1 753
Total for NOxand NH3emissions			77,758	78,119	78,119	27,994	28,156	28,156	4,366	4,384	4,384	109,314	109,846	109,846	611	613	613	115	117	117	28,736	28,822	28,822	29,457	29,548	29,548	137,748	138,364	138,364
PM2.5	PM2 5	mortality	9 693	10,624	47,240	4,868	5,219	17,591	1,340	1,368	3,322	15,868	17,174	67 718	1 977	1 986	2,439	345	352	750	37,407	37 580	64,250	39,690	39,878	67 349	55,270	56,737	133,169
		chronic illness	3,926	4,367	18,467	1,950	2,106	6,835	536	547	1,292	6 412	7,020	26,594	798	802	975	138	142	293	14,882	14,955	25,319	15,818	15,899	26,586	22,230	22,919	53 180
		asthma attacks	3	4	16	2	2	6	0	0	1	5	6	22	1	1	1	0	0	0	12	12	21	13	13	22	18	19	44
		RRAD	184	203	902	92	100	337	26	26	64	301	328	1 288	38	38	47	7	7	14	707	710	1,216	750	754	1,274	1,041	1,071	2,498
		lung cancer	199	199	199	103	103	103	29	29	29	331	331	331	18	18	18	3	3	3	360	360	360	381	381	381	712	712	712
Coarse PM10	coarse PM10	mortality	630	857	10 090	261	329	3,431	69	73	562	960	1,259	14,065	25	28	141	4	6	105	393	420	7,211	422	453	7,456	1,382	1,713	21,478
		chronic illness	254	375	3,874	104	140	1,314	28	30	215	385	545	5,402	10	11	54	2	3	40	155	168	2,741	167	183	2,835	552	727	8,238
		asthma attacks	0	0	3	0	0	1	0	0	0	0	0	5	0	0	0	0	0	0	0	0	2	0	0	2	0	1	7
		RRAD	12	17	195	5	6	66	1	1	11	18	25	272	0	1	3	0	0	2	7	8	139	8	9	144	26	34	414
Total for direct PM10emissions			14,902	16,645	80 987	7,385	8,006	29,684	2,029	2,075	5,495	24,282	26,688	115,698	2,867	2,884	3,677	499	513	1,208	53,923	54,215	101,258	57,249	57,570	106,050	81,233	83,932	219,740
SOx, NH3	sulfate PM10	mortality	7,359	10,267	10,267	2,758	4,112	4,112	417	555	555	10,523	14,908	14,908	652	670	670	131	153	153	11,830	12,672	12,672	12 610	13,490	13,490	23,077	28,315	28 315
		chronic illness	2,741	3,731	3,731	1,017	1,473	1,473	153	200	200	3,911	5,404	5 404	243	249	249	48	56	56	4,302	4,583	4,583	4,593	4,887	4,887	8,504	10,291	10,291
		asthma attacks	2	3	3	1	1	1	0	0	0	3	5	5	0	0	0	0	0	0	4	4	4	4	4	4	7	9	9
		RRAD	136	188	188	51	75	75	8	10	10	194	272	272	12	12	12	2	3	3	218	233	233	233	248	248	425	518	518
Total for SOxand NH3emissions			10,238	14,189	14,189	3,827	5,662	5,662	578	765	765	14,631	20,589	20,589	907	932	932	182	211	211	16,354	17,492	17,492	17,440	18,630	18,630	32,014	39,133	39,133
VOCs	organic PM10	mortality	3,268	3 991	3,991	1,267	1,582	1,582	359	393	393	4,892	5,962	5,962	9	13	13	2	6	6	696	881	881	707	899	899	5,597	6,859	6,859
	(SOA)	chronic illness	1,290	1 522	1,522	496	597	597	144	155	155	1,930	2,274	2,274	4	5	5	1	2	2	276	334	334	281	341	341	2,211	2,615	2,615
		asthma attacks	1	1	1	0	1	1	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
		RRAD	62	75	75	24	30	30	7	7	7	92	112	112	0	0	0	0	0	0	13	17	17	14	17	17	106	129	129
	acetaldehyde	oral cancer	11	11	11	5	5	5	1	1	1	17	17	17	0	0	0	0	0	0	0	0	0	0	0	0	17	17	17
	benzene	leukemia	103	103	103	41	41	41	7	7	7	150	150	150	0	0	0	0	0	0	4	4	4	5	5	5	155	155	155
	1,3-butadiene	cancer all sites	348	348	348	138	138	138	25	25	25	511	511	511	0	0	0	0	0	0	9	9	9	10	10	10	521	521	521
	fomaldehyde	oral cancer	4	4	4	2	2	2	0	0	0	6	6	6	0	0	0	0	0	0	0	0	0	0	0	0	6	6	6
Sub-total for VOC emissions			5,087	6,056	6,056	1,972	2,393	2,393	544	589	589	7,600	9,034	9,034	14	18	18	3	9	9	1,000	1,246	1,246	1,017	1,273	1,273	8,615	10,305	10,305
VOCs, NOx	O3	asthma attacks	212	220	220	80	84	84	14	14	14	301	311	311	1	1	1	0	0	0	47	49	49	49	50	50	359	367	367
		lower resp illness	411	425	425	152	158	158	25	26	26	603	624	624	2	2	2	0	0	0	89	91	91	91	94	94	740	760	760
		upper resp illness	125	129	129	46	48	48	8	8	8	184	190	190	1	1	1	0	0	0	27	28	28	28	29	29	225	231	231
		eye irritation	266	273	273	111	115	115	20	21	21	354	362	362	1	2	2	0	0	0	66	68	68	68	70	70	406	413	413
Subtotal mortality effects			76,973	82,010	127,859	29,371	31,573	47,046	5,366	5 582	8,025	111 120	118,549	181,899	3,080	3 113	3,679	562	597	1,094	69,784	71,070	104,531	73 377	74,732	109,205	183,490	192,214	288 411
Subtotal cancer effects			666	666	666	287	287	287	63	63	63	1,015	1,015	1,015	19	19	19	3	4	4	374	374	374	396	397	397	1,411	1,412	1,412
Subtotal chronic morbidity effects			29 113	30,991	48,591	10,993	11,783	17,686	2,043	2,119	3 048	42,149	44,892	69 324	1,218	1,231	1,447	219	233	422	27,381	27,830	40,765	28,818	29 294	42,633	70 967	74,186	111 957
Subtotal acute morbidity effects			7,273	7,418	8,310	2,725	2,790	3,093	475	482	530	10,005	10,212	11,440	90	91	102	17	18	27	2,779	2,813	3,461	2,884	2,920	3,587	12,560	12,787	14,627
Subtotal ambient PM10			104,415	111,423	175,764	39,838	42,870	64,549	7,303	7,599	11 019	150,947	161,256	250 265	4,373	4,421	5,213	795	845	1,540	98,815	100,573	147,617	103,933	105,788	154,268	253,838	265,941	401,749
Subtotal ambient O3			1,014	1,047	1,047	389	404	404	67	69	69	1,442	1,488	1,488	5	5	5	1	1	1	230	236	236	236	243	243	1,730	1,771	1 771
Subtotal ambient NO2			3,103	3,119	3,119	1 155	1 162	1,162	180	181	181	4 196	4,217	4,217	25	25	25	5	5	5	1,184	1,188	1,188	1 213	1,217	1,217	5,072	5 093	5,093
Subtotal ambient CO			5,026	5,029	5,029	1,811	1,813	1,813	363	363	363	7,020	7,025	7,025	2	2	2	0	0	0	75	76	76	78	79	79	7,089	7,094	7,094
Total all emissions, pollutants, effects			114,025	121,084	185,425	43,376	46,433	68,112	7,946	8,246	11,666	164,289	174,669	263,679	4,406	4,454	5,247	801	852	1,547	100,318	102,087	149,131	105,475	107,342	155,822	268,428	280,599	416,408

TABLE 11-A 5. COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (U..S TOTAL 1990) (LOWER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	30	30	30	11	11	11	2	2	2	43	43	43	0	0	0	0	0	0	0	0	0	0	0	0	43	43	43
		hospitalization	5	5	5	2	2	2	0	0	0	7	7	7	0	0	0	0	0	0	0	0	0	0	0	0	7	7	7
		headaches	31	31	31	11	11	11	2	2	2	44	44	44	0	0	0	0	0	0	0	0	0	0	0	0	45	45	45
NOx	NO2	sore throat	36	36	36	13	13	13	2	2	2	50	51	51	0	0	0	0	0	0	11	11	11	11	11	11	61	62	62
		excess phlegm	16	16	16	6	6	6	1	1	1	22	23	23	0	0	0	0	0	0	5	5	5	5	5	5	27	28	28
		eye irritation	14	15	15	5	5	5	1	1	1	20	21	21	0	0	0	0	0	0	4	4	4	5	5	5	25	25	25
NOx, NH3	nitrate PM10	mortality	344	347	347	125	126	126	15	16	16	484	488	488	3	3	3	1	1	1	103	104	104	106	107	107	590	596	596
		chronic illness	96	97	97	34	35	35	4	4	4	134	136	136	1	1	1	0	0	0	28	29	29	29	30	30	164	165	165
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	17	17	17	6	6	6	1	1	1	24	24	24	0	0	0	0	0	0	5	5	5	5	5	5	29	30	30
Total for NOxand NH3emissions			523	528	528	189	191	191	24	24	24	735	743	743	5	5	5	1	1	1	156	158	158	162	163	163	897	906	906
PM2.5	PM2 5	mortality	68	77	94	34	39	45	6	7	8	109	123	147	14	14	14	2	2	3	183	186	199	200	203	216	309	325	362
		chronic illness	20	22	26	10	11	12	2	2	2	31	35	41	4	4	4	1	1	1	50	51	54	55	56	59	86	91	99
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	3	4	5	2	2	2	0	0	0	5	6	7	1	1	1	0	0	0	9	9	10	10	10	11	15	16	18
		lung cancer	1	1	1	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	2	2	2	2	2	2	4	4	4
Coarse PM10	coarse PM10	mortality	22	25	116	9	10	41	2	2	7	33	37	163	1	1	2	0	0	1	10	10	77	11	11	80	44	48	243
		chronic illness	6	7	28	3	3	10	0	0	2	10	11	39	0	0	1	0	0	0	3	3	18	3	3	19	12	14	58
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	1	1	6	0	1	2	0	0	0	2	2	8	0	0	0	0	0	0	0	1	4	1	1	4	2	2	13
Total for direct PM10emissions			122	137	276	59	66	113	11	12	19	192	215	408	20	20	22	3	4	5	258	262	364	281	286	391	474	501	799
SOx, NH3	sulfate PM10	mortality	102	169	169	39	72	72	4	7	7	145	248	248	9	9	9	2	2	2	116	135	135	127	146	146	271	394	394
		chronic illness	28	44	44	10	19	19	1	2	2	39	65	65	2	3	3	0	1	1	30	34	34	33	38	38	72	103	103
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	5	8	8	2	4	4	0	0	0	7	12	12	0	0	0	0	0	0	6	7	7	6	7	7	14	20	20
Total for SOxand NH3emissions			135	222	222	51	95	95	5	9	9	191	326	326	12	12	12	2	3	3	151	176	176	166	191	191	357	517	517
VOCs	organic PM10	mortality	30	43	43	12	17	17	2	3	3	44	63	63	0	0	0	0	0	0	4	8	8	5	8	8	48	71	71
	(SOA)	chronic illness	9	11	11	3	5	5	1	1	1	12	17	17	0	0	0	0	0	0	1	2	2	1	2	2	14	19	19
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	1	2	2	1	1	1	0	0	0	2	3	3	0	0	0	0	0	0	0	0	0	0	0	0	2	4	4
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
	1,3-butadiene	cancer all sites	2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3
	formaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			43	60	60	17	24	24	3	4	4	63	88	88	0	0	0	0	0	0	6	10	10	6	10	10	69	98	98
VOCs, NOx	O3	asthma attacks	1	1	1	0	1	1	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
		lower resp illness	5	6	6	2	2	2	0	0	0	7	8	8	0	0	0	0	0	0	1	1	1	1	1	1	8	9	9
		upper resp illness	2	2	2	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3
		eye irritation	5	6	6	2	2	2	0	0	0	8	8	8	0	0	0	0	0	0	1	1	1	1	1	1	9	9	9
Subtotal mortality effects			596	691	799	229	276	312	31	36	42	857	1 002	1 153	27	28	29	5	6	7	416	442	522	448	476	558	1 305	1,478	1,711
Subtotal cancer effects			4	4	4	2	2	2	0	0	0	6	6	6	0	0	0	0	0	0	2	2	2	2	2	2	9	9	9
Subtotal chronic morbidity effects			158	182	206	60	72	80	8	9	11	227	263	297	8	8	8	1	2	2	112	119	137	121	128	147	349	391	444
Subtotal acute morbidity effects			144	150	156	53	56	58	7	8	8	204	214	222	2	2	2	0	0	0	44	46	50	47	48	53	250	262	275
Subtotal ambient PM10			754	877	1,016	291	351	398	40	45	53	1,085	1,273	1,466	36	37	38	7	8	9	552	586	688	595	630	735	1,679	1,903	2,201
Subtotal ambient O3			13	14	14	5	6	6	1	1	1	19	21	21	0	0	0	0	0	0	2	3	3	3	3	3	21	23	23
Subtotal ambient NO2			66	67	67	24	24	24	3	3	3	93	94	94	1	1	1	0	0	0	20	20	20	21	21	21	113	115	115
Subtotal ambient CO			66	66	66	24	24	24	4	4	4	94	94	94	0	0	0	0	0	0	1	1	1	1	1	1	95	95	95
Total all emissions, pollutants, effects			902	1,027	1,166	345	406	453	47	53	60	1,294	1,486	1 679	37	38	39	7	8	9	575	609	711	619	655	760	1,913	2,140	2,438

TABLE 11-A 6. COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEAI TH EFFECT, $ MILI ION (U S TOTAL 1990) (UPPER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			Total gasoline vehicles			LDDVs			LDDTs			HDDVs			Total diesel vehicles			Total all vehicles		
			V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD
CO	CO	mortality	374	375	375	135	135	135	27	27	27	537	537	537	0	0	0	0	0	0	6	6	6	6	6	6	543	543	543
		hospitalization	15	15	15	5	5	5	1	1	1	21	21	21	0	0	0	0	0	0	0	0	0	0	0	0	21	21	21
		headaches	186	186	186	67	67	67	13	13	13	266	267	267	0	0	0	0	0	0	3	3	3	3	3	3	269	270	270
NOx	NO2	sore throat	186	187	187	68	68	68	11	11	11	264	265	265	1	1	1	0	0	0	70	71	71	72	72	72	335	337	337
		excess phlegm	82	83	83	30	30	30	5	5	5	117	118	118	1	1	1	0	0	0	31	31	31	32	32	32	149	150	150
		eye irritation	75	76	76	27	28	28	4	4	4	107	107	107	1	1	1	0	0	0	28	29	29	29	29	29	136	137	137
NOx, NH3	nitrate PM10	mortality	5,619	5,646	5,646	2,034	2,046	2,046	315	317	317	7,962	8 003	8 003	43	44	44	8	8	8	2,095	2,101	2,101	2,147	2,153	2 153	10,102	10 150	10,150
		chronic illness	2,125	2,135	2,135	757	762	762	121	121	121	3,003	3,018	3,018	17	17	17	3	3	3	795	798	798	815	817	817	3,818	3,835	3,835
		asthma attacks	2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	1	1	1	1	1	1	3	3	3
		RRAD	105	106	106	38	38	38	6	6	6	149	150	150	1	1	1	0	0	0	39	40	40	40	41	41	189	190	190
Total for NOx and NH3 emissions			8,195	8,234	8,234	2,955	2,972	2,972	462	464	464	11,605	11 664	11 664	64	64	64	12	12	12	3,060	3,070	3,070	3,136	3,146	3,146	14,733	14,801	14,801
PM2.5	PM2 5	mortality	1,017	1,116	5 394	515	552	1,988	143	146	372	1,675	1,813	7 750	207	208	260	36	37	83	4,068	4,087	7,229	4,311	4 332	7,572	5,983	6,142	15 301
		chronic illness	398	443	1,921	198	214	710	55	56	134	652	714	2 765	81	81	99	14	14	30	1,527	1,535	2,621	1 622	1 631	2,750	2,274	2,344	5,515
		asthma attacks	0	0	2	0	0	1	0	0	0	1	1	2	0	0	0	0	0	0	1	1	2	1	1	2	2	2	5
		RRAD	19	21	101	10	10	37	3	3	7	32	34	145	4	4	5	1	1	2	76	77	135	81	81	141	112	115	286
		lung cancer	23	23	23	12	12	12	3	3	3	38	38	38	2	2	2	0	0	0	41	41	41	44	44	44	82	82	82
Coarse PM10	coarse PM10	mortality	66	89	1,172	28	35	398	7	8	65	101	132	1,635	3	3	16	0	1	12	42	45	841	45	49	870	146	180	2,504
		chronic illness	26	38	406	11	14	138	3	3	22	39	55	566	1	1	6	0	0	4	16	17	288	17	19	298	56	74	864
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		RRAD	1	2	22	1	1	7	0	0	1	2	3	31	0	0	0	0	0	0	1	1	16	1	1	16	3	3	47
Total for direct PM10 emissions			1,551	1,732	9 041	774	839	3,291	214	219	605	2,539	2,790	12,932	298	300	389	52	54	132	5,773	5,804	11 174	6,123	6,157	11,694	8 659	8,943	24,604
SOx, NH3	sulfate PM10	mortality	773	1 094	1,094	292	442	442	45	60	60	1,110	1 595	1,595	68	70	70	14	16	16	1 286	1,379	1,379	1,368	1,466	1,466	2,478	3,060	3,060
		chronic illness	278	381	381	104	152	152	16	21	21	398	553	553	25	25	25	5	6	6	442	471	471	472	502	502	869	1,056	1 056
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		RRAD	14	20	20	5	8	8	1	1	1	20	29	29	1	1	1	0	0	0	23	25	25	25	27	27	45	55	55
Total for SOx and NH3 emissions			1,066	1,495	1,495	401	602	602	61	81	81	1,528	2,178	2,178	94	97	97	19	22	22	1,752	1,876	1,876	1,866	1 995	1,995	3,393	4,172	4,172
VOCs	organic PM10	mortality	342	420	420	134	167	167	38	42	42	514	629	629	1	1	1	0	1	1	74	94	94	76	96	96	589	725	725
	(SOA)	chronic illness	131	155	155	50	61	61	15	16	16	196	231	231	0	0	0	0	0	0	28	34	34	29	35	35	225	266	266
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	6	8	8	2	3	3	1	1	1	10	12	12	0	0	0	0	0	0	1	2	2	1	2	2	11	13	13
	acetaldehyde	oral cancer	1	1	1	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
	benzene	leukemia	12	12	12	5	5	5	1	1	1	17	17	17	0	0	0	0	0	0	1	1	1	1	1	1	18	18	18
	1,3-butadiene	cancer all sites	40	40	40	16	16	16	3	3	3	59	59	59	0	0	0	0	0	0	1	1	1	1	1	1	60	60	60
	fomaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Sub-total for VOC emissions			533	636	636	208	253	253	57	62	62	798	950	950	1	2	2	0	1	1	106	132	132	107	135	135	905	1,085	1,085
VOCs, NOx	O3	asthma attacks	23	24	24	9	9	9	1	2	2	33	35	35	0	0	0	0	0	0	5	5	5	5	6	6	39	40	40
		lower resp illness	43	45	45	16	17	17	3	3	3	63	65	65	0	0	0	0	0	0	10	10	10	10	10	10	73	75	75
		upper resp illness	13	14	14	5	5	5	1	1	1	19	20	20	0	0	0	0	0	0	3	3	3	3	3	3	22	23	23
		eye irritation	32	33	33	12	13	13	2	2	2	46	48	48	0	0	0	0	0	0	7	7	7	7	8	8	53	55	55
Subtotal mortality effects			8,192	8,739	14,101	3,137	3,377	5,177	575	599	882	11,898	12,709	20 149	323	326	392	59	63	121	7 571	7,712	11,650	7,953	8,102	12,162	19,841	20,799	32,282
Subtotal cancer effects			76	76	76	33	33	33	7	7	7	117	117	117	2	2	2	0	0	0	43	43	43	46	46	46	162	162	162
Subtotal chronic morbidity effects			2,959	3,152	4,998	1,120	1,203	1,822	209	217	314	4,288	4,571	7 133	124	125	148	22	24	44	2,809	2,855	4,212	2,955	3,004	4,403	7,243	7,575	11 536
Subtotal acute morbidity effects			805	821	923	297	304	338	52	53	58	1,153	1,177	1,318	9	10	11	2	2	3	302	305	380	313	317	394	1,464	1,492	1,709
Subtotal ambient PM10			10,948	11,698	19,007	4,191	4 518	6,970	771	803	1 189	15,904	17 012	27,155	454	459	549	83	88	167	10,560	10,750	16,119	11,097	11,297	16,834	26,990	28,298	43,959
Subtotal ambient O3			112	116	116	43	44	44	7	8	8	161	167	167	1	1	1	0	0	0	25	26	26	26	27	27	187	194	194
Subtotal ambient NO2			344	346	346	125	126	126	19	20	20	488	490	490	3	3	3	1	1	1	130	130	130	133	133	133	620	623	623
Subtotal ambient CO			575	576	576	208	208	208	42	42	42	824	825	825	0	0	0	0	0	0	9	9	9	9	9	9	833	834	834
Total all emissions, pollutants, effects			12,032	12,789	20,097	4,588	4,917	7,370	843	875	1,261	17,456	18,574	28,716	458	463	552	84	89	168	10,725	10,916	16,285	11,267	11,468	17,005	28,711	30,030	45,690

TABLE 11-A 7 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (U..S URBAN 1990) (LOWER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	27	27	27	10	10	10	2	2	2	38	38	38	0	0	0	0	0	0	0	0	0	0	0	0	39	39	39
		hospitalization	4	4	4	2	2	2	0	0	0	6	6	6	0	0	0	0	0	0	0	0	0	0	0	0	6	6	6
		headaches	29	29	29	10	10	10	2	2	2	40	40	40	0	0	0	0	0	0	0	0	0	0	0	0	41	41	41
NOx	NO2	sore throat	33	34	34	12	12	12	1	1	1	47	47	47	0	0	0	0	0	0	10	10	10	10	10	10	57	57	57
		excess phlegm	15	15	15	5	5	5	1	1	1	21	21	21	0	0	0	0	0	0	4	4	4	4	5	5	25	25	25
		eye irritation	13	14	14	5	5	5	1	1	1	19	19	19	0	0	0	0	0	0	4	4	4	4	4	4	23	23	23
NOx, NH3	nitrate PM10	mortality	328	331	331	118	119	119	15	15	15	461	466	466	3	3	3	1	1	1	96	97	97	100	100	100	561	566	566
		chronic illness	94	95	95	34	34	34	4	4	4	132	133	133	1	1	1	0	0	0	28	28	28	29	29	29	161	162	162
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	16	16	16	6	6	6	1	1	1	23	23	23	0	0	0	0	0	0	5	5	5	5	5	5	28	28	28
Total for NOxand NH3emissions			501	505	505	180	182	182	22	22	22	702	710	710	5	5	5	1	1	1	147	148	148	152	153	153	854	863	863
PM2.5	PM2 5	mortality	65	74	89	33	37	42	6	6	7	104	117	138	13	13	14	2	2	3	171	174	185	187	189	201	291	307	338
		chronic illness	19	22	25	10	11	12	2	2	2	31	34	40	4	4	4	1	1	1	49	50	52	54	54	57	84	89	97
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	3	4	4	2	2	2	0	0	0	5	6	7	1	1	1	0	0	0	8	9	9	9	9	10	14	15	17
		lung cancer	1	1	1	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	2	2	2	2	2	2	4	4	4
Coarse PM10	coarse PM10	mortality	21	24	100	9	10	36	2	2	6	32	35	141	1	1	2	0	0	1	9	10	66	10	11	69	42	46	210
		chronic illness	6	7	26	3	3	9	0	0	1	9	10	36	0	0	0	0	0	0	3	3	17	3	3	17	12	13	54
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	1	1	5	0	0	2	0	0	0	2	2	7	0	0	0	0	0	0	0	0	3	0	1	3	2	2	10
Total for direct PM10emissions			118	132	250	57	64	103	10	11	17	185	207	371	19	19	21	3	3	5	243	247	334	265	269	359	450	476	730
SOx, NH3	sulfate PM10	mortality	98	161	161	37	68	68	4	7	7	138	235	235	9	9	9	2	2	2	107	125	125	118	136	136	256	371	371
		chronic illness	28	43	43	10	18	18	1	2	2	39	63	63	2	3	3	0	1	1	29	33	33	32	36	36	71	100	100
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	5	8	8	2	3	3	0	0	0	7	12	12	0	0	0	0	0	0	5	6	6	6	7	7	13	18	18
Total for SOxand NH3emissions			130	212	212	49	90	90	5	9	9	184	310	310	12	12	12	2	3	3	142	165	165	156	180	180	340	490	490
VOCs	organic PM10 (SOA)	mortality	29	41	41	11	17	17	2	3	3	42	61	61	0	0	0	0	0	0	4	7	7	4	7	7	46	68	68
		chronic illness	8	11	11	3	4	4	1	1	1	12	16	16	0	0	0	0	0	0	1	2	2	1	2	2	13	18	18
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	1	2	2	1	1	1	0	0	0	2	3	3	0	0	0	0	0	0	0	0	0	0	0	0	2	3	3
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
	1 3-butadiene	cancer all sites	2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3
	fomaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			41	57	57	16	23	23	3	4	4	60	84	84	0	0	0	0	0	0	6	10	10	6	10	10	66	94	94
VOCs, NOx	O3	asthma attacks	1	1	1	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
		lower resp illness	5	5	5	2	2	2	0	0	0	7	7	7	0	0	0	0	0	0	1	1	1	1	1	1	8	8	8
		upper resp illness	1	2	2	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
		eye irritation	5	5	5	2	2	2	0	0	0	7	8	8	0	0	0	0	0	0	1	1	1	1	1	1	8	9	9
Subtotal mortality effects			569	658	749	217	261	291	30	34	39	816	952	1 079	26	26	28	5	5	6	388	413	490	419	445	514	1 235	1,397	1,593
Subtotal cancer effects			4	4	4	2	2	2	0	0	0	5	5	5	0	0	0	0	0	0	2	2	2	2	2	2	8	8	8
Subtotal chronic morbidity effects			156	178	201	59	70	78	8	9	10	223	258	289	8	8	8	1	2	2	109	115	132	118	125	142	342	382	431
Subtotal acute morbidity effects			134	140	145	49	52	54	7	7	7	189	199	205	2	2	2	0	0	0	40	42	45	42	44	48	232	243	253
Subtotal ambient PM10			726	842	960	278	335	374	38	43	49	1 042	1,219	1,384	35	35	37	6	7	8	519	551	638	560	593	683	1,601	1,812	2,066
Subtotal ambient O3			12	13	13	5	5	5	1	1	1	18	19	19	0	0	0	0	0	0	2	2	2	2	2	2	20	22	22
Subtotal ambient NO2			62	62	62	22	23	23	3	3	3	86	87	87	1	1	1	0	0	0	18	18	18	19	19	19	105	106	106
Subtotal ambient CO			60	60	60	21	21	21	3	3	3	85	85	85	0	0	0	0	0	0	1	1	1	1	1	1	86	86	86
Total all emissions, pollutants, effects			862	980	1 098	327	385	424	44	50	56	1,234	1,414	1,579	35	36	38	7	7	9	540	572	659	582	615	705	1,816	2,029	2,284

TABLE 11-A 8. COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (U S URBAN 1990) (UPPER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	328	328	328	117	117	117	23	23	23	468	469	469	0	0	0	0	0	0	5	5	5	5	5	5	473	474	474
		hospitalization	13	13	13	5	5	5	1	1	1	19	19	19	0	0	0	0	0	0	0	0	0	0	0	0	19	19	19
		headaches	167	167	167	60	60	60	12	12	12	239	239	239	0	0	0	0	0	0	2	3	3	3	3	3	241	241	241
NOx	NO2	sore throat	175	176	176	63	63	63	10	10	10	247	249	249	1	1	1	0	0	0	65	65	65	66	66	66	313	315	315
		excess phlegm	77	78	78	28	28	28	4	4	4	109	110	110	1	1	1	0	0	0	29	29	29	29	29	29	138	139	139
		eye irritation	71	71	71	25	26	26	4	4	4	100	101	101	1	1	1	0	0	0	26	26	26	27	27	27	127	127	127
NOx, NH3	nitrate PM10	mortality	5,332	5,357	5,357	1,912	1,923	1,923	295	296	296	7,534	7,571	7,571	41	42	42	8	8	8	1,949	1,955	1,955	1,998	2,004	2,004	9 525	9 569	9 569
		chronic illness	2,090	2,100	2,100	743	747	747	118	119	119	2,951	2,965	2,965	16	16	16	3	3	3	777	779	779	796	798	798	3,747	3,763	3,763
		asthma attacks	2	2	2	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	1	1	1	1	1	1	3	3	3
		RRAD	101	101	101	36	36	36	6	6	6	143	143	143	1	1	1	0	0	0	37	37	37	38	38	38	181	181	181
Total for NOxand NH3emissions			7,848	7,885	7,885	2,808	2,824	2,824	437	439	439	11,087	11,141	11,141	61	61	61	12	12	12	2,882	2,891	2,891	2,955	2,964	2,964	14,034	14,098	14,098
PM2.5	PM2 5	mortality	971	1,065	4,766	487	522	1,765	134	137	332	1,592	1,724	6,859	198	199	244	35	35	75	3,769	3,787	6,505	4 001	4 020	6,823	5,591	5 741	13 663
		chronic illness	393	437	1,847	195	211	684	54	55	129	641	702	2,659	80	80	97	14	14	29	1,488	1,496	2,532	1,582	1,590	2,659	2,223	2,292	5,318
		asthma attacks	0	0	2	0	0	1	0	0	0	1	1	2	0	0	0	0	0	0	1	1	2	1	1	2	2	2	4
		RRAD	18	20	92	9	10	34	3	3	6	30	33	132	4	4	5	1	1	1	72	72	124	76	76	130	106	109	262
		lung cancer	20	20	20	10	10	10	3	3	3	33	33	33	2	2	2	0	0	0	36	36	36	38	38	38	71	71	71
Coarse PM10	coarse PM10	mortality	63	86	1,011	26	33	343	7	7	56	96	126	1,410	3	3	14	0	1	11	39	42	722	42	45	747	138	171	2,156
		chronic illness	25	37	387	10	14	131	3	3	21	39	54	540	1	1	5	0	0	4	15	17	274	17	18	284	55	73	824
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		RRAD	1	2	20	0	1	7	0	0	1	2	2	27	0	0	0	0	0	0	1	1	14	1	1	14	3	3	42
Total for direct PM10emissions			1,492	1,667	8,145	739	801	2,975	203	208	550	2,434	2,676	11,664	287	288	368	50	51	121	5,422	5,451	10,209	5,758	5,791	10,697	8,189	8,463	22,341
SOx, NH3	sulfate PM10	mortality	737	1 029	1,029	276	412	412	42	55	55	1,054	1,496	1,496	65	67	67	13	15	15	1 186	1,270	1,270	1,264	1 352	1,352	2,318	2,848	2,848
		chronic illness	274	373	373	102	147	147	15	20	20	391	540	540	24	25	25	5	6	6	430	458	458	459	489	489	850	1,029	1,029
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		RRAD	14	19	19	5	8	8	1	1	1	19	27	27	1	1	1	0	0	0	22	23	23	23	25	25	43	52	52
Total for SOxand NH3emissions			1,025	1,421	1,421	383	567	567	58	77	77	1,465	2,064	2,064	91	93	93	18	21	21	1,638	1,752	1,752	1 747	1,866	1,866	3,212	3,930	3,930
VOCs	organic PM10	mortality	327	399	399	127	158	158	36	39	39	490	597	597	1	1	1	0	1	1	70	88	88	71	90	90	560	687	687
	(SOA)	chronic illness	129	152	152	50	60	60	14	16	16	193	227	227	0	0	0	0	0	0	28	33	33	28	34	34	221	261	261
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	6	7	7	2	3	3	1	1	1	9	11	11	0	0	0	0	0	0	1	2	2	1	2	2	11	13	13
	acetaldehyde	oral cancer	1	1	1	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
	benzene	leukemia	10	10	10	4	4	4	1	1	1	15	15	15	0	0	0	0	0	0	0	0	0	0	0	0	16	16	16
	1,3-butadiene	cancer all sites	35	35	35	14	14	14	2	2	2	51	51	51	0	0	0	0	0	0	1	1	1	1	1	1	52	52	52
	fomaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Sub-total for VOC emissions			509	606	606	197	239	239	54	59	59	760	904	904	1	2	2	0	1	1	100	125	125	102	127	127	862	1,031	1,031
VOCs, NOx	O3	asthma attacks	21	22	22	8	8	8	1	1	1	31	32	32	0	0	0	0	0	0	5	5	5	5	5	5	35	37	37
		lower resp illness	40	41	41	15	16	16	3	3	3	58	60	60	0	0	0	0	0	0	8	9	9	9	9	9	67	69	69
		upper resp illness	12	13	13	5	5	5	1	1	1	18	18	18	0	0	0	0	0	0	3	3	3	3	3	3	20	21	21
		eye irritation	31	32	32	12	12	12	2	2	2	44	46	46	0	0	0	0	0	0	7	7	7	7	7	7	51	52	52
Subtotal mortality effects			7,758	8,265	12,891	2,945	3,166	4 718	537	558	803	11,234	11,982	18,402	308	311	368	56	60	109	7,017	7,147	10,545	7,381	7,517	11,021	18,605	19,489	29,396
Subtotal cancer effects			67	67	67	29	29	29	6	6	6	102	102	102	2	2	2	0	0	0	37	37	37	40	40	40	141	141	141
Subtotal chronic morbidity effects			2,911	3099	4,859	1 099	1 178	1 769	204	212	305	4,215	4 489	6,932	122	123	145	22	23	42	2,738	2,783	4,076	2,882	2,929	4 263	7,097	7,419	11,196
Subtotal acute morbidity effects			750	766	856	274	281	311	48	48	53	1,071	1,093	1,219	9	9	10	2	2	3	279	283	349	290	294	362	1,360	1,386	1,579
Subtotal ambient PM10			10,505	11 208	17,685	3,992	4,296	6,469	731	760	1 102	15,221	16,257	25 246	437	442	521	79	84	154	9,922	10,098	14,856	10,438	10,624	15,531	25,649	26,871	40 748
Subtotal ambient O3			104	108	108	39	41	41	7	7	7	150	156	156	0	1	1	0	0	0	22	23	23	23	23	23	173	179	179
Subtotal ambient NO2			323	325	325	116	117	117	18	18	18	457	459	459	3	3	3	0	0	0	119	120	120	122	123	123	578	581	581
Subtotal ambient CO			508	508	508	181	181	181	36	36	36	725	726	726	0	0	0	0	0	0	8	8	8	8	8	8	733	734	734
Total all emissions, pollutants, effects			11,487	12,196	18,673	4,347	4,653	6,827	795	825	1,167	16,622	17,666	26,655	441	446	525	80	85	155	10,072	10,250	15,008	10,592	10,780	15,686	27,203	28,434	42,312

TABLE 11-A 9 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (U S RURAL 1990) (LOWER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	3	3	3	1	1	1	0	0	0	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	5	5	5
		hospitalization	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		headaches	3	3	3	1	1	1	0	0	0	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	4	4	4
NOx	NO2	sore throat	2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	1	1	1	1	1	1	4	4	4
		excess phlegm	1	1	1	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
		eye irritation	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
NOx, NH3	nitrate PM10	mortality	15	15	15	6	6	6	1	1	1	23	23	23	0	0	0	0	0	0	7	7	7	7	7	7	29	30	30
		chronic illness	2	2	2	1	1	1	0	0	0	2	3	3	0	0	0	0	0	0	1	1	1	1	1	1	3	3	3
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
Total for NOxand NH3emissions			22	22	22	9	9	9	1	1	1	33	33	33	0	0	0	0	0	0	10	10	10	10	10	10	43	43	43
PM2.5	PM2 5	mortality	3	3	6	2	2	3	0	0	1	5	5	9	1	1	1	0	0	0	12	12	14	13	13	15	18	18	24
		chronic illness	0	0	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	1	2	1	1	2	2	2	3
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
		lung cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Coarse PM10	coarse PM10	mortality	1	1	16	0	0	5	0	0	1	1	2	22	0	0	0	0	0	0	1	1	11	1	1	12	2	2	34
		chronic illness	0	0	2	0	0	1	0	0	0	0	0	3	0	0	0	0	0	0	0	0	1	0	0	1	0	0	4
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	2
Total for direct PM10emissions			4	5	25	2	3	10	1	1	2	7	8	37	1	1	1	0	0	0	15	16	31	16	17	32	24	25	69
SOx, NH3	sulfate PM10	mortality	4	8	8	2	4	4	0	0	0	6	13	13	0	0	0	0	0	0	8	10	10	9	10	10	15	23	23
		chronic illness	0	1	1	0	1	1	0	0	0	1	2	2	0	0	0	0	0	0	1	1	1	1	1	1	2	3	3
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
Total for SOxand NH3emissions			5	10	10	2	5	5	0	1	1	7	16	16	0	0	0	0	0	0	10	11	11	10	12	12	17	27	27
VOCs	organic PM10 (SOA)	mortality	1	2	2	1	1	1	0	0	0	2	3	3	0	0	0	0	0	0	0	0	0	0	0	0	2	3	3
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1,3-butadiene	cancer all sites	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	formaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub total for VOC emissions			2	3	3	1	1	1	0	0	0	3	4	4	0	0	0	0	0	0	0	1	1	0	1	1	3	4	4
VOCs, NOx	O3	asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lower resp illness	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		upper resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		eye irritation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Subtotal mortality effects			27	33	50	12	15	21	2	2	3	41	50	74	1	1	1	0	0	0	28	30	42	29	31	44	71	81	118
Subtotal cancer effects			1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Subtotal chronic morbidity effects			3	4	6	1	2	2	0	0	0	4	6	8	0	0	0	0	0	0	3	3	5	3	3	5	7	9	14
Subtotal acute morbidity effects			10	10	11	4	4	5	1	1	1	14	15	17	0	0	0	0	0	0	4	4	5	4	4	5	18	19	22
Subtotal ambient PM10			28	35	56	13	16	23	2	2	3	43	54	82	1	1	2	0	0	1	33	35	50	35	37	52	78	91	135
Subtotal ambient O3			1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
Subtotal ambient NO2			4	4	4	2	2	2	0	0	0	6	6	6	0	0	0	0	0	0	2	2	2	2	2	2	8	8	8
Subtotal ambient CO			6	6	6	2	2	2	0	0	0	9	9	9	0	0	0	0	0	0	0	0	0	0	0	0	9	9	9
Total all emissions, pollutants, effects			40	47	67	17	21	28	3	3	4	60	71	100	1	1	2	0	0	1	35	37	52	37	39	55	97	111	154

TABLE 11-A 10 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (U S RURAL 1990) (UPPER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	46	47	47	18	18	18	4	4	4	68	68	68	0	0	0	0	0	0	1	1	1	1	1	1	69	69	69
		hospitalization	2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3
		headaches	19	19	19	7	7	7	1	1	1	28	28	28	0	0	0	0	0	0	0	0	0	0	0	0	28	28	28
NOx	NO2	sore throat	11	11	11	5	5	5	1	1	1	16	17	17	0	0	0	0	0	0	6	6	6	6	6	6	22	22	22
		excess phlegm	5	5	5	2	2	2	0	0	0	8	8	8	0	0	0	0	0	0	3	3	3	3	3	3	10	10	10
		eye irritation	5	5	5	2	2	2	0	0	0	7	7	7	0	0	0	0	0	0	2	2	2	2	2	2	9	9	9
NOx, NH3	nitrate PM10	mortality	286	289	289	122	123	123	21	21	21	428	432	432	2	2	2	0	0	0	146	147	147	149	149	149	577	581	581
		chronic illness	35	35	35	15	15	15	3	3	3	52	53	53	0	0	0	0	0	0	19	19	19	19	19	19	71	72	72
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	4	4	4	2	2	2	0	0	0	6	6	6	0	0	0	0	0	0	2	2	2	2	2	2	9	9	9
Total for NOxand NH3emissions			346	349	349	147	148	148	25	25	25	518	522	522	2	3	3	1	1	1	178	178	178	181	181	181	699	704	704
PM2.5	PM2 5	mortality	46	51	628	27	30	223	9	9	40	83	90	890	9	9	16	2	2	8	299	300	724	310	311	749	393	401	1,638
		chronic illness	6	7	74	3	4	26	1	1	5	10	12	105	1	1	2	0	0	1	39	39	89	41	41	92	51	52	197
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	1	1	9	0	0	3	0	0	1	1	1	13	0	0	0	0	0	0	4	5	11	5	5	11	6	6	24
		lung cancer	3	3	3	2	2	2	1	1	1	5	5	5	0	0	0	0	0	0	5	5	5	6	6	6	11	11	11
Coarse PM10	coarse PM10	mortality	3	4	161	1	2	55	0	0	9	5	6	225	0	0	2	0	0	2	3	3	119	3	3	123	8	9	348
		chronic illness	0	1	19	0	0	6	0	0	1	1	1	26	0	0	0	0	0	0	0	0	14	0	0	14	1	1	41
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	2	0	0	1	0	0	0	0	0	3	0	0	0	0	0	0	0	0	2	0	0	2	0	0	5
Total for direct PM10emissions			59	65	896	35	37	316	11	12	56	105	114	1,268	11	11	21	2	2	11	352	353	964	365	366	997	470	481	2,264
SOx, NH3	sulfate PM10	mortality	37	64	64	16	30	30	3	4	4	56	99	99	3	3	3	1	1	1	101	109	109	105	113	113	160	212	212
		chronic illness	4	8	8	2	4	4	0	1	1	6	13	13	0	0	0	0	0	0	12	13	13	12	14	14	19	27	27
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	2	2	2	2	2	2	2	3	3
Total for SOxand NH3emissions			41	74	74	18	35	35	3	5	5	63	114	114	4	4	4	1	1	1	114	124	124	119	129	129	181	242	242
VOCs	organic PM10 (SOA)	mortality	15	21	21	7	9	9	2	2	2	24	32	32	0	0	0	0	0	0	5	6	6	5	6	6	29	38	38
		chronic illness	2	2	2	1	1	1	0	0	0	3	4	4	0	0	0	0	0	0	1	1	1	1	1	1	4	5	5
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	1	1	1	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
	1 3-butadiene	cancer all sites	5	5	5	2	2	2	0	0	0	8	8	8	0	0	0	0	0	0	0	0	0	0	0	0	8	8	8
	fomaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			24	30	30	11	13	13	3	3	3	37	46	46	0	0	0	0	0	0	6	7	7	6	7	7	43	54	54
VOCs, NOx	O3	asthma attacks	2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	1	1	1	1	1	1	3	3	3
		lower resp illness	3	3	3	1	1	1	0	0	0	5	5	5	0	0	0	0	0	0	1	1	1	1	1	1	6	7	7
		upper resp illness	1	1	1	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
		eye irritation	2	2	2	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	1	1	1	1	1	1	3	3	3
Subtotal mortality effects			434	475	1,209	192	212	458	39	40	79	664	726	1 746	15	15	24	3	3	11	554	566	1,106	572	584	1,141	1,236	1,311	2,887
Subtotal cancer effects			9	9	9	5	5	5	1	1	1	15	15	15	0	0	0	0	0	0	6	6	6	6	6	6	21	21	21
Subtotal chronic morbidity effects			47	53	139	21	24	53	4	5	9	73	82	201	2	2	3	0	0	1	71	72	135	73	75	140	146	157	341
Subtotal acute morbidity effects			55	56	67	23	23	27	4	4	5	82	84	99	0	0	1	0	0	0	22	23	31	23	23	31	105	107	130
Subtotal ambient PM10			443	490	1 322	199	222	501	40	43	87	683	755	1 909	17	17	27	4	4	13	638	651	1,262	659	673	1,303	1,341	1,427	3,211
Subtotal ambient O3			8	8	8	3	3	3	1	1	1	11	12	12	0	0	0	0	0	0	3	3	3	3	3	3	14	15	15
Subtotal ambient NO2			21	21	21	9	9	9	1	1	1	31	31	31	0	0	0	0	0	0	11	11	11	11	11	11	42	42	42
Subtotal ambient CO			67	67	67	26	26	26	5	5	5	99	99	99	0	0	0	0	0	0	1	1	1	1	1	1	100	100	100
Total all emissions, pollutants, effects			545	593	1,424	240	264	543	48	50	94	834	907	2,061	17	18	28	4	4	13	653	667	1,278	674	688	1,318	1,508	1,595	3,378

TABLE 11-A 11 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (BOSTON MSA 1990) (LOWER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		hospitalization	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		headaches	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
NOx	NO2	sore throat	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
		excess phlegm	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		eye irritation	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
NOx, NH3	nitrate PM10	mortality	9	9	9	3	3	3	0	0	0	12	12	12	0	0	0	0	0	0	2	2	2	2	2	2	14	14	14
		chronic illness	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Total for NOxand NH3emissions			12	12	12	4	4	4	0	0	0	16	16	16	0	0	0	0	0	0	3	3	3	3	3	3	19	19	19
PM2.5	PM2 5	mortality	2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	4	4	5	5	5	5	7	7	8
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lung cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coarse PM10	coarse PM10	mortality	1	1	3	0	0	1	0	0	0	1	1	4	0	0	0	0	0	0	0	0	2	0	0	2	1	1	6
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for direct PM10emissions			2	3	6	1	1	2	0	0	0	4	4	8	0	0	0	0	0	0	5	5	7	6	6	8	10	10	16
SOx, NH3	sulfate PM10	mortality	3	3	3	1	1	1	0	0	0	4	5	5	0	0	0	0	0	0	3	3	3	3	4	4	7	8	8
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for SOxand NH3emissions			3	4	4	1	1	1	0	0	0	5	5	5	0	0	0	0	0	0	4	4	4	4	4	4	8	9	9
VOCs	organic PM10 (SOA)	mortality	1	1	1	0	0	0	0	0	0	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1,3-butadiene	cancer all sites	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	formaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			1	1	1	0	1	1	0	0	0	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2
VOCs, NOx	O3	asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lower resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		upper resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		eye irritation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal mortality effects			15	16	19	6	6	7	1	1	1	22	23	27	1	1	1	0	0	0	10	10	12	11	11	13	33	34	40
Subtotal cancer effects			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal chronic morbidity effects			1	1	1	0	0	1	0	0	0	2	2	2	0	0	0	0	0	0	1	1	1	1	1	1	2	3	3
Subtotal acute morbidity effects			4	4	4	1	2	2	0	0	0	6	6	6	0	0	0	0	0	0	1	1	1	1	1	1	7	7	7
Subtotal ambient PM10			16	17	20	6	7	8	1	1	1	23	24	29	1	1	1	0	0	0	11	12	14	12	12	15	35	37	43
Subtotal ambient O3			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Subtotal ambient NO2			2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	1	1	1	1	1	1	3	3	3
Subtotal ambient CO			2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3
Total all emissions, pollutants, effects			21	21	24	8	8	9	1	1	1	29	30	35	1	1	1	0	0	0	12	12	14	13	13	15	42	44	50

TABLE 11-A 12 COST OF AIR POLLUTION ATTRIBUTABI F TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (BOSTON MSA 1990) (UPPER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	11	11	11	4	4	4	1	1	1	16	16	16	0	0	0	0	0	0	0	0	0	0	0	0	16	16	16
		hospitalization	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		headaches	5	5	5	2	2	2	0	0	0	7	7	7	0	0	0	0	0	0	0	0	0	0	0	0	8	8	8
NOx	NO2	sore throat	5	5	5	2	2	2	0	0	0	7	7	7	0	0	0	0	0	0	2	2	2	2	2	2	9	9	9
		excess phlegm	2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	1	1	1	1	1	1	4	4	4
		eye irritation	2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	1	1	1	1	1	1	4	4	4
NOx, NH3	nitrate PM10	mortality	140	140	140	50	50	50	7	7	7	197	197	197	1	1	1	0	0	0	47	47	47	48	48	48	245	245	245
		chronic illness	22	22	22	8	8	8	1	1	1	30	30	30	0	0	0	0	0	0	7	7	7	7	7	7	38	38	38
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	3	3	3	1	1	1	0	0	0	4	4	4	0	0	0	0	0	0	1	1	1	1	1	1	4	4	4
Total for NOx and NH3 emissions			173	173	173	62	62	62	9	9	9	244	245	245	1	1	1	0	0	0	59	59	59	60	60	60	304	305	305
PM2.5	PM2.5	mortality	26	26	126	13	13	47	4	4	9	42	42	182	5	5	6	1	1	2	101	101	175	107	107	183	149	149	365
		chronic illness	4	4	19	2	2	7	1	1	1	6	6	28	1	1	1	0	0	0	15	15	27	16	16	28	23	23	56
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	2	0	0	1	0	0	0	1	1	3	0	0	0	0	0	0	2	2	3	2	2	3	3	3	7
		lung cancer	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2
Coarse PM10	coarse PM10	mortality	2	2	27	1	1	9	0	0	2	2	2	38	0	0	0	0	0	0	1	1	20	1	1	21	4	4	59
		chronic illness	0	0	4	0	0	1	0	0	0	0	0	6	0	0	0	0	0	0	0	0	3	0	0	3	1	1	9
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Total for direct PM10 emissions			32	33	181	16	16	66	4	4	12	53	53	259	6	6	8	1	1	3	120	120	229	128	128	240	181	181	498
SOx, NH3	sulfate PM10	mortality	23	24	24	9	9	9	1	1	1	33	35	35	2	2	2	0	0	0	38	38	38	41	41	41	73	76	76
		chronic illness	4	4	4	1	1	1	0	0	0	5	5	5	0	0	0	0	0	0	6	6	6	6	6	6	11	12	12
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
Total for SOx and NH3 emissions			27	28	28	10	11	11	2	2	2	39	41	41	2	2	2	0	0	0	45	45	45	47	48	48	86	89	89
VOCs	organic PM10 (SOA)	mortality	8	10	10	3	4	4	1	1	1	12	15	15	0	0	0	0	0	0	2	2	2	2	2	2	14	17	17
		chronic illness	1	2	2	0	1	1	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	3	3
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1,3-butadiene	cancer all sites	1	1	1	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
	fomaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			11	13	13	4	5	5	1	1	1	16	19	19	0	0	0	0	0	0	2	3	3	2	3	3	18	22	22
VOCs, NOx	O3	asthma attacks	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		lower resp illness	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
		upper resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		eye irritation	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Subtotal mortality effects			209	212	339	79	81	123	14	14	21	302	307	482	8	8	10	2	2	3	189	190	283	199	200	296	500	507	778
Subtotal cancer effects			2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	1	1	1	1	1	1	4	4	4
Subtotal chronic morbidity effects			30	31	50	12	12	18	2	2	3	44	45	72	1	1	2	0	0	0	29	29	43	30	31	45	75	75	117
Subtotal acute morbidity effects			21	22	24	8	8	9	1	1	1	31	31	34	0	0	0	0	0	0	7	7	9	8	8	10	38	39	44
Subtotal ambient PM10			232	236	384	88	90	140	16	16	24	336	343	548	10	10	12	2	2	3	222	223	332	234	235	347	570	577	895
Subtotal ambient O3			3	3	3	1	1	1	0	0	0	4	4	4	0	0	0	0	0	0	0	1	1	1	1	1	4	4	4
Subtotal ambient NO2			10	10	10	3	3	3	1	1	1	14	14	14	0	0	0	0	0	0	3	3	3	3	3	3	17	17	17
Subtotal ambient CO			17	17	17	6	6	6	1	1	1	24	24	24	0	0	0	0	0	0	0	0	0	0	0	0	24	24	24
Total all emissions, pollutants, effects			262	267	415	99	101	151	18	18	26	379	386	591	10	10	12	2	2	3	226	228	336	238	239	351	617	625	942

TABLE 11-A 13 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLF EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (DENVER MSA 1990) (LOWER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		hospitalization	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		headaches	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
NOx	NO2	sore throat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		excess phlegm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		eye irritation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NOx, NH3	nitrate PM10	mortality	2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	1	1	1	1	1	1	4	4	4
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for NOxand NH3emissions			3	3	3	1	1	1	0	0	0	4	4	4	0	0	0	0	0	0	1	1	1	1	1	1	5	5	5
PM2.5	PM2 5	mortality	0	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lung cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coarse PM10	coarse PM10	mortality	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for direct PM10emissions			1	1	1	0	0	1	0	0	0	1	1	2	0	0	0	0	0	0	2	2	2	2	2	2	3	3	4
SOx, NH3	sulfate PM10	mortality	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for SOxand NH3emissions			1	1	1	0	0	0	0	0	0	1	2	2	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2
VOCs	organic PM10 (SOA)	mortality	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1,3-butadiene	cancer all sites	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	fomaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
VOCs, NOx	O3	asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lower resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		upper resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		eye irritation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal mortality effects			4	5	5	2	2	2	0	0	0	6	7	7	0	0	0	0	0	0	3	3	3	3	3	3	9	10	11
Subtotal cancer effects			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal chronic morbidity effects			1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Subtotal acute morbidity effects			1	1	1	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
Subtotal ambient PM10			4	5	6	2	2	2	0	0	0	6	7	8	0	0	0	0	0	0	3	3	4	3	4	4	10	11	12
Subtotal ambient O3			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal ambient NO2			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Subtotal ambient CO			1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Total all emissions, pollutants, effects			6	6	7	2	2	3	0	0	0	8	9	10	0	0	0	0	0	0	3	4	4	4	4	4	12	13	14

TABLE 11-A 14 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEAI TH EFFECT, $ MILLION (DENVER MSA 1990) (UPPER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDG Is			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	4	4	4	2	2	2	0	0	0	6	6	6	0	0	0	0	0	0	0	0	0	0	0	0	6	6	6
		hospitalization	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		headaches	2	2	2	1	1	1	0	0	0	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	4	4	4
NOx	NO2	sore throat	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
		excess phlegm	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		eye irritation	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
NOx, NH3	nitrate PM10	mortality	30	30	30	10	10	10	1	1	1	42	42	42	0	0	0	0	0	0	11	11	11	11	11	11	53	53	53
		chronic illness	10	10	10	3	3	3	0	0	0	13	14	14	0	0	0	0	0	0	4	4	4	4	4	4	17	17	17
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Total for NOxand NH3emissions			42	43	43	15	15	15	2	2	2	59	59	59	0	0	0	0	0	0	15	15	15	16	16	16	75	75	75
PM2.5	PM2 5	mortality	5	6	26	3	3	9	1	1	2	9	9	37	1	1	1	0	0	0	20	21	35	22	22	37	30	31	74
		chronic illness	2	2	8	1	1	3	0	0	1	3	3	12	0	0	0	0	0	0	7	7	12	7	7	12	10	10	24
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	2
		lung cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Coarse PM10	coarse PM10	mortality	0	0	5	0	0	2	0	0	0	1	1	7	0	0	0	0	0	0	0	0	4	0	0	4	1	1	11
		chronic illness	0	0	2	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	1	0	0	4
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for direct PM10emissions			8	8	42	4	4	15	1	1	3	13	13	60	1	1	2	0	0	1	29	29	53	30	30	56	43	44	116
SOx, NH3	sulfate PM10	mortality	3	4	4	1	1	1	0	0	0	4	5	5	0	0	0	0	0	0	5	5	5	5	5	5	9	10	10
		chronic illness	1	1	1	0	0	0	0	0	0	1	2	2	0	0	0	0	0	0	2	2	2	2	2	2	3	3	3
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for SOxand NH3emissions			4	5	5	1	2	2	0	0	0	6	7	7	0	0	0	0	0	0	6	7	7	7	7	7	12	14	14
VOCs	organic PM10 (SOA)	mortality	2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	1	1	1	1	1	1	4	4	4
		chronic illness	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1 3-butadiene	cancer all sites	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
	fomaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			3	4	4	1	2	2	0	0	0	4	5	5	0	0	0	0	0	0	1	1	1	1	1	1	6	7	7
VOCs NOx	O3	asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lower resp illness	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		upper resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		eye irritation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Subtotal mortality effects			44	46	71	17	17	26	3	3	4	64	66	100	2	2	2	0	0	1	37	37	56	39	39	58	103	105	159
Subtotal cancer effects			1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
Subtotal chronic morbidity effects			13	14	22	5	5	8	1	1	1	19	19	31	1	1	1	0	0	0	12	12	18	13	13	19	31	32	50
Subtotal acute morbidity effects			7	7	7	3	3	3	0	0	0	9	10	11	0	0	0	0	0	0	2	2	2	2	2	3	11	12	13
Subtotal ambient PM10			55	57	91	20	21	33	3	3	5	78	81	128	2	2	3	0	0	1	51	51	76	53	54	79	131	135	207
Subtotal ambient O3			1	1	1	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
Subtotal ambient NO2			2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	1	1	1	1	1	1	3	3	3
Subtotal ambient CO			6	6	6	3	3	3	0	0	0	10	10	10	0	0	0	0	0	0	0	0	0	0	0	0	10	10	10
Total all emissions, pollutants, effects			65	67	100	24	25	37	4	4	6	93	96	143	2	2	3	0	0	1	52	52	77	54	55	80	147	151	223

TABLE 11-A 15 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (HOUSTON MSA 1990) (LOWER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		hospitalization	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		headaches	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
NOx	NO2	sore throat	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		excess phlegm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		eye irritation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NOx, NH3	nitrate PM10	mortality	4	4	4	1	2	2	0	0	0	5	6	6	0	0	0	0	0	0	1	1	1	1	1	1	6	7	7
		chronic illness	1	1	1	0	1	1	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for NOx and NH3 emissions			6	7	7	2	3	3	0	0	0	9	10	10	0	0	0	0	0	0	2	2	2	2	2	2	11	12	12
PM2.5	PM2.5	mortality	1	2	2	0	1	1	0	0	0	1	2	3	0	0	0	0	0	0	2	2	2	2	2	2	3	5	6
		chronic illness	0	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	2
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lung cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coarse PM10	coarse PM10	mortality	0	0	3	0	0	1	0	0	0	0	1	4	0	0	0	0	0	0	0	0	2	0	0	2	0	1	6
		chronic illness	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	2
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for direct PM10 emissions			1	3	7	1	1	3	0	0	0	2	4	10	0	0	0	0	0	0	3	3	6	3	3	6	5	7	16
SOx, NH3	sulfate PM10	mortality	1	4	4	0	1	1	0	0	0	1	5	5	0	0	0	0	0	0	1	2	2	1	2	2	2	7	7
		chronic illness	0	1	1	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	1	1	0	1	1	1	2	2
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for SOx and NH3 emissions			1	5	5	0	2	2	0	0	0	2	7	7	0	0	0	0	0	0	1	2	2	1	2	2	3	9	9
VOCs	organic PM10 (SOA)	mortality	0	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1,3-butadiene	cancer all sites	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	fomaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
VOCs, NOx	O3	asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lower resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		upper resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		eye irritation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal mortality effects			6	11	13	2	4	5	0	1	1	9	15	19	0	0	0	0	0	0	4	5	7	4	5	7	13	20	27
Subtotal cancer effects			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal chronic morbidity effects			2	3	4	1	1	2	0	0	0	3	5	6	0	0	0	0	0	0	1	2	2	1	2	2	4	6	8
Subtotal acute morbidity effects			2	2	3	1	1	1	0	0	0	3	3	4	0	0	0	0	0	0	1	1	1	1	1	1	3	4	4
Subtotal ambient PM10			8	14	18	3	6	7	0	1	1	12	20	26	0	0	0	0	0	0	5	7	10	6	7	10	18	28	36
Subtotal ambient O3			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal ambient NO2			1	1	1	0	0	0	0	0	0	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
Subtotal ambient CO			1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Total all emissions, pollutants, effects			11	16	20	4	6	8	0	1	1	15	24	29	0	0	0	0	0	0	6	7	10	6	8	11	21	31	40

TABLE 11-A 16 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (HOUSTON MSA 1990) (UPPER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	3	3	3	1	1	1	0	0	0	5	5	5	0	0	0	0	0	0	0	0	0	0	0	0	5	5	5
		hospitalization	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		headaches	3	3	3	1	1	1	0	0	0	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	4	4	4
NOx	NO2	sore throat	3	4	4	1	1	1	0	0	0	5	5	5	0	0	0	0	0	0	1	1	1	1	1	1	6	6	6
		excess phlegm	2	2	2	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	1	1	1	1	1	1	3	3	3
		eye irritation	1	1	1	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	0	1	1	1	1	1	2	3	3
NOx, NH3	nitrate PM10	mortality	54	56	56	20	20	20	3	3	3	77	79	79	0	0	0	0	0	0	19	20	20	20	20	20	96	100	100
		chronic illness	39	40	40	14	15	15	2	2	2	55	57	57	0	0	0	0	0	0	14	14	14	14	14	14	69	71	71
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	2	2	2	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	1	1	1	1	1	1	3	3	3
Total for NOx and NH3 emissions			101	105	105	36	38	38	5	6	6	143	148	148	1	1	1	0	0	0	36	36	36	37	37	37	180	186	186
PM2.5	PM2 5	mortality	10	13	77	5	6	28	1	2	5	16	21	109	2	2	3	0	0	1	36	37	84	39	39	88	54	61	197
		chronic illness	7	9	53	3	4	19	1	1	3	11	15	75	1	1	2	0	0	1	26	26	58	28	28	61	39	43	137
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	2	0	0	1	0	0	0	0	1	3	0	0	0	0	0	0	1	1	2	1	1	2	2	2	6
		lung cancer	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2
Coarse PM10	coarse PM10	mortality	1	1	18	0	0	6	0	0	1	1	1	25	0	0	0	0	0	0	0	0	13	0	0	13	1	2	38
		chronic illness	0	1	12	0	0	4	0	0	1	1	1	17	0	0	0	0	0	0	0	0	9	0	0	9	1	1	26
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Total for direct PM10 emissions			19	25	163	9	12	58	3	3	10	30	40	232	4	4	5	1	1	2	65	67	168	69	71	176	100	110	407
SOx, NH3	sulfate PM10	mortality	5	11	11	2	4	4	0	1	1	7	16	16	0	1	1	0	0	0	8	10	10	9	10	10	16	27	27
		chronic illness	4	8	8	1	3	3	0	0	0	5	11	11	0	0	0	0	0	0	6	7	7	6	7	7	12	18	18
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Total for SOx and NH3 emissions			9	19	19	3	8	8	1	1	1	13	28	28	1	1	1	0	0	0	14	17	17	15	18	18	28	46	46
VOCs	organic PM10 (SOA)	mortality	3	4	4	1	2	2	0	0	0	5	6	6	0	0	0	0	0	0	1	1	1	1	1	1	6	7	7
		chronic illness	3	3	3	1	1	1	0	0	0	4	4	4	0	0	0	0	0	0	0	1	1	0	1	1	4	5	5
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
	1,3-butadiene	cancer all sites	1	1	1	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
	formaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			8	9	9	3	3	3	1	1	1	11	13	13	0	0	0	0	0	0	1	1	1	1	1	1	13	15	15
VOCs, NOx	O3	asthma attacks	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		lower resp illness	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2
		upper resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		eye irritation	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Subtotal mortality effects			77	89	170	29	34	61	5	6	10	111	129	241	3	3	4	1	1	1	65	68	127	68	71	132	179	200	373
Subtotal cancer effects			2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	1	1	1	1	1	1	5	5	5
Subtotal chronic morbidity effects			53	61	116	20	23	42	4	4	7	76	88	165	2	2	3	0	0	1	46	48	89	49	51	93	125	139	257
Subtotal acute morbidity effects			14	14	17	5	5	6	1	1	1	20	21	24	0	0	0	0	0	0	5	5	7	5	5	7	24	26	31
Subtotal ambient PM10			129	150	288	49	57	104	9	10	17	187	217	409	5	5	7	1	1	3	114	119	221	120	125	230	307	342	639
Subtotal ambient O3			2	3	3	1	1	1	0	0	0	3	4	4	0	0	0	0	0	0	1	1	1	1	1	1	4	4	4
Subtotal ambient NO2			6	7	7	2	2	2	0	0	0	9	9	9	0	0	0	0	0	0	2	2	2	2	2	2	11	12	12
Subtotal ambient CO			6	6	6	2	2	2	0	0	0	9	9	9	0	0	0	0	0	0	0	0	0	0	0	0	9	9	9
Total all emissions, pollutants, effects			145	167	305	55	64	110	10	11	18	210	241	433	5	5	7	1	1	3	117	122	224	123	128	233	333	369	666

TABLE 11-A 17 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (LOS ANGELES MSA 1990) (LOWER BOUI

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	3	3	3	1	1	1	0	0	0	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	4	4	4
		hospitalization	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		headaches	4	4	4	1	1	1	0	0	0	6	6	6	0	0	0	0	0	0	0	0	0	0	0	0	6	6	6
NOx	NO2	sore throat	6	6	6	2	2	2	0	0	0	8	8	8	0	0	0	0	0	0	2	2	2	2	2	2	9	10	10
		excess phlegm	2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	1	1	1	1	1	1	4	4	4
		eye irritation	2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	1	1	1	1	1	1	4	4	4
NOx, NH3	nitrate PM10	mortality	76	76	76	26	27	27	4	4	4	106	107	107	1	1	1	0	0	0	22	23	23	23	24	24	129	130	130
		chronic illness	37	37	37	13	13	13	2	2	2	52	52	52	0	0	0	0	0	0	11	11	11	11	12	12	63	64	64
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	4	4	4	1	1	1	0	0	0	5	5	5	0	0	0	0	0	0	1	1	1	1	1	1	6	6	6
Total for NOxand NH3emissions			127	128	128	44	45	45	6	6	6	177	178	178	1	1	1	0	0	0	38	38	38	39	39	39	216	217	217
PM2.5	PM2 5	mortality	17	18	20	8	9	9	1	1	2	27	28	31	4	4	4	1	1	1	39	39	41	43	43	45	70	71	75
		chronic illness	8	9	10	4	4	5	1	1	1	13	13	15	2	2	2	0	0	0	19	19	20	21	21	22	34	35	37
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	2	2	2	2	2	2	3	3	4
		lung cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coarse PM10	coarse PM10	mortality	6	6	16	2	2	6	0	0	1	8	9	23	0	0	0	0	0	0	2	2	9	2	2	10	11	11	33
		chronic illness	3	3	8	1	1	3	0	0	0	4	4	11	0	0	0	0	0	0	1	1	5	1	1	5	5	5	16
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2
Total for direct PM10emissions			35	36	55	16	17	23	3	3	4	54	56	82	6	6	6	1	1	1	63	63	77	70	70	84	124	126	166
SOx, NH3	sulfate PM10	mortality	22	23	23	8	9	9	1	1	1	30	33	33	2	2	2	0	0	0	20	21	21	23	23	23	53	56	56
		chronic illness	11	11	11	4	4	4	0	0	0	15	16	16	1	1	1	0	0	0	10	10	10	11	11	11	26	27	27
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	1	1	1	0	0	0	0	0	0	1	2	2	0	0	0	0	0	0	1	1	1	1	1	1	3	3	3
Total for SOxand NH3emissions			33	36	36	12	13	13	1	1	1	47	50	50	3	3	3	1	1	1	31	32	32	35	36	36	81	86	86
VOCs	organic PM10	mortality	7	8	8	3	3	3	1	1	1	10	11	11	0	0	0	0	0	0	1	1	1	1	1	1	11	12	12
	(SOA)	chronic illness	3	4	4	1	1	1	0	0	0	5	5	5	0	0	0	0	0	0	0	0	0	0	0	0	5	6	6
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1 3-butadiene	cancer all sites	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	fomaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			11	12	12	4	4	4	1	1	1	16	17	17	0	0	0	0	0	0	1	2	2	1	2	2	17	19	19
VOCs, NOx	O3	asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lower resp illness	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		upper resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		eye irritation	1	1	1	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
Subtotal mortality effects			131	134	146	49	50	54	7	7	8	186	191	208	6	6	7	1	1	1	85	86	95	92	93	102	278	284	311
Subtotal cancer effects			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal chronic morbidity effects			62	64	70	23	24	26	3	3	4	89	91	99	3	3	3	1	1	1	42	42	46	45	46	50	134	137	149
Subtotal acute morbidity effects			23	24	24	8	8	9	1	1	1	33	33	34	0	0	0	0	0	0	8	8	8	8	8	9	41	41	42
Subtotal ambient PM10			196	201	220	73	75	82	10	10	11	280	287	313	10	10	10	2	2	2	130	132	146	142	144	158	421	430	471
Subtotal ambient O3			2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	4	4	4
Subtotal ambient NO2			10	10	10	4	4	4	0	0	0	14	14	14	0	0	0	0	0	0	3	3	3	3	3	3	17	17	17
Subtotal ambient CO			8	8	8	3	3	3	0	0	0	11	11	11	0	0	0	0	0	0	0	0	0	0	0	0	11	11	11
Total all emissions, pollutants, effects			217	222	240	80	82	89	11	11	12	308	315	341	10	10	10	2	2	2	134	135	149	146	147	161	453	462	503

TABLE 11-A 18 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (LOS ANGELES MSA 1990) (UPPER BOUN

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	34	34	34	11	11	11	3	3	3	48	48	48	0	0	0	0	0	0	1	1	1	1	1	1	48	48	48
		hospitalization	1	1	1	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
		headaches	21	21	21	7	7	7	2	2	2	30	30	30	0	0	0	0	0	0	0	0	0	0	0	0	30	30	30
NOx	NO2	sore throat	29	30	30	10	10	10	2	2	2	42	42	42	0	0	0	0	0	0	12	12	12	12	12	12	53	54	54
		excess phlegm	12	12	12	4	4	4	1	1	1	17	17	17	0	0	0	0	0	0	5	5	5	5	5	5	22	23	23
		eye irritation	12	12	12	4	4	4	1	1	1	16	16	16	0	0	0	0	0	0	5	5	5	5	5	5	21	21	21
NOx, NH3	nitrate PM10	mortality	879	881	881	307	308	308	55	55	55	1,240	1,243	1,243	7	7	7	1	1	1	354	355	355	363	364	364	1 600	1,604	1 604
		chronic illness	628	629	629	219	220	220	39	39	39	886	888	888	5	5	5	1	1	1	252	253	253	258	259	259	1,144	1,147	1 147
		asthma attacks	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		RRAD	19	19	19	7	7	7	1	1	1	27	27	27	0	0	0	0	0	0	8	8	8	8	8	8	34	34	34
Total for NOx and NH3 emissions			1,579	1,583	1,583	552	553	553	99	99	99	2,228	2,234	2,234	13	13	13	2	2	2	636	637	637	651	652	652	2,876	2,883	2,883
PM2.5	PM2 5	mortality	186	200	754	91	95	281	25	25	54	302	320	1,088	38	38	45	6	7	12	666	668	1,074	710	712	1 131	1 010	1 031	2,212
		chronic illness	133	143	538	65	68	200	18	18	39	215	228	776	27	27	32	5	5	9	474	475	765	505	507	806	720	735	1,582
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		RRAD	4	4	16	2	2	6	1	1	1	6	7	23	1	1	1	0	0	0	14	14	23	15	15	24	22	22	47
		lung cancer	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	2	2	2	2	2	2	3	3	3
Coarse PM10	coarse PM10	mortality	12	17	153	5	6	52	1	1	9	18	25	213	0	1	2	0	0	2	7	7	107	7	8	111	26	33	323
		chronic illness	9	12	109	3	5	37	1	1	6	13	18	152	0	0	2	0	0	1	5	5	76	5	6	79	18	24	230
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	3	0	0	1	0	0	0	0	1	5	0	0	0	0	0	0	0	0	2	0	0	2	1	1	7
Total for direct PM10 emissions			345	379	1,574	166	176	577	45	46	109	556	600	2,258	67	67	82	11	12	24	1,168	1,172	2,049	1,245	1,250	2,155	1,800	1,849	4,407
SOx, NH3	sulfate PM10	mortality	101	104	104	37	38	38	6	6	6	143	148	148	9	9	9	2	2	2	150	151	151	161	162	162	304	310	310
		chronic illness	72	74	74	26	27	27	4	4	4	102	105	105	6	6	6	1	1	1	107	107	107	114	115	115	216	220	220
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	3	3	3	3	3	3	7	7	7
Total for SOx and NH3 emissions			175	181	181	64	66	66	10	10	10	248	257	257	16	16	16	3	3	3	260	262	262	278	281	281	527	537	537
VOCs	organic PM10 (SOA)	mortality	57	59	59	21	22	22	7	7	7	85	88	88	0	0	0	0	0	0	12	12	12	12	12	12	98	100	100
		chronic illness	41	42	42	15	16	16	5	5	5	61	63	63	0	0	0	0	0	0	9	9	9	9	9	9	70	71	71
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	1	1	1	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
	1,3-butadiene	cancer all sites	2	2	2	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
	fomaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			101	104	104	38	39	39	12	12	12	151	155	155	0	0	0	0	0	0	21	21	21	21	22	22	173	177	177
VOCs, NOx	O3	asthma attacks	3	3	3	1	1	1	0	0	0	5	5	5	0	0	0	0	0	0	1	1	1	1	1	1	6	6	6
		lower resp illness	6	6	6	2	2	2	0	0	0	9	9	9	0	0	0	0	0	0	1	1	1	1	1	1	10	10	10
		upper resp illness	2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3
		eye irritation	7	7	7	3	3	3	1	1	1	10	10	10	0	0	0	0	0	0	1	1	1	1	1	1	11	11	11
Subtotal mortality effects			1,269	1,296	1,985	472	481	712	96	97	133	1,836	1,872	2,827	54	55	63	9	10	17	1,190	1,194	1,700	1,254	1 259	1,780	3,086	3,127	4,599
Subtotal cancer effects			3	3	3	1	1	1	0	0	0	5	5	5	0	0	0	0	0	0	2	2	2	2	2	2	6	6	6
Subtotal chronic morbidity effects			882	901	1 392	329	335	499	67	67	93	1,277	1,303	1 984	39	39	45	7	7	12	846	849	1 210	891	895	1 267	2,169	2,198	3,251
Subtotal acute morbidity effects			122	123	138	43	43	49	8	9	9	173	174	195	2	2	2	0	0	0	51	51	62	53	53	65	226	227	259
Subtotal ambient PM10			2,145	2,191	3,386	800	815	1,216	162	163	227	3,106	3,168	4,826	95	95	110	16	17	30	2,063	2,071	2,948	2,174	2 182	3,087	5,276	5,346	7 904
Subtotal ambient O3			19	19	19	7	7	7	1	1	1	27	27	27	0	0	0	0	0	0	4	4	4	4	4	4	31	31	31
Subtotal ambient NO2			53	54	54	19	19	19	3	3	3	75	75	75	0	0	0	0	0	0	21	21	21	22	22	22	97	97	97
Subtotal ambient CO			57	57	57	19	19	19	4	4	4	80	80	80	0	0	0	0	0	0	1	1	1	1	1	1	81	81	81
Total all emissions, pollutants, effects			2,276	2,322	3,518	845	860	1,262	171	173	236	3,291	3,353	5,011	95	96	110	17	17	30	2,089	2,097	2,974	2,200	2,209	3,114	5,487	5,558	8,116

TABLE 11-A 19 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (MINNEAPOLIS MSA 1990) (LOWER BOU

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
		hospitalization	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		headaches	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
NOx	NO2	sore throat	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		excess phlegm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		eye irritation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NOx, NH3	nitrate PM10	mortality	5	5	5	2	2	2	0	0	0	6	6	6	0	0	0	0	0	0	1	1	1	1	1	1	7	8	8
		chronic illness	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for NOxand NH3emissions			7	7	7	2	2	2	0	0	0	9	9	9	0	0	0	0	0	0	1	2	2	2	2	2	11	11	11
PM2.5	PM2 5	mortality	1	1	1	0	1	1	0	0	0	1	2	2	0	0	0	0	0	0	2	2	2	2	2	2	3	4	5
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lung cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coarse PM10	coarse PM10	mortality	0	0	2	0	0	1	0	0	0	0	1	3	0	0	0	0	0	0	0	0	1	0	0	1	0	1	4
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for direct PM10rmissions			1	2	4	1	1	2	0	0	0	2	3	6	0	0	0	0	0	0	2	3	4	3	3	5	5	6	11
SOx, NH3	sulfate PM10	mortality	1	2	2	0	1	1	0	0	0	1	3	3	0	0	0	0	0	0	1	1	1	1	1	1	2	4	4
		chronic illness	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for SOxand NH3emissions			1	3	3	0	1	1	0	0	0	2	4	4	0	0	0	0	0	0	1	2	2	1	2	2	3	6	6
VOCs	organic PM10 (SOA)	mortality	0	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1,3-butadiene	cancer all sites	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	fomaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
VOCs, NOx	O3	asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lower resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		upper resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		eye irritation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal mortality effects			7	9	11	3	4	4	0	0	1	10	13	16	0	0	0	0	0	0	4	4	6	4	5	6	15	18	22
Subtotal cancer effects			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal chronic morbidity effects			1	2	2	1	1	1	0	0	0	2	3	3	0	0	0	0	0	0	1	1	1	1	1	1	3	4	4
Subtotal acute morbidity effects			2	2	2	1	1	1	0	0	0	2	3	3	0	0	0	0	0	0	0	0	1	0	0	1	3	3	3
Subtotal ambient PM10			9	11	14	3	4	5	0	1	1	12	16	19	0	0	0	0	0	0	5	6	7	5	6	8	18	22	27
Subtotal ambient O3			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal ambient NO2			1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Subtotal ambient CO			1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Total all emissions, pollutants, effects			10	13	15	4	5	6	0	1	1	15	19	22	0	0	0	0	0	0	5	6	8	6	6	8	20	25	30

TABLE 11-A 20. COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (MINNEAPOLIS MSA 1990) (UPPER BOUN

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	4	4	4	1	1	1	0	0	0	6	6	6	0	0	0	0	0	0	0	0	0	0	0	0	6	6	6
		hospitalization	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		headaches	2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3
NOx	NO2	sore throat	2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	1	1	1	1	1	1	4	4	4
		excess phlegm	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
		eye irritation	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
NOx, NH3	nitrate PM10	mortality	63	64	64	22	22	22	3	3	3	88	89	89	0	0	0	0	0	0	18	18	18	19	19	19	106	107	107
		chronic illness	23	24	24	8	8	8	1	1	1	33	33	33	0	0	0	0	0	0	7	7	7	7	7	7	39	40	40
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	1	1	1	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
Total for NOxand NH3emissions			92	93	93	32	32	32	4	4	4	129	130	130	1	1	1	0	0	0	26	26	26	27	27	27	156	157	157
PM2.5	PM2.5	mortality	10	11	58	5	5	21	1	1	4	16	18	83	2	2	3	0	0	1	34	34	69	36	37	72	52	55	155
		chronic illness	4	4	21	2	2	8	0	0	1	6	7	31	1	1	1	0	0	0	12	13	25	13	13	26	19	20	57
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	1	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	1	1	2	1	1	2	1	1	4
		lung cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
Coarse PM10	coarse PM10	mortality	1	1	13	0	0	4	0	0	1	1	1	18	0	0	0	0	0	0	0	0	9	0	0	10	1	2	28
		chronic illness	0	0	5	0	0	2	0	0	0	0	0	7	0	0	0	0	0	0	0	0	3	0	0	4	1	1	10
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for direct PM10emissions			15	17	99	7	8	36	2	2	6	24	28	142	3	3	4	0	1	1	48	49	109	51	52	114	75	80	256
SOx, NH3	sulfate PM10	mortality	5	8	8	2	3	3	0	0	0	8	12	12	0	0	0	0	0	0	8	8	8	8	9	9	16	21	21
		chronic illness	2	3	3	1	1	1	0	0	0	3	4	4	0	0	0	0	0	0	3	3	3	3	3	3	6	8	8
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for SOxand NH3emissions			7	12	12	3	4	4	0	1	1	11	17	17	1	1	1	0	0	0	11	12	12	11	12	12	22	29	29
VOCs	organic PM10 (SOA)	mortality	4	5	5	1	2	2	0	0	0	5	7	7	0	0	0	0	0	0	1	1	1	1	1	1	6	8	8
		chronic illness	1	2	2	1	1	1	0	0	0	2	3	3	0	0	0	0	0	0	0	0	0	0	0	0	2	3	3
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1,3-butadiene	cancer all sites	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
	fomaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			6	7	7	2	3	3	0	1	1	9	11	11	0	0	0	0	0	0	1	1	1	1	1	1	10	12	12
VOCs, NOx	O3	asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lower resp illness	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		upper resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		eye irritation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal mortality effects			87	93	152	32	35	54	5	5	9	124	133	215	3	3	4	1	1	1	60	62	105	64	66	110	187	198	325
Subtotal cancer effects			1	1	1	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2
Subtotal chronic morbidity effects			31	33	55	11	12	19	2	2	3	44	47	77	1	1	1	0	0	0	22	23	39	23	24	40	67	71	118
Subtotal acute morbidity effects			9	10	11	3	3	4	0	1	1	13	14	16	0	0	0	0	0	0	3	3	4	3	3	4	16	17	20
Subtotal ambient PM10			115	124	206	43	46	74	7	7	12	165	178	292	4	4	5	1	1	2	84	87	147	89	92	154	253	269	445
Subtotal ambient O3			1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Subtotal ambient NO2			4	4	4	1	2	2	0	0	0	6	6	6	0	0	0	0	0	0	1	1	1	1	1	1	7	7	7
Subtotal ambient CO			7	7	7	2	2	2	0	0	0	9	9	9	0	0	0	0	0	0	0	0	0	0	0	0	9	9	9
Total all emissions, pollutants, effects			128	137	219	47	51	78	7	8	12	182	195	309	4	4	5	1	1	2	85	88	148	90	93	155	272	288	464

TABLE 11-A 21 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (NEW YORK MSA 1990) (LOWER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	4	4	4	1	1	1	0	0	0	5	5	5	0	0	0	0	0	0	0	0	0	0	0	0	5	5	5
		hospitalization	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		headaches	3	3	3	1	1	1	0	0	0	5	5	5	0	0	0	0	0	0	0	0	0	0	0	0	5	5	5
NOx	NO2	sore throat	4	4	4	1	1	1	0	0	0	6	6	6	0	0	0	0	0	0	1	1	1	1	1	1	7	7	7
		excess phlegm	2	2	2	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3
		eye irritation	2	2	2	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3
NOx, NH3	nitrate PM10	mortality	33	33	33	11	11	11	1	1	1	45	45	45	0	0	0	0	0	0	8	8	8	9	9	9	54	54	54
		chronic illness	6	6	6	2	2	2	0	0	0	9	9	9	0	0	0	0	0	0	2	2	2	2	2	2	10	10	10
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	2	2	2	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3
Total for NOxand NH3emissions			48	48	48	17	17	17	2	2	2	66	67	67	0	0	0	0	0	0	12	12	12	13	13	13	79	79	79
PM2.5	PM2.5	mortality	6	6	7	3	3	3	1	1	1	10	10	11	1	1	1	0	0	0	15	15	15	16	16	17	26	26	28
		chronic illness	1	1	1	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	3	3	3	3	3	3	5	5	5
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
		lung cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coarse PM10	coarse PM10	mortality	2	2	5	1	1	2	0	0	0	3	3	7	0	0	0	0	0	0	1	1	3	1	1	3	4	4	11
		chronic illness	0	0	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	1	0	0	1	1	1	2
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Total for direct PM10emissions			10	11	15	5	5	7	1	1	1	16	17	23	2	2	2	0	0	0	19	19	23	21	21	25	38	38	48
SOx, NH3	sulfate PM10	mortality	11	14	14	4	5	5	0	1	1	15	20	20	1	1	1	0	0	0	11	12	12	12	13	13	27	33	33
		chronic illness	2	3	3	1	1	1	0	0	0	3	4	4	0	0	0	0	0	0	2	2	2	2	2	2	5	6	6
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	1	1	1	1	1	1	2	2
Total for SOxand NH3emissions			14	17	17	5	7	7	0	1	1	19	25	25	1	1	1	0	0	0	13	14	14	15	16	16	34	41	41
VOCs	organic PM10 (SOA)	mortality	3	5	5	1	2	2	0	0	0	4	7	7	0	0	0	0	0	0	0	1	1	0	1	1	4	8	8
		chronic illness	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1,3-butadiene	cancer all sites	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	fomaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			4	6	6	1	2	2	0	0	0	5	9	9	0	0	0	0	0	0	0	1	1	0	1	1	6	10	10
VOCs, NOx	O3	asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lower resp illness	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		upper resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		eye irritation	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Subtotal mortality effects			58	63	67	21	24	25	3	3	3	82	90	95	3	3	3	0	1	1	35	36	39	38	40	42	120	130	138
Subtotal cancer effects			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Subtotal chronic morbidity effects			11	12	12	4	4	5	0	1	1	15	17	18	1	1	1	0	0	0	7	7	8	7	8	8	22	24	26
Subtotal acute morbidity effects			15	15	16	5	5	6	1	1	1	21	22	22	0	0	0	0	0	0	4	4	4	4	4	4	25	26	26
Subtotal ambient PM10			68	75	79	25	28	29	3	4	4	96	106	112	3	3	3	1	1	1	43	45	49	47	49	53	144	156	165
Subtotal ambient O3			1	1	1	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
Subtotal ambient NO2			7	7	7	3	3	3	0	0	0	10	10	10	0	0	0	0	0	0	2	2	2	2	2	2	12	12	12
Subtotal ambient CO			7	7	7	3	3	3	0	0	0	10	10	10	0	0	0	0	0	0	0	0	0	0	0	0	10	10	10
Total all emissions, pollutants, effects			84	91	96	31	34	35	4	4	5	119	129	135	3	3	3	1	1	1	46	48	51	50	52	55	168	180	190

TABLE 11-A 22 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (NEW YORK MSA 1990) (UPPER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	40	40	40	14	14	14	2	2	2	57	57	57	0	0	0	0	0	0	1	1	1	1	1	1	57	57	57
		hospitalization	2	2	2	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
		headaches	18	18	18	6	6	6	1	1	1	26	26	26	0	0	0	0	0	0	0	0	0	0	0	0	26	26	26
NOx	NO2	sore throat	21	21	21	7	7	7	1	1	1	30	30	30	0	0	0	0	0	0	6	6	6	6	6	6	36	36	36
		excess phlegm	9	9	9	3	3	3	0	0	0	13	13	13	0	0	0	0	0	0	3	3	3	3	3	3	16	16	16
		eye irritation	9	9	9	3	3	3	0	0	0	12	12	12	0	0	0	0	0	0	2	2	2	3	3	3	14	14	14
NOx, NH3	nitrate PM10	mortality	656	658	658	226	227	227	29	29	29	911	914	914	5	5	5	1	1	1	186	187	187	193	193	193	1,103	1 106	1 106
		chronic illness	193	194	194	66	67	67	9	9	9	268	269	269	2	2	2	0	0	0	54	54	54	56	56	56	324	325	325
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	11	11	11	4	4	4	0	0	0	15	15	15	0	0	0	0	0	0	3	3	3	3	3	3	18	18	18
Total for NOxand NH3emissions			899	902	902	310	311	311	40	40	40	1,249	1,252	1,252	7	7	7	1	1	1	255	256	256	263	264	264	1,511	1,516	1,516
PM2.5	PM2 5	mortality	113	115	405	55	56	153	13	13	28	181	184	586	23	23	26	4	4	7	347	348	561	374	375	594	555	558	1,179
		chronic illness	33	34	119	16	16	45	4	4	8	53	54	172	7	7	8	1	1	2	100	100	163	108	108	173	161	162	344
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	2	2	7	1	1	2	0	0	0	3	3	10	0	0	0	0	0	0	6	6	9	6	6	10	9	9	19
		lung cancer	2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	3	3	3	3	3	3	6	6	6
Coarse PM10	coarse PM10	mortality	7	7	77	3	3	26	1	1	4	11	11	108	0	0	1	0	0	1	4	4	55	4	4	57	15	15	165
		chronic illness	2	2	23	1	1	8	0	0	1	3	3	32	0	0	0	0	0	0	1	1	16	1	1	17	4	4	48
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	1	0	0	3
Total for direct PM10emissions			160	163	633	77	78	236	18	18	43	254	258	912	31	31	36	5	5	10	461	462	808	497	498	854	751	756	1,765
SOx, NH3	sulfate PM10	mortality	103	123	123	37	46	46	5	6	6	145	174	174	9	9	9	2	2	2	131	137	137	142	148	148	287	322	322
		chronic illness	30	37	37	11	14	14	1	2	2	43	52	52	3	3	3	1	1	1	38	40	40	41	43	43	84	95	95
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	2	2	2	1	1	1	0	0	0	2	3	3	0	0	0	0	0	0	2	2	2	2	2	2	5	5	5
Total for SOxand NH3emissions			135	161	161	49	60	60	6	8	8	190	229	229	12	12	12	2	3	3	171	179	179	185	194	194	375	423	423
VOCs	organic PM10 (SOA)	mortality	36	52	52	14	20	20	3	4	4	54	76	76	0	0	0	0	0	0	7	11	11	7	11	11	60	87	87
		chronic illness	11	15	15	4	6	6	1	1	1	16	23	23	0	0	0	0	0	0	2	3	3	2	3	3	18	26	26
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
	1,3-butadiene	cancer all sites	3	3	3	1	1	1	0	0	0	5	5	5	0	0	0	0	0	0	0	0	0	0	0	0	5	5	5
	fomaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			52	72	72	20	28	28	5	6	6	77	106	106	0	0	0	0	0	0	9	14	14	9	15	15	86	121	121
VOCs, NOx	O3	asthma attacks	2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3
		lower resp illness	4	4	4	1	1	1	0	0	0	5	5	5	0	0	0	0	0	0	1	1	1	1	1	1	6	6	6
		upper resp illness	1	1	1	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
		eye irritation	3	3	3	1	1	1	0	0	0	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	4	4	4
Subtotal mortality effects			956	995	1,355	349	365	486	54	55	74	1,358	1,415	1,914	38	38	42	7	7	11	675	687	951	719	732	1,004	2,077	2,146	2,916
Subtotal cancer effects			6	6	6	3	3	3	0	0	0	9	9	9	0	0	0	0	0	0	3	3	3	4	4	4	13	13	13
Subtotal chronic morbidity effects			270	282	387	98	103	139	15	15	21	383	401	547	11	11	12	2	2	3	195	199	276	208	212	291	591	613	838
Subtotal acute morbidity effects			83	85	91	29	30	32	4	4	5	117	119	127	1	1	1	0	0	0	24	24	29	25	26	30	142	144	157
Subtotal ambient PM10			1,203	1,254	1,725	440	462	619	67	69	94	1 709	1,785	2,438	50	50	56	9	9	14	884	899	1,245	942	958	1,315	2,651	2,742	3,751
Subtotal ambient O3			9	10	10	3	4	4	0	1	1	13	14	14	0	0	0	0	0	0	1	2	2	1	2	2	14	15	15
Subtotal ambient NO2			39	39	39	14	14	14	2	2	2	54	55	55	0	0	0	0	0	0	11	11	11	12	12	12	66	66	66
Subtotal ambient CO			60	60	60	21	21	21	4	4	4	85	85	85	0	0	0	0	0	0	1	1	1	1	1	1	86	86	86
Total all emissions, pollutants, effects			1,316	1,368	1,839	479	501	659	73	76	100	1,868	1,944	2,597	50	50	56	9	9	14	897	913	1,259	956	973	1,329	2,823	2,916	3,925

TABLE 11-A 23 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (PHILADELPHIA MSA 1990) (LOWER BOUI

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		hospitalization	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		headaches	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
NOx	NO2	sore throat	1	1	1	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
		excess phlegm	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		eye irritation	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
NOx, NH3	nitrate PM10	mortality	9	9	9	3	3	3	0	0	0	12	13	13	0	0	0	0	0	0	3	3	3	3	3	3	15	15	15
		chronic illness	2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	1	1	1	1	1	1	3	3	3
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Total for NOx and NH3 emissions			13	14	14	5	5	5	1	1	1	18	19	19	0	0	0	0	0	0	4	4	4	4	4	4	22	23	23
PM2.5	PM2.5	mortality	2	3	3	1	1	1	0	0	0	3	4	4	0	0	0	0	0	0	5	5	5	5	5	5	8	9	10
		chronic illness	0	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lung cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coarse PM10	coarse PM10	mortality	1	1	2	0	0	1	0	0	0	1	1	3	0	0	0	0	0	0	0	0	1	0	0	1	1	1	4
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for direct PM10 emissions			3	4	6	1	2	3	0	0	0	4	6	9	0	0	0	0	0	0	6	6	8	7	7	8	11	13	17
SOx, NH3	sulfate PM10	mortality	3	12	12	1	5	5	0	1	1	4	17	17	0	0	0	0	0	0	3	6	6	4	6	6	8	23	23
		chronic illness	1	2	2	0	1	1	0	0	0	1	4	4	0	0	0	0	0	0	1	1	1	1	1	1	2	5	5
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Total for SOx and NH3 emissions			4	15	15	1	6	6	0	1	1	5	22	22	0	0	0	0	0	0	4	7	7	5	7	7	10	29	29
VOCs	organic PM10 (SOA)	mortality	1	1	1	0	1	1	0	0	0	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1,3-butadiene	cancer all sites	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	fomaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			1	2	2	0	1	1	0	0	0	2	3	3	0	0	0	0	0	0	0	0	0	0	0	0	2	3	3
VOCs, NOx	O3	asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lower resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		upper resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		eye irritation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal mortality effects			16	27	28	6	11	11	1	1	1	22	38	40	1	1	1	0	0	0	11	13	15	12	14	16	34	53	56
Subtotal cancer effects			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal chronic morbidity effects			3	5	6	1	2	2	0	0	0	4	8	8	0	0	0	0	0	0	2	3	3	2	3	3	7	11	11
Subtotal acute morbidity effects			4	5	5	1	2	2	0	0	0	6	7	7	0	0	0	0	0	0	1	1	1	1	1	2	7	8	8
Subtotal ambient PM10			19	32	34	7	13	13	1	2	2	27	47	49	1	1	1	0	0	0	14	17	18	15	18	19	41	65	69
Subtotal ambient O3			0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Subtotal ambient NO2			2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	1	1	1	1	1	1	4	4	4
Subtotal ambient CO			2	2	2	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
Total all emissions, pollutants, effects			23	37	38	9	14	15	1	2	2	33	53	55	1	1	1	0	0	0	14	18	19	15	19	20	48	72	76

TABLE 11-A 24 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (PHILADELPHIA MSA 1990) (UPPER BOUN

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	10	10	10	3	3	3	1	1	1	14	14	14	0	0	0	0	0	0	0	0	0	0	0	0	14	14	14
		hospitalization	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		headaches	4	4	4	2	2	2	0	0	0	6	6	6	0	0	0	0	0	0	0	0	0	0	0	0	6	6	6
NOx	NO2	sore throat	6	6	6	2	2	2	0	0	0	8	9	9	0	0	0	0	0	0	2	2	2	2	2	2	10	11	11
		excess phlegm	3	3	3	1	1	1	0	0	0	4	4	4	0	0	0	0	0	0	1	1	1	1	1	1	5	5	5
		eye irritation	2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	1	1	1	1	1	1	4	4	4
NOx, NH3	nitrate PM10	mortality	190	193	193	67	69	69	10	10	10	266	271	271	1	1	1	0	0	0	63	64	64	65	66	66	331	337	337
		chronic illness	62	64	64	22	23	23	3	3	3	88	89	89	0	0	0	0	0	0	21	21	21	21	21	21	109	111	111
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	3	3	3	1	1	1	0	0	0	4	4	4	0	0	0	0	0	0	1	1	1	1	1	1	5	6	6
Total for NOx and NH3 emissions			266	271	271	94	96	96	13	14	14	374	381	381	2	2	2	0	0	0	89	89	89	91	92	92	465	473	473
PM2.5	PM2.5	mortality	33	40	140	16	19	53	4	5	10	53	64	203	7	7	8	1	1	2	119	122	195	127	129	205	180	194	408
		chronic illness	11	13	46	5	6	17	1	2	3	17	21	67	2	2	3	0	0	1	39	40	64	41	42	67	59	63	134
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	1	1	2	0	0	1	0	0	0	1	1	3	0	0	0	0	0	0	2	2	3	2	2	3	3	3	7
		lung cancer	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2
Coarse PM10	coarse PM10	mortality	2	2	26	1	1	9	0	0	1	3	3	37	0	0	0	0	0	0	1	1	19	1	1	20	5	5	56
		chronic illness	1	1	9	0	0	3	0	0	0	1	1	12	0	0	0	0	0	0	0	0	6	0	0	6	1	2	19
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Total for direct PM10 emissions			47	58	225	23	28	84	6	7	15	77	92	324	9	9	11	2	2	3	163	166	289	174	177	303	250	269	627
SOx, NH3	sulfate PM10	mortality	30	80	80	11	32	32	2	4	4	42	116	116	3	3	3	1	1	1	45	57	57	48	61	61	90	178	178
		chronic illness	10	27	27	4	11	11	1	1	1	14	39	39	1	1	1	0	0	0	15	19	19	16	20	20	30	59	59
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	1	1	0	1	1	0	0	0	1	2	2	0	0	0	0	0	0	1	1	1	1	1	1	1	3	3
Total for SOx and NH3 emissions			40	109	109	15	44	44	2	5	5	57	158	158	4	4	4	1	1	1	60	77	77	65	82	82	121	240	240
VOCs	organic PM10 (SOA)	mortality	11	15	15	4	6	6	1	1	1	17	23	23	0	0	0	0	0	0	2	3	3	2	3	3	19	26	26
		chronic illness	4	5	5	1	2	2	0	0	0	5	8	8	0	0	0	0	0	0	1	1	1	1	1	1	6	9	9
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1,3-butadiene	cancer all sites	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
	fomaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			16	22	22	6	9	9	2	2	2	24	33	33	0	0	0	0	0	0	3	5	5	3	5	5	27	38	38
VOCs, NOx	O3	asthma attacks	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		lower resp illness	1	1	1	0	1	1	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
		upper resp illness	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		eye irritation	1	1	1	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
Subtotal mortality effects			275	341	465	103	131	173	17	21	27	395	492	665	11	11	13	2	2	4	231	248	339	244	261	355	639	753	1,019
Subtotal cancer effects			2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	1	1	1	1	1	1	4	4	4
Subtotal chronic morbidity effects			87	110	150	33	42	56	5	7	9	125	158	215	4	4	4	1	1	1	75	81	111	80	85	116	205	244	331
Subtotal acute morbidity effects			24	25	27	9	9	10	1	1	2	33	36	39	0	0	0	0	0	0	8	9	10	9	9	11	42	45	49
Subtotal ambient PM10			357	447	614	134	172	228	23	27	36	514	646	878	15	15	17	3	3	5	311	334	456	329	352	479	843	997	1,355
Subtotal ambient O3			3	4	4	1	1	1	0	0	0	5	5	5	0	0	0	0	0	0	1	1	1	1	1	1	6	6	6
Subtotal ambient NO2			11	11	11	4	4	4	1	1	1	15	16	16	0	0	0	0	0	0	4	4	4	4	4	4	19	20	20
Subtotal ambient CO			14	15	15	5	5	5	1	1	1	21	21	21	0	0	0	0	0	0	0	0	0	0	0	0	21	21	21
Total all emissions, pollutants, effects			388	478	645	145	183	239	24	29	37	557	689	921	15	15	17	3	3	5	316	338	461	333	357	483	890	1,046	1,404

TABLE 11-A 25 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (PHOENIX MSA 1990) (LOWER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		hospitalization	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		headaches	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
NOx	NO2	sore throat	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		excess phlegm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		eye irritation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NOx, NH3	nitrate PM10	mortality	5	5	5	2	2	2	0	0	0	6	6	6	0	0	0	0	0	0	1	1	1	1	1	1	8	8	8
		chronic illness	2	2	2	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	1	1	1	1	1	1	3	3	3
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for NOxand NH3emissions			7	7	7	3	3	3	0	0	0	10	10	10	0	0	0	0	0	0	2	2	2	2	2	2	13	13	13
PM2.5	PM2 5	mortality	1	1	1	0	0	1	0	0	0	2	2	2	0	0	0	0	0	0	2	2	3	3	3	3	4	4	5
		chronic illness	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	2
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lung cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coarse PM10	coarse PM10	mortality	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	1	1	1	2
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for direct PM10emissions			2	2	3	1	1	1	0	0	0	3	3	5	0	0	0	0	0	0	4	4	5	4	4	5	7	7	10
SOx, NH3	sulfate PM10	mortality	1	2	2	0	2	2	0	0	0	2	4	4	0	0	0	0	0	0	1	2	2	1	2	2	3	6	6
		chronic illness	0	1	1	0	1	1	0	0	0	1	1	1	0	0	0	0	0	0	0	1	1	0	1	1	1	2	2
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for SOxand NH3emissions			2	3	3	1	2	2	0	0	0	2	6	6	0	0	0	0	0	0	2	2	2	2	2	2	4	8	8
VOCs	organic PM10 (SOA)	mortality	0	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1,3-butadiene	cancer all sites	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	fomaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2
VOCs, NOx	O3	asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lower resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		upper resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		eye irritation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal mortality effects			8	9	10	3	4	5	0	0	1	11	14	15	0	0	0	0	0	0	5	6	6	6	6	7	17	20	22
Subtotal cancer effects			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal chronic morbidity effects			3	3	3	1	1	2	0	0	0	4	5	5	0	0	0	0	0	0	2	2	2	2	2	2	6	7	8
Subtotal acute morbidity effects			2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	1	1	1	1	1	1	3	4	4
Subtotal ambient PM10			10	12	14	4	6	6	1	1	1	15	19	21	1	1	1	0	0	0	8	8	9	8	9	10	23	28	30
Subtotal ambient O3			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal ambient NO2			1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
Subtotal ambient CO			1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Total all emissions, pollutants, effects			13	15	16	5	7	7	1	1	1	18	22	24	1	1	1	0	0	0	8	8	9	8	9	10	26	31	34

TABLE 11-A 26 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (PHOENIX MSA 1990) (UPPER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	6	6	6	2	2	2	1	1	1	8	8	8	0	0	0	0	0	0	0	0	0	0	0	0	9	9	9
		hospitalization	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		headaches	3	3	3	1	1	1	0	0	0	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	4	4	4
NOx	NO2	sore throat	3	3	3	1	1	1	0	0	0	4	4	4	0	0	0	0	0	0	1	1	1	1	1	1	5	5	5
		excess phlegm	1	1	1	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	1	1	1	2	2	2
		eye irritation	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
NOx, NH3	nitrate PM10	mortality	81	81	81	29	29	29	5	5	5	114	114	114	1	1	1	0	0	0	35	35	35	36	36	36	150	150	150
		chronic illness	54	54	54	19	19	19	3	3	3	76	76	76	0	0	0	0	0	0	23	23	23	24	24	24	100	100	100
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	2	2	2	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	1	1	1	1	1	1	3	3	3
Total for NOxand NH3emissions			141	141	141	50	50	50	8	8	8	199	199	199	1	1	1	0	0	0	62	62	62	63	63	63	262	262	262
PM2.5	PM2.5	mortality	16	16	74	8	8	28	2	2	5	26	26	107	3	3	4	1	1	1	66	66	109	69	69	114	95	95	221
		chronic illness	10	10	49	5	5	18	2	2	4	17	17	71	2	2	3	0	0	1	43	43	72	46	46	75	63	63	146
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	2	0	0	1	0	0	0	1	1	2	0	0	0	0	0	0	1	1	2	1	1	2	2	2	5
		lung cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Coarse PM10	coarse PM10	mortality	1	1	15	0	0	5	0	0	1	2	2	21	0	0	0	0	0	0	1	1	11	1	1	11	2	2	32
		chronic illness	1	1	10	0	0	3	0	0	1	1	1	14	0	0	0	0	0	0	0	0	7	0	0	7	2	2	21
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Total for direct PM10emissions			28	28	150	14	14	55	4	4	11	46	46	216	5	5	7	1	1	2	112	112	202	118	118	211	165	165	426
SOx, NH3	sulfate PM10	mortality	9	9	9	3	4	4	1	1	1	12	13	13	1	1	1	0	0	0	15	15	15	16	16	16	28	29	29
		chronic illness	6	6	6	2	2	2	0	0	0	8	8	8	0	0	0	0	0	0	10	10	10	10	10	10	18	18	18
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Total for SOxand NH3emissions			14	15	15	5	6	6	1	1	1	21	21	21	1	1	1	0	0	0	25	25	25	26	26	26	47	48	48
VOCs	organic PM10 (SOA)	mortality	5	6	6	2	2	2	1	1	1	8	10	10	0	0	0	0	0	0	1	1	1	1	2	2	9	11	11
		chronic illness	4	4	4	1	2	2	0	1	1	5	6	6	0	0	0	0	0	0	1	1	1	1	1	1	6	7	7
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1 3-butadiene	cancer all sites	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	fomaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			9	11	11	4	4	4	1	1	1	14	17	17	0	0	0	0	0	0	2	3	3	2	3	3	16	19	19
VOCs, NOx	O3	asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		lower resp illness	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		upper resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		eye irritation	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Subtotal mortality effects			117	118	191	44	45	69	9	9	13	170	172	273	5	5	6	1	1	2	118	118	172	123	124	179	294	296	451
Subtotal cancer effects			1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Subtotal chronic morbidity effects			74	74	122	28	28	44	6	6	8	107	108	175	3	3	4	1	1	1	78	78	113	82	82	118	189	190	293
Subtotal acute morbidity effects			12	12	13	4	4	5	1	1	1	17	17	19	0	0	0	0	0	0	5	5	6	5	5	6	22	22	25
Subtotal ambient PM10			188	190	312	71	72	113	14	14	21	273	276	446	8	8	9	1	1	3	198	199	289	208	208	301	481	484	746
Subtotal ambient O3			2	2	2	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3
Subtotal ambient NO2			5	5	5	2	2	2	0	0	0	7	7	7	0	0	0	0	0	0	2	2	2	2	2	2	9	9	9
Subtotal ambient CO			9	9	9	3	3	3	1	1	1	13	13	13	0	0	0	0	0	0	0	0	0	0	0	0	13	13	13
Total all emissions, pollutants, effects			203	205	327	77	78	119	16	16	22	295	299	468	8	8	10	1	1	3	201	202	291	211	211	304	506	509	771

TABLE 11-A.27 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (ST LOUIS MSA 1990) (LOWER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		hospitalization	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		headaches	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NOx	NO2	sore throat	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		excess phlegm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		eye irritation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NOx, NH3	nitrate PM10	mortality	2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	1	1	1	1	1	1	3	4	4
		chronic illness	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for NOxand NH3emissions			3	4	4	1	1	1	0	0	0	5	5	5	0	0	0	0	0	0	1	1	1	1	1	1	6	6	6
PM2.5	PM2.5	mortality	0	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lung cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coarse PM10	coarse PM10	mortality	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	2
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for direct PM10emissions			1	1	2	0	0	1	0	0	0	1	2	3	0	0	0	0	0	0	1	2	2	2	2	2	3	3	5
SOx, NH3	sulfate PM10	mortality	1	6	6	0	3	3	0	0	0	1	8	8	0	0	0	0	0	0	1	2	2	1	2	2	1	10	10
		chronic illness	0	2	2	0	1	1	0	0	0	0	2	2	0	0	0	0	0	0	0	1	1	0	1	1	0	3	3
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for SOxand NH3emissions			1	7	7	0	3	3	0	0	0	1	11	11	0	0	0	0	0	0	1	2	2	1	3	3	2	14	14
VOCs	organic PM10 (SOA)	mortality	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1,3-butadiene	cancer all sites	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	fomaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
VOCs, NOx	O3	asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lower resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		upper resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		eye irritation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal mortality effects			4	9	10	1	4	4	0	0	0	5	14	15	0	0	0	0	0	0	2	4	4	3	4	5	8	18	19
Subtotal cancer effects			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal chronic morbidity effects			1	2	2	0	1	1	0	0	0	1	3	3	0	0	0	0	0	0	0	1	1	1	1	1	1	4	4
Subtotal acute morbidity effects			1	2	2	0	1	1	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	3	3
Subtotal ambient PM10			4	12	12	2	5	5	0	1	1	6	17	18	0	0	0	0	0	0	3	5	5	3	5	6	9	22	24
Subtotal ambient O3			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal ambient NO2			1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Subtotal ambient CO			1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Total all emissions, pollutants, effects			6	13	14	2	6	6	0	1	1	8	19	21	0	0	0	0	0	0	3	5	6	3	5	6	11	25	27

TABLE 11-A 28 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (ST LOUIS MSA 1990) (UPPER BOUND)

	Ambient		LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
Emission	pollutant	Health effect	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	4	4	4	1	1	1	0	0	0	5	5	5	0	0	0	0	0	0	0	0	0	0	0	0	5	5	5
		hospitalization	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		headaches	2	2	2	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
NOx	NO2	sore throat	2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	1	1	1	1	1	1	4	4	4
		excess phlegm	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
		eye irritation	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2
NOx, NH3	nitrate PM10	mortality	56	58	58	20	21	21	3	3	3	78	82	82	0	0	0	0	0	0	18	19	19	19	19	19	97	101	101
		chronic illness	15	16	16	5	6	6	1	1	1	21	22	22	0	0	0	0	0	0	5	5	5	5	5	5	26	28	28
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
Total for NOxand NH3emissions			76	79	79	27	28	28	4	4	4	106	111	111	1	1	1	0	0	0	25	25	25	25	26	26	132	137	137
PM2.5	PM2.5	mortality	10	12	55	5	6	20	1	1	4	16	19	80	2	2	3	0	0	1	37	38	70	40	40	73	56	59	153
		chronic illness	3	3	16	1	2	6	0	0	1	5	5	23	1	1	1	0	0	0	11	11	20	11	11	21	16	17	44
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	2
		lung cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Coarse PM10	coarse PM10	mortality	1	1	12	0	0	4	0	0	1	1	1	16	0	0	0	0	0	0	0	0	9	0	0	9	1	2	25
		chronic illness	0	0	3	0	0	1	0	0	0	0	0	5	0	0	0	0	0	0	0	0	2	0	0	2	0	0	7
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for direct PM10emissions			14	16	88	7	8	32	2	2	6	23	26	125	3	3	4	0	0	1	49	50	102	52	53	107	75	79	232
SOx, NH3	sulfate PM10	mortality	6	41	41	2	18	18	0	2	2	9	61	61	1	1	1	0	0	0	10	18	18	10	20	20	19	80	80
		chronic illness	2	14	14	1	6	6	0	1	1	3	21	21	0	0	0	0	0	0	3	6	6	3	6	6	6	27	27
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Total for SOxand NH3emissions			8	56	56	3	24	24	0	3	3	12	82	82	1	1	1	0	0	0	13	25	25	14	26	26	26	109	109
VOCs	organic PM10	mortality	3	4	4	1	2	2	0	0	0	5	7	7	0	0	0	0	0	0	1	1	1	1	1	1	6	8	8
	(SOA)	chronic illness	1	1	1	0	1	1	0	0	0	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1,3-butadiene	cancer all sites	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
	fomaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			5	6	6	2	3	3	0	1	1	7	10	10	0	0	0	0	0	0	1	1	1	1	1	1	8	11	11
VOCs, NOx	O3	asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lower resp illness	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		upper resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		eye irritation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal mortality effects			80	120	175	30	48	66	5	7	10	115	174	251	3	3	4	1	1	1	66	76	116	70	80	122	185	254	372
Subtotal cancer effects			1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Subtotal chronic morbidity effects			21	35	51	8	14	19	1	2	3	30	51	73	1	1	1	0	0	0	19	22	34	20	23	35	50	75	108
Subtotal acute morbidity effects			8	9	10	3	3	4	0	1	1	11	13	14	0	0	0	0	0	0	3	3	3	3	3	4	14	15	17
Subtotal ambient PM10			98	153	224	37	61	85	6	9	13	142	223	322	4	4	5	1	1	2	86	100	152	91	105	159	233	328	481
Subtotal ambient O3			1	1	1	0	0	0	0	0	0	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
Subtotal ambient NO2			4	4	4	1	1	1	0	0	0	5	6	6	0	0	0	0	0	0	1	1	1	1	1	1	7	7	7
Subtotal ambient CO			6	6	6	2	2	2	0	0	0	8	8	8	0	0	0	0	0	0	0	0	0	0	0	0	8	8	8
Total all emissions, pollutants, effects			109	164	236	41	65	89	7	10	13	158	239	338	4	4	5	1	1	2	88	101	154	93	107	161	250	346	499

TABLE 11-A 29 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (SPOKANE MSA 1990) (LOWER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		hospitalization	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		headaches	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NOx	NO2	sore throat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		excess phlegm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		eye irritation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NOx, NH3	nitrate PM10	mortality	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for NOxand NH3emissions			1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
PM2.5	PM2 5	mortality	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lung cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coarse PM10	coarse PM10	mortality	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for direct PM10emissions			0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1
SOx, NH3	sulfate PM10	mortality	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for SOxand NH3emissions			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
VOCs	organic PM10 (SOA)	mortality	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1,3-butadiene	cancer all sites	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	fomaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VOCs, NOx	O3	asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lower resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		upper resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		eye irritation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal mortality effects			1	1	1	0	0	0	0	0	0	1	1	2	0	0	0	0	0	0	0	0	0	1	1	1	1	1	2	2	2
Subtotal cancer effects			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal chronic morbidity effects			0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Subtotal acute morbidity effects			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Subtotal ambient PM10			1	1	1	0	0	1	0	0	0	1	2	2	0	0	0	0	0	0	1	1	1	1	1	1	2	3	3
Subtotal ambient O3			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal ambient NO2			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal ambient CO			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total all emissions, pollutants, effects			1	2	2	1	1	1	0	0	0	2	2	3	0	0	0	0	0	0	1	1	1	1	1	1	3	3	4		

TABLE 11-A 30 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE FMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (SPOKANE MSA 1990) (UPPER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	2	2	2	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
		hospitalization	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		headaches	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
NOx	NO2	sore throat	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		excess phlegm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		eye irritation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NOx, NH3	nitrate PM10	mortality	10	10	10	4	4	4	1	1	1	14	14	14	0	0	0	0	0	0	4	4	4	4	4	4	18	18	18
		chronic illness	4	4	4	1	1	1	0	0	0	5	5	5	0	0	0	0	0	0	2	2	2	2	2	2	7	7	7
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for NOxand NH3emissions			14	14	14	5	5	5	1	1	1	20	20	20	0	0	0	0	0	0	6	6	6	6	6	6	26	26	26
PM2.5	PM2 5	mortality	2	2	9	1	1	3	0	0	1	3	3	13	0	0	0	0	0	0	8	8	13	8	8	14	11	11	27
		chronic illness	1	1	3	0	0	1	0	0	0	1	1	5	0	0	0	0	0	0	3	3	5	3	3	5	4	4	10
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lung cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coarse PM10	coarse PM10	mortality	0	0	2	0	0	1	0	0	0	0	0	3	0	0	0	0	0	0	0	0	1	0	0	2	0	0	4
		chronic illness	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	2
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for direct PM10emissions			2	2	16	1	1	6	0	0	1	4	4	22	0	0	1	0	0	0	11	11	21	12	12	22	16	16	44
SOx, NH3	sulfate PM10	mortality	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	2	2	2	2	2	2	3	3	3
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for SOxand NH3emissions			1	1	1	0	1	1	0	0	0	2	2	2	0	0	0	0	0	0	2	3	3	3	3	3	4	4	4
VOCs	organic PM10 (SOA)	mortality	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1,3-butadiene	cancer all sites	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	fomaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			1	1	1	0	0	0	0	0	0	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2
VOCs, NOx	O3	asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lower resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		upper resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		eye irritation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal mortality effects			14	15	24	6	6	9	1	1	2	21	21	34	0	0	1	0	0	0	14	14	21	15	15	22	36	36	56
Subtotal cancer effects			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal chronic morbidity effects			5	5	8	2	2	3	0	0	1	7	7	12	0	0	0	0	0	0	5	5	8	5	5	8	12	13	20
Subtotal acute morbidity effects			2	2	2	1	1	1	0	0	0	2	3	3	0	0	0	0	0	0	1	1	1	1	1	1	3	3	3
Subtotal ambient PM10			18	18	31	7	7	12	1	1	2	26	27	45	1	1	1	0	0	0	20	20	29	20	21	30	47	47	75
Subtotal ambient O3			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal ambient NO2			1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Subtotal ambient CO			2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3
Total all emissions, pollutants, effects			21	21	34	8	8	13	2	2	2	31	31	49	1	1	1	0	0	0	20	20	30	21	21	31	51	52	80

TABLE 11-A 31 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (WASHINGTON D C MSA 1990) (LOWER B

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		hospitalization	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		headaches	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
NOx	NO2	sore throat	1	1	1	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
		excess phlegm	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		eye irritation	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
NOx, NH3	nitrate PM10	mortality	9	9	9	3	3	3	0	0	0	13	13	13	0	0	0	0	0	0	3	3	3	3	3	3	16	16	16
		chronic illness	1	1	1	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Total for NOxand NH3emissions			14	14	14	5	5	5	1	1	1	19	19	19	0	0	0	0	0	0	4	4	4	4	4	4	23	23	23
PM2.5	PM2.5	mortality	2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	5	5	5	5	5	5	8	8	9
		chronic illness	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lung cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coarse PM10	coarse PM10	mortality	1	1	2	0	0	1	0	0	0	1	1	3	0	0	0	0	0	0	0	0	1	0	0	1	1	1	4
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for direct PM10emissions			3	3	5	1	2	2	0	0	0	5	5	7	0	0	1	0	0	0	6	6	7	7	7	8	11	12	15
SOx, NH3	sulfate PM10	mortality	3	4	4	1	2	2	0	0	0	5	6	6	0	0	0	0	0	0	4	4	4	4	4	4	8	10	10
		chronic illness	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	1	1	1	1	1	1	2	2
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Total for SOxand NH3emissions			4	5	5	1	2	2	0	0	0	6	8	8	0	0	0	0	0	0	4	5	5	5	5	5	10	13	13
VOCs	organic PM10 (SOA)	mortality	1	1	1	0	1	1	0	0	0	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2
		chronic illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1,3-butadiene	cancer all sites	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	formaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			1	2	2	0	1	1	0	0	0	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	3	3
VOCs, NOx	O3	asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		lower resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		upper resp illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		eye irritation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal mortality effects			17	18	20	6	7	8	1	1	1	24	26	28	1	1	1	0	0	0	11	12	13	12	13	14	36	39	42
Subtotal cancer effects			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal chronic morbidity effects			3	3	3	1	1	1	0	0	0	4	4	4	0	0	0	0	0	0	2	2	2	2	2	2	6	6	7
Subtotal acute morbidity effects			5	5	5	2	2	2	0	0	0	7	7	7	0	0	0	0	0	0	1	1	1	1	1	1	8	8	9
Subtotal ambient PM10			19	21	23	7	8	9	1	1	1	27	31	33	1	1	1	0	0	0	14	14	16	15	15	17	42	46	50
Subtotal ambient O3			1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Subtotal ambient NO2			2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	1	1	1	1	1	1	4	4	4
Subtotal ambient CO			2	2	2	1	1	1	0	0	0	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3
Total all emissions, pollutants, effects			24	26	28	9	10	11	1	1	1	34	38	40	1	1	1	0	0	0	14	15	16	16	16	17	50	54	57

TABLE 11-A 32 COST OF AIR POI LUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY FMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $ MILLION (WASHINGTON D C MSA 1990) (UPPER B(

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	10	10	10	4	4	4	1	1	1	14	14	14	0	0	0	0	0	0	0	0	0	0	0	0	14	14	14
		hospitalization	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		headaches	6	6	6	2	2	2	0	0	0	8	8	8	0	0	0	0	0	0	0	0	0	0	0	0	9	9	9
NOx	NO2	sore throat	6	6	6	2	2	2	0	0	0	9	9	9	0	0	0	0	0	0	2	2	2	2	2	2	11	11	11
		excess phlegm	3	3	3	1	1	1	0	0	0	4	4	4	0	0	0	0	0	0	1	1	1	1	1	1	5	5	5
		eye irritation	3	3	3	1	1	1	0	0	0	4	4	4	0	0	0	0	0	0	1	1	1	1	1	1	5	5	5
NOx, NH3	nitrate PM10	mortality	166	166	166	60	60	60	9	9	9	234	235	235	1	1	1	0	0	0	56	56	56	57	58	58	291	292	292
		chronic illness	59	59	59	21	21	21	3	3	3	83	83	83	0	0	0	0	0	0	20	20	20	20	20	20	103	103	103
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	4	4	4	1	1	1	0	0	0	5	5	5	0	0	0	0	0	0	1	1	1	1	1	1	6	6	6
Total for NOxand NH3emissions			240	241	241	86	86	86	13	13	13	339	339	339	2	2	2	0	0	0	81	81	81	83	83	83	421	422	422
PM2.5	PM2 5	mortality	29	29	110	14	15	42	4	4	8	47	47	160	6	6	7	1	1	2	107	107	167	114	114	175	161	162	335
		chronic illness	10	10	38	5	5	15	1	1	3	16	17	56	2	2	2	0	0	1	37	37	58	40	40	61	56	56	117
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	1	1	2	0	0	1	0	0	0	1	1	4	0	0	0	0	0	0	2	2	4	3	3	4	4	4	7
		lung cancer	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
Coarse PM10	coarse PM10	mortality	2	2	22	1	1	7	0	0	1	3	3	30	0	0	0	0	0	0	1	1	16	1	1	16	4	4	46
		chronic illness	1	1	7	0	0	3	0	0	0	1	1	10	0	0	0	0	0	0	0	0	5	0	0	6	1	1	16
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Total for direct PM10emissions			42	43	181	21	21	67	6	6	13	69	70	261	8	8	10	1	1	3	149	149	251	159	159	263	227	228	524
SOx, NH3	sulfate PM10	mortality	26	30	30	10	12	12	1	2	2	37	44	44	2	2	2	0	0	0	41	42	42	43	45	45	80	88	88
		chronic illness	9	11	11	3	4	4	0	1	1	13	15	15	1	1	1	0	0	0	14	15	15	15	15	15	28	31	31
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2
Total for SOxand NH3emissions			35	41	41	13	16	16	2	2	2	51	60	60	3	3	3	1	1	1	56	57	57	59	61	61	110	121	121
VOCs	organic PM10	mortality	9	12	12	4	5	5	1	1	1	14	18	18	0	0	0	0	0	0	2	3	3	2	3	3	16	21	21
	(SOA)	chronic illness	3	4	4	1	2	2	0	0	0	5	6	6	0	0	0	0	0	0	1	1	1	1	1	1	5	7	7
		asthma attacks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		RRAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	acetaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	benzene	leukemia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1,3-butadiene	cancer all sites	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
	fomaldehyde	oral cancer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total for VOC emissions			13	17	17	5	7	7	1	2	2	20	26	26	0	0	0	0	0	0	3	4	4	3	4	4	23	30	30
VOCs, NOx	O3	asthma attacks	1	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		lower resp illness	2	2	2	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3
		upper resp illness	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
		eye irritation	1	1	1	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2
Subtotal mortality effects			241	249	350	91	95	129	16	16	21	348	361	500	9	9	11	2	2	3	207	209	283	218	221	297	566	581	796
Subtotal cancer effects			1	1	1	1	1	1	0	0	0	2	2	2	0	0	0	0	0	0	1	1	1	1	1	1	3	3	3
Subtotal chronic morbidity effects			82	84	119	31	32	44	5	5	7	118	122	170	3	3	4	1	1	1	72	73	98	76	77	103	194	199	274
Subtotal acute morbidity effects			27	28	30	10	10	11	2	2	2	39	40	43	0	0	0	0	0	0	9	10	11	10	10	12	49	49	54
Subtotal ambient PM10			318	329	467	121	126	172	21	21	29	460	477	668	13	13	15	2	2	4	284	287	389	300	303	407	759	779	1,075
Subtotal ambient O3			4	4	4	2	2	2	0	0	0	6	6	6	0	0	0	0	0	0	1	1	1	1	1	1	7	7	7
Subtotal ambient NO2			12	12	12	4	4	4	1	1	1	17	17	17	0	0	0	0	0	0	4	4	4	4	4	4	21	21	21
Subtotal ambient CO			16	16	16	6	6	6	1	1	1	23	23	23	0	0	0	0	0	0	0	0	0	0	0	0	24	24	24
Total all emissions, pollutants, effects			352	363	500	133	138	185	23	23	31	507	524	715	13	13	15	2	2	4	289	292	394	305	308	412	811	832	1,127

TABLE 11-A-33 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $/1000 VMT (U .S. TOTAL 1990) (LOWER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	0 19	0 19	0 19	0 28	0 28	0 28	0 68	0 69	0 69	0 22	0 22	0 22	0 01	0 01	0 01	0 00	0 00	0 00	0 03	0 03	0 03	0 02	0 02	0 02	0 20	0 20	0 20
		hospitalization	0 03	0 03	0 03	0 04	0 04	0 04	0 11	0 11	0 11	0 03	0 03	0 03	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 03	0 03	0 03
		headaches	0 20	0 20	0 20	0 29	0 29	0 29	0 70	0 71	0 71	0 22	0 22	0 22	0 01	0 01	0 01	0 00	0 00	0 00	0 03	0 03	0 03	0 02	0 02	0 02	0 21	0 21	0 21
NOx	NO2	sore throat	0 23	0 23	0 23	0 33	0 34	0 34	0 63	0 64	0 64	0 25	0 26	0 26	0 13	0 13	0 13	0 04	0 04	0 04	0 82	0 82	0 82	0 65	0 66	0 66	0 29	0 29	0 29
		excess phlegm	0 10	0 10	0 10	0 15	0 15	0 15	0 28	0 28	0 28	0 11	0 11	0 11	0 06	0 06	0 06	0 02	0 02	0 02	0 36	0 37	0 37	0 29	0 29	0 29	0 13	0 13	0 13
		eye irritation	0 09	0 09	0 09	0 13	0 14	0 14	0 26	0 26	0 26	0 10	0 10	0 10	0 05	0 05	0 05	0 02	0 02	0 02	0 33	0 33	0 33	0 26	0 27	0 27	0 12	0 12	0 12
NOx, NH3	nitrate PM10	mortality	2 20	2 22	2 22	3 18	3 22	3 22	6 07	6 13	6 13	2 45	2 47	2 47	1 26	1 27	1 27	0 41	0 42	0 42	7 78	7 84	7 84	6 22	6 27	6 27	2 75	2 77	2 77
		chronic illness	0 61	0 62	0 62	0 88	0 89	0 89	1 69	1 71	1 71	0 68	0 69	0 69	0 36	0 36	0 36	0 11	0 12	0 12	2 15	2 17	2 17	1 72	1 74	1 74	0 76	0 77	0 77
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 11	0 11	0 11	0 16	0 16	0 16	0 30	0 31	0 31	0 12	0 12	0 12	0 06	0 06	0 06	0 02	0 02	0 02	0 39	0 39	0 39	0 31	0 32	0 32	0 14	0 14	0 14
Total for NOxand NH3emissions			3 35	3 38	3 38	4 83	4 89	4 89	9 24	9 33	9 33	3 72	3 76	3 76	1 92	1 94	1 94	0 62	0 65	0 65	11 84	11 93	11 93	9 47	9 55	9 55	4 18	4 22	4 22
PM2.5	PM2.5	mortality	0 44	0 49	0 60	0 88	0 99	1 14	2 52	2 68	3 04	0 55	0 62	0 74	5 63	5 65	5 74	1 69	1 73	1 86	13 89	14 09	15.06	11 68	11.84	12.61	1 44	1 51	1 69
		chronic illness	0 13	0 14	0 17	0 25	0 28	0 32	0 70	0 75	0 83	0 16	0 18	0 21	1 63	1 64	1 66	0 48	0 49	0 52	3 81	3 86	4 08	3 21	3 26	3 44	0 40	0 42	0 46
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 00	0 00	0 00
		RRAD	0 02	0 02	0 03	0 04	0 05	0 06	0 13	0 13	0 15	0 03	0 03	0 04	0 28	0 28	0 29	0 08	0 09	0 09	0 70	0 71	0 76	0 59	0 59	0 64	0 07	0 08	0 08
		lung cancer	0 01	0 01	0 01	0 02	0 02	0 02	0 05	0 05	0 05	0 01	0 01	0 01	0 06	0 06	0 06	0 02	0 02	0 02	0 16	0 16	0 16	0 14	0 14	0 14	0 02	0 02	0 02
Coarse PM10	coarse PM10	mortality	0 14	0 16	0 74	0 24	0 26	1 04	0 65	0 69	2 58	0 17	0 19	0 82	0 36	0 37	0 82	0 11	0 12	0 80	0 72	0 77	5 84	0 62	0 66	4 69	0 20	0 22	1 13
		chronic illness	0 04	0 05	0 18	0 07	0 07	0 25	0 18	0 19	0 62	0 05	0 05	0 20	0 10	0 11	0 21	0 03	0 03	0 19	0 20	0 21	1 36	0 17	0 18	1 09	0 06	0 06	0 27
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 01	0 01	0 04	0 01	0 01	0 05	0 03	0 03	0 13	0 01	0 01	0 04	0 02	0 02	0 04	0 01	0 01	0 04	0 04	0 04	0 31	0 03	0 03	0 25	0 01	0 01	0 06
Total for direct PM10emissions			0 78	0 88	1 77	1 51	1 70	2 89	4 27	4 53	7 41	0 97	1 09	2 06	8 09	8 12	8 81	2 42	2 49	3 52	19 53	19 85	27 58	16 44	16 71	22 86	2 20	2 33	3 72
SOx, NH3	sulfate PM10	mortality	0 65	1 08	1 08	0 99	1 84	1 84	1 57	2 80	2 80	0 73	1 26	1 26	3 68	3 84	3 84	1 27	1 60	1 60	8 76	10 18	10 18	7 40	8 55	8 55	1 26	1 84	1 84
		chronic illness	0 18	0 28	0 28	0 27	0 48	0 48	0 41	0 71	0 71	0 20	0 33	0 33	1 01	1 05	1 05	0 34	0 42	0 42	2 26	2 60	2 60	1 92	2 20	2 20	0 34	0 48	0 48
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 00	0 00	0 00
		RRAD	0 03	0 05	0 05	0 05	0 09	0 09	0 08	0 14	0 14	0 04	0 06	0 06	0 18	0 19	0 19	0 06	0 08	0 08	0 44	0 51	0 51	0 37	0 43	0 43	0 06	0 09	0 09
Total for SOxand NH3emissions			0 87	1 42	1 42	1 30	2 42	2 42	2 06	3 65	3 65	0 97	1 65	1 65	4 87	5 08	5 08	1 68	2 11	2 11	11 47	13 31	13 31	9 69	11 18	11 18	1 66	2 41	2 41
VOCs	organic PM10 (SOA)	mortality	0 19	0 28	0 28	0 30	0 44	0 44	0 88	1 12	1 12	0 22	0 32	0 32	0 03	0 06	0 06	0 01	0 06	0 06	0 34	0 58	0 58	0 27	0 46	0 46	0 23	0 33	0 33
		chronic illness	0 05	0 07	0 07	0 08	0 12	0 12	0 25	0 30	0 30	0 06	0 08	0 08	0 01	0 01	0 01	0 00	0 01	0 01	0 09	0 15	0 15	0 07	0 12	0 12	0 06	0 09	0 09
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 01	0 01	0 01	0 01	0 02	0 02	0 04	0 06	0 06	0 01	0 02	0 02	0 00	0 00	0 00	0 00	0 00	0 00	0 02	0 03	0 03	0 01	0 02	0 02	0 01	0 02	0 02
	acetaldehyde	oral cancer	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
	benzene	leukemia	0 00	0 00	0 00	0 01	0 01	0 01	0 02	0 02	0 02	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
	1,3-butadiene	cancer all sites	0 01	0 01	0 01	0 02	0 02	0 02	0 05	0 05	0 05	0 02	0 02	0 02	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 02	0 02	0 02
	formaldehyde	oral cancer	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
Sub-total for VOC emissions			0 28	0 38	0 38	0 43	0 61	0 61	1 24	1 55	1 55	0 32	0 44	0 44	0 05	0 08	0 08	0 02	0 08	0 08	0 45	0 77	0 77	0 36	0 61	0 61	0 32	0 46	0 46
VOCs, NOx	O3	asthma attacks	0 01	0 01	0 01	0 01	0 01	0 01	0 03	0 03	0 03	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 02	0 02	0 02	0 01	0 02	0 02	0 01	0 01	0 01
		lower resp illness	0 03	0 04	0 04	0 05	0 05	0 05	0 10	0 11	0 11	0 04	0 04	0 04	0 01	0 01	0 01	0 00	0 01	0 01	0 07	0 08	0 08	0 06	0 06	0 06	0 04	0 04	0 04
		upper resp illness	0 01	0 01	0 01	0 01	0 02	0 02	0 03	0 03	0 03	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 02	0 02	0 02	0 02	0 02	0 02	0 01	0 01	0 01
		eye irritation	0 03	0 04	0 04	0 05	0 06	0 06	0 11	0 12	0 12	0 04	0 04	0 04	0 01	0 01	0 01	0 00	0 01	0 01	0 07	0 08	0 08	0 06	0 06	0 06	0 04	0 04	0 04
Subtotal mortality effects			3 82	4 43	5 12	5 86	7 04	7 97	12 37	14 10	16 35	4 34	5 07	5 83	10 97	11 19	11 73	3 49	3 94	4 74	31 52	33 50	39 53	26.20	27.80	32 61	6 08	6 88	7 96
Subtotal cancer effects			0 03	0 03	0 03	0 05	0 05	0 05	0 12	0 12	0 12	0 03	0 03	0 03	0 06	0 06	0 06	0 02	0 02	0 02	0 17	0 17	0 17	0 14	0 14	0 14	0 04	0 04	0 04
Subtotal chronic morbidity effects			1 02	1 16	1 32	1 54	1 84	2 05	3 24	3 66	4 17	1 15	1 33	1 50	3 11	3 16	3 29	0 97	1 08	1 26	8 51	8 99	10 36	7 10	7 49	8 58	1 62	1 82	2 07
Subtotal acute morbidity effects			0 92	0 96	1 00	1 36	1 44	1 49	2 85	2 98	3 10	1 03	1 08	1 12	0 84	0 85	0 88	0 27	0 30	0 34	3 34	3 47	3 79	2 72	2 82	3 08	1 16	1 22	1 28
Subtotal ambient PM10			4 84	5 62	6 51	7 43	8 97	10 15	15 58	17.81	20 69	5 49	6 44	7 41	14 69	14 97	15 67	4 66	5 23	6 27	41 77	44 33	52 06	34 75	36.82	42 97	7 82	8 86	10 25
Subtotal ambient O3			0 08	0 09	0 09	0 13	0 14	0 14	0 27	0 29	0 29	0 10	0 10	0 10	0 03	0 03	0 03	0 01	0 01	0 01	0 19	0 20	0 20	0 15	0 16	0 16	0 10	0 11	0 11
Subtotal ambient NO2			0 42	0 43	0 43	0 61	0 62	0 62	1 17	1 18	1 18	0 47	0 47	0 47	0 24	0 24	0 24	0 08	0 08	0 08	1 51	1 52	1 52	1 21	1 22	1 22	0 53	0 53	0 53
Subtotal ambient CO			0 42	0 42	0 42	0 61	0 61	0 61	1 50	1 50	1 50	0 47	0 48	0 48	0 01	0 01	0 01	0 00	0 01	0 01	0 06	0 06	0 06	0 05	0 05	0 05	0 44	0 44	0 44
Total all emissions, pollutants, effects			5 79	6 58	7 47	8.81	10 37	11 56	18.58	20.86	23 74	6 55	7 52	8 49	14 98	15.27	15 96	4 76	5.34	6 37	43 53	46 12	53.85	36 16	38.25	44 41	8 91	9 96	11 35

TABLE 11-A 34 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $/1000 VMT (U S TOTAL 1990) (UPPER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			Total gasoline vehicles			LDDVs			LDDTs			HDDVs			Total diesel vehicles			Total all vehicles		
			V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD
CO	CO	mortality	2 40	2.40	2 40	3 46	3 46	3 46	10 61	10 61	10 61	2 71	2 72	2 72	0 07	0 07	0 07	0 02	0 02	0 02	0 43	0 44	0 44	0 35	0 35	0 35	2 53	2 53	2 53
		hospitalization	0 09	0 09	0 09	0 14	0 14	0 14	0 42	0 42	0 42	0 11	0 11	0 11	0 00	0 00	0 00	0 00	0 00	0 00	0 02	0 02	0 02	0 01	0 01	0 01	0 10	0 10	0 10
		headaches	1 19	1 19	1 19	1 71	1 72	1 72	5 29	5 29	5 29	1 35	1 35	1 35	0 03	0 03	0 03	0 01	0 01	0 01	0 21	0 22	0 22	0 17	0 17	0 17	1 25	1 25	1 25
NOx	NO2	sore throat	1 19	1 20	1 20	1 73	1 74	1 74	4 14	4 16	4 16	1 33	1 34	1 34	0 59	0 59	0 59	0 19	0 20	0 20	5 32	5 34	5 34	4 21	4 22	4 22	1 56	1 57	1 57
		excess phlegm	0 53	0 53	0 53	0 77	0 77	0 77	1 83	1 84	1 84	0 59	0 59	0 59	0 26	0 26	0 26	0 08	0 09	0 09	2 36	2 36	2 36	1 86	1 87	1 87	0 69	0 70	0 70
		eye irritation	0 48	0 49	0 49	0 70	0 70	0 70	1 67	1 68	1 68	0 54	0 54	0 54	0 24	0 24	0 24	0 08	0 08	0 08	2 15	2 16	2 16	1 70	1 71	1 71	0 63	0 64	0 64
NOx, NH3	nitrate PM10	mortality	36 02	36 19	36 19	51 94	52.25	52.25	123 89	124 40	124 40	40.28	40 48	40 48	17 69	17 75	17 75	5 77	5 88	5 88	158 57	159 07	159 07	125 46	125.86	125 86	47 03	47.25	47 25
		chronic illness	13 62	13 69	13 69	19 34	19 45	19 45	47 45	47 63	47 63	15 19	15.27	15.27	6 76	6 78	6 78	2 15	2 19	2 19	60.21	60 38	60 38	47 64	47 78	47 78	17 78	17.85	17 85
		asthma attacks	0 01	0 01	0 01	0 02	0 02	0 02	0 04	0 04	0 04	0 01	0 01	0 01	0 01	0 01	0 01	0 00	0 00	0 00	0 05	0 05	0 05	0 04	0 04	0 04	0 02	0 02	0 02
		RRAD	0 67	0 68	0 68	0 97	0 98	0 98	2 33	2 34	2 34	0 75	0.76	0 76	0 33	0 33	0 33	0 11	0 11	0 11	2 98	2 99	2 99	2 36	2 37	2 37	0 88	0 89	0 89
Total for NOx and NH3 emissions			52.53	52 79	52 79	75 47	75 91	75 91	181 36	182.09	182 09	58 70	59 00	59 00	25.87	25 96	25 96	8 38	8 55	8.55	231 64	232.35	232.35	183.28	183.85	183 85	68 59	68 91	68 91
PM2.5	PM2 5	mortality	6.52	7 15	34 58	13 15	14 10	50 78	56 17	57 35	146 15	8 47	9 17	39.20	84 30	84 66	105 98	25 30	25.81	57 69	307 93	309 36	547.20	251 98	253 17	442.54	27.85	28 59	71 23
		chronic illness	2 55	2.84	12 31	5 07	5 48	18 13	21 50	21 97	52 60	3.30	3 61	13 98	32 96	33 14	40 49	9 75	9 99	20 99	115 61	116 18	198 38	94.82	95 31	160 75	10 59	10 91	25 67
		asthma attacks	0 00	0 00	0 01	0 00	0.00	0 02	0 02	0 02	0 05	0 00	0 00	0 01	0 03	0 03	0.03	0 01	0 01	0 02	0 10	0 10	0 17	0 08	0 08	0 14	0 01	0 01	0 02
		RRAD	0 12	0 14	0 65	0.25	0.27	0 95	1 06	1 08	2 73	0 16	0 17	0 73	1 59	1 60	1 99	0 48	0 49	1 08	5 77	5 79	10.22	4 72	4 74	8.27	0 52	0 54	1 33
		lung cancer	0 15	0 15	0 15	0.31	0 31	0.31	1.36	1.36	1.36	0 19	0 19	0 19	0.80	0.80	0.80	0.25	0.25	0.25	3 14	3 14	3 14	2.56	2 56	2 56	0.38	0.38	0 38
Coarse PM10	coarse PM10	mortality	0 42	0 57	7.52	0 70	0.88	10 16	2 90	3 07	25 53	0 51	0 67	8.27	1 07	1 17	6 57	0 32	0 45	8 51	3.21	3.42	63 68	2 66	2.85	50.83	0 68	0.84	11 66
		chronic illness	0 17	0.24	2 60	0.27	0.36	3 52	1 11	1 19	8.83	0.20	0.28	2.87	0 42	0 47	2 31	0 12	0 19	2 93	1.20	1 31	21 79	1 01	1 09	17 41	0.26	0 34	4.02
		asthma attacks	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 02	0 00	0 00	0 02	0 00	0 00	0 00
		RRAD	0 01	0 01	0 14	0 01	0 02	0 19	0 05	0 06	0 48	0 01	0 01	0 15	0 02	0 02	0 12	0 01	0 01	0 16	0 06	0 06	1 19	0 05	0 05	0 95	0 01	0 02	0 22
Total for direct PM10 emissions			9 94	11 10	57 96	19.76	21 42	84.06	84 18	86 11	237.74	12.84	14 11	65 42	121 19	121 89	158.29	36.22	37.20	91 63	437 02	439 37	845 79	357.87	359.86	683.46	40.31	41.64	114 54
SOx, NH3	sulfate PM10	mortality	4 96	7 01	7 01	7 46	11.29	11.29	17 53	23 46	23 46	5 62	8 07	8 07	27 87	28 66	28 66	9 65	11.27	11.27	97 35	104 38	104 38	79 98	85 66	85 66	11 54	14.24	14 24
		chronic illness	1 78	2.44	2 44	2 65	3.87	3.87	6 16	8 07	8 07	2 01	2.80	2 80	10 02	10.28	10.28	3 42	3 94	3 94	33 47	35 69	35 69	27.57	29.36	29 36	4 05	4 92	4 92
		asthma attacks	0 00	0 00	0.00	0.00	0 00	0 00	0 01	0 01	0 01	0.00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0.03	0.03	0 03	0 02	0 03	0 03	0 00	0 00	0.00
		RRAD	0 09	0 13	0 13	0 14	0.20	0.20	0 32	0 42	0 42	0 10	0 15	0 15	0 51	0.52	0 52	0 18	0.20	0.20	1 77	1 90	1 90	1 46	1 56	1 56	0.21	0 26	0.26
Total for SOx and NH3 emissions			6.83	9.58	9.58	10.25	15.37	15.37	24 01	31 96	31 96	7 73	11.02	11.02	38 41	39 47	39 47	13.24	15.41	15 41	132 63	141 99	141 99	109.04	116 60	116 60	15.80	19 42	19 42
VOCs	organic PM10 (SOA)	mortality	2 19	2 69	2 69	3 41	4.27	4.27	14.87	16 31	16.31	2 60	3 18	3 18	0 39	0 55	0 55	0 15	0 43	0 43	5 63	7 12	7 12	4 42	5 62	5 62	2 74	3 37	3 37
		chronic illness	0.84	0 99	0 99	1.29	1.55	1 55	5 76	6.20	6.20	0 99	1 17	1 17	0 14	0 19	0 19	0 05	0 14	0 14	2 14	2 59	2 59	1 68	2 04	2 04	1 05	1 24	1 24
		asthma attacks	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 04	0 05	0 05	0 06	0 08	0 08	0 28	0 31	0 31	0 05	0 06	0 06	0 01	0 01	0 01	0 00	0 01	0 01	0 11	0 13	0 13	0 08	0 10	0 10	0 05	0 06	0 06
	acetaldehyde	oral cancer	0 01	0 01	0 01	0 01	0 01	0 01	0 04	0 04	0 04	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01
	benzene	leukemia	0 08	0 08	0 08	0 12	0 12	0 12	0 34	0 34	0 34	0 09	0 09	0 09	0 01	0 01	0 01	0 00	0 02	0 02	0 04	0 04	0 04	0 03	0 03	0 03	0 08	0 08	0 08
	1 3-butadiene	cancer all sites	0.25	0.25	0.25	0 41	0 41	0 41	1 14	1 14	1 14	0 30	0 30	0.30	0 02	0 02	0 02	0 01	0 04	0 04	0 09	0 09	0 09	0 07	0 07	0 07	0 28	0 28	0 28
	fomaldehyde	oral cancer	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
Sub-total for VOC emissions			3 42	4 08	4 08	5 31	6 45	6 45	22 45	24 35	24 35	4 04	4 81	4 81	0 57	0 78	0 78	0 21	0 64	0 64	8 01	9 98	9 98	6 28	7 87	7 87	4 21	5 05	5 05
VOCs, NOx	O3	asthma attacks	0 15	0 15	0 15	0 22	0 23	0 23	0 58	0 61	0 61	0 17	0 18	0 18	0 04	0 05	0 05	0 02	0 02	0 02	0 40	0 41	0 41	0 31	0 32	0 32	0 18	0 19	0 19
		lower resp illness	0 28	0 29	0 29	0 42	0 44	0 44	1 09	1 13	1 13	0 32	0 33	0 33	0 08	0 09	0 09	0 03	0 03	0 03	0 74	0 76	0 76	0 59	0 60	0 60	0 34	0 35	0 35
		upper resp illness	0 08	0 09	0 09	0 13	0 13	0 13	0 33	0 34	0 34	0 10	0 10	0 10	0 03	0 03	0 03	0 01	0 01	0 01	0 23	0 23	0 23	0 18	0 18	0 18	0 10	0 11	0 11
		eye irritation	0.21	0.21	0.21	0.32	0.33	0.33	0.84	0.86	0.86	0.23	0.24	0.24	0 06	0.06	0.06	0 02	0 02	0.02	0 54	0 56	0 56	0 43	0 44	0 44	0.25	0.26	0.26
Subtotal mortality effects			52 52	56 02	90 39	80 12	86 26	132 22	225.97	235 20	346 46	60 19	64.29	101 92	131 39	132 86	159 57	41 19	43.87	83.82	573 13	583 79	881 90	464.84	473 51	710 85	92.37	96.83	150.29
Subtotal cancer effects			0 49	0 49	0 49	0.85	0.85	0.85	2.89	2.89	2.89	0 59	0 59	0 59	0.83	0.83	0.83	0.26	0 30	0 30	3.27	3.27	3.27	2 66	2 67	2 67	0 76	0 76	0 76
Subtotal chronic morbidity effects			18 97	20.21	32 04	28 62	30 72	46 53	81 98	85 07	123 33	21 69	23 12	36 08	50.31	50.86	60 05	15 49	16 45	30 19	212 63	216 14	318.83	172 71	175 58	257 34	33 72	35.27	53 71
Subtotal acute morbidity effects			5 16	5.27	5 92	7 59	7.77	8 64	20 31	20 62	22 73	5.83	5 95	6 66	3.84	3.88	4 38	1.22	1.29	2 05	22.83	23 12	28 76	18.28	18.52	23 01	6.82	6 95	7 96
Subtotal ambient PM10			70 18	74 99	121.85	107 04	115 39	178 03	302 82	315 30	466 93	80 45	86.06	137 36	184 93	186 98	223 39	57 69	61 38	115 82	799 34	813 71	1,220 13	648 58	660.28	983 87	125 65	131 74	204 65
Subtotal ambient O3			0 72	0 74	0 74	1 09	1 13	1 13	2.85	2 95	2 95	0.82	0 85	0.85	0 22	0.22	0.22	0 07	0 09	0 09	1 90	1 96	1 96	1 51	1.55	1 55	0.87	0 90	0 90
Subtotal ambient NO2			2 20	2.22	2 22	3 19	3 21	3.21	7 65	7 68	7 68	2 47	2 48	2 48	1 08	1 09	1 09	0 35	0 36	0 36	9.83	9 86	9.86	7 77	7 80	7.80	2 89	2 90	2 90
Subtotal ambient CO			3 69	3 69	3 69	5 31	5 31	5 31	16 31	16 32	16.32	4 17	4 17	4 17	0 10	0 11	0 11	0 03	0 03	0 03	0 66	0 67	0 67	0 53	0 54	0 54	3 88	3 88	3 88
Total all emissions, pollutants, effects			77 13	81 98	128 84	117 18	125 60	188 24	331 16	343 78	495 41	88 30	93 95	145 26	186 37	188 43	224 84	58 16	61 92	116 35	811 86	826 32	1,232 75	658 50	670.27	993.87	133 66	139 80	212.71

TABLE 11-A 35 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $/1000 VMT (URBAN U..S TOTAL 1990) (LOWER BOUN

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	0.23	0.23	0.23	0.35	0.35	0.35	0.91	0.91	0.91	0.26	0.26	0.26	0.01	0.01	0.01	0.00	0.00	0.00	0.04	0.04	0.04	0.03	0.03	0.03	0.24	0.24	0.24
		hospitalization	0.04	0.04	0.04	0.06	0.06	0.06	0.14	0.14	0.14	0.04	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.04	0.04	0.04
		headaches	0.24	0.24	0.24	0.37	0.37	0.37	0.96	0.96	0.96	0.27	0.27	0.27	0.01	0.01	0.01	0.00	0.00	0.00	0.04	0.04	0.04	0.03	0.03	0.03	0.26	0.26	0.26
NOx	NO2	sore throat	0.28	0.28	0.28	0.44	0.44	0.44	0.87	0.88	0.88	0.32	0.32	0.32	0.16	0.16	0.16	0.06	0.06	0.06	1.11	1.12	1.12	0.87	0.87	0.87	0.36	0.36	0.36
		excess phlegm	0.12	0.13	0.13	0.19	0.20	0.20	0.38	0.39	0.39	0.14	0.14	0.14	0.07	0.07	0.07	0.02	0.03	0.03	0.49	0.49	0.49	0.38	0.39	0.39	0.16	0.16	0.16
		eye irritation	0.11	0.11	0.11	0.18	0.18	0.18	0.35	0.35	0.35	0.13	0.13	0.13	0.07	0.07	0.07	0.02	0.02	0.02	0.45	0.45	0.45	0.35	0.35	0.35	0.14	0.15	0.15
NOx, NH3	nitrate PM10	mortality	2.77	2.79	2.79	4.28	4.33	4.33	8.56	8.65	8.65	3.12	3.15	3.15	1.59	1.60	1.60	0.55	0.57	0.57	10.93	11.02	11.02	8.53	8.60	8.60	3.51	3.55	3.55
		chronic illness	0.79	0.80	0.80	1.22	1.23	1.23	2.48	2.51	2.51	0.89	0.90	0.90	0.46	0.46	0.46	0.16	0.16	0.16	3.15	3.18	3.18	2.46	2.48	2.48	1.01	1.02	1.02
		asthma attacks	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
		RRAD	0.14	0.14	0.14	0.21	0.21	0.21	0.42	0.43	0.43	0.15	0.16	0.16	0.08	0.08	0.08	0.03	0.03	0.03	0.54	0.55	0.55	0.42	0.43	0.43	0.17	0.18	0.18
Total for NOxand NH3emissions			4.22	4.26	4.26	6.51	6.59	6.59	13.08	13.21	13.21	4.75	4.80	4.80	2.43	2.45	2.45	0.84	0.87	0.87	16.68	16.81	16.81	13.02	13.13	13.13	5.35	5.40	5.40
PM2.5	PM2.5	mortality	0.55	0.62	0.75	1.19	1.34	1.52	3.57	3.79	4.25	0.71	0.79	0.93	7.12	7.14	7.24	2.29	2.34	2.50	19.46	19.74	20.98	15.99	16.21	17.17	1.82	1.92	2.12
		chronic illness	0.16	0.18	0.21	0.35	0.39	0.44	1.03	1.09	1.21	0.21	0.23	0.27	2.11	2.12	2.14	0.67	0.69	0.73	5.56	5.64	5.95	4.58	4.64	4.88	0.53	0.56	0.61
		asthma attacks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.00
		RRAD	0.03	0.03	0.04	0.06	0.07	0.08	0.18	0.19	0.21	0.03	0.04	0.05	0.35	0.35	0.36	0.11	0.12	0.12	0.97	0.98	1.04	0.79	0.80	0.85	0.09	0.10	0.10
		lung cancer	0.01	0.01	0.01	0.02	0.02	0.02	0.07	0.07	0.07	0.01	0.01	0.01	0.07	0.07	0.07	0.02	0.02	0.02	0.21	0.21	0.21	0.17	0.17	0.17	0.02	0.02	0.02
Coarse PM10	coarse PM10	mortality	0.18	0.20	0.84	0.32	0.36	1.29	0.92	0.97	3.36	0.21	0.24	0.96	0.45	0.46	0.96	0.14	0.16	0.97	1.01	1.08	7.47	0.85	0.90	5.87	0.26	0.29	1.31
		chronic illness	0.05	0.06	0.22	0.09	0.10	0.33	0.27	0.28	0.87	0.06	0.07	0.25	0.13	0.14	0.26	0.04	0.05	0.25	0.29	0.31	1.88	0.24	0.26	1.48	0.08	0.08	0.34
		asthma attacks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
		RRAD	0.01	0.01	0.04	0.02	0.02	0.06	0.05	0.05	0.17	0.01	0.01	0.05	0.02	0.02	0.05	0.01	0.01	0.05	0.05	0.05	0.37	0.04	0.04	0.29	0.01	0.01	0.07
Total for direct PM10emissions			0.99	1.11	2.11	2.05	2.30	3.74	6.08	6.45	10.13	1.25	1.40	2.51	10.27	10.31	11.09	3.29	3.38	4.63	27.57	28.03	37.93	22.69	23.05	30.74	2.82	2.98	4.57
SOx, NH3	sulfate PM10	mortality	0.82	1.35	1.35	1.33	2.46	2.46	2.21	3.94	3.94	0.93	1.59	1.59	4.63	4.84	4.84	1.72	2.16	2.16	12.21	14.21	14.21	10.08	11.66	11.66	1.60	2.33	2.33
		chronic illness	0.23	0.36	0.36	0.37	0.66	0.66	0.60	1.03	1.03	0.26	0.43	0.43	1.31	1.35	1.35	0.48	0.59	0.59	3.29	3.79	3.79	2.73	3.12	3.12	0.44	0.62	0.62
		asthma attacks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
		RRAD	0.04	0.07	0.07	0.07	0.12	0.12	0.11	0.19	0.19	0.05	0.08	0.08	0.23	0.24	0.24	0.09	0.11	0.11	0.61	0.71	0.71	0.50	0.58	0.58	0.08	0.11	0.11
Total for SOxand NH3emissions			1.10	1.79	1.79	1.77	3.24	3.24	2.93	5.17	5.17	1.24	2.10	2.10	6.17	6.43	6.43	2.28	2.85	2.85	16.12	18.71	18.71	13.32	15.37	15.37	2.13	3.07	3.07
VOCs	organic PM10 (SOA)	mortality	0.24	0.35	0.35	0.41	0.60	0.60	1.26	1.60	1.60	0.28	0.41	0.41	0.04	0.08	0.08	0.02	0.08	0.08	0.48	0.83	0.83	0.37	0.64	0.64	0.29	0.43	0.43
		chronic illness	0.07	0.09	0.09	0.12	0.16	0.16	0.37	0.44	0.44	0.08	0.11	0.11	0.01	0.02	0.02	0.00	0.02	0.02	0.14	0.21	0.21	0.10	0.17	0.17	0.08	0.12	0.12
		asthma attacks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		RRAD	0.01	0.02	0.02	0.02	0.03	0.03	0.06	0.08	0.08	0.01	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.04	0.02	0.03	0.03	0.01	0.02	0.02
	acetaldehyde	oral cancer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	benzene	leukemia	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
	1,3-butadiene	cancer all sites	0.02	0.02	0.02	0.03	0.03	0.03	0.07	0.07	0.07	0.02	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02
	fomaldehyde	oral cancer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sub-total for VOC emissions			0.35	0.48	0.48	0.58	0.83	0.83	1.77	2.21	2.21	0.41	0.57	0.57	0.06	0.10	0.10	0.02	0.11	0.11	0.64	1.09	1.09	0.50	0.85	0.85	0.41	0.59	0.59
VOCs, NOx	O3	asthma attacks	0.01	0.01	0.01	0.02	0.02	0.02	0.04	0.04	0.04	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01
		lower resp illness	0.04	0.04	0.04	0.06	0.07	0.07	0.14	0.15	0.15	0.05	0.05	0.05	0.01	0.02	0.02	0.01	0.01	0.01	0.09	0.10	0.10	0.07	0.08	0.08	0.05	0.05	0.05
		upper resp illness	0.01	0.01	0.01	0.02	0.02	0.02	0.04	0.05	0.05	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.02	0.02
		eye irritation	0.04	0.05	0.05	0.07	0.08	0.08	0.15	0.17	0.17	0.05	0.05	0.05	0.02	0.02	0.02	0.01	0.01	0.01	0.10	0.11	0.11	0.08	0.09	0.09	0.05	0.05	0.05
Subtotal mortality effects			4.80	5.55	6.31	7.87	9.44	10.55	17.42	19.86	22.71	5.51	6.44	7.29	13.85	14.12	14.72	4.72	5.31	6.28	44.12	46.91	54.54	35.85	38.05	43.97	7.73	8.75	9.98
Subtotal cancer effects			0.03	0.03	0.03	0.06	0.06	0.06	0.15	0.15	0.15	0.04	0.04	0.04	0.07	0.07	0.07	0.02	0.03	0.03	0.22	0.22	0.22	0.18	0.18	0.18	0.05	0.05	0.05
Subtotal chronic morbidity effects			1.31	1.50	1.69	2.15	2.55	2.82	4.75	5.36	6.06	1.51	1.74	1.95	4.03	4.09	4.24	1.36	1.50	1.74	12.43	13.12	15.00	10.12	10.67	12.13	2.14	2.39	2.70
Subtotal acute morbidity effects			1.13	1.18	1.22	1.78	1.88	1.94	3.90	4.08	4.23	1.28	1.34	1.39	1.04	1.06	1.09	0.36	0.40	0.45	4.56	4.74	5.13	3.63	3.77	4.08	1.45	1.52	1.58
Subtotal ambient PM10			6.12	7.09	8.09	10.07	12.11	13.55	22.16	25.34	29.02	7.04	8.24	9.35	18.63	18.99	19.77	6.34	7.10	8.35	58.95	62.57	72.47	47.92	50.77	58.46	10.03	11.35	12.94
Subtotal ambient O3			0.10	0.11	0.11	0.17	0.18	0.18	0.37	0.41	0.41	0.12	0.13	0.13	0.04	0.04	0.04	0.01	0.02	0.02	0.25	0.27	0.27	0.19	0.21	0.21	0.12	0.13	0.13
Subtotal ambient NO2			0.52	0.52	0.52	0.80	0.82	0.82	1.60	1.62	1.62	0.58	0.59	0.59	0.30	0.30	0.30	0.10	0.11	0.11	2.05	2.07	2.07	1.60	1.61	1.61	0.66	0.66	0.66
Subtotal ambient CO			0.51	0.51	0.51	0.78	0.78	0.78	2.01	2.01	2.01	0.57	0.57	0.57	0.02	0.02	0.02	0.01	0.01	0.01	0.08	0.08	0.08	0.06	0.07	0.07	0.54	0.54	0.54
Total all emissions, pollutants, effects			7.27	8.26	9.26	11.86	13.93	15.37	26.23	29.46	33.15	8.34	9.56	10.67	18.99	19.35	20.13	6.46	7.24	8.49	61.33	65.00	74.90	49.78	52.67	60.36	11.37	12.71	14.31

TABLE 11-A.36 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH FFFECT, $/1000 VMT (URBAN U..S TOTAL 1990) (UPPER BOUNI

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			Total gasoline vehicles			LDDVs			LDDTs			HDDVs			Total diesel vehicles			Total all vehicles		
			V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD
CO	CO	mortality	2 76	2 76	2 76	4 24	4 24	4 24	13 80	13 81	13 81	3 16	3 17	3 17	0 08	0 08	0 08	0 03	0 03	0 03	0 55	0 56	0 56	0 43	0 43	0 43	2 96	2 97	2 97
		hospitalization	0 11	0 11	0 11	0 17	0 17	0 17	0 55	0 55	0 55	0 13	0 13	0 13	0 00	0 00	0 00	0 00	0 00	0 00	0 02	0 02	0 02	0 02	0 02	0 02	0 12	0 12	0 12
		headaches	1 41	1 41	1 41	2 16	2 16	2 16	7 07	7 07	7 07	1 61	1 61	1 61	0 04	0 04	0 04	0 01	0 01	0 01	0 28	0 28	0 28	0 22	0 22	0 22	1 51	1 51	1 51
NOx	NO2	sore throat	1 48	1 48	1 48	2 28	2 30	2 30	5 76	5 78	5 78	1 67	1 68	1 68	0 73	0 73	0 73	0 25	0 26	0 26	7 35	7 37	7 37	5 67	5 69	5 69	1 96	1 97	1 97
		excess phlegm	0 65	0 65	0 65	1 01	1 01	1 01	2 54	2 55	2 55	0 74	0 74	0 74	0 32	0 32	0 32	0 11	0 11	0 11	3 24	3 25	3 25	2 50	2 51	2 51	0 87	0 87	0 87
		eye irritation	0 60	0 60	0 60	0 92	0 93	0 93	2 32	2 33	2 33	0 68	0 68	0 68	0 29	0 30	0 30	0 10	0 10	0 10	2 96	2 97	2 97	2 29	2 30	2 30	0 79	0 80	0 80
NOx, NH3	nitrate PM10	mortality	44 94	45 16	45 16	69 23	69 64	69 64	173 93	174 63	174 63	50 92	51 17	51 17	22 16	22 23	22 23	7 72	7 87	7 87	221 50	222 18	222 18	171 01	171 54	171 54	59 67	59 94	59 94
		chronic illness	17 62	17 70	17 70	26 89	27 04	27 04	69 69	69 95	69 95	19 94	20 04	20 04	8 75	8 78	8 78	2 99	3 05	3 05	88 27	88 53	88 53	68 13	68 33	68 33	23 47	23 57	23 57
		asthma attacks	0 01	0 01	0 01	0 02	0 02	0 02	0 06	0 06	0 06	0 02	0 02	0 02	0 01	0 01	0 01	0 00	0 00	0 00	0 07	0 07	0 07	0 06	0 06	0 06	0 02	0 02	0 02
		RRAD	0 85	0 86	0 86	1 31	1 32	1 32	3 32	3 34	3 34	0 96	0 97	0 97	0 42	0 42	0 42	0 15	0 15	0 15	4 23	4 25	4 25	3 27	3 28	3 28	1 13	1 14	1 14
Total for NOxand NH3emissions			66 15	66 46	66 46	101 66	102 25	102 25	257 62	258 63	258 63	74 93	75 30	75 30	32 69	32 79	32 79	11 33	11 55	11 55	327 63	328 62	328 62	252 92	253 70	253 70	87 91	88 31	88 31
PM2.5	PM2 5	mortality	8 19	8 98	40 17	17 64	18 92	63 91	79 03	80 68	196 04	10 76	11 65	46 36	105 85	106 29	130 54	33 96	34 66	73 76	428 42	430 41	739 35	342 45	344 09	583 96	35 02	35 96	85 58
		chronic illness	3 31	3 68	15 56	7 06	7 63	24 75	31 58	32 28	76 18	4 33	4 74	17 97	42 71	42 93	52 16	13 58	13 92	28 79	169 15	169 98	287 78	135 38	136 08	227 55	13 93	14 36	33 31
		asthma attacks	0 00	0 00	0 01	0 01	0 01	0 02	0 03	0 03	0 06	0 00	0 00	0 02	0 03	0 03	0 04	0 01	0 01	0 02	0 14	0 14	0 24	0 11	0 11	0 19	0 01	0 01	0 03
		RRAD	0 16	0 17	0 77	0 34	0 36	1 23	1 51	1 54	3 76	0 20	0 22	0 89	2 01	2 02	2 49	0 65	0 66	1 41	8 15	8 19	14 13	6 51	6 55	11 16	0 67	0 69	1 64
		lung cancer	0 17	0 17	0 17	0 37	0 37	0 37	1 72	1 72	1 72	0 22	0 22	0 22	0 96	0 96	0 96	0 31	0 31	0 31	4 09	4 09	4 09	3 26	3 26	3 26	0 45	0 45	0 45
Coarse PM10	coarse PM10	mortality	0 53	0 72	8 52	0 94	1 19	12 43	4 09	4 33	33 14	0 65	0 85	9 53	1 34	1 48	7 53	0 42	0 61	10 38	4 46	4 77	82 06	3 61	3 88	63 90	0 87	1 07	13 51
		chronic illness	0 21	0 32	3 27	0 38	0 51	4 76	1 63	1 76	12 65	0 26	0 37	3 65	0 54	0 61	2 91	0 17	0 27	3 96	1 76	1 91	31 15	1 43	1 56	24 27	0 35	0 46	5 16
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 03	0 00	0 00	0 02	0 00	0 00	0 00
		RRAD	0 01	0 01	0 16	0 02	0 02	0 24	0 08	0 08	0 64	0 01	0 02	0 18	0 03	0 03	0 15	0 01	0 01	0 20	0 08	0 09	1 59	0 07	0 07	1 23	0 02	0 02	0 26
Total for direct PM10emissions			12 58	14 05	68 65	26 76	29 01	107 71	119 66	122 41	324 20	16 45	18 08	78 84	153 47	154 36	196 79	49 11	50 45	118 85	616 25	619 99	1,160 42	492 83	495 60	915 54	51 30	53 01	139 94
SOx, NH3	sulfate PM10	mortality	6 21	8 67	8 67	9 99	14 90	14 90	24 58	32 72	32 72	7 13	10 11	10 11	34 91	35 86	35 86	12 91	15 01	15 01	134 75	144 36	144 36	108 18	115 75	115 75	14 52	17 84	17 84
		chronic illness	2 31	3 14	3 14	3 68	5 33	5 33	9 04	11 80	11 80	2 64	3 65	3 65	12 98	13 31	13 31	4 76	5 46	5 46	48 90	52 09	52 09	39 31	41 83	41 83	5 33	6 45	6 45
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 04	0 04	0 04	0 03	0 04	0 04	0 00	0 01	0 01
		RRAD	0 11	0 16	0 16	0 18	0 27	0 27	0 45	0 60	0 60	0 13	0 18	0 18	0 64	0 66	0 66	0 24	0 28	0 28	2 49	2 66	2 66	2 00	2 14	2 14	0 27	0 33	0 33
Total for SOxand NH3emissions			8 64	11 98	11 98	13 86	20 52	20 52	34 09	45 14	45 14	9 90	13 95	13 95	48 54	49 85	49 85	17 91	20 75	20 75	186 19	199 16	199 16	149 52	159 75	159 75	20 12	24 62	24 62
VOCs	organic PM10 (SOA)	mortality	2 76	3 37	3 37	4 59	5 73	5 73	21 17	23 18	23 18	3 31	4 03	4 03	0 49	0 69	0 69	0 20	0 58	0 58	7 91	10 01	10 01	6 05	7 70	7 70	3 51	4 30	4 30
		chronic illness	1 09	1 28	1 28	1 80	2 16	2 16	8 50	9 15	9 15	1 30	1 54	1 54	0 19	0 25	0 25	0 07	0 19	0 19	3 14	3 80	3 80	2 40	2 92	2 92	1 38	1 64	1 64
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 05	0 06	0 06	0 09	0 11	0 11	0 40	0 44	0 44	0 08	0 08	0 08	0 01	0 01	0 01	0 00	0 01	0 01	0 15	0 19	0 19	0 12	0 15	0 15	0 07	0 08	0 08
	acetaldehyde	oral cancer	0 01	0 01	0 01	0 02	0 02	0 02	0 05	0 05	0 05	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01
	benzene	leukemia	0 09	0 09	0 09	0 15	0 15	0 15	0 43	0 43	0 43	0 10	0 10	0 10	0 01	0 01	0 01	0 01	0 02	0 02	0 05	0 05	0 05	0 04	0 04	0 04	0 10	0 10	0 10
	1,3-butadiene	cancer all sites	0 29	0 29	0 29	0 50	0 50	0 50	1 47	1 47	1 47	0 35	0 35	0 35	0 02	0 02	0 02	0 01	0 05	0 05	0 11	0 11	0 11	0 09	0 09	0 09	0 33	0 33	0 33
	fomaldehyde	oral cancer	0 00	0 00	0 00	0 01	0 01	0 01	0 02	0 02	0 02	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
Sub-total for VOC emissions			4 29	5 11	5 11	7 14	8 67	8 67	32 06	34 74	34 74	5 14	6 11	6 11	0 72	0 99	0 99	0 29	0 85	0 85	11 37	14 17	14 17	8 70	10 90	10 90	5 40	6 46	6 46
VOCs, NOx	O3	asthma attacks	0 18	0 19	0 19	0 29	0 30	0 30	0 80	0 83	0 83	0 21	0 22	0 22	0 05	0 06	0 06	0 02	0 02	0 02	0 52	0 53	0 53	0 40	0 41	0 41	0 22	0 23	0 23
		lower resp illness	0 34	0 35	0 35	0 54	0 57	0 57	1 50	1 55	1 55	0 39	0 40	0 40	0 10	0 10	0 10	0 04	0 04	0 04	0 97	1 00	1 00	0 75	0 77	0 77	0 42	0 43	0 43
		upper resp illness	0 10	0 11	0 11	0 17	0 17	0 17	0 46	0 47	0 47	0 12	0 12	0 12	0 03	0 03	0 03	0 01	0 01	0 01	0 29	0 30	0 30	0 23	0 23	0 23	0 13	0 13	0 13
		eye irritation	0 26	0 27	0 27	0 42	0 44	0 44	1 19	1 23	1 23	0 30	0 31	0 31	0 08	0 08	0 08	0 03	0 03	0 03	0 75	0 77	0 77	0 58	0 59	0 59	0 32	0 33	0 33
Subtotal mortality effects			65 39	69 66	108 66	106 64	114 63	170 85	316 99	329 34	473 51	75 93	80 99	124 38	164 82	166 63	196 94	55 24	58 75	107 62	797 60	812 29	1,198 53	631 73	643 39	943 29	116 54	122 08	184 14
Subtotal cancer effects			0 56	0 56	0 56	1 04	1 04	1 04	3 69	3 69	3 69	0 69	0 69	0 69	1 00	1 00	1 00	0 33	0 38	0 38	4 25	4 25	4 25	3 39	3 40	3 40	0 88	0 88	0 88
Subtotal chronic morbidity effects			24 54	26 12	40 96	39 80	42 66	64 04	120 46	124 94	179 73	28 49	30 34	46 85	65 16	65 88	77 40	21 57	22 89	41 46	311 22	316 32	463 34	246 65	250 72	364 89	44 45	46 47	70 13
Subtotal acute morbidity effects			6 32	6 45	7 22	9 93	10 17	11 27	28 04	28 46	31 29	7 24	7 39	8 24	4 82	4 87	5 46	1 64	1 73	2 69	31 74	32 14	39 71	24 82	25 13	31 01	8 52	8 68	9 89
Subtotal ambient PM10			88 54	94 47	149 06	144 55	155 54	234 24	430 83	448 30	650 08	102 88	109 88	170 63	234 04	236 60	279 02	78 15	83 06	151 46	1,127 73	1,147 78	1,688 61	893 38	909 32	1,329 26	160 67	168 32	255 25
Subtotal ambient O3			0 88	0 91	0 91	1 42	1 48	1 48	3 94	4 08	4 08	1 01	1 05	1 05	0 26	0 27	0 27	0 09	0 11	0 11	2 52	2 60	2 60	1 95	2 01	2 01	1 08	1 12	1 12
Subtotal ambient NO2			2 72	2 74	2 74	4 21	4 24	4 24	10 61	10 66	10 66	3 09	3 10	3 10	1 35	1 35	1 35	0 47	0 48	0 48	13 55	13 59	13 59	10 46	10 49	10 49	3 62	3 64	3 64
Subtotal ambient CO			4 28	4 28	4 28	6 57	6 57	6 57	21 42	21 43	21 43	4 90	4 91	4 91	0 13	0 13	0 13	0 04	0 04	0 04	0 85	0 86	0 86	0 67	0 67	0 67	4 59	4 60	4 60
Total all emissions, pollutants, effects			96 82	102 79	157 39	157 41	168 50	247 20	468 78	486 44	688 22	112 34	119 40	180 16	235 81	238 39	280 81	78 77	83 77	152 16	1,144 81	1,165 00	1,705 83	906 59	922 64	1,342 58	170 40	178 11	265 05

TABLE 11-A 37 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $/1000 VMT (RURAL U S TOTAL 1990) (LOWER BOUN

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	0 08	0 08	0 08	0 10	0 10	0 10	0.24	0.24	0.24	0 09	0 09	0 09	0 00	0 00	0 00	0.00	0 00	0 00	0 01	0 01	0.01	0 01	0 01	0 01	0 08	0 08	0 08
		hospitalization	0 01	0 01	0 01	0 02	0 02	0 02	0 04	0 04	0 04	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01
		headaches	0 07	0 07	0 07	0 09	0 09	0 09	0.20	0.20	0.20	0 08	0 08	0 08	0.00	0.00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 07	0 07	0 07
NOx	NO2	sore throat	0 06	0 06	0 06	0 08	0 09	0 09	0 17	0 17	0 17	0 07	0 07	0 07	0 03	0 03	0 03	0 01	0 01	0 01	0 23	0 23	0 23	0 19	0 19	0 19	0 08	0 08	0 08
		excess phlegm	0 03	0 03	0 03	0 04	0 04	0 04	0 08	0 08	0 08	0 03	0 03	0 03	0 02	0 02	0 02	0 00	0 00	0 00	0 11	0 11	0 11	0 09	0 09	0 09	0 04	0 04	0 04
		eye irritation	0 03	0 03	0 03	0 03	0 04	0 04	0 07	0 07	0 07	0 03	0 03	0 03	0 01	0 01	0 01	0 00	0 00	0 00	0 10	0 10	0 10	0 08	0 08	0 08	0 03	0 03	0 03
NOx, NH3	nitrate PM10	mortality	0 41	0 41	0 41	0 56	0 56	0 56	1 09	1 10	1 10	0 45	0 46	0 46	0 22	0 22	0 22	0 07	0 07	0 07	1 50	1 50	1 50	1 24	1 25	1 25	0 53	0 54	0 54
		chronic illness	0 04	0 05	0 05	0 06	0 06	0 06	0 12	0 12	0 12	0 05	0 05	0 05	0 02	0 02	0 02	0 01	0 01	0 01	0 17	0 17	0 17	0 14	0 14	0 14	0 06	0 06	0 06
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 02	0 02	0 02	0 03	0 03	0 03	0 07	0 07	0 07	0 03	0 03	0 03	0 01	0 01	0 01	0 00	0 00	0 00	0 09	0 09	0 09	0 07	0 08	0 08	0 03	0 03	0 03
Total for NOxand NH3emissions			0 59	0 60	0 60	0 81	0 82	0 82	1 59	1 61	1 61	0 66	0 67	0 67	0 32	0 32	0 32	0 10	0 10	0 10	2 18	2 20	2 20	1 82	1 83	1 83	0 77	0 78	0 78
PM2.5	PM2 5	mortality	0 07	0 08	0 15	0 14	0 16	0 23	0 44	0 47	0 63	0 09	0 11	0 18	0 91	0 91	0 97	0 26	0 27	0 33	2 78	2 82	3 26	2 38	2 41	2 78	0 32	0 33	0 44
		chronic illness	0 01	0 01	0 02	0 02	0 02	0 03	0 05	0 05	0 07	0 01	0 01	0 02	0 10	0 10	0 11	0 03	0 03	0 04	0 31	0 32	0 37	0 27	0 27	0 32	0 04	0 04	0 05
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 00	0 01	0 01	0 01	0 01	0 01	0 03	0 03	0 04	0 01	0 01	0 01	0 05	0 05	0 06	0 02	0 02	0 02	0 17	0 17	0 20	0 14	0 14	0 17	0 02	0 02	0 03
		lung cancer	0 00	0 00	0 00	0 01	0 01	0 01	0 03	0 03	0 03	0 01	0 01	0 01	0 02	0 02	0 02	0 01	0 01	0 01	0 07	0 07	0 07	0 06	0 06	0 06	0 01	0 01	0 01
Coarse PM10	coarse PM10	mortality	0 02	0 03	0 42	0 04	0 04	0 46	0 11	0 12	1 02	0 03	0 03	0 44	0 06	0 06	0 36	0 02	0 02	0 39	0 15	0 15	2 57	0 13	0 13	2 16	0 04	0 04	0 61
		chronic illness	0 00	0 00	0 05	0 00	0 00	0 06	0 01	0 01	0 12	0 00	0 00	0 05	0 01	0 01	0 04	0 00	0 00	0 05	0 02	0 02	0 31	0 01	0 01	0 26	0 00	0 00	0 07
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 00	0 00	0 03	0 00	0 00	0 03	0 01	0 01	0 07	0 00	0 00	0 03	0 00	0 00	0 02	0 00	0 00	0 03	0 01	0 01	0 17	0 01	0 01	0 14	0 00	0 00	0 04
Total for direct PM10emissions			0 11	0 13	0 68	0 21	0 24	0 83	0 68	0 72	1 98	0 15	0 17	0 74	1 16	1 16	1 59	0 33	0 34	0 86	3 50	3 55	6 95	3 00	3 04	5 89	0 43	0 45	1 25
SOx, NH3	sulfate PM10	mortality	0 11	0 22	0 22	0 16	0 36	0 36	0 29	0 51	0 51	0 13	0 26	0 26	0 63	0 67	0 67	0 21	0 28	0 28	1 88	2 16	2 16	1 62	1 85	1 85	0 27	0 42	0 42
		chronic illness	0 01	0 03	0 03	0 02	0 06	0 06	0 03	0 07	0 07	0 01	0 04	0 04	0 06	0 07	0 07	0 02	0 03	0 03	0 19	0 24	0 24	0 16	0 21	0 21	0 03	0 06	0 06
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 01	0 01	0 01	0 01	0 02	0 02	0 02	0 03	0 03	0 01	0 02	0 02	0 04	0 04	0 04	0 01	0 02	0 02	0 11	0 13	0 13	0 10	0 11	0 11	0 02	0 02	0 02
Total for SOxand NH3emissions			0 13	0 27	0 27	0 19	0 45	0 45	0 34	0 61	0 61	0 15	0 31	0 31	0 74	0 78	0 78	0 24	0 32	0 32	2 19	2 53	2 53	1 88	2 17	2 17	0 32	0 50	0 50
VOCs	organic PM10 (SOA)	mortality	0 03	0 05	0 05	0 04	0 07	0 07	0 13	0 17	0 17	0 04	0 06	0 06	0 01	0 01	0 01	0 00	0 01	0 01	0 06	0 10	0 10	0 05	0 08	0 08	0 04	0 06	0 06
		chronic illness	0 00	0 01	0 01	0 00	0 01	0 01	0 01	0 02	0 02	0 00	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 00	0 01	0 01
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0.01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00
	acetaldehyde	oral cancer	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
	benzene	leukemia	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
	1,3-butadiene	cancer all sites	0 01	0 01	0 01	0 01	0 01	0 01	0 02	0 02	0 02	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
	fomaldehyde	oral cancer	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01
Sub-total for VOC emissions			0 05	0 07	0 07	0 07	0 10	0 10	0 18	0 23	0 23	0 05	0 08	0 08	0 01	0 01	0 01	0 00	0 01	0 01	0 07	0 12	0 12	0 06	0 10	0 10	0 05	0 08	0 08
VOCs, NOx	O3	asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 00	0 00	0 00
		lower resp illness	0 01	0 01	0 01	0 01	0 02	0 02	0 03	0 03	0 03	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 03	0 03	0 03	0 02	0 03	0 03	0 01	0 01	0 01
		upper resp illness	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 00	0 00	0 00
		eye irritation	0 01	0 01	0 01	0 01	0 01	0 01	0 02	0 02	0 02	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 02	0 02	0 02	0 02	0 02	0 02	0 01	0 01	0 01
Subtotal mortality effects			0 73	0 88	1 34	1 04	1 30	1.79	2 30	2 61	3 67	0 83	1 00	1 48	1 83	1 88	2 23	0 55	0 64	1 07	6 38	6 74	9 60	5 43	5 74	8 13	1 28	1 47	2 14
Subtotal cancer effects			0 01	0 01	0 01	0 02	0 02	0 02	0 06	0 06	0 06	0 02	0 02	0 02	0 02	0 02	0 02	0 01	0 01	0 01	0 07	0 07	0 07	0 06	0 06	0 06	0 02	0 02	0 02
Subtotal chronic morbidity effects			0 07	0 09	0 15	0 10	0 15	0 22	0 23	0 28	0 41	0 08	0 11	0 17	0 20	0 20	0 25	0 06	0 07	0 13	0 69	0 75	1 10	0 59	0 64	0 93	0 13	0 16	0 25
Subtotal acute morbidity effects			0 26	0 27	0 30	0 35	0 37	0 41	0 74	0 77	0 84	0 29	0 30	0 34	0 18	0 19	0 21	0 06	0 06	0 09	0 89	0 92	1 11	0 75	0 78	0 94	0 33	0 35	0 40
Subtotal ambient PM10			0 76	0 94	1 49	1 10	1 43	2 02	2 44	2 82	4 08	0 87	1 09	1 66	2 15	2 21	2 64	0 65	0 76	1 27	7 51	7 96	11 36	6 39	6 77	9 62	1 41	1 65	2 44
Subtotal ambient O3			0 02	0 03	0 03	0 03	0 04	0 04	0 07	0 07	0 07	0 03	0 03	0 03	0 01	0 01	0 01	0 00	0 00	0 00	0 07	0 07	0 07	0 05	0 06	0 06	0 03	0 03	0 03
Subtotal ambient NO2			0 12	0 12	0 12	0 16	0 16	0 16	0 31	0 32	0 32	0 13	0 13	0 13	0 06	0 06	0 06	0 02	0 02	0 02	0 43	0 43	0 43	0 36	0 36	0 36	0 15	0 15	0 15
Subtotal ambient CO			0 16	0 16	0 16	0 21	0 21	0 21	0 48	0 48	0 48	0 18	0 18	0 18	0 00	0 00	0 00	0 00	0 00	0 00	0 02	0 02	0 02	0 02	0 02	0 02	0 16	0 16	0 16
Total all emissions, pollutants, effects			1 07	1.26	1.80	1 51	1 84	2.44	3 33	3 71	4 98	1.21	1.44	2.01	2.23	2.29	2.72	0 68	0 78	1.30	8 03	8 49	11.89	6.83	7.21	10.06	1.76	2.00	2.80

TABLE 11-A 38 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $/1000 VMT (RURAL U S TOTAL 1990) (UPPER BOUNE

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	1.24	1.25	1.25	1 58	1 59	1 59	4.24	4.24	4.24	1 37	1 38	1 38	0 03	0 03	0 03	0 01	0 01	0 01	0.20	0.20	0.20	0 16	0 17	0 17	1.26	1.26	1.26
		hospitalization	0 05	0 05	0 05	0 06	0 06	0 06	0 17	0 17	0 17	0 05	0 05	0 05	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 05	0 05	0 05
		headaches	0 51	0 51	0.51	0 65	0 65	0 65	1 73	1 73	1 73	0.56	0.56	0 56	0 01	0 01	0 01	0 00	0 00	0 00	0 08	0 08	0 08	0.07	0.07	0.07	0 51	0 51	0 51
NOx	NO2	sore throat	0 29	0 30	0.30	0 40	0 41	0 41	0 92	0 93	0 93	0 33	0 33	0 33	0 14	0 14	0 14	0 04	0 04	0 04	1 28	1.29	1.29	1 06	1 06	1 06	0 40	0 41	0 41
		excess phlegm	0 14	0 14	0 14	0 19	0 19	0 19	0 43	0 43	0 43	0 15	0 15	0 15	0 06	0 06	0 06	0 02	0 02	0 02	0 59	0 59	0 59	0 49	0 49	0 49	0 19	0 19	0 19
		eye irritation	0 12	0 12	0 12	0 17	0 17	0 17	0 38	0 39	0.39	0 14	0 14	0 14	0 06	0 06	0 06	0 02	0 02	0 02	0 53	0 53	0.53	0 44	0 44	0 44	0 17	0 17	0 17
NOx, NH3	nitrate PM10	mortality	7 67	7 73	7 73	10 54	10 63	10 63	24 13	24.26	24.26	8 62	8 68	8 68	3 50	3 52	3.52	1 09	1 12	1 12	33 11	33.23	33.23	27 39	27 50	27 50	10 46	10 53	10 53
		chronic illness	0 94	0 94	0 94	1.28	1 29	1.29	3 09	3 10	3 10	1 05	1 06	1 06	0 43	0 43	0 43	0 13	0 14	0 14	4.25	4 26	4.26	3.51	3 53	3 53	1 30	1 30	1 30
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 00	0 00	0 00
		RRAD	0 11	0 12	0 12	0 16	0 16	0 16	0 36	0 36	0 36	0 13	0 13	0 13	0 05	0 05	0.05	0 02	0 02	0 02	0 50	0 50	0 50	0 41	0 41	0 41	0 16	0 16	0 16
Total for NOxand NH3emissions			9.27	9.35	9 35	12 74	12.85	12.85	29.32	29 48	29 48	10 42	10 50	10 50	4.23	4.26	4.26	1.32	1.36	1 36	40.26	40 41	40 41	33.31	33 44	33 44	12 67	12 76	12 76
PM2.5	PM2 5	mortality	1.23	1.36	16.81	2.38	2 56	19 34	10 61	10.85	46 68	1 66	1.80	17 90	15.88	15 93	27 93	4 55	4 63	19.21	67 71	68 01	164 10	57 14	57 40	137 98	7 12	7 27	29 70
		chronic illness	0 16	0 18	1 98	0.30	0 33	2.29	1 39	1 42	5 60	0.21	0.23	2 11	2 01	2 02	3 42	0 58	0 59	2.29	8.87	8 90	20 13	7 47	7 51	16 92	0 93	0 95	3 57
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 00	0 00	0 00	0 00	0 00	0 01	0 00	0 00	0 00	0 02	0 02	0 04	0 01	0 01	0 03	0 00	0 00	0 01
		RRAD	0 02	0 02	0.24	0 04	0 04	0.28	0 16	0 16	0 68	0 02	0 03	0.26	0.24	0.24	0 41	0 07	0 07	0.28	1 02	1 02	2 41	0.86	0.86	2 03	0 11	0 11	0 43
		lung cancer	0.07	0 07	0.07	0 14	0 14	0 14	0 64	0 64	0 64	0 10	0 10	0 10	0.29	0.29	0.29	0 08	0 08	0 08	1.24	1.24	1.24	1.05	1.05	1 05	0 19	0 19	0 19
Coarse PM10	coarse PM10	mortality	0 08	0 10	4.32	0 13	0 14	4 74	0 55	0 57	10 37	0 10	0 11	4 52	0.20	0.21	3 49	0 06	0 07	4 06	0 71	0 73	27 03	0 60	0.62	22 68	0 15	0 16	6 31
		chronic illness	0 01	0 01	0 50	0 02	0 02	0 55	0 07	0 08	1.21	0 01	0 02	0.53	0 03	0 03	0 41	0 01	0 01	0 47	0 09	0 10	3 14	0 08	0 08	2 64	0 02	0 02	0 73
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0.00	0 00	0 01	0 00	0 00	0 00
		RRAD	0 00	0 00	0 06	0 00	0 00	0 07	0 01	0 01	0 15	0 00	0 00	0 07	0 00	0 00	0.05	0 00	0 00	0 06	0 01	0 01	0 39	0 01	0 01	0.33	0 00	0 00	0 09
Total for direct PM10emissions			1 58	1 74	24 00	3.01	3.24	27 42	13 43	13 73	65.35	2 11	2.29	25 50	18 65	18 73	36 02	5.34	5 45	26.46	79 66	80.03	218 49	67.23	67.55	183 67	8.52	8 71	41.04
SOx, NH3	sulfate PM10	mortality	0 98	1 72	1 72	1 41	2 64	2.64	3 47	4 98	4 98	1 12	1 99	1 99	5 51	5 77	5 77	1.83	2.32	2.32	22 78	24 66	24 66	19.27	20.86	20.86	2 90	3.85	3.85
		chronic illness	0 11	0.22	0.22	0 16	0 37	0.37	0 41	0 63	0 63	0 13	0.26	0.26	0 63	0 66	0 66	0.21	0.27	0.27	2 71	2 98	2 98	2.29	2 52	2 52	0 34	0 48	0 48
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0.00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 01	0 03	0 03	0 02	0 04	0 04	0 05	0 07	0.07	0 02	0.03	0 03	0 08	0 09	0 09	0 03	0.03	0 03	0 34	0 37	0 37	0.29	0 31	0 31	0 04	0 06	0 06
Total for SOxand NH3emissions			1 10	1 97	1 97	1.59	3 05	3.05	3 93	5 69	5 69	1.27	2.28	2.28	6.22	6.52	6 52	2 07	2 63	2 63	25.84	28.01	28 01	21.85	23 70	23 70	3.29	4 39	4.39
VOCs	organic PM10	mortality	0 41	0 55	0 55	0.59	0.78	0.78	2.30	2.61	2 61	0 48	0 64	0 64	0 07	0 11	0 11	0 03	0 09	0 09	1 08	1.37	1 37	0.89	1 13	1 13	0 52	0 69	0 69
	(SOA)	chronic illness	0 05	0 07	0 07	0 07	0 09	0 09	0 30	0 33	0 33	0 06	0 08	0 08	0 01	0 01	0 01	0 00	0 01	0 01	0 14	0 17	0 17	0 12	0 14	0 14	0 07	0 08	0 08
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 01	0 01	0 01	0 01	0 01	0 01	0 03	0 04	0 04	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 02	0 02	0 02	0 01	0 02	0 02	0 01	0 01	0 01
	acetaldehyde	oral cancer	0 00	0 00	0 00	0 01	0 01	0 01	0 02	0 02	0 02	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
	benzene	leukemia	0 04	0 04	0.04	0 06	0.06	0 06	0 15	0 15	0 15	0 05	0 05	0 05	0 00	0 00	0 00	0 00	0 01	0 01	0 02	0 02	0 02	0 01	0 01	0 01	0 04	0 04	0 04
	1,3-butadiene	cancer all sites	0 13	0 13	0 13	0 19	0 19	0 19	0 49	0 49	0 49	0 15	0 15	0 15	0 01	0 01	0 01	0 00	0 01	0 01	0 04	0 04	0 04	0 04	0 04	0 04	0 14	0 14	0 14
	fomaldehyde	oral cancer	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
Sub-total for VOC emissions			0 64	0.80	0.80	0 93	1 15	1 15	3.30	3 64	3 64	0 75	0 93	0 93	0 09	0 14	0 14	0 03	0 12	0 12	1.30	1 63	1 63	1 07	1.35	1 35	0 78	0 97	0 97
VOCs, NOx	O3	asthma attacks	0 05	0 05	0 05	0 07	0 07	0 07	0 15	0 16	0 16	0 05	0 06	0 06	0 02	0 02	0 02	0 01	0 01	0 01	0 16	0 16	0 16	0 13	0 13	0 13	0 06	0 06	0 06
		lower resp illness	0 09	0 09	0 09	0 12	0 13	0 13	0 29	0 30	0 30	0 10	0 10	0 10	0 03	0 03	0 03	0 01	0 01	0 01	0 29	0 30	0 30	0 24	0 24	0 24	0 11	0 12	0 12
		upper resp illness	0 03	0 03	0 03	0 04	0 04	0 04	0 09	0 09	0 09	0 03	0 03	0 03	0 01	0 01	0 01	0 00	0 00	0 00	0 09	0 09	0 09	0 07	0 07	0 07	0 03	0 04	0 04
		eye irritation	0 04	0 04	0 04	0 06	0 06	0 06	0 13	0 14	0 14	0 05	0 05	0.05	0 01	0.01	0 01	0 00	0.01	0.01	0 13	0 14	0 14	0 11	0 11	0 11	0.05	0.05	0 05
Subtotal mortality effects			11 61	12 71	32 38	16 63	18 34	39 72	45 30	47 50	93 13	13 35	14 61	35 12	25 18	25 56	40.85	7.56	8.24	26.81	125 58	128 20	250 59	105 45	107 68	210 33	22 41	23 76	52 33
Subtotal cancer effects			0.25	0.25	0.25	0 40	0 40	0 40	1 30	1 30	1 30	0 30	0 30	0 30	0 31	0 31	0 31	0 09	0 10	0 10	1 31	1.31	1 31	1 10	1 10	1 10	0 38	0 38	0 38
Subtotal chronic morbidity effects			1.27	1 42	3 71	1.84	2 11	4 60	5.27	5 56	10.88	1 47	1 65	4 04	3 10	3 16	4 94	0 93	1 02	3 19	16 07	16 42	30 69	13 48	13 77	25 74	2 65	2 84	6 18
Subtotal acute morbidity effects			1 47	1 50	1 79	1 98	2 02	2 34	4.92	4 98	5 65	1 64	1 68	1 98	0 72	0.73	0 96	0.22	0.24	0 51	5 07	5 13	6 93	4.22	4.27	5 78	1 90	1 94	2.35
Subtotal ambient PM10			11.87	13 13	35.39	17.25	19.26	43 44	47 59	50 12	101 74	13 72	15 18	38 38	28 93	29 37	46 66	8 68	9 46	30 47	144 60	147 61	286 07	121 42	123 98	240 10	24 31	25 88	58 20
Subtotal ambient O3			0.20	0 21	0.21	0 28	0 29	0 29	0 66	0 68	0 68	0.23	0.24	0.24	0 07	0 07	0 07	0 02	0 03	0 03	0 67	0 68	0 68	0 55	0 56	0 56	0 26	0 27	0 27
Subtotal ambient NO2			0 55	0 56	0 56	0 76	0 77	0 77	1 73	1 75	1 75	0 62	0 63	0 63	0 25	0 26	0 26	0 08	0 08	0 08	2 40	2 41	2 41	1 99	2 00	2 00	0 75	0 76	0 76
Subtotal ambient CO			1 80	1 80	1 80	2 29	2 30	2 30	6 14	6 14	6 14	1 99	1 99	1 99	0 04	0 04	0 04	0 01	0 01	0 01	0 28	0 29	0 29	0 24	0 24	0 24	1 82	1 82	1 82
Total all emissions, pollutants, effects			14 60	15 88	38 14	20 84	22 88	47 06	56 78	59 35	110 97	16 77	18 24	41 44	29 31	29 76	47 05	8 80	9 60	30 61	148 02	151 05	289.51	124.25	126.83	242.95	27 34	28 92	61 24

TABLE 11-A 39 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $/1000 VMT (BOSTON MSA 1990) (LOWER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	0.26	0.26	0.26	0.59	0.59	0.59	1.62	1.62	1.62	0.31	0.31	0.31	0.01	0.01	0.01	0.00	0.00	0.00	0.06	0.06	0.06	0.04	0.04	0.04	0.30	0.30	0.30
		hospitalization	0.04	0.04	0.04	0.09	0.09	0.09	0.26	0.26	0.26	0.05	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.05	0.05	0.05
		headaches	0.25	0.25	0.25	0.59	0.59	0.59	1.60	1.60	1.60	0.31	0.31	0.31	0.01	0.01	0.01	0.00	0.00	0.00	0.06	0.06	0.06	0.04	0.04	0.04	0.29	0.29	0.29
NOx	NO2	sore throat	0.29	0.29	0.29	0.68	0.68	0.68	1.47	1.47	1.47	0.35	0.35	0.35	0.16	0.16	0.16	0.09	0.09	0.09	1.80	1.80	1.80	1.25	1.25	1.25	0.40	0.40	0.40
		excess phlegm	0.13	0.13	0.13	0.30	0.30	0.30	0.65	0.65	0.65	0.16	0.16	0.16	0.07	0.07	0.07	0.04	0.04	0.04	0.80	0.80	0.80	0.56	0.56	0.56	0.18	0.18	0.18
		eye irritation	0.12	0.12	0.12	0.28	0.28	0.28	0.60	0.60	0.60	0.14	0.14	0.14	0.06	0.06	0.06	0.03	0.03	0.03	0.73	0.73	0.73	0.51	0.51	0.51	0.16	0.16	0.16
NOx, NH3	nitrate PM10	mortality	2.37	2.37	2.37	5.46	5.47	5.47	11.57	11.58	11.58	2.84	2.85	2.85	1.30	1.30	1.30	0.69	0.70	0.70	14.04	14.06	14.06	9.79	9.80	9.80	3.21	3.22	3.22
		chronic illnese	0.19	0.19	0.19	0.43	0.43	0.43	0.91	0.91	0.91	0.23	0.23	0.23	0.10	0.10	0.10	0.06	0.06	0.06	1.09	1.10	1.10	0.76	0.77	0.77	0.26	0.26	0.26
		asthma attacks	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
		RRAD	0.12	0.12	0.12	0.28	0.28	0.28	0.58	0.59	0.59	0.14	0.14	0.14	0.07	0.07	0.07	0.04	0.04	0.04	0.71	0.71	0.71	0.49	0.49	0.49	0.16	0.16	0.16
Total for NOxand NH3emissions			3.21	3.21	3.21	7.43	7.44	7.44	15.79	15.81	15.81	3.86	3.87	3.87	1.76	1.76	1.76	0.94	0.95	0.95	19.18	19.21	19.21	13.37	13.39	13.39	4.36	4.37	4.37
PM2.5	PM2.5	mortality	0.45	0.46	0.57	1.47	1.48	1.73	4.95	4.97	5.70	0.62	0.62	0.76	5.80	5.80	5.89	2.82	2.82	3.04	27.06	27.09	29.06	19.79	19.81	21.17	1.64	1.64	1.85
		chronic illness	0.04	0.04	0.04	0.11	0.12	0.13	0.38	0.38	0.44	0.05	0.05	0.06	0.46	0.46	0.46	0.22	0.22	0.24	2.06	2.06	2.21	1.51	1.51	1.61	0.13	0.13	0.14
		asthma attacks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.00	0.00
		RRAD	0.02	0.02	0.03	0.07	0.07	0.09	0.25	0.25	0.29	0.03	0.03	0.04	0.29	0.29	0.30	0.14	0.14	0.15	1.36	1.36	1.46	0.99	1.00	1.06	0.08	0.08	0.09
		lung cancer	0.01	0.01	0.01	0.03	0.03	0.03	0.10	0.10	0.10	0.01	0.01	0.01	0.08	0.08	0.08	0.04	0.04	0.04	0.35	0.35	0.35	0.25	0.25	0.25	0.03	0.03	0.03
Coarse PM10	coarse PM10	mortality	0.14	0.15	0.76	0.39	0.39	1.74	1.28	1.28	5.15	0.19	0.19	0.92	0.37	0.37	0.85	0.18	0.18	1.34	1.41	1.41	11.81	1.05	1.05	8.24	0.23	0.23	1.31
		chronic illness	0.01	0.01	0.06	0.03	0.03	0.13	0.10	0.10	0.39	0.01	0.01	0.07	0.03	0.03	0.07	0.01	0.01	0.10	0.11	0.11	0.90	0.08	0.08	0.63	0.02	0.02	0.10
		asthma attacks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00
		RRAD	0.01	0.01	0.04	0.02	0.02	0.09	0.06	0.06	0.26	0.01	0.01	0.05	0.02	0.02	0.04	0.01	0.01	0.07	0.07	0.07	0.59	0.05	0.05	0.41	0.01	0.01	0.07
Total for direct PM10emissions			0.68	0.69	1.52	2.13	2.14	3.93	7.12	7.15	12.34	0.92	0.93	1.92	7.04	7.04	7.69	3.42	3.42	4.98	32.44	32.47	46.41	23.75	23.78	33.41	2.13	2.14	3.59
SOx, NH3	sulfate PM10	mortality	0.79	0.87	0.87	1.92	2.18	2.18	3.58	4.01	4.01	0.96	1.07	1.07	4.43	4.46	4.46	2.48	2.59	2.59	19.82	20.40	20.40	14.58	14.98	14.98	1.68	1.80	1.80
		chronic illness	0.06	0.07	0.07	0.15	0.17	0.17	0.28	0.31	0.31	0.08	0.08	0.08	0.35	0.35	0.35	0.19	0.20	0.20	1.50	1.55	1.55	1.11	1.14	1.14	0.13	0.14	0.14
		asthma attacks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.00
		RRAD	0.04	0.04	0.04	0.10	0.11	0.11	0.18	0.20	0.20	0.05	0.05	0.05	0.22	0.22	0.22	0.12	0.13	0.13	1.00	1.02	1.02	0.73	0.75	0.75	0.08	0.09	0.09
Total for SOxand NH3emissions			0.89	0.98	0.98	2.17	2.47	2.47	4.04	4.52	4.52	1.08	1.20	1.20	5.01	5.03	5.03	2.80	2.92	2.92	22.34	22.99	22.99	16.44	16.89	16.89	1.90	2.03	2.03
VOCs	organic PM10	mortality	0.19	0.30	0.30	0.48	0.77	0.77	1.55	2.15	2.15	0.24	0.37	0.37	0.04	0.07	0.07	0.02	0.13	0.13	0.64	1.23	1.23	0.44	0.86	0.86	0.25	0.40	0.40
	(SOA)	chronic illness	0.01	0.02	0.02	0.04	0.06	0.06	0.12	0.17	0.17	0.02	0.03	0.03	0.00	0.01	0.01	0.00	0.01	0.01	0.05	0.09	0.09	0.03	0.07	0.07	0.02	0.03	0.03
		asthma attacks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		RRAD	0.01	0.01	0.01	0.02	0.04	0.04	0.08	0.11	0.11	0.01	0.02	0.02	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.06	0.06	0.02	0.04	0.04	0.01	0.02	0.02
	acetaldehyde	oral cancer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	benzene	leukemia	0.00	0.00	0.00	0.01	0.01	0.01	0.03	0.03	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
	1 3-butadiene	cancer all sites	0.02	0.02	0.02	0.04	0.04	0.04	0.10	0.10	0.10	0.02	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02
	fomaldehyde	oral cancer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
Sub-total for VOC emissions			0.23	0.35	0.35	0.59	0.93	0.93	1.89	2.56	2.56	0.29	0.45	0.45	0.04	0.08	0.08	0.03	0.15	0.15	0.73	1.40	1.40	0.50	0.97	0.97	0.30	0.47	0.47
VOCs, NOx	O3	asthma attacks	0.01	0.01	0.01	0.02	0.02	0.02	0.05	0.05	0.05	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01
		lower resp illness	0.03	0.04	0.04	0.08	0.09	0.09	0.18	0.19	0.19	0.04	0.04	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.12	0.13	0.13	0.08	0.09	0.09	0.04	0.05	0.05
		upper resp illness	0.01	0.01	0.01	0.02	0.03	0.03	0.05	0.06	0.06	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.04	0.02	0.03	0.03	0.01	0.01	0.01
		eye irritation	0.03	0.03	0.03	0.07	0.08	0.08	0.17	0.18	0.18	0.04	0.04	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.11	0.12	0.12	0.08	0.08	0.08	0.04	0.04	0.04
Subtotal mortality effects			4.20	4.39	5.13	10.31	10.89	12.48	24.54	25.61	30.21	5.16	5.41	6.29	11.94	12.00	12.57	6.19	6.42	7.80	63.03	64.26	76.62	45.69	46.55	55.10	7.31	7.59	8.87
Subtotal cancer effects			0.03	0.03	0.03	0.08	0.08	0.08	0.23	0.23	0.23	0.04	0.04	0.04	0.08	0.08	0.08	0.04	0.04	0.04	0.36	0.36	0.36	0.26	0.26	0.26	0.05	0.05	0.05
Subtotal chronic morbidity effects			0.31	0.33	0.38	0.77	0.81	0.93	1.78	1.86	2.22	0.38	0.40	0.47	0.94	0.95	0.99	0.48	0.50	0.61	4.81	4.90	5.85	3.50	3.56	4.21	0.55	0.57	0.67
Subtotal acute morbidity effects			1.11	1.13	1.17	2.63	2.68	2.76	6.20	6.29	6.52	1.35	1.37	1.42	0.94	0.94	0.97	0.50	0.51	0.58	6.91	7.01	7.64	4.90	4.97	5.41	1.54	1.56	1.63
Subtotal ambient PM10			4.46	4.68	5.51	11.01	11.67	13.46	25.98	27.18	32.38	5.49	5.77	6.76	13.56	13.63	14.27	7.03	7.28	8.84	71.35	72.73	86.66	51.73	52.70	62.33	7.94	8.26	9.71
Subtotal ambient O3			0.08	0.09	0.09	0.20	0.22	0.22	0.45	0.49	0.49	0.10	0.11	0.11	0.03	0.03	0.03	0.02	0.02	0.02	0.29	0.32	0.32	0.20	0.22	0.22	0.10	0.11	0.11
Subtotal ambient NO2			0.53	0.53	0.53	1.25	1.26	1.26	2.72	2.72	2.72	0.64	0.65	0.65	0.29	0.29	0.29	0.16	0.16	0.16	3.33	3.34	3.34	2.32	2.32	2.32	0.73	0.73	0.73
Subtotal ambient CO			0.55	0.55	0.55	1.27	1.27	1.27	3.47	3.47	3.47	0.67	0.67	0.67	0.02	0.02	0.02	0.01	0.01	0.01	0.14	0.14	0.14	0.10	0.10	0.10	0.64	0.64	0.64
Total all emissions, pollutants, effects			5.65	5.88	6.71	13.79	14.46	16.26	32.76	33.99	39.19	6.93	7.22	8.21	13.90	13.97	14.61	7.21	7.48	9.04	75.12	76.53	90.47	54.36	55.35	64.98	9.44	9.77	11.22

TABLE 11-A 40 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $/1000 VMT (BOSTON MSA 1990) (UPPER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	3 03	3 03	3 03	6 96	6 96	6 96	24 16	24 16	24 16	3 70	3 70	3 70	0 07	0 07	0 07	0 04	0 04	0 04	0 95	0 95	0 95	0 66	0 66	0 66	3 54	3 54	3 54
		hospitalization	0 12	0 12	0 12	0 28	0 28	0 28	0 96	0 96	0 96	0 15	0 15	0 15	0 00	0 00	0 00	0 00	0 00	0 00	0 04	0 04	0 04	0 03	0 03	0 03	0 14	0 14	0 14
		headaches	1 45	1 45	1 45	3 33	3 33	3 33	11 58	11 58	11 58	1 77	1 77	1 77	0 03	0 03	0 03	0 02	0 02	0 02	0 46	0 46	0 46	0 32	0 32	0 32	1 69	1 69	1 69
NOx	NO2	sore throat	1 43	1 43	1 43	3 35	3 35	3 35	9 43	9 43	9 43	1 74	1 74	1 74	0 67	0 67	0 67	0 36	0 36	0 36	11 53	11 54	11 54	7 92	7 93	7 93	2 06	2 06	2 06
		excess phlegm	0 64	0 64	0 64	1 49	1 50	1 50	4 20	4 21	4 21	0 78	0 78	0 78	0 30	0 30	0 30	0 16	0 16	0 16	5 14	5 15	5 15	3 54	3 54	3 54	0 92	0 92	0 92
		eye irritation	0 58	0 58	0 58	1 36	1 36	1 36	3 83	3 83	3 83	0 71	0 71	0 71	0 27	0 27	0 27	0 15	0 15	0 15	4 69	4 69	4 69	3 22	3 22	3 22	0 84	0 84	0 84
NOx, NH3	nitrate PM10	mortality	38 44	38 48	38 48	88 75	88 86	88 86	245 41	245 61	245 61	46 61	46 66	46 66	18 11	18 13	18 13	9 68	9 74	9 74	297 63	297 89	297 89	204 77	204 95	204 95	54 97	55 02	55 02
		chronic illness	5 92	5 93	5 93	13 64	13 65	13 65	37 63	37 66	37 66	7 18	7 19	7 19	2 79	2 79	2 79	1 49	1 50	1 50	45 58	45 62	45 62	31 36	31 39	31 39	8 46	8 47	8 47
		asthma attacks	0 01	0 01	0 01	0 03	0 03	0 03	0 08	0 08	0 08	0 02	0 02	0 02	0 01	0 01	0 01	0 00	0 00	0 00	0 10	0 10	0 10	0 07	0 07	0 07	0 02	0 02	0 02
		RRAD	0 69	0 69	0 69	1 60	1 60	1 60	4 44	4 45	4 45	0 84	0 84	0 84	0 33	0 33	0 33	0 17	0 18	0 18	5 39	5 40	5 40	3 71	3 71	3 71	0 99	0 99	0 99
Total for NOxand NH3emissions			47 72	47 76	47 76	110 22	110 35	110 35	305 03	305 27	305 27	57 87	57 93	57 93	22 47	22 49	22 49	12 02	12 08	12 08	370 06	370 38	370 38	254 59	254 81	254 81	68 26	68 33	68 33
PM2.5	PM2 5	mortality	7 03	7 05	34 83	22 75	22 81	83 05	116 99	116 71	291 19	9 91	9 94	43 08	89 98	90 00	111 58	43 63	43 67	96 02	636 23	636 40	1,103 93	452 12	452 24	775 46	33 34	33 37	81 81
		chronic illness	1 09	1 09	5 31	3 51	3 52	12 66	17 91	17 93	44 39	1 53	1 54	6 57	13 92	13 92	17 20	6 73	6 73	14 67	97 38	97 40	168 41	69 24	69 26	118 36	5 12	5 12	12 49
		asthma attacks	0 00	0 00	0 01	0 01	0 01	0 03	0 04	0 04	0 09	0 00	0 00	0 01	0 03	0 03	0 04	0 01	0 01	0 03	0 21	0 21	0 35	0 15	0 15	0 25	0 01	0 01	0 03
		RRAD	0 13	0 13	0 63	0 41	0 41	1 50	2 12	2 12	5 26	0 18	0 18	0 78	1 62	1 62	2 01	0 79	0 79	1 73	11 59	11 59	20 00	8 23	8 23	14 05	0 61	0 61	1 48
		lung cancer	0 16	0 16	0 16	0 54	0 54	0 54	2 75	2 75	2 75	0 23	0 23	0 23	0 96	0 96	0 96	0 47	0 47	0 47	6 72	6 72	6 72	4 78	4 78	4 78	0 47	0 47	0 47
Coarse PM10	coarse PM10	mortality	0 45	0 45	7 52	1 20	1 21	16 54	6 03	6 03	50 43	0 59	0 59	9 03	1 14	1 14	6 63	0 54	0 55	13 87	6 63	6 64	125 76	4 77	4 77	87 14	0 81	0 81	13 17
		chronic illness	0 07	0 07	1 14	0 19	0 19	2 51	0 93	0 93	7 65	0 09	0 09	1 37	0 18	0 18	1 01	0 08	0 08	2 10	1 01	1 01	19 05	0 73	0 73	13 20	0 12	0 12	2 00
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 01	0 00	0 00	0 02	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 04	0 00	0 00	0 03	0 00	0 00	0 00
		RRAD	0 01	0 01	0 14	0 02	0 02	0 30	0 11	0 11	0 91	0 01	0 01	0 16	0 02	0 02	0 12	0 01	0 01	0 25	0 12	0 12	2 26	0 09	0 09	1 57	0 01	0 01	0 24
Total for direct PM10emissions			8 94	8 96	49 73	28 62	28 70	117 11	146 48	146 62	402 69	12 55	12 58	61 23	107 86	107 87	139 55	52 26	52 31	129 14	759 89	760 10	1,446 53	540 11	540 25	1,014 81	40 49	40 53	111 67
SOx, NH3	sulfate PM10	mortality	6 32	6 69	6 69	15 35	16 60	16 60	43 54	45 50	45 50	7 79	8 29	8 29	35 55	35 64	35 64	19 84	20 29	20 29	240 50	242 99	242 99	171 57	173 31	173 31	16 47	17 03	17 03
		chronic illness	0 98	1 03	1 03	2 37	2 56	2 56	6 69	6 99	6 99	1 20	1 28	1 28	5 50	5 51	5 51	3 06	3 13	3 13	36 77	37 16	37 16	26 25	26 52	26 52	2 53	2 62	2 62
		asthma attacks	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 08	0 08	0 08	0 06	0 06	0 06	0 01	0 01	0 01
		RRAD	0 11	0 12	0 12	0 28	0 30	0 30	0 79	0 83	0 83	0 14	0 15	0 15	0 64	0 64	0 64	0 36	0 37	0 37	4 38	4 43	4 43	3 13	3 16	3 16	0 30	0 31	0 31
Total for SOxand NH3emissions			7 42	7 84	7 84	17 99	19 47	19 47	51 03	53 32	53 32	9 14	9 72	9 72	41 70	41 80	41 80	23 27	23 79	23 79	281 73	284 66	284 66	201 01	203 04	203 04	19 30	19 96	19 96
VOCs	organic PM10 (SOA)	mortality	2 18	2 74	2 74	5 57	7 09	7 09	27 50	30 61	30 61	2 81	3 52	3 52	0 43	0 62	0 62	0 28	0 80	0 80	11 22	14 28	14 28	7 65	9 79	9 79	3 07	3 85	3 85
		chronic illness	0 34	0 42	0 42	0 86	1 10	1 10	4 25	4 73	4 73	0 44	0 54	0 54	0 07	0 09	0 09	0 04	0 12	0 12	1 72	2 18	2 18	1 18	1 49	1 49	0 47	0 60	0 60
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 04	0 05	0 05	0 10	0 13	0 13	0 50	0 55	0 55	0 05	0 06	0 06	0 01	0 01	0 01	0 01	0 01	0 01	0 20	0 26	0 26	0 14	0 18	0 18	0 06	0 07	0 07
	acetaldehyde	oral cancer	0 01	0 01	0 01	0 02	0 02	0 02	0 08	0 08	0 08	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 01	0 01	0 01
	benzene	leukemia	0 08	0 08	0 08	0 22	0 22	0 22	0 68	0 68	0 68	0 11	0 11	0 11	0 01	0 01	0 01	0 01	0 03	0 03	0 08	0 08	0 08	0 06	0 06	0 06	0 10	0 10	0 10
	1,3-butadiene	cancer all sites	0 28	0 28	0 28	0 73	0 73	0 73	2 31	2 31	2 31	0 36	0 36	0 36	0 03	0 03	0 03	0 02	0 07	0 07	0 18	0 18	0 18	0 13	0 13	0 13	0 35	0 35	0 35
	fomaldehyde	oral cancer	0 00	0 00	0 00	0 01	0 01	0 01	0 03	0 03	0 03	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
Sub-total for VOC emissions			2 94	3 60	3 60	7 51	9 30	9 30	35 34	38 99	38 99	3 78	4 61	4 61	0 55	0 76	0 76	0 35	1 04	1 04	13 43	16 99	16 99	9 17	11 67	11 67	4 07	4 98	4 98
VOCs, NOx	O3	asthma attacks	0 15	0 15	0 15	0 36	0 38	0 38	1 09	1 11	1 11	0 18	0 19	0 19	0 04	0 04	0 04	0 02	0 03	0 03	0 65	0 67	0 67	0 45	0 46	0 46	0 20	0 20	0 20
		lower resp illness	0 28	0 29	0 29	0 68	0 70	0 70	2 03	2 08	2 08	0 34	0 35	0 35	0 08	0 08	0 08	0 04	0 05	0 05	1 22	1 25	1 25	0 84	0 87	0 87	0 37	0 38	0 38
		upper resp illness	0 08	0 09	0 09	0 21	0 21	0 21	0 62	0 63	0 63	0 10	0 11	0 11	0 02	0 02	0 02	0 01	0 02	0 02	0 37	0 38	0 38	0 25	0 26	0 26	0 11	0 12	0 12
		eye irritation	0 19	0 19	0 19	0 47	0 48	0 48	1 41	1 44	1 44	0 23	0 24	0 24	0 05	0 06	0 06	0 03	0 04	0 04	0 84	0 86	0 86	0 58	0 60	0 60	0 25	0 26	0 26
Subtotal mortality effects			57 45	58 43	93 28	140 58	143 53	219 10	463 22	468 61	687 49	71 42	72 70	114 27	145 29	145 59	172 66	74 02	75 08	140 75	1,193 16	1,199 14	1,785 80	841 54	845 72	1,251 30	112 19	113 62	174 42
Subtotal cancer effects			0 54	0 54	0 54	1 51	1 51	1 51	5 85	5 85	5 85	0 71	0 71	0 71	1 00	1 00	1 00	0 49	0 58	0 58	6 99	6 99	6 99	4 97	4 98	4 98	0 94	0 94	0 94
Subtotal chronic morbidity effects			8 40	8 55	13 83	20 56	21 02	32 48	67 41	68 23	101 42	10 44	10 64	16 95	22 45	22 50	26 60	11 40	11 56	21 51	182 47	183 37	272 42	128 76	129 40	190 96	16 71	16 93	26 17
Subtotal acute morbidity effects			5 91	5 95	6 59	13 97	14 10	15 49	43 24	43 48	47 49	7 24	7 30	8 06	4 14	4 16	4 65	2 16	2 21	3 41	47 00	47 23	57 96	32 70	32 86	40 28	8 59	8 65	9 76
Subtotal ambient PM10			63 98	65 13	105 91	157 17	160 63	249 04	517 33	523 64	779 71	79 63	81 13	129 78	171 30	171 65	203.33	87.21	88 44	165 27	1,403 48	1,410 48	2,096 91	990 00	994.88	1 469 44	127 83	129 51	200 65
Subtotal ambient O3			0 70	0 72	0 72	1 71	1 77	1 77	5 14	5 27	5 27	0 86	0 89	0 89	0 20	0 21	0 21	0 11	0 13	0 13	3 07	3 17	3 17	2 12	2 19	2 19	0 93	0 96	0 96
Subtotal ambient NO2			2 65	2 65	2 65	6 20	6 21	6 21	17 46	17 47	17 47	3 22	3 23	3 23	1 24	1 24	1 24	0 67	0 67	0 67	21 36	21 38	21 38	14 68	14 69	14 69	3 83	3 83	3 83
Subtotal ambient CO			4 59	4 59	4 59	10 57	10 57	10 57	36 69	36 70	36 70	5 62	5 62	5 62	0 11	0 11	0 11	0 06	0 06	0 06	1 44	1 44	1 44	1 00	1 00	1 00	5 37	5 37	5 37
Total all emissions, pollutants, effects			72.29	73 48	114.25	176.62	180 17	268 58	579 72	586 17	842.24	89.81	91 34	139 99	172.89	173.24	204 92	88 07	89 42	166 25	1,429 62	1,436.74	2,123 17	1,007 98	1,012 96	1,487 52	138 42	140 14	211.28

TABLE 11-A 41 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $/1000 VMT (DENVER MSA 1990) (LOWER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	0.27	0.27	0.27	1.92	1.92	1.92	1.70	1.70	1.70	0.37	0.37	0.37	0.01	0.01	0.01	0.02	0.02	0.02	0.08	0.08	0.08	0.06	0.06	0.06	0.35	0.35	0.35
		hospitalization	0.04	0.04	0.04	0.30	0.30	0.30	0.27	0.27	0.27	0.06	0.06	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.06	0.06	0.06
		headaches	0.34	0.34	0.34	2.46	2.46	2.46	2.18	2.18	2.18	0.48	0.48	0.48	0.01	0.01	0.01	0.02	0.02	0.02	0.10	0.10	0.10	0.08	0.08	0.08	0.45	0.45	0.45
NOx	NO2	sore throat	0.14	0.14	0.14	0.84	0.84	0.84	0.46	0.47	0.47	0.19	0.19	0.19	0.09	0.09	0.09	0.12	0.12	0.12	0.82	0.82	0.82	0.63	0.64	0.64	0.21	0.21	0.21
		excess phlegm	0.07	0.07	0.07	0.38	0.39	0.39	0.21	0.21	0.21	0.09	0.09	0.09	0.04	0.04	0.04	0.05	0.05	0.05	0.38	0.38	0.38	0.29	0.29	0.29	0.10	0.10	0.10
		eye irritation	0.06	0.06	0.06	0.35	0.35	0.35	0.19	0.19	0.19	0.08	0.08	0.08	0.04	0.04	0.04	0.05	0.05	0.05	0.34	0.34	0.34	0.26	0.26	0.26	0.09	0.09	0.09
NOx, NH3	nitrate PM10	mortality	1.90	1.91	1.91	11.03	11.11	11.11	6.07	6.13	6.13	2.45	2.47	2.47	1.14	1.14	1.14	1.55	1.58	1.58	10.79	10.83	10.83	8.32	8.35	8.35	2.81	2.83	2.83
		chronic illness	0.26	0.26	0.26	1.49	1.51	1.51	0.82	0.83	0.83	0.33	0.33	0.33	0.15	0.15	0.15	0.21	0.21	0.21	1.47	1.47	1.47	1.13	1.13	1.13	0.38	0.38	0.38
		asthma attacks	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
		RRAD	0.10	0.10	0.10	0.58	0.58	0.58	0.32	0.32	0.32	0.13	0.13	0.13	0.06	0.06	0.06	0.08	0.08	0.08	0.56	0.57	0.57	0.43	0.44	0.44	0.15	0.15	0.15
Total for NOx and NH3 emissions			2.53	2.54	2.54	14.68	14.79	14.79	8.08	8.16	8.16	3.26	3.28	3.28	1.51	1.52	1.52	2.07	2.10	2.10	14.37	14.42	14.42	11.08	11.12	11.12	3.74	3.76	3.76
PM2.5	PM2.5	mortality	0.36	0.40	0.47	3.05	3.30	3.68	3.43	3.60	3.96	0.54	0.59	0.68	4.64	4.65	4.71	5.86	5.95	6.28	18.91	19.05	20.02	15.28	15.39	16.13	1.45	1.50	1.63
		chronic illness	0.05	0.05	0.06	0.41	0.45	0.50	0.46	0.49	0.54	0.07	0.08	0.09	0.63	0.63	0.64	0.79	0.81	0.85	2.57	2.59	2.72	2.08	2.09	2.19	0.20	0.20	0.22
		asthma attacks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.00	0.00
		RRAD	0.02	0.02	0.02	0.16	0.17	0.19	0.18	0.19	0.21	0.03	0.03	0.04	0.24	0.24	0.25	0.31	0.31	0.33	0.99	0.99	1.04	0.80	0.80	0.84	0.08	0.08	0.08
		lung cancer	0.01	0.01	0.01	0.08	0.08	0.08	0.09	0.09	0.09	0.02	0.02	0.02	0.08	0.08	0.08	0.10	0.10	0.10	0.33	0.33	0.33	0.27	0.27	0.27	0.03	0.03	0.03
Coarse PM10	coarse PM10	mortality	0.12	0.13	0.47	0.81	0.91	2.79	0.89	0.95	2.72	0.16	0.18	0.62	0.30	0.30	0.56	0.37	0.40	2.04	0.98	1.04	5.80	0.81	0.85	4.50	0.20	0.22	0.86
		chronic illness	0.02	0.02	0.06	0.11	0.12	0.38	0.12	0.13	0.37	0.02	0.02	0.08	0.04	0.04	0.08	0.05	0.06	0.28	0.13	0.14	0.79	0.11	0.12	0.61	0.03	0.03	0.12
		asthma attacks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
		RRAD	0.01	0.01	0.02	0.04	0.05	0.15	0.05	0.05	0.14	0.01	0.01	0.03	0.02	0.02	0.03	0.02	0.02	0.11	0.05	0.05	0.30	0.04	0.04	0.23	0.01	0.01	0.04
Total for direct PM10 emissions			0.58	0.64	1.12	4.68	5.09	7.78	5.22	5.51	8.04	0.85	0.93	1.56	5.95	5.97	6.34	7.50	7.66	10.00	23.99	24.22	31.03	19.40	19.58	24.80	1.99	2.08	2.98
SOx, NH3	sulfate PM10	mortality	0.45	0.70	0.70	2.85	4.60	4.60	1.77	2.97	2.97	0.60	0.94	0.94	2.54	2.64	2.64	3.68	4.48	4.48	9.90	11.09	11.09	8.04	8.98	8.98	1.05	1.43	1.43
		chronic illness	0.06	0.10	0.10	0.39	0.64	0.64	0.24	0.42	0.42	0.08	0.13	0.13	0.34	0.36	0.36	0.50	0.61	0.61	1.35	1.52	1.52	1.09	1.23	1.23	0.14	0.20	0.20
		asthma attacks	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
		RRAD	0.02	0.04	0.04	0.15	0.24	0.24	0.09	0.16	0.16	0.03	0.05	0.05	0.13	0.14	0.14	0.19	0.23	0.23	0.52	0.58	0.58	0.42	0.47	0.47	0.05	0.07	0.07
Total for SOx and NH3 emissions			0.54	0.84	0.84	3.38	5.48	5.48	2.10	3.54	3.54	0.71	1.12	1.12	3.01	3.13	3.13	4.38	5.34	5.34	11.77	13.20	13.20	9.56	10.68	10.68	1.25	1.71	1.71
VOCs	organic PM10 (SOA)	mortality	0.16	0.25	0.25	1.16	1.80	1.80	1.29	1.74	1.74	0.22	0.35	0.35	0.04	0.07	0.07	0.07	0.32	0.32	0.95	1.41	1.41	0.72	1.08	1.08	0.25	0.40	0.40
		chronic illness	0.02	0.03	0.03	0.16	0.24	0.24	0.17	0.24	0.24	0.03	0.05	0.05	0.01	0.01	0.01	0.01	0.04	0.04	0.13	0.19	0.19	0.10	0.15	0.15	0.03	0.05	0.05
		asthma attacks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		RRAD	0.01	0.01	0.01	0.06	0.09	0.09	0.07	0.09	0.09	0.01	0.02	0.02	0.00	0.00	0.00	0.00	0.02	0.02	0.05	0.07	0.07	0.04	0.06	0.06	0.01	0.02	0.02
	acetaldehyde	oral cancer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	benzene	leukemia	0.00	0.00	0.00	0.04	0.04	0.04	0.03	0.03	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
	1,3-butadiene	cancer all sites	0.02	0.02	0.02	0.12	0.12	0.12	0.10	0.10	0.10	0.02	0.02	0.02	0.00	0.00	0.00	0.00	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02
	formaldehyde	oral cancer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sub-total for VOC emissions			0.21	0.32	0.32	1.54	2.31	2.31	1.67	2.21	2.21	0.30	0.45	0.45	0.05	0.09	0.09	0.09	0.40	0.40	1.15	1.70	1.70	0.87	1.30	1.30	0.33	0.50	0.50
VOCs, NOx	O3	asthma attacks	0.01	0.01	0.01	0.07	0.08	0.08	0.05	0.06	0.06	0.01	0.02	0.02	0.00	0.00	0.00	0.01	0.01	0.01	0.04	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02
		lower resp illness	0.04	0.05	0.05	0.27	0.30	0.30	0.19	0.22	0.22	0.05	0.06	0.06	0.02	0.02	0.02	0.02	0.03	0.03	0.14	0.16	0.16	0.11	0.12	0.12	0.06	0.06	0.06
		upper resp illness	0.01	0.01	0.01	0.08	0.09	0.09	0.06	0.07	0.07	0.02	0.02	0.02	0.00	0.01	0.01	0.01	0.01	0.01	0.04	0.05	0.05	0.03	0.04	0.04	0.02	0.02	0.02
		eye irritation	0.04	0.04	0.04	0.26	0.29	0.29	0.18	0.21	0.21	0.05	0.06	0.06	0.02	0.02	0.02	0.02	0.03	0.03	0.14	0.15	0.15	0.11	0.12	0.12	0.06	0.06	0.06
Subtotal mortality effects			3.25	3.66	4.07	20.82	23.64	25.91	15.14	17.08	19.22	4.35	4.91	5.43	8.66	8.81	9.13	11.55	12.75	14.72	41.61	43.50	49.23	33.23	34.71	39.10	6.12	6.73	7.49
Subtotal cancer effects			0.03	0.03	0.03	0.25	0.25	0.25	0.23	0.23	0.23	0.05	0.05	0.05	0.09	0.09	0.09	0.11	0.13	0.13	0.35	0.35	0.35	0.28	0.28	0.28	0.06	0.06	0.06
Subtotal chronic morbidity effects			0.40	0.46	0.52	2.56	2.96	3.27	1.82	2.10	2.39	0.54	0.62	0.69	1.17	1.19	1.23	1.56	1.73	2.00	5.65	5.92	6.69	4.51	4.72	5.31	0.78	0.87	0.97
Subtotal acute morbidity effects			0.91	0.95	0.97	6.01	6.26	6.38	4.51	4.69	4.80	1.23	1.28	1.31	0.68	0.69	0.70	0.92	1.02	1.12	4.21	4.36	4.66	3.31	3.43	3.66	1.36	1.41	1.45
Subtotal ambient PM10			3.56	4.05	4.53	22.55	25.92	28.61	16.07	18.40	20.94	4.74	5.41	6.03	10.36	10.54	10.92	13.81	15.25	17.58	49.72	51.98	58.79	39.71	41.48	46.70	6.88	7.62	8.52
Subtotal ambient O3			0.10	0.11	0.11	0.67	0.76	0.76	0.48	0.55	0.55	0.14	0.15	0.15	0.04	0.04	0.04	0.06	0.09	0.09	0.35	0.40	0.40	0.27	0.31	0.31	0.15	0.16	0.16
Subtotal ambient NO2			0.27	0.27	0.27	1.57	1.58	1.58	0.86	0.87	0.87	0.35	0.35	0.35	0.16	0.16	0.16	0.22	0.22	0.22	1.53	1.54	1.54	1.18	1.19	1.19	0.40	0.40	0.40
Subtotal ambient CO			0.65	0.65	0.65	4.68	4.68	4.68	4.15	4.15	4.15	0.91	0.91	0.91	0.02	0.02	0.02	0.04	0.05	0.05	0.19	0.19	0.19	0.15	0.15	0.15	0.86	0.86	0.86
Total all emissions, pollutants, effects			4.60	5.10	5.59	29.64	33.11	35.80	21.70	24.11	26.65	6.16	6.85	7.47	10.59	10.78	11.15	14.14	15.63	17.96	51.82	54.13	60.94	41.33	43.13	48.35	8.32	9.07	9.98

TABLE 11-A 42 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $/1000 VMT (DENVER MSA 1990) (UPPER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	3 04	3 04	3 04	21 86	21 87	21 87	23 87	23 87	23 87	4 29	4 29	4 29	0 09	0 09	0 09	0 17	0 18	0 18	1 07	1 07	1 07	0 82	0 82	0 82	4 07	4 07	4 07
		hospitalization	0 12	0 12	0 12	0 86	0 87	0 87	0 94	0 94	0 94	0 17	0 17	0 17	0 00	0 00	0 00	0 01	0 01	0 01	0 04	0 04	0 04	0 03	0 03	0 03	0 16	0 16	0 16
		headaches	1 89	1 89	1 89	13 64	13 64	13 64	14 89	14 89	14 89	2 66	2 67	2 67	0 05	0 06	0 06	0 11	0 11	0 11	0 67	0 67	0 67	0 51	0 52	0 52	2 53	2 53	2 53
NOx	NO2	sore throat	0 80	0 80	0 80	4 63	4 65	4 65	3 18	3 19	3 19	1 04	1 04	1 04	0 41	0 41	0 41	0 56	0 57	0 57	5 64	5 65	5 65	4 30	4 31	4 31	1 23	1 24	1 24
		excess phlegm	0 37	0 37	0 37	2 12	2 13	2 13	1 46	1 46	1 46	0 47	0 48	0 48	0 19	0 19	0 19	0 26	0 26	0 26	2 58	2 59	2 59	1 97	1 97	1 97	0 57	0 57	0 57
		eye irritation	0 33	0 33	0 33	1 91	1 92	1 92	1 31	1 32	1 32	0 43	0 43	0 43	0 17	0 17	0 17	0 23	0 23	0 23	2 32	2 33	2 33	1 77	1 78	1 78	0 51	0 51	0 51
NOx, NH3	nitrate PM10	mortality	24 04	24 11	24 11	138 54	139 09	139 09	94 87	95 22	95 22	31 11	31 21	31 21	12 39	12 41	12 41	16 78	16 99	16 99	167 33	167 65	167 65	127 63	127 88	127 88	37 01	37 12	37 12
		chronic illness	7 73	7 76	7 76	44 89	45 07	45 07	31 04	31 17	31 17	10 03	10 07	10 07	3 97	3 98	3 98	5 42	5 49	5 49	55 10	55 21	55 21	42 00	42 09	42 09	11 99	12 03	12 03
		asthma attacks	0 01	0 01	0 01	0 08	0 08	0 08	0 05	0 05	0 05	0 02	0 02	0 02	0 01	0 01	0 01	0 01	0 01	0 01	0 09	0 09	0 09	0 07	0 07	0 07	0 02	0 02	0 02
		RRAD	0 60	0 61	0 61	3 50	3 51	3 51	2 40	2 41	2 41	0 78	0 79	0 79	0 31	0 31	0 31	0 42	0 43	0 43	4 26	4 27	4 27	3 25	3 25	3 25	0 93	0 94	0 94
Total for NOxand NH3emissions			33 88	33 99	33 99	195 67	196 45	196 45	134 32	134 83	134 83	43 87	44 02	44 02	17 45	17 49	17 49	23 68	23 98	23 98	237 32	237 78	237 78	180 99	181 35	181 35	52 26	52 42	52 42
PM2.5	PM2.5	mortality	4 26	4 41	20 38	35 50	36 53	125 88	57 92	58 64	142 96	6 51	6 72	27 43	54 53	54 58	66 99	68 16	68 56	146 22	315 05	315 64	541 67	248 49	248 96	422 11	21 34	21 56	51 58
		chronic illness	1 36	1 42	6 65	11 45	11 81	41 07	18 90	19 15	46 76	2 09	2 16	8 95	17 44	17 46	21 52	21 99	22 13	47 56	104 08	104 29	178 38	81 95	82 11	138 88	6 99	7 06	16 92
		asthma attacks	0 00	0 00	0 01	0 02	0 02	0 07	0 03	0 03	0 08	0 00	0 00	0 02	0 03	0 03	0 04	0 04	0 04	0 08	0 18	0 18	0 31	0 14	0 14	0 24	0 01	0 01	0 03
		RRAD	0 11	0 11	0 52	0 89	0 92	3 20	1 46	1 48	3 64	0 16	0 17	0 70	1 37	1 37	1 68	1 72	1 73	3 71	8 03	8 04	13 82	6 33	6 34	10 76	0 54	0 55	1 31
		lung cancer	0 18	0 18	0 18	1 54	1 54	1 54	2 52	2 52	2 52	0 28	0 28	0 28	1 10	1 10	1 10	1 38	1 38	1 38	6 30	6 30	6 30	4 97	4 97	4 97	0 57	0 57	0 57
Coarse PM10	coarse PM10	mortality	0 27	0 28	4 13	1 88	1 95	23 48	2 99	3 04	23 36	0 39	0 40	5 39	0 69	0 69	3 68	0 85	0 88	19 58	3 28	3 32	57 83	2 62	2 65	44 41	0 52	0 54	7 78
		chronic illness	0 09	0 09	1 35	0 61	0 63	7 68	0 98	0 99	7 64	0 12	0 13	1 76	0 22	0 22	1 20	0 27	0 28	6 41	1 08	1 10	18 94	0 86	0 88	14 54	0 17	0 17	2 55
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 01	0 00	0 00	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 00	0 00	0 03	0 00	0 00	0 03	0 00	0 00	0 00
		RRAD	0 01	0 01	0 11	0 05	0 05	0 60	0 08	0 08	0 60	0 01	0 01	0 14	0 02	0 02	0 09	0 02	0 02	0 50	0 08	0 08	1 48	0 07	0 07	1 14	0 01	0 01	0 20
Total for direct PM10emissions			6 28	6 50	33 33	51 95	53 46	203 54	84 89	85 95	227 58	9 57	9 88	44 68	75 40	75 48	96 32	94 43	95 03	225 44	438 09	438 96	818 75	345 44	346 12	637 07	30 15	30 48	80 94
SOx, NH3	sulfate PM10	mortality	2 30	2 95	2 95	14 40	18 92	18 92	12 99	16 07	16 07	3 08	3 97	3 97	12 94	13 20	13 20	18 61	20 67	20 67	71 47	74 55	74 55	56 60	59 01	59 01	6 36	7 34	7 34
		chronic illness	0 74	0 96	0 96	4 64	6 23	6 23	4 24	5 32	5 32	0 99	1 30	1 30	4 14	4 23	4 23	6 00	6 73	6 73	23 64	24 72	24 72	18 69	19 53	19 53	2 07	2 42	2 42
		asthma attacks	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 04	0 04	0 04	0 03	0 03	0 03	0 00	0 00	0 00
		RRAD	0 06	0 08	0 08	0 36	0 48	0 48	0 33	0 41	0 41	0 08	0 10	0 10	0 32	0 33	0 33	0 47	0 52	0 52	1 82	1 91	1 91	1 44	1 51	1 51	0 16	0 19	0 19
Total for SOxand NH3emissions			3 10	3 99	3 99	19 41	25 64	25 64	17 56	21 81	21 81	4 15	5 37	5 37	17 42	17 77	17 77	25 09	27 94	27 94	96 97	101 22	101 22	76 76	80 08	80 08	8 60	9 95	9 95
VOCs	organic PM10 (SOA)	mortality	1 39	1 78	1 78	10 15	12 77	12 77	16 58	18 42	18 42	2 02	2 55	2 55	0 35	0 49	0 49	0 63	1 62	1 62	12 04	13 92	13 92	9 05	10 50	10 50	2 45	3 04	3 04
		chronic illness	0 44	0 57	0 57	3 26	4 12	4 12	5 34	5 94	5 94	0 65	0 82	0 82	0 11	0 16	0 16	0 20	0 52	0 52	3 93	4 55	4 55	2 95	3 43	3 43	0 79	0 98	0 98
		asthma attacks	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 00	0 00	0 00
		RRAD	0 03	0 04	0 04	0 25	0 32	0 32	0 42	0 46	0 46	0 05	0 06	0 06	0 01	0 01	0 01	0 02	0 04	0 04	0 30	0 35	0 35	0 23	0 27	0 27	0 06	0 08	0 08
	acetaldehyde	oral cancer	0 01	0 01	0 01	0 07	0 07	0 07	0 08	0 08	0 08	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 01	0 01	0 01	0 01	0 01
	benzene	leukemia	0 09	0 09	0 09	0 66	0 66	0 66	0 70	0 70	0 70	0 13	0 13	0 13	0 01	0 01	0 01	0 02	0 06	0 06	0 08	0 08	0 08	0 06	0 06	0 06	0 12	0 12	0 12
	1,3-butadiene	cancer all sites	0 30	0 30	0 30	2 22	2 22	2 22	2 32	2 32	2 32	0 43	0 43	0 43	0 04	0 04	0 04	0 07	0 26	0 26	0 32	0 32	0 32	0 25	0 26	0 26	0 42	0 42	0 42
	fomaldehyde	oral cancer	0 00	0 00	0 00	0 03	0 03	0 03	0 03	0 03	0 03	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01
Sub-total for VOC emissions			2 27	2 80	2 80	16 65	20 20	20 20	25 47	27 96	27 96	3 30	4 01	4 01	0 52	0 70	0 70	0 94	2 52	2 52	16 71	19 25	19 25	12 56	14 54	14 54	3 86	4 65	4 65
VOCs, NOx	O3	asthma attacks	0 18	0 19	0 19	1 21	1 27	1 27	1 06	1 11	1 11	0 25	0 26	0 26	0 06	0 06	0 06	0 09	0 11	0 11	0 79	0 82	0 82	0 60	0 63	0 63	0 27	0 28	0 28
		lower resp illness	0 35	0 36	0 36	2 26	2 37	2 37	1 98	2 07	2 07	0 47	0 49	0 49	0 11	0 12	0 12	0 16	0 20	0 20	1 48	1 53	1 53	1 13	1 17	1 17	0 51	0 53	0 53
		upper resp illness	0 11	0 11	0 11	0 69	0 72	0 72	0 60	0 63	0 63	0 14	0 15	0 15	0 03	0 04	0 04	0 05	0 06	0 06	0 45	0 47	0 47	0 34	0 36	0 36	0 16	0 16	0 16
		eye irritation	0 24	0 25	0 25	1 60	1 67	1 67	1 41	1 47	1 47	0 33	0 34	0 34	0 08	0 08	0 08	0 12	0 14	0 14	1 05	1 09	1 09	0 80	0 83	0 83	0 35	0 37	0 37
Subtotal mortality effects			35 29	36 57	56 38	222 34	231 13	342 00	209 23	215 27	319 91	47 39	49 13	74 83	81 00	81 46	96 86	105 21	108 90	205 25	570 24	576 15	856 68	445 21	449 83	664 73	71 75	73 67	110 93
Subtotal cancer effects			0 59	0 59	0 59	4 52	4 52	4 52	5 65	5 65	5 65	0 86	0 86	0 86	1 15	1 15	1 15	1 46	1 71	1 71	6 72	6 72	6 72	5 29	5 30	5 30	1 13	1 13	1 13
Subtotal chronic morbidity effects			10 36	10 80	17 29	64 84	67 86	104 17	60 50	62 57	96 83	13 88	14 48	22 90	25 89	26 05	31 09	33 89	35 16	66 71	187 84	189 87	281 80	146 46	148 04	218 47	22 01	22 67	34 89
Subtotal acute morbidity effects			5 21	5 29	5 81	34 09	34 65	37 54	31 62	32 05	34 78	7 07	7 18	7 85	3 19	3 22	3 62	4 29	4 50	7 01	29 84	30 16	37 49	23 03	23 28	28 89	8 04	8 16	9 13
Subtotal ambient PM10			43 63	45 37	72 20	272 04	284 08	434 15	253 17	261 46	403 09	58 38	60 76	95 56	109 98	110 61	131 46	143 02	148 07	278 49	778 13	786 23	1,166 02	607 39	613 70	904 66	92 01	94 63	145 09
Subtotal ambient O3			0 88	0 92	0 92	5 75	6 03	6 03	5 05	5 29	5 29	1 19	1 24	1 24	0 29	0 30	0 30	0 42	0 51	0 51	3 77	3 91	3 91	2 88	2 99	2 99	1 29	1 35	1 35
Subtotal ambient NO2			1 49	1 50	1 50	8 67	8 70	8 70	5 95	5 97	5 97	1 94	1 94	1 94	0 77	0 77	0 77	1 05	1 06	1 06	10 54	10 56	10 56	8 04	8 05	8 05	2 31	2 32	2 32
Subtotal ambient CO			5 04	5 04	5 04	36 36	36 37	36 37	39 70	39 70	39 70	7 12	7 12	7 12	0 15	0 15	0 15	0 29	0 29	0 29	1 78	1 78	1 78	1 36	1 37	1 37	6 77	6 77	6 77
Total all emissions, pollutants, effects			51 45	53 24	80 07	325 80	338 16	488 23	306 99	315 54	457 17	69 20	71 64	106 44	111 23	111 88	132 72	144 86	150 27	280 69	794 64	802 90	1,182 69	619 99	626 45	917 40	102 94	105 62	156 08

TABLE 11-A 43 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH FFFECT, $/1000 VMT (HOUSTON MSA 1990) (LOWER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	0 10	0 10	0 10	0 10	0 10	0 10	0 36	0 37	0 37	0 11	0 11	0 11	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 10	0 10	0 10
		hospitalization	0 02	0 02	0 02	0 02	0 02	0 02	0 06	0 06	0 06	0 02	0 02	0 02	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 02	0 02	0 02
		headaches	0 18	0 18	0 18	0 17	0 17	0 17	0 64	0 64	0 64	0 18	0 19	0 19	0 01	0 01	0 01	0 00	0 00	0 00	0 02	0 03	0 03	0 02	0 02	0 02	0 17	0 17	0 17
NOx	NO2	sore throat	0.25	0.27	0.27	0.23	0.25	0.25	0 62	0 69	0 69	0.24	0.27	0.27	0 15	0 15	0 15	0 03	0 04	0 04	0 79	0 83	0 83	0 60	0 63	0 63	0.27	0 29	0 29
		excess phlegm	0 11	0 12	0 12	0 10	0 11	0 11	0.27	0 30	0 30	0 11	0 12	0 12	0 06	0 07	0 07	0 01	0 02	0 02	0 35	0 37	0 37	0 26	0 28	0 28	0 12	0 13	0 13
		eye irritation	0 10	0 11	0 11	0 09	0 10	0 10	0 25	0 28	0 28	0 10	0 11	0 11	0 06	0 06	0 06	0 01	0 02	0 02	0 32	0 34	0 34	0 24	0 26	0 26	0 11	0 12	0 12
NOx, NH3	nitrate PM10	mortality	1 64	1 79	1 79	1 53	1 69	1 69	4 18	4 63	4 63	1 64	1 79	1 79	0 98	1 02	1 02	0 21	0 25	0 25	5 31	5 61	5 61	4 03	4 27	4 27	1 81	1 97	1 97
		chronic illness	0 54	0 59	0 59	0 50	0 55	0 55	1.36	1 50	1 50	0 54	0 59	0 59	0 32	0 33	0 33	0 07	0 08	0 08	1 72	1 82	1 82	1 31	1 38	1 38	0 59	0 65	0 65
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 08	0 09	0 09	0 08	0 09	0 09	0 21	0 23	0 23	0 08	0 09	0 09	0 05	0 05	0 05	0 01	0 01	0 01	0 27	0 28	0 28	0 20	0 22	0 22	0 09	0 10	0 10
Total for NOxand NH3emissions			2 71	2 96	2 96	2 53	2 80	2 80	6 90	7 64	7 64	2 71	2 96	2 96	1 62	1 68	1 68	0 34	0 42	0 42	8 76	9 26	9 26	6 66	7 04	7 04	3 00	3 26	3 26
PM2.5	PM2 5	mortality	0 31	0 69	0 89	0 40	0 80	0 97	1 74	2 92	3 57	0 35	0 75	0 94	4 04	4 17	4 32	0 77	0 93	1 07	9 24	10 28	12 02	7 41	8 20	9 51	0 87	1 29	1 56
		chronic illness	0 10	0 22	0 28	0 13	0 26	0 31	0 57	0 93	1 14	0 12	0 24	0 30	1 33	1 37	1 42	0 25	0 30	0 35	2 99	3 31	3 86	2 40	2 65	3 06	0 28	0 42	0 50
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 00	0 00	0 00
		RRAD	0 02	0 04	0 04	0 02	0 04	0 05	0 09	0 15	0 18	0 02	0 04	0 05	0 20	0 21	0 22	0 04	0 05	0 05	0 47	0 52	0 61	0 37	0 41	0 48	0 04	0 07	0 08
		lung cancer	0 02	0 02	0 02	0 02	0 02	0 02	0 09	0 09	0 09	0 02	0 02	0 02	0 14	0 14	0 14	0 03	0 03	0 03	0 33	0 33	0 33	0 27	0 27	0 27	0 04	0 04	0 04
Coarse PM10	coarse PM10	mortality	0 10	0 16	1.22	0 11	0 17	1.09	0 45	0 65	4.24	0 11	0 17	1.22	0.26	0.28	1 10	0 05	0 08	0.87	0 48	0 66	10.29	0.39	0 53	7 76	0 13	0 20	1 70
		chronic illness	0 03	0 05	0 38	0 04	0 06	0 34	0 15	0 21	1 32	0 04	0 06	0 38	0 08	0 09	0 35	0 02	0 02	0 27	0 16	0 21	3 20	0 13	0 17	2 42	0 04	0 06	0 53
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 00	0 00	0 01	0 00	0 00	0 00
		RRAD	0 01	0 01	0 06	0 01	0 01	0 06	0 02	0 03	0 22	0 01	0 01	0 06	0 01	0 01	0 06	0 00	0 00	0 04	0 02	0 03	0 52	0 02	0 03	0 39	0 01	0 01	0 09
Total for direct PM10emissions			0 59	1 19	2 89	0.72	1.36	2.83	3 11	4 98	10.76	0.65	1.28	2 96	6 07	6.28	7 59	1 15	1 41	2 69	13 69	15.35	30.85	10 99	12.26	23 91	1 41	2 08	4.49
SOx, NH3	sulfate PM10	mortality	0 39	1 52	1 52	0.37	1 56	1 56	0 90	4.35	4 35	0 39	1 56	1 56	2.21	2 69	2 69	0 48	1 06	1 06	4.82	8 40	8 40	3.89	6 64	6 64	0 65	1 93	1 93
		chronic illness	0 13	0 48	0 48	0 12	0 49	0 49	0 29	1 35	1 35	0 13	0 49	0 49	0 73	0 88	0 88	0 16	0 34	0 34	1 56	2 66	2 66	1.26	2 11	2 11	0 21	0 61	0 61
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 00	0 01	0 01	0 00	0 00	0 00
		RRAD	0 02	0 08	0 08	0 02	0 08	0 08	0 05	0 22	0 22	0 02	0 08	0 08	0 11	0 14	0 14	0 02	0 05	0 05	0 24	0 42	0 42	0 20	0 34	0 34	0 03	0 10	0 10
Total for SOxand NH3emissions			0 54	2.07	2 07	0.52	2 13	2.13	1.24	5 92	5.92	0 54	2 13	2.13	3 05	3.71	3 71	0 67	1 45	1 45	6 62	11 50	11.50	5 34	9 09	9 09	0.89	2.64	2 64
VOCs	organic PM10	mortality	0 15	0 23	0 23	0 14	0 24	0 24	0 65	0 91	0 91	0 15	0 24	0 24	0 03	0 05	0 05	0 01	0 03	0 03	0 22	0 46	0 46	0 17	0 35	0 35	0 15	0 25	0 25
	(SOA)	chronic illness	0 05	0 08	0 08	0 05	0 08	0 08	0 21	0 30	0 30	0 05	0 08	0 08	0 01	0 02	0 02	0 00	0 01	0 01	0 07	0 15	0 15	0 05	0 11	0 11	0 05	0 08	0 08
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 01	0 01	0 01	0 01	0 01	0 01	0 03	0 05	0 05	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 02	0 02	0 01	0 02	0 02	0 01	0 01	0 01
	acetaldehyde	oral cancer	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
	benzene	leukemia	0 01	0 01	0 01	0 01	0 01	0 01	0 03	0 03	0 03	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01
	1,3-butadiene	cancer all sites	0 03	0 03	0 03	0 03	0 03	0 03	0 10	0 10	0 10	0 03	0 03	0 03	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 03	0 03	0 03
	fomaldehyde	oral cancer	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
Sub-total for VOC emissions			0 24	0 36	0 36	0 24	0 36	0 36	1 03	1 39	1 39	0 25	0 37	0 37	0 04	0 07	0 07	0 01	0 05	0 05	0 32	0 65	0 65	0 24	0 49	0 49	0 25	0 38	0 38
VOCs, NOx	O3	asthma attacks	0 01	0 01	0 01	0 01	0 01	0 01	0 03	0 05	0 05	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 02	0 02	0 02	0 02	0 02	0 02	0 01	0 01	0 01
		lower resp illness	0 04	0 04	0 04	0 04	0 04	0 04	0 11	0 17	0 17	0 04	0 04	0 04	0 01	0 02	0 02	0 00	0 01	0 01	0 07	0 09	0 09	0 06	0 07	0 07	0 04	0 05	0 05
		upper resp illness	0 01	0 01	0 01	0 01	0 01	0 01	0 03	0 05	0 05	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 02	0 03	0 03	0 02	0 02	0 02	0 01	0 01	0 01
		eye irritation	0 05	0 06	0 06	0 05	0 06	0 06	0 14	0 23	0 23	0 05	0 06	0 06	0 02	0 02	0 02	0 00	0 01	0 01	0 10	0 12	0 12	0 08	0 09	0 09	0 05	0 06	0 06
Subtotal mortality effects			2 70	4.50	5 75	2 65	4 56	5 65	8.28	13.82	18.06	2 75	4 62	5.85	7 51	8.21	9 18	1 51	2 35	3.29	20 08	25 43	36.81	15.89	20 00	28 55	3 71	5 74	7 51
Subtotal cancer effects			0 05	0 05	0 05	0 06	0 06	0 06	0 22	0 22	0 22	0 06	0 06	0 06	0 14	0 14	0 14	0 03	0 03	0 03	0 34	0 34	0 34	0 27	0 27	0 27	0 07	0 07	0 07
Subtotal chronic morbidity effects			0.86	1 41	1.80	0.84	1 43	1 77	2.57	4 30	5 61	0.87	1 45	1.84	2 48	2 69	2 99	0 50	0 76	1 05	6 49	8 16	11 69	5 15	6 42	9 08	1 18	1 82	2 36
Subtotal acute morbidity effects			0.89	1 04	1 11	0.84	1 00	1 06	2.57	3 15	3 37	0 90	1 06	1 12	0.70	0 75	0.80	0 14	0 21	0.26	2 73	3 13	3 72	2 11	2 41	2.86	0 98	1 15	1.25
Subtotal ambient PM10			3 60	6 05	7 75	3 55	6 15	7 62	10 99	18 53	24 31	3 67	6.22	7 90	10 50	11 46	12 78	2 11	3.26	4 54	27 92	35.21	50 70	22 11	27 70	39 35	5 01	7 79	10 19
Subtotal ambient O3			0 11	0 13	0 13	0 10	0 12	0 12	0 31	0 49	0 49	0 11	0 13	0 13	0 04	0 05	0 05	0 01	0 02	0 02	0 22	0 26	0 26	0 16	0 20	0 20	0 11	0 13	0 13
Subtotal ambient NO2			0 45	0 49	0 49	0 42	0 47	0 47	1 15	1 27	1 27	0 45	0 49	0 49	0 27	0 28	0 28	0 06	0 07	0 07	1 46	1 54	1 54	1 11	1 17	1 17	0 50	0 54	0 54
Subtotal ambient CO			0.30	0 31	0.31	0.28	0.28	0.28	1 06	1 07	1.07	0 31	0 31	0.31	0 01	0 01	0 01	0 00	0 00	0 00	0 04	0 04	0 04	0 03	0 03	0 03	0 29	0 29	0 29
Total all emissions, pollutants, effects			4 50	7.01	8 71	4.39	7.06	8.53	13 64	21 49	27.27	4 57	7 18	8.86	10.83	11.80	13 12	2 18	3 35	4 63	29 65	37 06	52.56	23 42	29 11	40 76	5 95	8 79	11 19

TABLE 11-A 44 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $/1000 VMT (HOUSTON MSA 1990) (UPPER BOUND)

	Ambient		LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
Emission	pollutant	Health effect	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	1 35	1 36	1.36	1.26	1.26	1.26	6 45	6 46	6 46	1.38	1 39	1 39	0 03	0 04	0 04	0 01	0 01	0 01	0.23	0.24	0.24	0 17	0 18	0 18	1 30	1 30	1 30
		hospitalization	0 05	0 05	0 05	0 05	0 05	0 05	0.26	0.26	0.26	0 05	0 05	0 05	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0.01	0 01	0 01	0 01	0 05	0 05	0 05
		headaches	1 15	1 15	1 15	1 07	1 07	1.07	5 49	5 49	5 49	1 17	1 18	1 18	0 03	0 03	0.03	0 01	0 01	0 01	0.20	0.20	0.20	0 15	0 15	0 15	1 10	1 10	1 10
NOx	NO2	sore throat	1 48	1 53	1 53	1 38	1 43	1 43	5 18	5.33	5 33	1 49	1 54	1 54	0 76	0 77	0 77	0 16	0 17	0 17	6 53	6 64	6 64	4.89	4 97	4 97	1 74	1 79	1 79
		excess phlegm	0 65	0 68	0 68	0 61	0 63	0 63	2.28	2 35	2 35	0 66	0 68	0 68	0 34	0 34	0.34	0 07	0 08	0 08	2.88	2 93	2 93	2 16	2 19	2 19	0 77	0 79	0 79
		eye irritation	0 60	0 62	0 62	0.56	0 58	0.58	2.09	2 15	2 15	0 60	0 62	0 62	0.31	0 31	0.31	0.06	0 07	0 07	2 64	2 68	2 68	1 97	2.01	2.01	0 70	0 72	0 72
NOx, NH3	nitrate PM10	mortality	23 17	23 96	23 96	21 55	22.44	22 44	80.86	83.29	83.29	23 35	24 18	24 18	11 90	12 10	12 10	2 49	2 75	2 75	102 14	103 84	103.84	76 43	77 72	77 72	27 21	28 08	28 08
		chronic illness	16 68	17.21	17.21	15 46	16.05	16 05	57 93	59 53	59 53	16.80	17 36	17 36	8 57	8 70	8 70	1 79	1 96	1 96	72 98	74 09	74 09	54 62	55 47	55.47	19 56	20 14	20 14
		asthma attacks	0 01	0 01	0 01	0.01	0 01	0.01	0 04	0 04	0 04	0 01	0 01	0 01	0 01	0 01	0 01	0 00	0 00	0 00	0 05	0 05	0 05	0 03	0 04	0 04	0 01	0 01	0 01
		RRAD	0 66	0 68	0 68	0 61	0 64	0 64	2.30	2 37	2.37	0 66	0 69	0 69	0 34	0 34	0 34	0 07	0 08	0 08	2 91	2 95	2 95	2 17	2.21	2.21	0 77	0 80	0 80
Total for NOxand NH3emissions			43.25	44 68	44 68	40.17	41 77	41 77	150 68	155 05	155 05	43 58	45.08	45.08	22.22	22.57	22.57	4 65	5 11	5 11	190 13	193 17	193 17	142.27	144 60	144 60	50 77	52 33	52 33
PM2.5	PM2.5	mortality	4 16	5 71	32.86	5.26	6 90	30 45	36 67	41 48	133 94	4.82	6 44	33.29	53 38	53 90	75 01	10.08	10 74	31.20	192.49	196.60	444 30	149 13	152 29	338 35	15 36	17 08	55 49
		chronic illness	3 00	4 01	22 61	3 78	4.85	20 97	26.32	29 45	92 73	3 48	4 53	22.94	38 50	38.84	53.28	7.25	7 67	21 68	137 49	140 17	309 98	106.58	108 64	236 21	11 01	12 13	38 51
		asthma attacks	0 00	0.00	0 01	0 00	0 00	0 01	0 02	0 02	0 06	0 00	0 00	0 02	0 02	0 02	0 03	0 00	0 00	0 01	0 09	0 09	0.20	0 07	0 07	0 15	0 01	0 01	0 03
		RRAD	0 12	0 16	0 93	0 15	0.20	0.86	1 04	1 18	3 79	0 14	0 18	0 94	1 52	1 53	2 13	0.29	0 31	0.88	5 48	5 59	12 57	4 24	4 33	9 57	0 44	0 48	1 57
		lung cancer	0.29	0.29	0.29	0 37	0.37	0.37	2.65	2.65	2 65	0 34	0.34	0.34	1.70	1 70	1 70	0.33	0.33	0 33	6 43	6.43	6 43	4 97	4 97	4 97	0 68	0 68	0 68
Coarse PM10	coarse PM10	mortality	0.26	0 31	7 62	0.28	0.33	6 67	1 90	2 04	26 92	0.29	0.34	7 57	0 67	0 69	6 37	0 13	0 15	5 65	2 00	2.13	68.89	1 57	1 67	51.82	0.38	0 43	10 80
		chronic illness	0 19	0.22	5 21	0.20	0.23	4 55	1.36	1 46	18 42	0.21	0.24	5 17	0 49	0 50	4 37	0 09	0 10	3.86	1 43	1 51	47 02	1 12	1 19	35.37	0.27	0 31	7 38
		asthma attacks	0 00	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 03	0.00	0 00	0 02	0 00	0 00	0 00
		RRAD	0 01	0 01	0.21	0 01	0.01	0 19	0 05	0 06	0 76	0 01	0.01	0.21	0 02	0 02	0 18	0 00	0.00	0 16	0 06	0 06	1 94	0 04	0 05	1 46	0 01	0 01	0 30
Total for direct PM10emissions			8 04	10 73	69 75	10 05	12.90	64 07	70 02	78.34	279 28	9.28	12.07	70 48	96 30	97.21	143 07	18 17	19.30	63 78	345 47	352 59	891.36	267 74	273.20	677 94	28 15	31 14	114 76
SOx, NH3	sulfate PM10	mortality	2.24	4.84	4.84	2 12	4.88	4.88	8.20	16 17	16 17	2.28	4 98	4 98	12 61	13 74	13 74	2 74	4 08	4 08	43 36	51 69	51 69	33 74	40 14	40 14	4 57	7 54	7 54
		chronic illness	1 62	3.28	3.28	1 53	3.28	3.28	5.88	10 97	10 97	1 64	3 36	3.36	9.09	9.81	9.81	1 97	2.83	2.83	30 92	36 26	36.26	24 08	28 18	28 18	3.28	5 18	5 18
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 00	0 00	0 00	0 01	0 01	0 01	0.00	0 00	0 00	0 02	0 02	0 02	0 02	0 02	0.02	0 00	0 00	0 00
		RRAD	0 06	0 14	0 14	0.06	0 14	0 14	0.23	0 45	0 45	0 06	0 14	0 14	0 36	0 39	0 39	0 08	0 11	0 11	1.23	1 46	1 46	0 96	1 14	1 14	0 13	0 21	0 21
Total for SOxand NH3emissions			3 92	8.25	8.25	3 71	8.30	8.30	14.31	27 61	27 61	3 98	8 48	8 48	22.06	23 94	23 94	4.79	7 03	7 03	75 53	89 44	89 44	58 79	69.47	69 47	7 98	12 93	12 93
VOCs	organic PM10	mortality	1 49	1 77	1 77	1 43	1 73	1 73	10 47	11 36	11 36	1 57	1 87	1 87	0 26	0 34	0 34	0 07	0 16	0 16	3 50	4.29	4.29	2 60	3.20	3.20	1 65	1 97	1 97
	(SOA)	chronic illness	1.07	1.27	1.27	1 03	1.24	1.24	7.55	8 16	8 16	1 13	1.34	1 34	0 19	0.25	0.25	0 05	0 11	0 11	2 51	3 06	3 06	1 86	2.28	2.28	1 19	1 41	1 41
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.01	0 01	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 04	0 05	0 05	0 04	0 05	0 05	0 30	0.32	0 32	0 04	0.05	0 05	0 01	0 01	0 01	0 00	0 00	0 00	0 10	0 12	0 12	0 07	0 09	0 09	0 05	0 06	0 06
	acetaldehyde	oral cancer	0 02	0 02	0 02	0 02	0 02	0 02	0 08	0 08	0 08	0 02	0 02	0 02	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 02	0 02	0 02
	benzene	leukemia	0 15	0 15	0 15	0 15	0 15	0 15	0 69	0 69	0 69	0 15	0 15	0 15	0 02	0 02	0 02	0 01	0 02	0 02	0 08	0 08	0 08	0 06	0 06	0 06	0 15	0 15	0 15
	1,3-butadiene	cancer all sites	0 51	0 51	0 51	0 50	0 50	0 50	2.34	2.34	2 34	0 53	0 53	0 53	0 04	0 04	0 04	0 01	0 05	0 05	0 15	0 15	0 15	0 12	0 12	0 12	0 50	0 50	0 50
	fomaldehyde	oral cancer	0 01	0 01	0 01	0 01	0.01	0 01	0 03	0 03	0 03	0 01	0.01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01
Sub-total for VOC emissions			3.29	3 78	3 78	3 17	3 69	3 69	21 46	22 98	22 98	3 45	3 97	3 97	0.52	0 67	0 67	0 13	0 35	0.35	6.36	7 71	7 71	4 72	5 76	5 76	3 55	4 10	4 10
VOCs, NOx	O3	asthma attacks	0.20	0.21	0.21	0 19	0.20	0 20	0 79	0 90	0 90	0.20	0.21	0.21	0 06	0 07	0 07	0 01	0 02	0 02	0 52	0 54	0 54	0 39	0 41	0 41	0.22	0.23	0 23
		lower resp illness	0 37	0 39	0 39	0 35	0 38	0 38	1 48	1 67	1 67	0 38	0 40	0 40	0 12	0 12	0 12	0 03	0 03	0 03	0 97	1 02	1 02	0 73	0 76	0 76	0 41	0 43	0 43
		upper resp illness	0 11	0 12	0 12	0 11	0 11	0 11	0 45	0 51	0 51	0 12	0 12	0 12	0 04	0 04	0 04	0 01	0 01	0 01	0 29	0 31	0 31	0 22	0 23	0 23	0 12	0 13	0 13
		eye irritation	0 34	0.36	0.36	0.32	0.35	0.35	1.37	1.55	1 55	0.34	0.36	0.36	0 11	0 11	0 11	0 02	0.03	0 03	0.88	0 93	0 93	0 66	0 70	0 70	0 36	0 39	0 39
Subtotal mortality effects			32 68	37 96	72 41	31.89	37 54	67 42	144 56	160 81	278 15	33 69	39 19	73.27	78.85	80.81	107 59	15.51	17.89	43.86	343 73	358 80	673.25	263 64	275 20	511 42	50 46	56 40	105 18
Subtotal cancer effects			0 97	0 97	0 97	1 04	1 04	1 04	5 78	5 78	5 78	1 04	1 04	1 04	1 77	1 77	1 77	0.34	0 40	0 40	6 67	6 67	6 67	5 15	5 16	5 16	1 34	1 34	1 34
Subtotal chronic morbidity effects			22 57	25 99	49 57	21 99	25 65	46 10	99 03	109 57	189.81	23 26	26.82	50 17	56.83	58 09	76 41	11 14	12 67	30 43	245 33	255 08	470 40	188.26	195 75	357 51	35 31	39 16	72 61
Subtotal acute morbidity effects			5.87	6 16	7 15	5 52	5.84	6 70	23.37	24 65	28 01	5 96	6.27	7.25	4 04	4.14	4 91	0.82	0 94	1 68	24.85	25 60	34 60	18 79	19 36	26.12	6.89	7.22	8 62
Subtotal ambient PM10			55 09	63 93	122 96	53.89	63 35	114 53	243 78	271 02	471 97	56.83	66 05	124 46	139 63	142 90	188 77	27 43	31 39	75.87	605 19	630 42	1,169 19	464 31	483 67	888 42	86.57	96 53	180 15
Subtotal ambient O3			1 02	1 08	1 08	0 97	1 04	1 04	4 08	4 63	4 63	1 04	1 11	1 11	0 33	0 34	0 34	0 07	0 09	0 09	2.67	2.79	2 79	2.00	2 10	2 10	1 11	1 18	1 18
Subtotal ambient NO2			2.73	2 82	2 82	2 54	2 64	2 64	9 55	9.82	9 82	2 75	2 85	2 85	1 41	1 43	1 43	0.29	0 32	0 32	12.06	12 24	12.24	9 02	9 16	9 16	3 21	3 30	3 30
Subtotal ambient CO			2.56	2.56	2.56	2 37	2 38	2.38	12.20	12.21	12.21	2.61	2 62	2.62	0 06	0 07	0 07	0 01	0.02	0.02	0 44	0 45	0 45	0.33	0 34	0 34	2.45	2.45	2 45
Total all emissions, pollutants, effects			62.08	71 08	130 11	60 45	70 08	121 26	272.75	300.81	501 76	63 94	73 32	131 73	141 50	144 81	190 67	27.82	31.89	76 37	620 58	646 15	1,184 92	475.84	495.46	900 21	94 00	104 13	187 75

TABLE 11-A 45 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $/1000 VMT (LOS ANGELES MSA 1990) (LOWER BOUN

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	0 33	0 33	0 33	0 84	0 84	0 84	1 43	1 43	1 43	0 40	0 40	0 40	0 02	0 02	0 02	0 01	0 01	0 01	0 06	0 06	0 06	0 05	0 05	0 05	0 37	0 37	0 37
		hospitalization	0 05	0 05	0 05	0 13	0 13	0 13	0 23	0 23	0 23	0 06	0 06	0 06	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 06	0 06	0 06
		headaches	0 43	0 43	0 43	1 09	1 09	1 09	1 85	1 85	1 85	0 52	0 52	0 52	0 02	0 02	0 02	0 01	0 01	0 01	0 07	0 07	0 07	0 06	0 06	0 06	0 48	0 48	0 48
NOx	NO2	sore throat	0 58	0 59	0 59	1 57	1 59	1 59	2 03	2 05	2 05	0 71	0 72	0 72	0 35	0 35	0 35	0 20	0 21	0 21	2 51	2 53	2 53	2 00	2 02	2 02	0 80	0 81	0 81
		excess phlegm	0 24	0 25	0 25	0 66	0 66	0 66	0 85	0 86	0 86	0 30	0 30	0 30	0 15	0 15	0 15	0 08	0 09	0 09	1 05	1 06	1 06	0 84	0 85	0 85	0 34	0 34	0 34
		eye irritation	0 23	0 23	0 23	0 62	0 62	0 62	0 80	0 80	0 80	0 28	0 28	0 28	0 14	0 14	0 14	0 08	0 08	0 08	0 98	0 99	0 99	0 78	0 79	0 79	0 32	0 32	0 32
NOx, NH3	nitrate PM10	mortality	7 91	7 97	7 97	21 33	21 49	21 49	27 65	27 83	27 83	9 66	9 73	9 73	4 70	4 74	4 74	2 72	2 83	2 83	34 21	34 49	34 49	27 30	27 52	27 52	10 93	11 01	11 01
		chronic illness	3 86	3 88	3 88	10 41	10 48	10 48	13 56	13 64	13 64	4 71	4 74	4 74	2 29	2 30	2 30	1 32	1 37	1 37	16 80	16 92	16 92	13 40	13 50	13 50	5 34	5 37	5 37
		asthma attacks	0 01	0 01	0 01	0 02	0 02	0 02	0 02	0 02	0 02	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 03	0 03	0 03	0 02	0 02	0 02	0 01	0 01	0 01
		RRAD	0 38	0 38	0 38	1 03	1 04	1 04	1 33	1 34	1 34	0 46	0 47	0 47	0 23	0 23	0 23	0 13	0 14	0 14	1 65	1 66	1 66	1 32	1 33	1 33	0 52	0 53	0 53
Total for NOx and NH3 emissions			13 21	13 30	13 30	35 64	35 90	35 90	46 25	46 54	46 54	16 13	16 24	16 24	7 86	7 91	7 91	4 54	4 72	4 72	57 24	57 69	57 69	45 67	46 03	46 03	18 26	18 38	18 38
PM2.5	PM2 5	mortality	1 80	1 85	2 06	6 77	6 90	7 47	11 44	11 57	12 44	2 48	2 53	2 79	23 22	23 25	23 42	13 00	13 09	13 58	59 24	59 44	61 78	50 39	50 55	52 41	5 94	6 00	6 38
		chronic illness	0 88	0 90	1 00	3 30	3 36	3 64	5 61	5 67	6 10	1 21	1 23	1 36	11 30	11 32	11 40	6 34	6 38	6 62	29 12	29 20	30 36	24 74	24 81	25 73	2 91	2 93	3 12
		asthma attacks	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 00	0 00	0 00	0 02	0 02	0 02	0 01	0 01	0 01	0 05	0 05	0 05	0 04	0 04	0 05	0 01	0 01	0 01
		RRAD	0 09	0 09	0 10	0 33	0 33	0 36	0 55	0 56	0 60	0 12	0 12	0 13	1 12	1 12	1 13	0 63	0 63	0 66	2 85	2 86	2 98	2 43	2 43	2 52	0 29	0 29	0 31
		lung cancer	0 01	0 01	0 01	0 02	0 02	0 02	0 03	0 03	0 03	0 01	0 01	0 01	0 05	0 05	0 05	0 03	0 03	0 03	0 12	0 12	0 12	0 11	0 11	0 11	0 01	0 01	0 01
Coarse PM10	coarse PM10	mortality	0 59	0 61	1 66	1 82	1 88	4 61	2 96	3 01	7 21	0 75	0 78	2 06	1 48	1 50	2 31	0 81	0 86	3 23	3 08	3 15	14 43	2 68	2 74	11 68	0 89	0 92	2 75
		chronic illness	0 28	0 30	0 82	0 89	0 92	2 27	1 45	1 47	3 55	0 37	0 38	1 01	0 72	0 73	1 13	0 40	0 42	1 59	1 51	1 55	7 13	1 31	1 34	5 77	0 43	0 45	1 36
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 00	0 00	0 01	0 00	0 00	0 00
		RRAD	0 03	0 03	0 08	0 09	0 09	0 22	0 14	0 15	0 35	0 04	0 04	0 10	0 07	0 07	0 11	0 04	0 04	0 16	0 15	0 15	0 70	0 13	0 13	0 56	0 04	0 04	0 13
Total for direct PM10 emissions			3 67	3 77	5 73	13 22	13 51	18 59	22 19	22 46	30 30	4 97	5 09	7 47	37 99	38 06	39 58	21 25	21 46	25 87	96 13	96 53	117 56	81 82	82 15	98 84	10 52	10 66	14 07
SOx, NH3	sulfate PM10	mortality	2 26	2 43	2 43	6 34	6 89	6 89	5 91	6 53	6 53	2 76	2 99	2 99	12 69	12 80	12 80	8 17	8 56	8 56	30 81	31 75	31 75	26 39	27 15	27 15	4 47	4 73	4 73
		chronic illness	1 10	1 17	1 17	3 09	3 33	3 33	2 90	3 16	3 16	1 34	1 44	1 44	6 17	6 22	6 22	3 98	4 15	4 15	15 15	15 55	15 55	12 96	13 29	13 29	2 18	2 30	2 30
		asthma attacks	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 03	0 03	0 03	0 02	0 02	0 02	0 00	0 00	0 00
		RRAD	0 11	0 12	0 12	0 31	0 33	0 33	0 29	0 32	0 32	0 13	0 14	0 14	0 61	0 62	0 62	0 39	0 41	0 41	1 48	1 53	1 53	1 27	1 31	1 31	0 22	0 23	0 23
Total for SOx and NH3 emissions			3 47	3 73	3 73	9 74	10 56	10 56	9 10	10 02	10 02	4 24	4 57	4 57	19 48	19 66	19 66	12 55	13 12	13 12	47 47	48 86	48 86	40 64	41 77	41 77	6 87	7 26	7 26
VOCs	organic PM10	mortality	0 74	0 79	0 79	2 13	2 30	2 30	4 17	4 36	4 36	0 93	1 00	1 00	0 11	0 12	0 12	0 06	0 09	0 09	1 44	1 52	1 52	1 13	1 19	1 19	0 95	1 02	1 02
	(SOA)	chronic illness	0 36	0 39	0 39	1 04	1 12	1 12	2 04	2 13	2 13	0 46	0 49	0 49	0 05	0 06	0 06	0 03	0 04	0 04	0 71	0 74	0 74	0 56	0 58	0 58	0 46	0 50	0 50
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 04	0 04	0 04	0 10	0 11	0 11	0 20	0 21	0 21	0 05	0 05	0 05	0 01	0 01	0 01	0 00	0 00	0 00	0 07	0 07	0 07	0 05	0 06	0 06	0 05	0 05	0 05
	acetaldehyde	oral cancer	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
	benzene	leukemia	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
	1 3-butadiene	cancer all sites	0 01	0 01	0 01	0 03	0 03	0 03	0 04	0 04	0 04	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01
	formaldehyde	oral cancer	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
Sub-total for VOC emissions			1 15	1 23	1 23	3 31	3 57	3 57	6 46	6 76	6 76	1 45	1 56	1 56	0 17	0 18	0 18	0 09	0 14	0 14	2 23	2 34	2 34	1 75	1 84	1 84	1 47	1 58	1 58
VOCs, NOx	O3	asthma attacks	0 02	0 02	0 02	0 06	0 06	0 06	0 08	0 08	0 08	0 03	0 03	0 03	0 01	0 01	0 01	0 00	0 00	0 00	0 04	0 05	0 05	0 04	0 04	0 04	0 03	0 03	0 03
		lower resp illness	0 08	0 08	0 08	0 22	0 22	0 22	0 31	0 31	0 31	0 10	0 10	0 10	0 02	0 03	0 03	0 01	0 02	0 02	0 17	0 17	0 17	0 14	0 14	0 14	0 10	0 10	0 10
		upper resp illness	0 02	0 02	0 02	0 07	0 07	0 07	0 09	0 09	0 09	0 03	0 03	0 03	0 01	0 01	0 01	0 00	0 00	0 00	0 05	0 05	0 05	0 04	0 04	0 04	0 03	0 03	0 03
		eye irritation	0 12	0 12	0 12	0 35	0 35	0 35	0 49	0 49	0 49	0 15	0 15	0 15	0 04	0 04	0 04	0 02	0 02	0 02	0 27	0 27	0 27	0 22	0 22	0 22	0 15	0 16	0 16
Subtotal mortality effects			13 62	13 98	15 24	39 24	40 31	43 60	53 55	54 72	59 80	16 98	17 43	18 97	42 22	42 43	43 41	24 77	25 43	28 29	128 85	130 41	144 03	107 93	109 20	120 00	23 55	24 05	26 26
Subtotal cancer effects			0 02	0 02	0 02	0 05	0 05	0 05	0 08	0 08	0 08	0 02	0 02	0 02	0 05	0 05	0 05	0 03	0 03	0 03	0 13	0 13	0 13	0 11	0 11	0 11	0 03	0 03	0 03
Subtotal chronic morbidity effects			6 48	6 63	7 26	18 72	19 20	20 83	25 56	26 08	28 99	8 08	8 28	9 04	20 54	20 63	21 12	12 07	12 36	13 77	63 29	63 96	70 70	52 97	53 52	58 87	11 32	11 55	12 64
Subtotal acute morbidity effects			2 43	2 46	2 52	6 65	6 74	6 90	9 28	9 38	9 62	2 98	3 02	3 09	2 81	2 83	2 88	1 64	1 69	1 83	11 48	11 60	12 27	9 41	9 52	10 05	3 44	3 48	3 59
Subtotal ambient PM10			20 43	20 95	22 91	59 02	60 63	65 71	80 28	82 03	89 87	25 49	26 15	28 53	64 87	65 18	66 70	38 07	39 06	43 47	198 52	200 83	221 86	166 25	168 13	184 82	35 65	36 40	39 81
Subtotal ambient O3			0 24	0 25	0 25	0 69	0 70	0 70	0 97	0 98	0 98	0 30	0 31	0 31	0 08	0 08	0 08	0 05	0 05	0 05	0 54	0 54	0 54	0 43	0 44	0 44	0 31	0 31	0 31
Subtotal ambient NO2			1 06	1 06	1 06	2 85	2 87	2 87	3 68	3 70	3 70	1 29	1 30	1 30	0 63	0 64	0 64	0 36	0 38	0 38	4 54	4 58	4 58	3 63	3 66	3 66	1 46	1 47	1 47
Subtotal ambient CO			0 81	0 81	0 81	2 07	2 07	2 07	3 50	3 50	3 50	0 98	0 98	0 98	0 04	0 04	0 04	0 02	0 02	0 02	0 14	0 14	0 14	0 11	0 11	0 11	0 92	0 92	0 92
Total all emissions, pollutants, effects			22 55	23 09	25 04	64 67	66 31	71 38	88 47	90 26	98 10	28 07	28 75	31 13	65 63	65 94	67 46	38 50	39 51	43 92	203 74	206 10	227 13	170 42	172 34	189 03	38 35	39 11	42 52

TABLE 11-A 46 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $/1000 VMT (LOS ANGELES MSA 1990) (UPPER BOUNI

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			Total gasoline vehicles			LDDVs			LDDTs			HDDVs			Total diesel vehicles			Total all vehicles		
			V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD
CO	CO	mortality	3 54	3.54	3 54	9 09	9 09	9 09	20 78	20 78	20 78	4 37	4 37	4 37	0 16	0 16	0 16	0 07	0 07	0 07	0 81	0 81	0 81	0 66	0 66	0 66	4 10	4 10	4 10
		hospitalization	0 14	0 14	0 14	0 36	0 36	0 36	0 82	0 82	0 82	0 17	0 17	0 17	0 01	0 01	0 01	0 00	0 00	0 00	0 03	0 03	0 03	0 03	0 03	0 03	0 16	0 16	0 16
		headaches	2 23	2 23	2 23	5 72	5 72	5 72	13 09	13 09	13 09	2 75	2 75	2 75	0 10	0 10	0 10	0 05	0 05	0 05	0 51	0 51	0 51	0 41	0 41	0 41	2 58	2 58	2 58
NOx	NO2	sore throat	3 07	3 08	3 08	8 29	8 32	8 32	14 57	14 60	14 60	3 78	3 79	3 79	1 57	1 58	1 58	0 91	0 92	0 92	17 97	18 01	18 01	14 15	14 18	14 18	4 52	4 53	4 53
		excess phlegm	1 29	1 29	1 29	3 47	3 48	3 48	6 09	6 10	6 10	1 59	1 59	1 59	0 66	0 66	0 66	0 38	0 39	0 39	7 53	7 54	7 54	5 93	5 94	5 94	1 90	1 91	1 91
		eye irritation	1 20	1 21	1 21	3 25	3 26	3 26	5 70	5 72	5 72	1 49	1 49	1 49	0 62	0 62	0 62	0 36	0 36	0 36	7 04	7 06	7 06	5 54	5 56	5 56	1 78	1 78	1 78
NOx, NH3	nitrate PM10	mortality	91 53	91 76	91 76	247 51	248 22	248 22	436 02	436 81	436 81	113 01	113 30	113 30	46 72	46 87	46 87	27 01	27 50	27 50	539 66	540 86	540 86	424 87	425 84	425 84	135 34	135 67	135 67
		chronic illness	65 39	65 54	65 54	176 41	176 88	176 88	310 09	310 62	310 62	80 78	80 98	80 98	33 31	33 41	33 41	19 24	19 57	19 57	383 78	384 58	384 58	302 17	302 83	302 83	96 77	97 00	97 00
		asthma attacks	0 04	0 04	0 04	0 10	0 10	0 10	0 18	0 18	0 18	0 05	0 05	0 05	0 02	0 02	0 02	0 01	0 01	0 01	0 22	0 22	0 22	0 18	0 18	0 18	0 06	0 06	0 06
		RRAD	1 96	1 97	1 97	5 31	5 33	5 33	9 34	9 36	9 36	2 42	2 43	2 43	1 00	1 01	1 01	0 58	0 59	0 59	11 55	11 58	11 58	9 09	9 12	9 12	2 90	2 90	2 90
Total for NOxand NH3emissions			164 48	164 88	164.88	444 34	445 58	445 58	782 00	783 39	783.39	203 12	203 62	203 62	83 90	84 16	84 16	48 49	49 35	49.35	967 75	969 85	969.85	761 93	763 64	763 64	243 26	243 85	243.85
PM2.5	PM2.5	mortality	19 39	20.86	78 54	73 02	76 40	226 17	195 68	197 70	429 13	27 49	29 18	99 18	250 01	251 10	295 99	140 16	142.84	273 08	1 013 60	1,016 25	1 634 67	831 38	833 75	1 324 25	85 45	87 18	187 12
		chronic illness	13.83	14.89	56 00	52 03	54 47	161 05	139 19	140 63	305.21	19 60	20.82	70 77	178 29	179 08	211 00	99.85	101 79	194 39	721 11	723 00	1,164 62	591 68	593 38	943 73	60 92	62 17	133 81
		asthma attacks	0 01	0 01	0 03	0 03	0 03	0 09	0 08	0 08	0 18	0 01	0 01	0 04	0 10	0 10	0 12	0 06	0 06	0 11	0 42	0 42	0 68	0 34	0 34	0 55	0 04	0 04	0 08
		RRAD	0.42	0 45	1 68	1 57	1 64	4.85	4 19	4.24	9.20	0 59	0 63	2 13	5 37	5 40	6 36	3 01	3 07	5 86	21 68	21 74	34 96	17 78	17.84	28 32	1.83	1.87	4 00
		lung cancer	0.09	0.09	0 09	0 36	0.36	0 36	0 95	0 95	0 95	0 13	0 13	0 13	0 60	0 60	0 60	0 34	0.34	0 34	2 41	2.41	2 41	1 98	1 98	1 98	0.27	0.27	0.27
Coarse PM10	coarse PM10	mortality	1.25	1.80	15.89	3.89	5 11	41 65	10 12	10 77	67.21	1 65	2.28	19 39	3 16	3 57	14 52	1 74	2 73	34 48	10 56	11 39	162 78	8 78	9 54	129 64	2 16	2.80	27 34
		chronic illness	0.89	1.29	11 31	2 77	3 66	29 65	7.20	7 67	47.81	1 18	1 63	13.81	2.25	2.55	10 34	1.24	1 96	24 54	7 50	8 10	115.81	6.24	6 79	92 24	1 54	2.00	19 47
		asthma attacks	0 00	0 00	0 01	0 00	0 00	0 02	0.00	0 00	0 03	0 00	0 00	0 01	0 00	0 00	0 01	0 00	0 00	0 01	0 00	0 00	0 07	0 00	0 00	0 05	0 00	0 00	0 01
		RRAD	0.03	0 04	0.34	0 08	0 11	0 90	0.22	0.23	1 44	0 04	0 05	0 42	0 07	0 08	0 31	0 04	0 06	0 74	0 23	0.25	3 49	0 19	0.21	2 78	0 05	0 06	0 59
Total for direct PM10emissions			35 91	39 43	163 90	133.75	141 79	464.74	357 63	362 29	861 15	50 69	54 73	205.88	439.86	442 49	539.24	246 43	252.84	533 55	1,777 51	1,783 55	3,119 48	1,458.38	1,463.83	2,523 54	152.25	156 39	372.69
SOx, NH3	sulfate PM10	mortality	10 51	10.87	10.87	29 58	30 69	30.69	43 77	45 02	45 02	13.05	13 51	13 51	59 12	59 35	59 35	38 13	38 91	38 91	228 43	230 32	230 32	188.24	189 78	189 78	25 70	26.23	26.23
		chronic illness	7 50	7 74	7 74	21.07	21.81	21.81	31 13	31 96	31 96	9 31	9 61	9 61	42 16	42 31	42 31	27 16	27 68	27 68	162 27	163 52	163 52	133 76	134 77	134 77	18 30	18 65	18 65
		asthma attacks	0 00	0 00	0 00	0 01	0 01	0 01	0 02	0 02	0 02	0 01	0 01	0 01	0 02	0 02	0 02	0 02	0 02	0 02	0 09	0 09	0 09	0 08	0 08	0 08	0 01	0 01	0 01
		RRAD	0.23	0.23	0.23	0 63	0 66	0 66	0 94	0 97	0 97	0 28	0 29	0 29	1 27	1 28	1 28	0 82	0 84	0 84	4 89	4 93	4 93	4 03	4 06	4 06	0 55	0 56	0 56
Total for SOxand NH3emissions			18.24	18.85	18.85	51.30	53 18	53 18	75.86	77 96	77.96	22.65	23 41	23 41	102.57	102.97	102.97	66.13	67.43	67 43	395 68	398.87	398.87	326 10	328 69	328 69	44 55	45 45	45 45
VOCs	organic PM10 (SOA)	mortality	5 96	6.13	6 13	17.22	17 76	17 76	53 38	54 00	54 00	7 78	8 00	8 00	0.88	0 90	0 90	0 46	0 55	0 55	18 52	18 76	18 76	14 43	14 62	14.62	8.26	8 48	8 48
		chronic illness	4 25	4 38	4 38	12.28	12 66	12 66	38 02	38 47	38 47	5 55	5 71	5 71	0 63	0 64	0 64	0 33	0 39	0 39	13 17	13 34	13 34	10.26	10 40	10 40	5 89	6 05	6.05
		asthma attacks	0 00	0 00	0 00	0 01	0 01	0 01	0 02	0 02	0.02	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0.01	0 01	0 00	0 00	0 00
		RRAD	0.13	0 13	0 13	0 37	0.38	0 38	1 15	1 16	1 16	0 17	0 17	0 17	0 02	0 02	0 02	0 01	0 01	0 01	0 40	0 40	0 40	0 31	0 31	0 31	0 18	0 18	0 18
	acetaldehyde	oral cancer	0 01	0 01	0 01	0.02	0 02	0 02	0 03	0.03	0 03	0 01	0 01	0.01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01
	benzene	leukemia	0 05	0 05	0 05	0 14	0 14	0 14	0.28	0.28	0.28	0 06	0 06	0 06	0 01	0 01	0 01	0 00	0 02	0 02	0 03	0 03	0 03	0 02	0 03	0 03	0 06	0 06	0 06
	1,3-butadiene	cancer all sites	0 16	0 16	0 16	0 47	0 47	0 47	0 94	0 94	0 94	0.21	0.21	0.21	0 01	0 01	0 01	0 01	0 04	0 04	0 06	0 06	0 06	0 05	0 05	0 05	0.20	0 20	0.20
	fomaldehyde	oral cancer	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
Sub-total for VOC emissions			10 56	10.86	10.86	30.50	31 45	31 45	93.83	94 91	94 91	13.78	14 16	14 16	1 54	1 59	1.59	0.81	1.01	1 01	32.20	32 61	32 61	25 09	25 42	25 42	14 60	14 97	14 97
VOCs, NOx	O3	asthma attacks	0 35	0 36	0 36	1.00	1.01	1 01	1 90	1 91	1 91	0 44	0 45	0 45	0 09	0 09	0 09	0 05	0 05	0 05	0 99	0 99	0 99	0 78	0 78	0 78	0 47	0 47	0 47
		lower resp illness	0 67	0 67	0 67	1 87	1 88	1 88	3 56	3 57	3 57	0 84	0 84	0 84	0 17	0 17	0 17	0 10	0 10	0 10	1 85	1 85	1 85	1 46	1 46	1 46	0 88	0 89	0 89
		upper resp illness	0.20	0.20	0.20	0 57	0 57	0.57	1 08	1 09	1 09	0.25	0.26	0 26	0 05	0 05	0 05	0 03	0 03	0 03	0 56	0 56	0 56	0 44	0 44	0 44	0 27	0 27	0 27
		eye irritation	0 74	0 74	0 74	2 11	2.12	2 12	4 04	4.05	4 05	0 92	0 93	0 93	0.20	0.20	0.20	0 11	0 12	0 12	2.09	2.10	2 10	1 65	1 66	1 66	0 97	0 97	0 97
Subtotal mortality effects			132 18	134 96	206.73	380.29	387.27	573 58	759 75	765 09	1,052 95	167.35	170 63	257 74	360 05	361 96	417.80	207.57	212.60	374 60	1,811 59	1,818 39	2,588.21	1,468 35	1,474 20	2,084 79	261 00	264 46	388 94
Subtotal cancer effects			0 31	0 31	0 31	0 99	0 99	0 99	2.21	2.21	2.21	0 41	0 41	0 41	0 62	0 62	0 62	0 34	0 39	0 39	2 51	2.51	2 51	2 06	2 06	2 06	0 53	0 53	0 53
Subtotal chronic morbidity effects			91 86	93 83	144 97	264 56	269 48	402 06	525 64	529 35	734 06	116 42	118 75	180 87	256 64	258 00	297 70	147.83	151 38	266 57	1,287 83	1,292 54	1,841 87	1 044 11	1,048 17	1,483 97	183 42	185 86	274 98
Subtotal acute morbidity effects			12 71	12.80	14 36	34.77	35 00	39 07	67 01	67.21	73 50	15.80	15 90	17.80	11.35	11 41	12 63	6 52	6 68	10.22	78 05	78.30	95 09	62 39	62 61	75 92	19 13	19.24	21 95
Subtotal ambient PM10			223 42	228 22	352 69	644.25	656 30	979 26	1,281 70	1,290 87	1,789 73	283 11	288 78	439 93	625 01	628 32	725 08	360.20	368 90	649 62	3,140 51	3,152.18	4,488 11	2,545.80	2,555.82	3,615 53	446 20	452 18	668 48
Subtotal ambient O3			1 97	1 97	1 97	5 56	5 58	5 58	10 58	10 61	10 61	2 46	2 47	2 47	0 51	0 52	0 52	0 29	0 30	0 30	5 48	5 51	5 51	4 32	4 34	4 34	2 59	2 60	2 60
Subtotal ambient NO2			5 56	5 58	5 58	15.01	15 05	15 05	26 37	26 42	26 42	6.86	6.88	6.88	2.85	2.86	2.86	1 64	1 67	1 67	32 54	32 61	32 61	25 62	25 68	25 68	8 20	8 22	8 22
Subtotal ambient CO			5 90	5 90	5 90	15 17	15 17	15 17	34 70	34 70	34 70	7.28	7.28	7.28	0.27	0.27	0.27	0 12	0 12	0 12	1 36	1 36	1.36	1 10	1 10	1 10	6.84	6.84	6.84
Total all emissions, pollutants, effects			237 07	241 90	366 37	680 61	692.74	1,015 69	1,354 61	1,363.86	1,862 72	299 98	305 69	456 83	628 66	631 99	728 74	362.27	371 06	651 77	3,179 98	3,191 75	4,527 67	2,576 92	2,587.03	3,646 74	464 08	470 09	686.39

TABLE 11-A 47 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $/1000 VMT (MINNEAPOLIS MSA 1990) (LOWER BOUN

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			Total gasoline vehicles			LDDVs			LDDTs			HDDVs			Total diesel vehicles			Total all vehicles		
			V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD	V	V+U	V+U+RD
CO	CO	mortality	0 19	0 19	0 19	2.26	2 30	2 30	1.24	1.26	1.26	0.26	0.26	0.26	0 00	0 01	0 01	0 01	0 03	0 03	0 05	0 06	0 06	0 03	0 04	0 04	0 25	0 25	0 25
		hospitalization	0 03	0 03	0 03	0 36	0 36	0 36	0 20	0 20	0 20	0 04	0 04	0 04	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 04	0 04	0 04
		headaches	0.21	0.22	0.22	2 50	2 54	2.54	1.37	1 39	1.39	0.29	0.29	0.29	0 01	0.01	0.01	0 01	0 03	0 03	0 05	0 07	0 07	0 04	0 05	0 05	0.27	0.28	0.28
NOx	NO2	sore throat	0.24	0.24	0 24	2 78	2.83	2.83	1 33	1 35	1 35	0 32	0 32	0 32	0 12	0 13	0 13	0 34	0.35	0 35	1 57	1 59	1 59	1 10	1 12	1 12	0.36	0 36	0 36
		excess phlegm	0 11	0 11	0 11	1.25	1.27	1.27	0 59	0 61	0 61	0 14	0 15	0 15	0 06	0 06	0 06	0 15	0 16	0 16	0 71	0 71	0 71	0 50	0 50	0 50	0 16	0 16	0 16
		eye irritation	0 10	0 10	0 10	1 13	1 15	1 15	0.54	0.55	0 55	0 13	0 13	0 13	0 05	0 05	0 05	0 14	0 14	0 14	0 64	0 65	0 65	0 45	0 46	0 46	0 14	0 15	0 15
NOx, NH3	nitrate PM10	mortality	2 47	2 51	2 51	28 72	29 27	29.27	13 99	13.87	13.87	3 30	3 36	3 36	1 29	1 30	1 30	3 48	3 64	3 64	16 06	16.24	16.24	11.29	11 42	11 42	3 68	3 74	3 74
		chronic illness	0 50	0 51	0.51	5.83	5 93	5 93	2 75	2.80	2.80	0 67	0 68	0 68	0.26	0.27	0.27	0 71	0 74	0 74	3.24	3.28	3.28	2.28	2 30	2.30	0 75	0 76	0 76
		asthma attacks	0 00	0 00	0 00	0 02	0 03	0.03	0.01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0.01	0 01	0 00	0 00	0 00
		RRAD	0 13	0 13	0 13	1 49	1.52	1 52	0 71	0 72	0 72	0 17	0 17	0 17	0 07	0 07	0 07	0 18	0 19	0 19	0 84	0 85	0 85	0 59	0 60	0 60	0 19	0 19	0 19
Total for NOxand NH3emissions			3.54	3 60	3 60	41.24	42 01	42.01	19 52	19 92	19.92	4 74	4.82	4.82	1.86	1.87	1.87	5 00	5.23	5.23	23.07	23 33	23 33	16.22	16 40	16 40	5.28	5 36	5 36
PM2.5	PM2.5	mortality	0 41	0 62	0 78	6 74	9 62	11 33	5.29	7 10	8.31	0 62	0 93	1 13	5 35	5 45	5 57	12 97	14 48	15 97	27 77	30 37	33 61	20 52	22 44	24 69	1 57	1 95	2.25
		chronic illness	0 08	0 13	0 16	1 37	1 95	2 30	1 07	1 45	1 69	0 13	0 19	0.23	1 09	1 11	1 14	2 63	2 95	3 25	5 60	6 17	6.82	4 16	4 56	5 01	0 32	0 40	0 46
		asthma attacks	0.00	0 00	0 00	0 01	0 01	0 01	0 00	0 01	0 01	0 00	0 00	0 00	0 00	0.00	0 00	0 01	0 01	0 01	0 02	0 03	0 03	0 02	0 02	0 02	0 00	0 00	0 00
		RRAD	0 02	0 03	0 04	0 35	0 50	0 59	0.28	0.37	0 43	0 03	0 05	0 06	0.28	0.28	0.29	0 67	0 75	0 83	1 45	1 59	1 76	1 08	1 17	1 29	0 08	0 10	0 12
		lung cancer	0 01	0 01	0 01	0 15	0 15	0 15	0 12	0 12	0 12	0 01	0 01	0 01	0 08	0 08	0 08	0 20	0 20	0 20	0 43	0 43	0 43	0 32	0 32	0 32	0 03	0 03	0 03
Coarse PM10	coarse PM10	mortality	0 14	0 20	1 04	1 85	2 71	12 00	1 37	1 90	8 44	0 20	0 29	1 40	0 34	0 37	1 02	0 82	1 25	9 32	1 44	2 16	19 73	1 09	1 60	13 80	0 24	0 35	1 99
		chronic illness	0 03	0 04	0 21	0 38	0 55	2 44	0 28	0 39	1 72	0 04	0 06	0 28	0 07	0 08	0 21	0 17	0 26	1 90	0 29	0 45	4 01	0 22	0 33	2 81	0 05	0 07	0 40
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 01	0 00	0 00	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 00	0 00	0 02	0 00	0 00	0 01	0 00	0 00	0 00
		RRAD	0 01	0 01	0 05	0 10	0 14	0 63	0 07	0 10	0 44	0 01	0 01	0 07	0 02	0 02	0 05	0 04	0 07	0 49	0 08	0 11	1 04	0 06	0 08	0 73	0 01	0 02	0 10
Total for direct PM10emissions			0 69	1 05	2 29	10 94	15 65	29 47	8 49	11.44	21 18	1 04	1 54	3 20	7 23	7 40	8.36	17 51	19 97	31 98	37 08	41 31	67 45	27 57	30 52	48 69	2.30	2 92	5 36
SOx, NH3	sulfate PM10	mortality	0 52	1 16	1 16	6.36	15.39	15.39	2 75	7 33	7 33	0 71	1 62	1 62	2 93	3 19	3 19	8 18	12.24	12.24	14 55	19.24	19.24	10.87	14 20	14 20	1 19	2.21	2.21
		chronic illness	0 11	0.23	0 23	1 29	3 05	3 05	0 56	1 45	1 45	0 14	0 32	0 32	0 60	0 65	0 65	1 66	2 45	2 45	2 93	3.85	3.85	2 19	2.84	2.84	0 24	0 44	0 44
		asthma attacks	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 02	0 02	0 01	0 01	0 01	0 00	0 00	0 00
		RRAD	0 03	0 06	0 06	0 33	0.81	0.81	0 14	0 39	0.39	0 04	0 08	0 08	0 15	0 17	0 17	0 43	0 64	0 64	0 76	1 01	1 01	0 57	0 74	0 74	0 06	0 12	0 12
Total for SOxand NH3emissions			0 66	1 46	1 46	7 99	19.27	19.27	3 45	9 17	9 17	0.89	2 02	2.02	3.69	4.01	4 01	10.28	15 33	15.33	18.25	24 11	24 11	13 64	17.80	17.80	1 49	2.77	2.77
VOCs	organic PM10 (SOA)	mortality	0.21	0 35	0.35	2 66	4 60	4 60	1.83	2.81	2.81	0.29	0 49	0 49	0 04	0 07	0 07	0 11	0 67	0 67	0 68	1 48	1 48	0 47	1 03	1 03	0.30	0 51	0 51
		chronic illness	0 04	0 07	0 07	0 54	0 96	0 96	0.37	0 58	0 58	0.06	0 10	0 10	0 01	0 01	0 01	0 02	0 14	0 14	0 14	0 30	0 30	0 10	0.21	0.21	0 06	0 11	0 11
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 01	0 02	0 02	0 14	0.24	0.24	0 09	0 15	0 15	0 02	0 03	0 03	0 00	0 00	0 00	0 01	0 03	0 03	0 04	0 08	0 08	0 02	0 05	0 05	0 02	0 03	0 03
	acetaldehyde	oral cancer	0 00	0 00	0 00	0 01	0.01	0 01	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
	benzene	leukemia	0 00	0 00	0 00	0 06	0 06	0 06	0 03	0 03	0 03	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 00	0 00	0 00	0 01	0 01	0 01
	1,3-butadiene	cancer all sites	0 02	0 02	0 02	0 21	0 21	0 21	0 11	0 11	0 11	0 02	0 02	0 02	0 00	0 00	0 00	0 00	0 02	0 02	0 01	0 01	0 01	0 01	0 01	0 01	0 02	0 02	0 02
	fomaldehyde	oral cancer	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
Sub-total for VOC emissions			0.28	0 46	0 46	3 61	6.07	6 07	2.44	3 69	3 69	0.39	0 64	0 64	0 05	0 09	0 09	0 15	0.88	0.88	0.87	1.87	1.87	0 60	1 31	1.31	0 40	0 68	0 68
VOCs, NOx	O3	asthma attacks	0 01	0 01	0 01	0 06	0.07	0 07	0 03	0 04	0 04	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 01	0 01	0 02	0 02	0 02	0 01	0 02	0 02	0 01	0 01	0 01
		lower resp illness	0 02	0 02	0 02	0 24	0 28	0 28	0 12	0 17	0 17	0 03	0 03	0 03	0 01	0 01	0 01	0 02	0 03	0 03	0 07	0 09	0 09	0 05	0 06	0 06	0 03	0 03	0 03
		upper resp illness	0 01	0 01	0 01	0 07	0 08	0 08	0 04	0 05	0.05	0 01	0 01	0 01	0 00	0 00	0 00	0 01	0 01	0 01	0 02	0 03	0 03	0 02	0 02	0 02	0 01	0 01	0 01
		eye irritation	0 01	0.02	0 02	0 17	0.20	0.20	0 09	0 12	0 12	0 02	0 02	0.02	0 00	0.00	0 00	0 01	0.02	0 02	0 05	0 06	0 06	0 04	0 04	0 04	0 02	0 02	0 02
Subtotal mortality effects			3 94	5 04	6 03	48 59	63 89	74 90	26 07	34.28	42 03	5 37	6 94	8.26	9 96	10 40	11 16	25.58	32 31	41.87	60 55	69 56	90 36	44 38	50 73	65 19	7.23	9 02	10 96
Subtotal cancer effects			0 03	0 03	0 03	0 43	0 43	0 43	0 27	0 27	0 27	0 04	0 04	0 04	0 08	0 08	0 08	0 21	0 23	0 23	0 45	0 45	0 45	0 33	0 33	0 33	0 06	0 06	0 06
Subtotal chronic morbidity effects			0 76	0 98	1 18	9 41	12 45	14 68	5 03	6 67	8.24	1 04	1 35	1 62	2 03	2.11	2.27	5 19	6 53	8 47	12.20	14 04	18.26	8 95	10.25	13 18	1 42	1 77	2 17
Subtotal acute morbidity effects			0 93	1 00	1 05	11 01	12 06	12 65	5 62	6.24	6 65	1 25	1.35	1 43	0 78	0 81	0 85	2 03	2 47	2 98	6 36	6 92	8 03	4 56	4 96	5 73	1 40	1 52	1 63
Subtotal ambient PM10			4 71	6 09	7 33	58 33	77 46	91.29	31 30	41 57	51 31	6 44	8 39	10 05	12.59	13 13	14 10	32 31	40 72	52 73	76 34	87 66	113.80	55 97	63 95	82 11	8 79	11 03	13 47
Subtotal ambient O3			0 04	0 05	0 05	0 54	0 63	0 63	0 28	0 38	0 38	0 06	0 07	0 07	0 01	0 02	0 02	0 04	0 07	0 07	0 17	0 20	0 20	0 12	0 14	0 14	0 06	0 07	0 07
Subtotal ambient NO2			0 44	0 45	0 45	5 16	5.26	5.26	2 46	2 51	2 51	0 59	0 60	0 60	0.23	0.23	0.23	0 63	0 65	0 65	2 92	2 95	2 95	2 05	2 07	2 07	0 66	0 67	0 67
Subtotal ambient CO			0 43	0 44	0 44	5 12	5.21	5.21	2.80	2.85	2.85	0 58	0 59	0 59	0 01	0 01	0.01	0 03	0 07	0 07	0 10	0 14	0 14	0 07	0 10	0 10	0 56	0 57	0 57
Total all emissions, pollutants, effects			5 65	7 05	8.29	69 43	88.84	102 66	36 99	47 46	57.20	7 70	9 68	11 34	12.85	13 40	14.36	33.01	41 54	53.55	79 55	90 97	117 11	58.23	66.27	84 44	10 10	12.37	14.81

TABLE 11-A 48 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $/1000 VMT (MINNEAPOLIS MSA 1990) (UPPER BOUNI

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	2.24	2.26	2.26	26 47	26 64	26 64	18 51	18 60	18 60	3 05	3 07	3 07	0 05	0 05	0 05	0 13	0.20	0 20	0 68	0 76	0 76	0 47	0 53	0 53	2 93	2 95	2 95
		hospitalization	0 09	0 09	0 09	1 05	1 05	1 05	0 73	0 74	0 74	0 12	0 12	0 12	0 00	0 00	0 00	0 00	0 01	0 01	0 03	0 03	0 03	0 02	0 02	0 02	0 12	0 12	0 12
		headaches	1.22	1.23	1.23	14 44	14 54	14 54	10 08	10 14	10 14	1 66	1 67	1 67	0 03	0 03	0 03	0 07	0 11	0 11	0 37	0 42	0 42	0 26	0 29	0 29	1 60	1 61	1 61
NOx	NO2	sore throat	1.25	1.26	1.26	14 53	14 67	14 67	8 85	8 91	8 91	1 68	1 69	1 69	0.56	0 56	0 56	1 51	1 55	1 55	10 42	10 47	10 47	7.23	7.26	7.26	1 94	1 95	1 95
		excess phlegm	0 56	0 56	0 56	6 51	6 57	6 57	3 96	3 99	3 99	0 75	0 76	0 76	0.25	0.25	0.25	0 68	0 70	0 70	4 67	4 69	4 69	3.24	3.25	3.25	0 87	0 88	0 88
		eye irritation	0.51	0 51	0 51	5 92	5 98	5 98	3 60	3 63	3.63	0 68	0 69	0 69	0.23	0.23	0.23	0 62	0 63	0 63	4.25	4.27	4.27	2 94	2 96	2 96	0 79	0.80	0.80
NOx, NH3	nitrate PM10	mortality	34 16	34 41	34 41	395 97	399 54	399 54	238 86	240 63	240 63	45 95	46 30	46 30	15 41	15 47	15 47	41.25	42 35	42 35	280 15	281 43	281 43	194 36	195.27	195 27	52 96	53 35	53 35
		chronic illness	12 68	12 77	12 77	146.24	147 61	147 61	87 38	88 06	88 06	17 03	17 17	17 17	5 72	5 74	5 74	15.25	15 67	15 67	102 19	102 68	102.68	70 93	71.28	71 28	19 59	19 74	19 74
		asthma attacks	0 01	0.01	0 01	0 17	0 17	0 17	0 10	0 10	0 10	0 02	0 02	0 02	0 01	0 01	0 01	0 02	0 02	0 02	0 12	0 12	0 12	0 08	0 08	0 08	0 02	0 02	0 02
		RRAD	0 79	0.80	0.80	9.21	9.30	9 30	5 54	5 59	5 59	1.07	1 08	1.08	0 36	0 36	0 36	0 96	0 99	0 99	6 51	6 54	6 54	4 51	4 54	4 54	1 23	1.24	1 24
Total for NOxand NH3emissions			49 96	50.33	50.33	578.55	583.85	583 85	348 29	350 92	350 92	67 18	67 71	67.71	22 53	22 63	22 63	60.28	61 90	61 90	408 30	410 20	410.20	283 30	284 64	284 64	77 41	77 98	77 98
PM2.5	PM2.5	mortality	5.23	6 18	31 52	86 02	98 66	381 57	100 71	108 79	308.21	8 19	9 53	43 43	68 75	69.20	88.89	165 58	172.31	418 24	521 19	533 01	1,067 19	375 68	383 92	755 10	25 63	27 30	77 12
		chronic illness	1 94	2 31	11 59	31 78	36 68	140 20	36.87	40 01	112.96	3 03	3 55	15 97	25 50	25 67	32.88	61 17	63 79	153 74	189 79	194 42	390 16	136 97	140 20	276 23	9 39	10 04	28.33
		asthma attacks	0 00	0 00	0 01	0 04	0 04	0 17	0 04	0 05	0 13	0 00	0 00	0 02	0 03	0 03	0 04	0 07	0 07	0 18	0 23	0 23	0 46	0 16	0 17	0 33	0 01	0 01	0 03
		RRAD	0 12	0 15	0 75	2 00	2 32	9 06	2 33	2 54	7 29	0 19	0 22	1 03	1 59	1 61	2 07	3 85	4 02	9 88	12 11	12 40	25 11	8 72	8 93	17 76	0 59	0 64	1 82
		lung cancer	0 16	0 16	0 16	2 78	2 78	2 78	3 30	3 30	3 30	0 26	0 26	0 26	1 06	1 06	1 06	2 60	2 60	2 60	8 37	8 37	8 37	6 02	6 02	6.02	0 53	0 53	0 53
Coarse PM10	coarse PM10	mortality	0 35	0 41	7 06	4 69	5 44	79 68	5 21	5 67	57 99	0 51	0 59	9 50	0 87	0 89	6 06	2 07	2 45	66 97	5 42	6 06	146 42	3 96	4 41	101 95	0 67	0 77	13 88
		chronic illness	0 13	0 15	2 59	1 73	2 02	29 18	1 91	2 09	21 22	0 19	0 22	3 48	0 32	0 33	2 22	0 76	0 91	24 51	1 97	2 22	53.56	1 44	1 62	37 30	0 25	0 29	5 08
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 03	0 00	0 00	0 03	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 03	0 00	0 00	0 06	0 00	0 00	0 04	0 00	0 00	0 01
		RRAD	0 01	0 01	0 17	0 11	0 13	1 90	0 12	0 13	1 38	0 01	0 01	0 23	0 02	0 02	0 14	0 05	0 06	1 60	0 13	0 14	3 49	0 09	0 10	2 43	0 02	0 02	0 33
Total for direct PM10emissions			7 95	9 38	53.85	129 15	148 07	644.56	150 50	162 59	512.52	12.38	14.39	73 92	98 15	98.82	133.38	236.14	246 20	677 74	739 20	756 85	1,694.84	533.06	545 37	1,197 16	37 10	39 60	127 15
SOx, NH3	sulfate PM10	mortality	2.91	4 49	4 49	35.28	57.29	57.29	22 72	33 99	33 99	3 98	6.21	6.21	16.36	16 99	16 99	45.38	55 38	55 38	118 35	130 00	130 00	85 71	93 97	93 97	7.86	10.37	10 37
		chronic illness	1 08	1 68	1 68	13 00	21 48	21 48	8.29	12 62	12 62	1 47	2 33	2 33	6 06	6 30	6 30	16 72	20 56	20 56	42.85	47.32	47 32	31.08	34.25	34.25	2.88	3.84	3 84
		asthma attacks	0 00	0 00	0 00	0 02	0 03	0 03	0 01	0 02	0.02	0 00	0 00	0 00	0 01	0 01	0 01	0 02	0 02	0 02	0 05	0 06	0 06	0 04	0 04	0 04	0 00	0 00	0 00
		RRAD	0 07	0 11	0 11	0.82	1 40	1 40	0 53	0.82	0.82	0 09	0 15	0 15	0 38	0 40	0 40	1 05	1 32	1 32	2 75	3 05	3 05	1 99	2.21	2.21	0 18	0 25	0 25
Total for SOxand NH3emissions			4.06	6.28	6.28	49 12	80.19	80 19	31.54	47 45	47 45	5.54	8 69	8 69	22.80	23 69	23 69	63 17	77.29	77.29	164.00	180 44	180 44	118.81	130 46	130 46	10 92	14 47	14 47
VOCs	organic PM10 (SOA)	mortality	2.02	2.61	2 61	25.57	33.86	33.86	26 42	30 63	30 63	2.86	3 70	3 70	0 34	0.50	0 50	1 10	3 44	3.44	9 72	13 08	13 08	6 68	9 04	9 04	3 04	3 95	3 95
		chronic illness	0 75	0 98	0 98	9 48	12 67	12 67	9 74	11 35	11.35	1 06	1 39	1 39	0 13	0 19	0 19	0 41	1 29	1.29	3 56	4.83	4.83	2 44	3 34	3 34	1 13	1 48	1 48
		asthma attacks	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0.01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 05	0 06	0 06	0 59	0 79	0 79	0 61	0 71	0 71	0 07	0 09	0 09	0 01	0 01	0 01	0 03	0 08	0 08	0 23	0 31	0 31	0 15	0 21	0 21	0 07	0 09	0 09
	acetaldehyde	oral cancer	0 01	0 01	0 01	0 12	0 12	0 12	0 08	0 08	0 08	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 00	0 00	0 00	0 01	0 01	0 01
	benzene	leukemia	0 08	0 08	0 08	1 10	1 10	1 10	0 73	0 73	0 73	0 12	0 12	0 12	0 01	0 01	0 01	0 04	0 19	0 19	0 10	0 10	0 10	0 07	0 08	0 08	0 12	0 12	0 12
	1,3-butadiene	cancer all sites	0.29	0.29	0.29	3.75	3 75	3.75	2 49	2 49	2 49	0 40	0 40	0 40	0 02	0 02	0 02	0 08	0 33	0 33	0 18	0 18	0 18	0 13	0 14	0 14	0 39	0 39	0.39
	fomaldehyde	oral cancer	0 00	0 00	0 00	0 05	0 05	0 05	0 03	0 03	0 03	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0 00	0 00	0 00
Sub-total for VOC emissions			3.20	4 04	4 04	40 67	52.35	52.35	40 11	46 04	46 04	4 53	5 72	5 72	0.52	0 73	0.73	1 66	5 35	5.35	13.80	18 52	18.52	9 49	12.82	12.82	4.77	6 05	6 05
VOCs, NOx	O3	asthma attacks	0 10	0 11	0 11	1 29	1 38	1 38	0.81	0 92	0 92	0 14	0 15	0 15	0 03	0 03	0 03	0 07	0 10	0 10	0 46	0 49	0 49	0.32	0 34	0 34	0 15	0 16	0 16
		lower resp illness	0 20	0 21	0.21	2 41	2 58	2 58	1 51	1 72	1 72	0.27	0.29	0.29	0 05	0 05	0 05	0 14	0 19	0 19	0 85	0 91	0 91	0 59	0 63	0 63	0 28	0 30	0 30
		upper resp illness	0 06	0 06	0 06	0 73	0 78	0 78	0 46	0 52	0 52	0 08	0 09	0 09	0 02	0 02	0 02	0 04	0 06	0 06	0.26	0.28	0.28	0 18	0 19	0 19	0 09	0 09	0 09
		eye irritation	0 09	0 10	0 10	1 17	1.25	1.25	0 74	0 84	0 84	0 13	0 14	0 14	0 02	0 03	0 03	0 07	0 09	0 09	0 41	0 44	0 44	0.29	0.31	0.31	0 14	0 14	0 14
Subtotal mortality effects			46 92	50 37	82 35	573.99	621 43	978 58	412 43	438 32	690 06	64 53	69 40	112.21	101 78	103 11	127 97	255 50	276 12	586 58	935 51	964 34	1 638.89	666.86	687 13	1,155 85	93 10	98 69	161 63
Subtotal cancer effects			0 55	0 55	0 55	7 79	7 79	7 79	6 63	6 63	6 63	0.80	0.80	0.80	1 10	1 10	1 10	2 72	3 14	3 14	8 66	8 66	8 66	6.23	6.24	6.24	1.06	1 06	1 06
Subtotal chronic morbidity effects			16 57	17 90	29 61	202.24	220 46	351 14	144 18	154 14	246.22	22 78	24 65	40 33	37 72	38.23	47 33	94 31	102.22	215 77	340 35	351 48	598 56	242.86	250 69	422 39	33 24	35 39	58 48
Subtotal acute morbidity effects			5 13	5.28	6 05	61 01	63 00	71.67	40 05	41 38	47 49	6 97	7 18	8.21	3 59	3 64	4.24	9.25	10.02	17.56	43.83	44.84	61.20	30.83	31 54	42 91	8 10	8 33	9.85
Subtotal ambient PM10			62 47	67 32	111 79	765 50	832.22	1,328 72	550 71	587 13	937 07	85 98	92 82	152 35	142 92	144 79	179 35	358 33	387.33	818 86	1,305 67	1,346 28	2,284.27	931 04	959 59	1,611 38	126 07	133 94	221 49
Subtotal ambient O3			0 45	0 48	0 48	5 59	5 99	5 99	3 52	3 99	3 99	0 62	0 66	0 66	0 12	0 12	0 12	0 33	0 44	0 44	1 98	2 11	2 11	1.38	1 47	1 47	0 66	0 70	0 70
Subtotal ambient NO2			2 31	2 33	2 33	26 97	27 22	27 22	16 41	16 54	16 54	3 12	3 14	3 14	1 04	1 05	1 05	2 80	2 88	2 88	19 34	19 43	19 43	13 41	13 47	13 47	3 60	3 63	3 63
Subtotal ambient CO			3 56	3 58	3 58	41 95	42 24	42.24	29 33	29 47	29 47	4.83	4.86	4.86	0 07	0 08	0 08	0.20	0 32	0 32	1 07	1.20	1 20	0 75	0.84	0.84	4 64	4 67	4 67
Total all emissions, pollutants, effects			69 18	74 09	118 56	845 03	912 68	1,409 18	603 30	640 47	990 40	95 09	102 03	161 55	144 19	146.08	180 64	361.78	391.51	823 04	1,328 35	1,369 32	2,307.31	946 78	975 60	1,627 39	135 49	143 47	231 02

TABLE 11-A 49. COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $/1000 VMT (NEW YORK MSA 1990) (LOWER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	0 45	0 45	0 45	0 82	0 82	0 82	2 30	2 30	2 30	0 53	0 53	0 53	0 01	0 01	0 01	0 01	0 01	0 01	0 09	0 09	0 09	0 07	0 07	0 07	0 50	0 50	0 50
		hospitalization	0 07	0 07	0 07	0 13	0 13	0 13	0 36	0 36	0 36	0 08	0 08	0 08	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 08	0 08	0 08
		headaches	0 42	0 42	0 42	0 77	0 77	0 77	2 14	2 14	2 14	0 49	0 49	0 49	0 01	0 01	0 01	0 01	0 01	0 01	0 08	0 09	0 09	0 06	0 06	0 06	0 46	0 46	0 46
NOx	NO2	sore throat	0 51	0 51	0 51	0 93	0 94	0 94	1 93	1 94	1 94	0 59	0 59	0 59	0 30	0 30	0 30	0 13	0 13	0 13	2 38	2 39	2 39	1 76	1 76	1 76	0 66	0 66	0 66
		excess phlegm	0 22	0 23	0 23	0 41	0 41	0 41	0 85	0 85	0 85	0 26	0 26	0 26	0 13	0 13	0 13	0 06	0 06	0 06	1 04	1 05	1 05	0 77	0 77	0 77	0 29	0 29	0 29
		eye irritation	0 21	0 21	0 21	0 38	0 38	0 38	0 78	0 78	0 78	0 24	0 24	0 24	0 12	0 12	0 12	0 05	0 05	0 05	0 96	0 96	0 96	0 71	0 71	0 71	0 27	0 27	0 27
NOx, NH3	nitrate PM10	mortality	4 18	4 20	4 20	7 60	7 64	7 64	15 66	15 73	15 73	4 82	4 84	4 84	2 42	2 43	2 43	1 03	1 05	1 05	19 25	19 34	19 34	14 22	14 28	14 28	5 39	5 42	5 42
		chronic illness	0 81	0 81	0 81	1 46	1 47	1 47	2 99	3 01	3 01	0 93	0 94	0 94	0 47	0 47	0 47	0 20	0 20	0 20	3 66	3 68	3 68	2 71	2 72	2 72	1 04	1 05	1 05
		asthma attacks	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 00	0 00	0 00
		RRAD	0 21	0 21	0 21	0 38	0 38	0 38	0 77	0 78	0 78	0 24	0 24	0 24	0 12	0 12	0 12	0 05	0 05	0 05	0 95	0 96	0 96	0 70	0 71	0 71	0 27	0 27	0 27
Total for NOxand NH3emissions			6 14	6 16	6 16	11 16	11 22	11 22	22 99	23 10	23 10	7 08	7 11	7 11	3 56	3 57	3 57	1 51	1 54	1 54	28 26	28 38	28 38	20 88	20 97	20 97	7 92	7 96	7 96
PM2.5	PM2 5	mortality	0 80	0 83	0 91	2 06	2 13	2 27	6 54	6 66	7 07	1 05	1 09	1 18	10 34	10 35	10 42	3 95	3 98	4 11	34 12	34 26	35 36	26 61	26 72	27 52	2 61	2 65	2 79
		chronic illness	0 16	0 16	0 18	0 40	0 42	0 44	1 27	1 30	1 37	0 21	0 21	0 23	2 04	2 04	2 05	0 78	0 78	0 81	6 58	6 61	6 81	5 14	5 16	5 31	0 51	0 52	0 54
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 02	0 02	0 02	0 02	0 02	0 02	0 00	0 00	0 00
		RRAD	0 04	0 04	0 05	0 10	0 10	0 11	0 32	0 33	0 35	0 05	0 05	0 06	0 51	0 51	0 51	0 20	0 20	0 20	1 69	1 69	1 75	1 31	1 32	1 36	0 13	0 13	0 14
		lung cancer	0 01	0 01	0 01	0 03	0 03	0 03	0 11	0 11	0 11	0 02	0 02	0 02	0 11	0 11	0 11	0 04	0 04	0 04	0 38	0 38	0 38	0 30	0 30	0 30	0 03	0 03	0 03
Coarse PM10	coarse PM10	mortality	0 26	0 27	0 66	0 55	0 57	1 26	1 69	1 73	3 67	0 32	0 33	0 78	0 66	0 66	0 97	0 25	0 26	0 86	1 77	1 82	7 04	1 41	1 45	5 26	0 38	0 40	1 05
		chronic illness	0 05	0 05	0 13	0 11	0 11	0 24	0 33	0 34	0 70	0 06	0 06	0 15	0 13	0 13	0 19	0 05	0 05	0 16	0 34	0 35	1 32	0 27	0 28	0 99	0 08	0 08	0 20
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 01	0 01	0 03	0 03	0 03	0 06	0 08	0 09	0 18	0 02	0 02	0 04	0 03	0 03	0 05	0 01	0 01	0 04	0 09	0 09	0 35	0 07	0 07	0 26	0 02	0 02	0 05
Total for direct PM10emissions			1 34	1 38	1 97	3 28	3 39	4 43	10 35	10 55	13 46	1 73	1 78	2 46	13 84	13 86	14 31	5 28	5 33	6 23	44 99	45 24	53 05	35 14	35 32	41 03	3 76	3 83	4 81
SOx, NH3	sulfate PM10	mortality	1 41	1 79	1 79	2 70	3 57	3 57	4 73	6 41	6 41	1 64	2 12	2 12	7 91	8 11	8 11	3 48	3 97	3 97	24 76	26 98	26 98	19 45	21 11	21 11	2 73	3 27	3 27
		chronic illness	0 28	0 36	0 36	0 53	0 71	0 71	0 92	1 27	1 27	0 32	0 42	0 42	1 56	1 60	1 60	0 68	0 79	0 79	4 77	5 24	5 24	3 76	4 10	4 10	0 53	0 65	0 65
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 02	0 02	0 02	0 01	0 01	0 01	0 00	0 00	0 00
		RRAD	0 07	0 09	0 09	0 13	0 18	0 18	0 23	0 32	0 32	0 08	0 10	0 10	0 39	0 40	0 40	0 17	0 20	0 20	1 22	1 33	1 33	0 96	1 04	1 04	0 13	0 16	0 16
Total for SOxand NH3emissions			1 76	2 24	2 24	3 36	4 46	4 46	5 89	8 01	8 01	2 05	2 64	2 64	9 87	10 12	10 12	4 34	4 96	4 96	30 77	33 57	33 57	24 18	26 27	26 27	3 40	4 09	4 09
VOCs	organic PM10 (SOA)	mortality	0 35	0 59	0 59	0 70	1 21	1 21	2 29	3 37	3 37	0 42	0 71	0 71	0 07	0 17	0 17	0 04	0 26	0 26	0 86	2 12	2 12	0 63	1 56	1 56	0 43	0 76	0 76
		chronic illness	0 07	0 12	0 12	0 14	0 24	0 24	0 45	0 66	0 66	0 08	0 14	0 14	0 01	0 03	0 03	0 01	0 05	0 05	0 17	0 42	0 42	0 12	0 31	0 31	0 09	0 15	0 15
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 02	0 03	0 03	0 03	0 06	0 06	0 11	0 17	0 17	0 02	0 04	0 04	0 00	0 01	0 01	0 00	0 01	0 01	0 04	0 10	0 10	0 03	0 08	0 08	0 02	0 04	0 04
	acetaldehyde	oral cancer	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
	benzene	leukemia	0 01	0 01	0 01	0 01	0 01	0 01	0 03	0 03	0 03	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01
	1,3-butadiene	cancer all sites	0 02	0 02	0 02	0 04	0 04	0 04	0 11	0 11	0 11	0 03	0 03	0 03	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 01	0 01	0 03	0 03	0 03
	fomaldehyde	oral cancer	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
Sub-total for VOC emissions			0 46	0 76	0 76	0 93	1 57	1 57	3 00	4 35	4 35	0 56	0 92	0 92	0 09	0 21	0 21	0 05	0 33	0 33	1 08	2 66	2 66	0 79	1 96	1 96	0 57	0 99	0 99
VOCs, NOx	O3	asthma attacks	0 01	0 02	0 02	0 03	0 03	0 03	0 06	0 07	0 07	0 02	0 02	0 02	0 00	0 01	0 01	0 00	0 00	0 00	0 03	0 04	0 04	0 03	0 03	0 03	0 02	0 02	0 02
		lower resp illness	0 05	0 06	0 06	0 10	0 12	0 12	0 23	0 27	0 27	0 06	0 07	0 07	0 02	0 02	0 02	0 01	0 01	0 01	0 14	0 16	0 16	0 10	0 12	0 12	0 06	0 07	0 07
		upper resp illness	0 02	0 02	0 02	0 03	0 04	0 04	0 07	0 08	0 08	0 02	0 02	0 02	0 01	0 01	0 01	0 00	0 00	0 00	0 04	0 05	0 05	0 03	0 04	0 04	0 02	0 02	0 02
		eye irritation	0 06	0 06	0 06	0 11	0 12	0 12	0 25	0 28	0 28	0 06	0 07	0 07	0 02	0 02	0 02	0 01	0 01	0 01	0 14	0 17	0 17	0 11	0 12	0 12	0 07	0 08	0 08
Subtotal mortality effects			7 45	8 13	8 60	14 43	15 94	16 78	33 22	36 20	38 56	8 78	9 61	10 16	21 42	21 74	22 11	8 75	9 52	10 25	80 85	84 62	90 94	62 39	65 19	69 81	12 05	13 00	13 80
Subtotal cancer effects			0 04	0 04	0 04	0 09	0 09	0 09	0 26	0 26	0 26	0 05	0 05	0 05	0 12	0 12	0 12	0 05	0 05	0 05	0 39	0 39	0 39	0 31	0 31	0 31	0 07	0 07	0 07
Subtotal chronic morbidity effects			1 37	1 51	1 59	2 64	2 95	3 11	5 96	6 57	7 01	1 61	1 78	1 88	4 22	4 28	4 35	1 71	1 87	2 01	15 52	16 29	17 47	12 00	12 58	13 43	2 24	2 44	2 59
Subtotal acute morbidity effects			1 92	1 98	2 00	3 56	3 69	3 73	8 22	8 48	8 60	2 23	2 30	2 33	1 68	1 71	1 73	0 70	0 76	0 79	8 88	9 15	9 47	6 69	6 89	7 13	2 51	2 58	2 62
Subtotal ambient PM10			8 72	9 58	10 17	16 96	18 86	19 90	38 53	42 28	45 19	10 29	11 33	12 01	26 81	27 21	27 67	10 94	11 91	12 81	100 71	105 44	113 25	77 74	81 26	86 97	14 40	15 60	16 59
Subtotal ambient O3			0 14	0 16	0 16	0 26	0 31	0 31	0 61	0 70	0 70	0 16	0 18	0 18	0 05	0 05	0 05	0 02	0 04	0 04	0 35	0 41	0 41	0 26	0 31	0 31	0 17	0 19	0 19
Subtotal ambient NO2			0 94	0 95	0 95	1 72	1 73	1 73	3 56	3 58	3 58	1 09	1 09	1 09	0 55	0 55	0 55	0 23	0 24	0 24	4 38	4 40	4 40	3 24	3 25	3 25	1 22	1 22	1 22
Subtotal ambient CO			0 94	0 94	0 94	1 72	1 72	1 72	4 80	4 80	4 80	1 10	1 10	1 10	0 03	0 03	0 03	0 01	0 01	0 01	0 19	0 19	0 19	0 14	0 14	0 14	1 04	1 04	1 04
Total all emissions, pollutants, effects			10 78	11 66	12 24	20 73	22 68	23 71	47 65	51 51	54 42	12 67	13 75	14 43	27 44	27 85	28 30	11 21	12 20	13 11	105 65	110 46	118 27	81 39	84 97	90 68	16 86	18 09	19 08

TABLE 11-A 50. COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $/1000 VMT (NEW YORK MSA 1990) (UPPER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	5 18	5 18	5 18	9 45	9 45	9 45	29 23	29 23	29 23	6 07	6 07	6 07	0 14	0 14	0 14	0 06	0 06	0 06	1 17	1 17	1 17	0 86	0 86	0 86	5 75	5 75	5 75
		hospitalization	0 20	0 20	0 20	0 37	0 37	0 37	1 16	1 16	1 16	0 24	0 24	0 24	0 01	0 01	0 01	0 00	0 00	0 00	0 05	0 05	0 05	0 03	0 03	0 03	0 23	0 23	0 23
		headaches	2 35	2 35	2 35	4 29	4 29	4 29	13 18	13 18	13 18	2 75	2 75	2 75	0 06	0 06	0 06	0 03	0 03	0 03	0 52	0 53	0 53	0 39	0 39	0 39	2 61	2 61	2 61
NOx	NO2	sore throat	2 73	2 74	2 74	4 97	4 99	4 99	11 53	11 56	11 56	3 16	3 17	3 17	1 36	1 36	1 36	0 58	0 59	0 59	14 15	14 19	14 19	10 35	10 38	10 38	3 59	3 60	3 60
		excess phlegm	1 20	1 20	1 20	2 18	2 19	2 19	5 06	5 08	5 08	1 39	1 39	1 39	0 60	0 60	0 60	0 25	0 26	0 26	6 22	6 24	6 24	4 55	4 56	4 56	1 58	1 58	1 58
		eye irritation	1 10	1 10	1 10	2 00	2 01	2 01	4 64	4 66	4 66	1 27	1 28	1 28	0 55	0 55	0 55	0 23	0 24	0 24	5 70	5 72	5 72	4 17	4 18	4 18	1 45	1 45	1 45
NOx, NH3	nitrate PM10	mortality	84 09	84 33	84 33	152 67	153 24	153 24	353 59	354 62	354 62	97 26	97 56	97 56	41 88	41 97	41 97	17 73	18 00	18 00	432 63	433 86	433 86	316 53	317 43	317 43	110 58	110 91	110 91
		chronic illness	24 80	24 87	24 87	44 82	44 99	44 99	102 80	103 11	103 11	28 65	28 74	28 74	12 35	12 38	12 38	5 22	5 29	5 29	125 52	125 88	125 88	91 88	92 15	92 15	32 51	32 61	32 61
		asthma attacks	0 02	0 02	0 02	0 04	0 04	0 04	0 09	0 09	0 09	0 03	0 03	0 03	0 01	0 01	0 01	0 00	0 00	0 00	0 11	0 11	0 11	0 08	0 08	0 08	0 03	0 03	0 03
		RRAD	1 36	1 37	1 37	2 48	2 49	2 49	5 74	5 76	5 76	1 58	1 58	1 58	0 68	0 68	0 68	0 29	0 29	0 29	7 03	7 05	7 05	5 14	5 16	5 16	1 79	1 80	1 80
Total for NOxand NH3emissions			115 30	115 63	115 63	209 18	209 95	209 95	483 46	484 87	484 87	133 33	133 74	133 74	57 43	57 56	57 56	24 31	24 67	24 67	591 36	593 04	593 04	432 70	433 95	433 95	151 53	151 99	151 99
PM2.5	PM2 5	mortality	14 51	14 76	51 91	37 01	37 66	103 36	155 14	156 26	340 57	19 31	19 63	62 58	186 50	186 60	215 47	71 15	71 42	128 52	805 58	806 96	1,300 86	614 68	615 71	976 49	55 61	55 97	118 21
		chronic illness	4 28	4 36	15 23	10 88	11 08	30 29	45 07	45 42	99 28	5 69	5 79	18 35	55 06	55 09	63 52	20 92	21 00	37 69	232 44	232 86	377 42	177 66	177 97	283 57	16 18	16 29	34 53
		asthma attacks	0 00	0 00	0 01	0 01	0 01	0 03	0 04	0 04	0 09	0 01	0 01	0 02	0 05	0 05	0 06	0 02	0 02	0 03	0 21	0 21	0 34	0 16	0 16	0 26	0 01	0 01	0 03
		RRAD	0 24	0 24	0 85	0 60	0 61	1 68	2 51	2 53	5 54	0 31	0 32	1 02	3 03	3 03	3 50	1 15	1 16	2 09	13 05	13 08	21 13	9 96	9 98	15 86	0 90	0 91	1 92
		lung cancer	0 24	0 24	0 24	0 61	0 61	0 61	2 57	2 57	2 57	0 31	0 31	0 31	1 68	1 68	1 68	0 64	0 64	0 64	7 30	7 30	7 30	5 57	5 57	5 57	0 63	0 63	0 63
Coarse PM10	coarse PM10	mortality	0 93	0 94	9 89	1 98	2 02	17 83	8 02	8 09	52 45	1 16	1 18	11 52	2 37	2 38	9 32	0 89	0 91	14 65	8 38	8 47	127 49	6 49	6 56	93 51	1 48	1 51	16 52
		chronic illness	0 27	0 28	2 89	0 58	0 59	5 21	2 33	2 35	15 30	0 34	0 35	3 37	0 70	0 70	2 73	0 26	0 27	4 28	2 42	2 45	37 19	1 88	1 90	27 28	0 43	0 44	4 83
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 03	0 00	0 00	0 02	0 00	0 00	0 00
		RRAD	0 02	0 02	0 16	0 03	0 03	0 29	0 13	0 13	0 86	0 02	0 02	0 19	0 04	0 04	0 15	0 01	0 01	0 24	0 14	0 14	2 08	0 11	0 11	1 53	0 02	0 02	0 27
Total for direct PM10emissions			20 48	20 84	81 18	51 69	52 60	159 30	215 83	217 40	516 67	27 15	27 60	97 36	249 42	249 56	296 43	95 05	95 42	188 15	1,069 52	1,071 47	1,873 84	816 51	817 95	1,404 09	75 27	75 79	176 95
SOx, NH3	sulfate PM10	mortality	13 21	15 71	15 71	25 26	30 94	30 94	58 32	69 18	69 18	15 51	18 59	18 59	74 20	75 48	75 48	32 58	35 76	35 76	303 71	318 11	318 11	233 05	243 80	243 80	28 77	32 32	32 32
		chronic illness	3 90	4 69	4 69	7 43	9 22	9 22	16 95	20 38	20 38	4 57	5 55	5 55	21 91	22 31	22 31	9 58	10 58	10 58	87 53	92 05	92 05	67 29	70 67	70 67	8 40	9 52	9 52
		asthma attacks	0 00	0 00	0 00	0 01	0 01	0 01	0 02	0 02	0 02	0 00	0 00	0 00	0 02	0 02	0 02	0 01	0 01	0 01	0 08	0 08	0 08	0 06	0 06	0 06	0 01	0 01	0 01
		RRAD	0 21	0 26	0 26	0 41	0 50	0 50	0 94	1 13	1 13	0 25	0 30	0 30	1 20	1 23	1 23	0 53	0 58	0 58	4 92	5 16	5 16	3 78	3 96	3 96	0 47	0 53	0 53
Total for SOxand NH3emissions			17 32	20 66	20 66	33 11	40 67	40 67	76 23	90 71	90 71	20 34	24 44	24 44	97 33	99 04	99 04	42 70	46 93	46 93	396 24	415 41	415 41	304 18	318 48	318 48	37 65	42 37	42 37
VOCs	organic PM10 (SOA)	mortality	4 67	6 63	6 63	9 41	13 57	13 57	40 66	49 40	49 40	5 74	8 11	8 11	0 95	1 72	1 72	0 48	2 26	2 26	15 24	25 47	25 47	11 03	18 59	18 59	6 06	8 75	8 75
		chronic illness	1 38	1 97	1 97	2 78	4 02	4 02	11 91	14 53	14 53	1 70	2 40	2 40	0 28	0 51	0 51	0 14	0 67	0 67	4 43	7 48	7 48	3 21	5 46	5 46	1 79	2 59	2 99
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 08	0 11	0 11	0 15	0 22	0 22	0 66	0 80	0 80	0 09	0 13	0 13	0 02	0 03	0 03	0 01	0 04	0 04	0 25	0 41	0 41	0 18	0 30	0 30	0 10	0 14	0 14
	acetaldehyde	oral cancer	0 01	0 01	0 01	0 03	0 03	0 03	0 07	0 07	0 07	0 02	0 02	0 02	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 02	0 02	0 02
	benzene	leukemia	0 12	0 12	0 12	0 24	0 24	0 24	0 67	0 67	0 67	0 14	0 14	0 14	0 02	0 02	0 02	0 01	0 05	0 05	0 09	0 09	0 09	0 07	0 07	0 07	0 14	0 14	0 14
	1,3-butadiene	cancer all sites	0 40	0 40	0 40	0 82	0 82	0 82	2 29	2 29	2 29	0 49	0 49	0 49	0 04	0 04	0 04	0 02	0 09	0 09	0 17	0 17	0 17	0 13	0 13	0 13	0 46	0 46	0 46
	fomaldehyde	oral cancer	0 00	0 00	0 00	0 01	0 01	0 01	0 03	0 03	0 03	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01
Sub-total for VOC emissions			6 67	9 25	9 25	13 44	18 91	18 91	56 30	67 80	67 80	8 18	11 30	11 30	1 30	2 33	2 33	0 66	3 11	3 11	20 19	33 63	33 63	14 62	24 57	24 57	8 58	12 11	12 11
VOCs, NOx	O3	asthma attacks	0 24	0 26	0 26	0 46	0 50	0 50	1 19	1 27	1 27	0 28	0 31	0 31	0 07	0 08	0 08	0 03	0 04	0 04	0 68	0 73	0 73	0 50	0 54	0 54	0 30	0 32	0 32
		lower resp illness	0 45	0 49	0 49	0 87	0 94	0 94	2 22	2 38	2 38	0 53	0 58	0 58	0 13	0 14	0 14	0 06	0 08	0 08	1 27	1 37	1 37	0 93	1 01	1 01	0 56	0 60	0 60
		upper resp illness	0 14	0 15	0 15	0 26	0 29	0 29	0 67	0 72	0 72	0 16	0 17	0 17	0 04	0 04	0 04	0 02	0 03	0 03	0 39	0 42	0 42	0 28	0 31	0 31	0 17	0 18	0 18
		eye irritation	0 34	0 37	0 37	0 66	0 72	0 72	1 70	1 82	1 82	0 40	0 43	0 43	0 10	0 11	0 11	0 04	0 06	0 06	0 96	1 05	1 05	0 71	0 77	0 77	0 42	0 45	0 45
Subtotal mortality effects			122 59	127 56	173 65	235 78	246 87	328 39	644 97	666 78	895 44	145 05	151 13	204 42	306 04	308 30	344 11	122 90	128 41	199 26	1,566 71	1 594 04	2,206 95	1,182 65	1,202 96	1,650 68	208 25	215 20	292 46
Subtotal cancer effects			0 78	0 78	0 78	1 70	1 70	1 70	5 63	5 63	5 63	0 97	0 97	0 97	1 74	1 74	1 74	0 67	0 78	0 78	7 56	7 56	7 56	5 77	5 78	5 78	1 26	1 26	1 26
Subtotal chronic morbidity effects			34 64	36 17	49 64	66 49	69 90	93 72	179 07	185 79	252 60	40 95	42 83	58 41	90 30	90 99	101 46	36 12	37 81	58 51	452 33	460 72	640 01	341 91	348 15	479 13	59 31	61 45	84 08
Subtotal acute morbidity effects			10 69	10 87	11 64	19 81	20 23	21 58	51 49	52 34	56 13	12 47	12 70	13 59	7 96	8 04	8 63	3 27	3 45	4 62	55 73	56 54	66 71	41 38	41 99	49 41	14 23	14 48	15 76
Subtotal ambient PM10			154 22	160 80	221 13	297 16	311 85	418 54	807 52	836 42	1,135 69	182 54	190 60	260 35	402 91	405 91	452 78	161 63	168 92	261 64	2,050 97	2,087 14	2,889 51	1,548 74	1,575 62	2,161 75	265 79	274 99	376 15
Subtotal ambient O3			1 17	1 26	1 26	2 26	2 45	2 45	5 77	6 19	6 19	1 38	1 49	1 49	0 35	0 37	0 37	0 15	0 22	0 22	3 29	3 57	3 57	2 42	2 63	2 63	1 44	1 55	1 55
Subtotal ambient NO2			5 03	5 04	5 04	9 16	9 20	9 20	21 24	21 30	21 30	5 82	5 83	5 83	2 51	2 51	2 51	1 06	1 08	1 08	26 07	26 15	26 15	19 07	19 13	19 13	6 62	6 64	6 64
Subtotal ambient CO			7 74	7 74	7 74	14 11	14 11	14 11	43 56	43 57	43 57	9 06	9 06	9 06	0 21	0 21	0 21	0 09	0 09	0 09	1 74	1 74	1 74	1 28	1 28	1 28	8 58	8 59	8 99
Total all emissions, pollutants, effects			168 69	175 37	235 71	323 78	338 70	445 40	881 15	910 54	1,209 81	199 44	207 63	277 38	406 03	409 07	455 94	162 96	170 45	263 17	2,082 33	2,118 86	2,921 23	1,571 71	1,598 87	2,185 00	283 05	292 39	393 55

TABLE 11-A.51 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $/1000 VMT (PHILADELPHIA MSA 1990) (LOWER BOUI

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	0 27	0 28	0.28	0 39	0 39	0 39	1.23	1.24	1.24	0 31	0 31	0 31	0 01	0 01	0 01	0 00	0 00	0 00	0 05	0 06	0 06	0 04	0 04	0 04	0 29	0 29	0 29
		hospitalization	0 04	0 04	0 04	0 06	0 06	0 06	0 19	0 20	0 20	0 05	0 05	0 05	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 05	0 05	0 05
		headaches	0.25	0.25	0.25	0 35	0 36	0 36	1 13	1 14	1 14	0.28	0.28	0.28	0 01	0 01	0 01	0.00	0.00	0 00	0.05	0 05	0 05	0 04	0 04	0.04	0.26	0 27	0 27
NOx	NO2	sore throat	0 39	0 41	0 41	0 56	0 59	0 59	1 35	1 40	1 40	0 44	0.45	0 45	0.23	0.23	0.23	0.08	0 08	0 08	1 74	1 77	1 77	1 30	1 33	1.33	0 49	0 51	0 51
		excess phlegm	0 17	0 18	0 18	0.25	0.26	0.26	0 60	0 62	0 62	0 19	0 20	0.20	0 10	0 10	0 10	0 03	0 04	0 04	0 77	0 78	0 78	0 57	0 59	0 59	0.22	0.22	0 22
		eye irritation	0 16	0 16	0 16	0.23	0.24	0.24	0.55	0.57	0.57	0 18	0 18	0 18	0 09	0 09	0 09	0.03	0.03	0.03	0 70	0 72	0 72	0.53	0 54	0.54	0.20	0.21	0.21
NOx, NH3	nitrate PM10	mortality	3 06	3 16	3 16	4 38	4 55	4 55	10 53	10 92	10 92	3 40	3 51	3 51	1 76	1 78	1 78	0 59	0 63	0 63	13 57	13.82	13.82	10 16	10 35	10 35	3 84	3 96	3 96
		chronic illness	0 64	0 66	0 66	0 91	0 94	0 94	2 17	2.25	2.25	0 71	0 73	0 73	0 37	0 37	0 37	0 12	0 13	0 13	2 79	2 84	2.84	2 09	2 12	2 12	0 80	0 82	0.82
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 00	0 00	0 00
		RRAD	0 15	0 15	0 15	0 21	0.22	0.22	0 51	0 53	0 53	0 17	0 17	0 17	0 09	0 09	0 09	0 03	0 03	0 03	0 66	0 67	0 67	0 50	0 51	0 51	0 19	0 19	0 19
Total for NOx and NH3 emissions			4 58	4 73	4 73	6 55	6.80	6.80	15 72	16.29	16.29	5 07	5.25	5.25	2 63	2.67	2 67	0.87	0 95	0 95	20.24	20 61	20 61	15 15	15 43	15 43	5 74	5 92	5 92
PM2.5	PM2 5	mortality	0 58	0 92	1 00	1 17	1 76	1.87	4 44	5 78	6 13	0 74	1 13	1.22	7 51	7 63	7 69	2.27	2 50	2 60	24 48	25 95	26.87	19.21	20 32	21 00	1 96	2 40	2 53
		chronic illness	0 12	0 19	0.21	0.24	0 37	0 39	0 91	1 19	1.26	0 15	0.24	0.25	1 55	1 58	1 59	0 47	0.52	0 53	4 97	5.27	5 46	3 91	4 13	4.27	0 40	0 49	0 52
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 02	0 02	0 02	0 01	0 01	0 01	0 00	0 00	0 00
		RRAD	0 03	0 04	0 05	0 06	0 09	0 09	0.22	0.28	0 30	0 04	0 06	0 06	0 37	0 37	0 38	0 11	0 12	0 13	1.20	1.27	1 32	0 94	0 99	1 03	0 10	0 12	0 12
		lung cancer	0.01	0 01	0 01	0 02	0 02	0 02	0.08	0.08	0.08	0.01	0 01	0 01	0 09	0 09	0 09	0 03	0.03	0 03	0.28	0.28	0.28	0.22	0.22	0.22	0 03	0 03	0.03
Coarse PM10	coarse PM10	mortality	0 19	0.23	0 62	0.32	0.38	0 91	1 15	1.32	2 99	0.22	0.27	0 70	0 48	0.50	0.80	0 14	0 17	0 63	1.27	1 53	6 02	1 02	1.21	4 54	0.27	0 33	0 96
		chronic illness	0 04	0 05	0 13	0 06	0 08	0 19	0.23	0.27	0 61	0 05	0 06	0 14	0 10	0 10	0 16	0 03	0 04	0 13	0 26	0 31	1.23	0 21	0 25	0 93	0 06	0 07	0.20
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 01	0 01	0 03	0 02	0 02	0 04	0 06	0 06	0 15	0 01	0 01	0 03	0 02	0 02	0 04	0 01	0 01	0 03	0 06	0 08	0.29	0 05	0 06	0.22	0 01	0 02	0 05
Total for direct PM10 emissions			0 98	1 45	2 05	1.89	2 72	3.52	7 08	9 00	11.52	1.22	1 78	2 43	10 12	10.29	10 75	3 05	3.38	4 08	32 54	34 71	41 49	25 57	27 19	32.24	2.83	3 46	4 40
SOx, NH3	sulfate PM10	mortality	1 02	4 14	4 14	1 54	6 78	6 78	3.21	15 15	15 15	1 15	4 77	4 77	5 74	7 00	7 00	1 99	4 35	4 35	17.84	29 68	29 68	14 08	23 09	23 09	2 00	5 98	5 98
		chronic illness	0 21	0.86	0.86	0 32	1 41	1 41	0 66	3 15	3 15	0 24	0 99	0 99	1 19	1 45	1 45	0 41	0 90	0 90	3 62	6 09	6 09	2 86	4 74	4 74	0 41	1 24	1 24
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 02	0 02	0 01	0 02	0 02	0 00	0 00	0 00
		RRAD	0 05	0 20	0 20	0 08	0 33	0 33	0 16	0 74	0 74	0 06	0 23	0 23	0 28	0 34	0 34	0 10	0 21	0 21	0 87	1 45	1 45	0 69	1 13	1 13	0 10	0 29	0 29
Total for SOx and NH3 emissions			1 28	5 20	5 20	1 94	8 53	8 53	4 03	19 05	19 05	1 44	6 00	6 00	7 21	8 79	8 79	2 50	5 47	5 47	22 34	37 24	37 24	17 64	28 97	28 97	2 51	7 52	7 52
VOCs	organic PM10 (SOA)	mortality	0.26	0 46	0 46	0 41	0 76	0 76	1 56	2 31	2 31	0 31	0 54	0.54	0 05	0 12	0 12	0 02	0 15	0 15	0 61	1 43	1 43	0 45	1 07	1 07	0 32	0 58	0 58
		chronic illness	0 05	0 10	0 10	0 09	0 16	0 16	0 32	0 47	0 47	0 06	0 11	0 11	0 01	0 03	0 03	0 00	0 03	0 03	0 12	0 30	0 30	0 09	0 22	0.22	0 07	0 12	0 12
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 01	0 02	0 02	0 02	0 04	0 04	0 08	0 11	0 11	0 01	0 03	0 03	0 00	0 01	0 01	0 00	0 01	0 01	0 03	0 07	0 07	0 02	0 05	0 05	0 02	0 03	0 03
	acetaldehyde	oral cancer	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
	benzene	leukemia	0 01	0 01	0 01	0 01	0 01	0 01	0 02	0 02	0 02	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01
	1,3-butadiene	cancer all sites	0 02	0 02	0 02	0 03	0 03	0 03	0 08	0 08	0 08	0 02	0 02	0 02	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 01	0 01	0 02	0 02	0 02
	fomaldehyde	oral cancer	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
Sub-total for VOC emissions			0 36	0 61	0 61	0 56	1 00	1 00	2.07	3 01	3 01	0 41	0.71	0 71	0 07	0 16	0 16	0 03	0 19	0 19	0 77	1.81	1.81	0 57	1 35	1 35	0 42	0.75	0.75
VOCs, NOx	O3	asthma attacks	0 01	0 02	0 02	0 02	0 02	0 02	0 05	0 07	0 07	0 02	0.02	0 02	0 01	0 01	0 01	0 00	0 00	0 00	0 04	0 04	0.04	0 03	0 03	0 03	0 02	0 02	0 02
		lower resp illness	0 05	0 06	0 06	0 08	0 10	0 10	0.21	0.28	0.28	0 06	0 07	0 07	0 02	0 02	0 02	0 01	0 01	0 01	0 14	0 17	0 17	0 11	0 13	0 13	0 06	0 08	0 08
		upper resp illness	0 02	0 02	0 02	0 02	0 03	0 03	0 06	0 09	0 09	0 02	0 02	0 02	0 01	0 01	0 01	0 00	0 00	0 00	0 04	0 05	0 05	0 03	0 04	0 04	0 02	0 02	0 02
		eye irritation	0 06	0 07	0 07	0 09	0 11	0 11	0.24	0.32	0.32	0.07	0 08	0 08	0 02	0 03	0 03	0 01	0.01	0 01	0 16	0 19	0 19	0 12	0 14	0 14	0 07	0 08	0 08
Subtotal mortality effects			5 39	9 19	9 66	8.22	14 63	15.27	22 12	36 73	38 74	6 12	10 53	11 06	15 55	17 04	17 40	5 01	7.82	8 37	57.82	72 48	77.88	44 95	56 07	60 10	8 69	13 55	14 30
Subtotal cancer effects			0 04	0 04	0 04	0 06	0 06	0 06	0 19	0 19	0 19	0.04	0 04	0 04	0 09	0 09	0 09	0 03	0 03	0 03	0.29	0.29	0.29	0.23	0 23	0 23	0 05	0 05	0 05
Subtotal chronic morbidity effects			1 06	1.85	1 95	1 62	2 95	3 09	4 28	7 33	7 74	1.20	2 12	2.23	3.21	3 52	3 60	1 03	1 62	1 73	11 76	14 80	15 91	9 15	11 46	12.28	1 73	2 74	2 90
Subtotal acute morbidity effects			1 42	1.66	1 68	2 06	2 46	2 49	5 43	6 44	6 54	1 58	1.86	1.89	1.25	1 34	1.36	0 41	0 58	0 60	6 52	7 38	7 65	4 96	5 62	5.82	1.81	2 11	2 14
Subtotal ambient PM10			6 45	11.21	11.81	9 86	17 92	18 72	26.29	44 65	47 18	7 32	12.87	13 52	19 61	21 48	21 94	6.31	9.84	10 53	72 67	91.09	97.87	56 52	70 49	75 53	10 57	16 68	17 63
Subtotal ambient O3			0 14	0 17	0 17	0 22	0 26	0.26	0 57	0 76	0 76	0 16	0 19	0 19	0 05	0 06	0 06	0 02	0 03	0 03	0 38	0 46	0 46	0 29	0 34	0 34	0 17	0 20	0.20
Subtotal ambient NO2			0 73	0 75	0 75	1 04	1 08	1 08	2 49	2 59	2 59	0 81	0 83	0 83	0 42	0 42	0 42	0 14	0 15	0 15	3.21	3 27	3.27	2 40	2 45	2 45	0 91	0 94	0 94
Subtotal ambient CO			0 57	0 57	0 57	0.80	0.81	0.81	2.56	2.57	2.57	0 63	0 64	0 64	0.02	0 02	0 02	0 01	0 01	0 01	0 11	0 12	0 12	0 08	0 09	0 09	0 60	0 60	0 60
Total all emissions, pollutants, effects			7.91	12 73	13 32	11 96	20 11	20 91	32.03	50 68	53.21	8 95	14 56	15.21	20 10	21 99	22 45	6 48	10.04	10 73	76.38	94 95	101 73	59 30	73 38	78 43	12.28	18 45	19 40

TABLE 11-A 52 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $/1000 VMT (PHILADELPHIA MSA 1990) (UPPER BOUN

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	3 38	3 40	3 40	4 78	4 80	4 80	17 80	17 85	17 85	3 80	3 81	3 81	0 09	0 09	0 09	0 03	0 04	0 04	0 73	0 77	0 77	0 54	0 58	0 58	3 59	3 60	3 60
		hospitalization	0 13	0 13	0 13	0 19	0 19	0 19	0 70	0 71	0 71	0 15	0 15	0 15	0 00	0 00	0 00	0 00	0 00	0 00	0 03	0 03	0 03	0 02	0 02	0 02	0 14	0 14	0 14
		headaches	1 50	1 50	1 50	2 12	2 13	2 13	7 90	7 93	7 93	1 68	1 69	1 69	0 04	0 04	0 04	0 01	0 02	0 02	0 32	0 34	0 34	0 24	0 26	0 26	1 59	1 60	1 60
NOx	NO2	sore throat	2 07	2 10	2 10	2 95	3 01	3 01	8 37	8 51	8 51	2 30	2 34	2 34	1 02	1 03	1 03	0 34	0 36	0 36	10 73	10 83	10 83	7 95	8 03	8 03	2 67	2 71	2 71
		excess phlegm	0 91	0 93	0 93	1 30	1 33	1 33	3 69	3 76	3 76	1 02	1 04	1 04	0 45	0 45	0 45	0 15	0 16	0 16	4 74	4 78	4 78	3 51	3 54	3 54	1 18	1 20	1 20
		eye irritation	0 84	0 85	0 85	1 19	1 21	1 21	3 38	3 44	3 44	0 93	0 95	0 95	0 41	0 42	0 42	0 14	0 14	0 14	4 33	4 37	4 37	3 21	3 24	3 24	1 08	1 10	1 10
NOx, NH3	nitrate PM10	mortality	65 75	66 93	66 93	93 45	95 42	95 42	265 06	269 60	269 60	73 14	74 51	74 51	32 38	32 69	32 69	10 71	11 31	11 31	339 48	342 48	342 48	251 64	253 92	253 92	84 91	86 34	86 34
		chronic illness	21 65	22 04	22 04	30 72	31 37	31 37	86 95	88 45	88 45	24 09	24 54	24 54	10 65	10 75	10 75	3 52	3 71	3 71	111 30	112 28	112 28	82 51	83 25	83 25	27 96	28 43	28 43
		asthma attacks	0 02	0 02	0 02	0 02	0 03	0 03	0 07	0 07	0 07	0 02	0 02	0 02	0 01	0 01	0 01	0 00	0 00	0 00	0 09	0 09	0 09	0 07	0 07	0 07	0 02	0 02	0 02
		RRAD	1 08	1 10	1 10	1 54	1 57	1 57	4 38	4 46	4 46	1 20	1 22	1 22	0 53	0 54	0 54	0 18	0 19	0 19	5 62	5 67	5 67	4 17	4 21	4 21	1 40	1 42	1 42
Total for NOxand NH3emissions			92.31	93 97	93 97	131 17	133.94	133 94	371 91	378.29	378.29	102 70	104.62	104 62	45 46	45.89	45.89	15 03	15.87	15.87	476 29	480 50	480.50	353.06	356.26	356 26	119 22	121 22	121 22
PM2.5	PM2 5	mortality	11 30	13 95	48 63	22.55	27.00	73 67	118 06	128 72	276.08	14 57	17 66	55.80	145 41	146 39	173 34	43 54	45 41	85 97	641 49	652 78	1 047 59	492 70	501.21	794 84	46.21	49 65	104 61
		chronic illness	3 71	4 60	15 99	7 38	8.89	24.20	38 57	42 16	90 49	4 78	5.82	18 34	47 70	48 03	56.86	14.26	14.88	28 18	209 21	212 98	342 66	160.76	163 59	260 05	15 10	16.26	34 34
		asthma attacks	0 00	0 00	0 01	0 01	0.01	0 02	0 03	0 03	0 07	0 00	0 00	0 01	0 04	0 04	0 05	0 01	0 01	0 02	0 17	0 17	0 28	0 13	0 13	0 21	0 01	0 01	0 03
		RRAD	0 19	0 23	0 81	0 37	0 45	1 22	1 95	2 13	4 58	0 24	0 29	0 93	2 38	2 40	2 85	0 72	0 75	1 42	10 63	10 83	17 39	8 16	8 31	13 19	0 76	0 82	1 71
		lung cancer	0 20	0 20	0 20	0 39	0 39	0 39	2 08	2 08	2 08	0 25	0 25	0 25	1 19	1 19	1 19	0 36	0 36	0 36	5 35	5 35	5 35	4 11	4 11	4 11	0 51	0 51	0 51
Coarse PM10	coarse PM10	mortality	0 72	0 78	9 12	1 20	1 30	12 52	6 10	6 37	41 77	0 87	0 94	10 11	1 84	1 87	8 34	0 54	0 59	10 34	6 67	7 06	102 05	5 19	5 48	76 13	1 16	1 24	14 48
		chronic illness	0 24	0 26	2 99	0 39	0 43	4 10	1 99	2 08	13 69	0 29	0 31	3 32	0 60	0 61	2 74	0 18	0 19	3 39	2 18	2 30	33 46	1 69	1 79	24 96	0 38	0 41	4 75
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 03	0 00	0 00	0 02	0 00	0 00	0 00
		RRAD	0 01	0 01	0 15	0 02	0 02	0 21	0 10	0 11	0 70	0 01	0 02	0 17	0 03	0 03	0 14	0 01	0 01	0 17	0 11	0 12	1 70	0 09	0 09	1 27	0 02	0 02	0 24
Total for direct PM10emissions			16.36	20 03	77 90	32.32	38 49	116.34	168 88	183 68	429 48	21 02	25.29	88 93	199 20	200 56	245 52	59 61	62.21	129 86	875 82	891 59	1,550 52	672.84	684 71	1,174 78	64 15	68 92	160 70
SOx, NH3	sulfate PM10	mortality	10.27	27.80	27.80	15 36	44 71	44 71	44.24	111 49	111 49	11 61	31 96	31 96	57 64	64 70	64 70	19.84	33 14	33.14	241 58	308 33	308 33	186 42	237 17	237 17	23 17	45 53	45 53
		chronic illness	3 37	9 36	9 36	5 03	15 05	15 05	14 45	37 41	37 41	3 81	10 76	10 76	18 91	21 31	21 31	6 50	11 03	11.03	78 73	101 51	101.51	60 78	78 10	78 10	7 58	15 22	15 22
		asthma attacks	0 00	0 01	0 01	0 00	0 01	0 01	0 01	0 03	0 03	0 00	0 01	0 01	0 02	0 02	0 02	0 01	0 01	0 01	0 06	0 08	0 08	0 05	0 06	0 06	0 01	0 01	0 01
		RRAD	0 17	0 47	0 47	0 25	0 76	0 76	0 73	1 89	1 89	0 19	0 54	0 54	0 94	1 07	1 07	0 33	0 56	0 56	4 01	5 16	5 16	3 09	3 97	3 97	0 38	0 77	0 77
Total for SOxand NH3emissions			13.81	37 64	37 64	20 64	60.53	60 53	59 44	150.82	150.82	15 61	43.27	43.27	77 51	87 10	87 10	26 67	44.73	44 73	324 39	415 08	415 08	250 34	319 29	319 29	31 14	61 52	61 52
VOCs	organic PM10 (SOA)	mortality	3.88	5 35	5.35	6 04	8 64	8 64	31 80	37 32	37 32	4 58	6.31	6 31	0 76	1 27	1 27	0 30	1 23	1.23	12 12	18.28	18.28	8 91	13 54	13 54	4 87	6 79	6 79
		chronic illness	1 27	1 76	1 76	1 98	2 84	2 84	10 42	12 23	12.23	1 50	2 07	2 07	0 25	0 42	0 42	0 10	0 41	0 41	3 96	6 00	6 00	2 91	4 44	4 44	1 60	2 23	2 23
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 06	0 09	0 09	0 10	0 14	0 14	0 52	0 61	0 61	0 07	0 10	0 10	0 01	0 02	0 02	0 00	0 02	0 02	0 20	0 30	0 30	0 15	0 22	0 22	0 08	0 11	0 11
	acetaldehyde	oral cancer	0 01	0 01	0 01	0 02	0 02	0 02	0 06	0 06	0 06	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01
	benzene	leukemia	0 10	0 10	0 10	0 16	0 16	0 16	0 53	0 53	0 53	0 12	0 12	0 12	0 02	0 02	0 02	0 01	0 03	0 03	0 06	0 06	0 06	0 05	0 05	0 05	0 11	0 11	0 11
	1,3-butadiene	cancer all sites	0 34	0 34	0 34	0 53	0 53	0 53	1 81	1 81	1 81	0 39	0 39	0 39	0 03	0 03	0 03	0 01	0 05	0 05	0 13	0 13	0 13	0 10	0 11	0 11	0 37	0 37	0 37
	fomaldehyde	oral cancer	0 00	0 00	0 00	0 01	0 01	0 01	0 02	0 02	0 02	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
Sub-total for VOC emissions			5 67	7 65	7 65	8.84	12.33	12.33	45.16	52 59	52 59	6 68	9.02	9.02	1.07	1.76	1.76	0 42	1 74	1.74	16 49	24 79	24 79	12 12	18 37	18 37	7.04	9 63	9 63
VOCs, NOx	O3	asthma attacks	0 24	0 26	0 26	0 36	0 40	0 40	1 13	1 28	1 28	0 28	0 30	0 30	0 07	0 08	0 08	0 03	0 04	0 04	0 72	0 78	0 78	0 54	0 58	0 58	0 29	0 32	0 32
		lower resp illness	0 46	0 49	0 49	0 68	0 74	0 74	2 12	2 40	2 40	0 52	0 56	0 56	0 14	0 15	0 15	0 05	0 07	0 07	1 35	1 45	1 45	1 00	1 08	1 08	0 55	0 59	0 59
		upper resp illness	0 14	0 15	0 15	0 21	0 23	0 23	0 65	0 73	0 73	0 16	0 17	0 17	0 04	0 05	0 05	0 01	0 02	0 02	0 41	0 44	0 44	0 31	0 33	0 33	0 17	0 18	0 18
		eye irritation	0 37	0 40	0 40	0 56	0 61	0 61	1 74	1 97	1 97	0 42	0 45	0 45	0 11	0 12	0 12	0 04	0 05	0 05	1 10	1 19	1 19	0 82	0 88	0 88	0 44	0 47	0 47
Subtotal mortality effects			95 30	118 21	161.23	143 37	181.87	239 75	483 07	571 35	754 11	108 57	135.20	182.50	238 13	247 02	280 44	74 96	91 71	142 02	1,242 07	1,329 69	1,819 50	945 41	1 011.89	1,376 17	163 90	193 14	261 34
Subtotal cancer effects			0 65	0 65	0 65	1 11	1 11	1 11	4 50	4 50	4 50	0 78	0 78	0 78	1 24	1 24	1 24	0 38	0 44	0 44	5 56	5 56	5 56	4 27	4 27	4 27	1 01	1 01	1 01
Subtotal chronic morbidity effects			30 24	38 02	52 14	45 51	58 58	77 57	152 39	182 34	242 28	34 46	43 50	59 04	78 11	81 12	92 09	24 55	30 23	46 72	405 37	435 06	595 90	308 65	331 17	450 80	52 61	62 55	84 97
Subtotal acute morbidity effects			8 19	8 75	9 48	11.88	12.83	13.81	37.50	40 05	43 14	9.20	9.85	10 65	6.26	6 46	7 03	2 02	2 40	3 25	44 66	46 65	54 92	33.52	35 03	41 18	10.80	11 51	12 66
Subtotal ambient PM10			123 88	154 95	212.82	186 82	239 04	316 88	627 54	747 25	993 05	141.23	177 35	240 99	321 31	333 36	378 31	101 09	123.81	191 46	1 672 98	1,791 78	2,450 70	1 273 53	1 363 66	1,853 72	216 11	255 79	347 56
Subtotal ambient O3			1.21	1 30	1.30	1.81	1 97	1 97	5 64	6 38	6 38	1 37	1 48	1 48	0.37	0 40	0 40	0 13	0 18	0 18	3 59	3.86	3.86	2 67	2.87	2.87	1 45	1 57	1 57
Subtotal ambient NO2			3.82	3.88	3.88	5 44	5 55	5 55	15 44	15 71	15 71	4 25	4 32	4 32	1 88	1 90	1 90	0 62	0 66	0 66	19.80	19 98	19.98	14 68	14 81	14 81	4 93	5 01	5 01
Subtotal ambient CO			5 02	5 03	5 03	7 09	7 12	7 12	26 41	26 48	26 48	5 64	5 66	5 66	0 13	0 14	0 14	0 04	0 06	0 06	1.08	1 14	1 14	0.81	0.85	0.85	5.32	5.34	5 34
Total all emissions, pollutants, effects			134 37	165 62	223 49	201.86	254.38	332.23	677 45	798 24	1,044 03	153.00	189.33	252 97	323 74	335 84	380.80	101 90	124 78	192 43	1,697 66	1,816 96	2,475.89	1,291 84	1,382.36	1,872.42	228 31	268 21	359 98

TABLE 11-A 53 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $/1000 VMT (PHOENIX MSA 1990) (LOWER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	0 44	0 44	0 44	0 26	0 26	0 26	1 58	1 58	1 58	0 39	0 39	0 39	0 02	0 02	0 02	0 00	0 00	0 00	0 06	0 06	0 06	0 05	0 05	0 05	0 36	0 36	0 36
		hospitalization	0 07	0 07	0 07	0 04	0 04	0 04	0 25	0 25	0 25	0 06	0 06	0 06	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 06	0 06	0 06
		headaches	0 45	0 45	0 45	0 26	0 26	0 26	1 59	1 59	1 59	0 40	0 40	0 40	0 02	0 02	0 02	0 00	0 00	0 00	0 06	0 06	0 06	0 05	0 05	0 05	0 37	0 37	0 37
NOx	NO2	sore throat	0 45	0 45	0 45	0 28	0 28	0 28	0 84	0 84	0 84	0 39	0 39	0 39	0 30	0 30	0 30	0 04	0 04	0 04	1 20	1 20	1 20	0 95	0 95	0 95	0 44	0 44	0 44
		excess phlegm	0 20	0 20	0 20	0 12	0 12	0 12	0 37	0 37	0 37	0 17	0 17	0 17	0 13	0 13	0 13	0 02	0 02	0 02	0 53	0 53	0 53	0 42	0 42	0 42	0 19	0 19	0 19
		eye irritation	0 18	0 18	0 18	0 11	0 11	0 11	0 34	0 34	0 34	0 16	0 16	0 16	0 12	0 12	0 12	0 02	0 02	0 02	0 48	0 48	0 48	0 38	0 38	0 38	0 18	0 18	0 18
NOx, NH3	nitrate PM10	mortality	4 27	4 27	4 27	2 63	2 63	2 63	7 92	7 92	7 92	3 73	3 73	3 73	2 83	2 83	2 83	0 40	0 40	0 40	11 39	11 39	11 39	9 01	9 01	9 01	4 19	4 19	4 19
		chronic illness	1 52	1 52	1 52	0 93	0 93	0 93	2 81	2 81	2 81	1 32	1 32	1 32	1 00	1 00	1 00	0 14	0 14	0 14	4 05	4 05	4 05	3 20	3 20	3 20	1 49	1 49	1 49
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 00	0 00	0 00
		RRAD	0 20	0 20	0 20	0 13	0 13	0 13	0 38	0 38	0 38	0 18	0 18	0 18	0 13	0 13	0 13	0 02	0 02	0 02	0 54	0 54	0 54	0 43	0 43	0 43	0 20	0 20	0 20
Total for NOx and NH3 emissions			6 82	6 82	6 82	4 20	4 20	4 20	12 66	12 66	12 66	5 95	5 95	5 95	4 51	4 51	4 51	0 64	0 65	0 65	18 20	18 20	18 20	14 40	14 40	14 40	6 70	6 70	6 70
PM2.5	PM2 5	mortality	0 89	0 89	1 04	0 77	0 77	0 86	3 54	3 55	3 90	0 88	0 89	1 02	11 49	11 49	11 60	1 49	1 49	1 57	19 58	19 59	20 53	16 28	16 28	17 02	2 24	2 25	2 43
		chronic illness	0 31	0 32	0 37	0 27	0 27	0 30	1 25	1 25	1 37	0 31	0 31	0 36	4 06	4 06	4 10	0 53	0 53	0 55	6 90	6 91	7 24	5 74	5 74	6 00	0 79	0 79	0 86
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 02	0 02	0 02	0 02	0 02	0 02	0 00	0 00	0 00
		RRAD	0 04	0 04	0 05	0 04	0 04	0 04	0 17	0 17	0 19	0 04	0 04	0 05	0 55	0 55	0 55	0 07	0 07	0 07	0 93	0 93	0 98	0 78	0 78	0 81	0 11	0 11	0 12
		lung cancer	0 01	0 01	0 01	0 01	0 01	0 01	0 04	0 04	0 04	0 01	0 01	0 01	0 08	0 08	0 08	0 01	0 01	0 01	0 14	0 14	0 14	0 11	0 11	0 11	0 02	0 02	0 02
Coarse PM10	coarse PM10	mortality	0 29	0 29	1 00	0 21	0 21	0 62	0 92	0 92	2 58	0 27	0 27	0 89	0 73	0 73	1 29	0 09	0 09	0 45	1 02	1 02	5 48	0 86	0 86	4 36	0 32	0 32	1 20
		chronic illness	0 10	0 10	0 35	0 07	0 07	0 22	0 32	0 32	0 91	0 09	0 09	0 31	0 26	0 26	0 45	0 03	0 03	0 16	0 36	0 36	1 93	0 30	0 30	1 54	0 11	0 11	0 42
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 01	0 01	0 05	0 01	0 01	0 03	0 04	0 04	0 12	0 01	0 01	0 04	0 03	0 03	0 06	0 00	0 00	0 02	0 05	0 05	0 26	0 04	0 04	0 21	0 02	0 02	0 06
Total for direct PM10 emissions			1 66	1 67	2 88	1 38	1 39	2 09	6 29	6 30	9 12	1 62	1 63	2 68	17 21	17 21	18 15	2 23	2 23	2 84	29 00	29 02	36 58	24 13	24 14	30 08	3 61	3 62	5 10
SOx, NH3	sulfate PM10	mortality	1 12	2 25	2 25	0 72	2 77	2 77	1 83	3 95	3 95	0 99	2 46	2 46	6 27	6 36	6 36	0 94	1 13	1 13	10 15	13 08	13 08	8 49	10 76	10 76	1 65	3 19	3 19
		chronic illness	0 40	0 76	0 76	0 26	0 92	0 92	0 65	1 34	1 34	0 35	0 83	0 83	2 22	2 25	2 25	0 33	0 39	0 39	3 58	4 54	4 54	2 99	3 73	3 73	0 58	1 09	1 09
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 00	0 00	0 00
		RRAD	0 05	0 11	0 11	0 03	0 13	0 13	0 09	0 19	0 19	0 05	0 12	0 12	0 30	0 30	0 30	0 04	0 05	0 05	0 48	0 63	0 63	0 41	0 52	0 52	0 08	0 15	0 15
Total for SOx and NH3 emissions			1 57	3 12	3 12	1 02	3 83	3 83	2 57	5 48	5 48	1 38	3 41	3 41	8 80	8 92	8 92	1 31	1 58	1 58	14 23	18 26	18 26	11 90	15 02	15 02	2 31	4 44	4 44
VOCs	organic PM10 (SOA)	mortality	0 40	0 61	0 61	0 26	0 41	0 41	1 48	1 92	1 92	0 37	0 56	0 56	0 08	0 15	0 15	0 01	0 06	0 06	0 50	0 89	0 89	0 39	0 70	0 70	0 37	0 57	0 57
		chronic illness	0 14	0 22	0 22	0 09	0 15	0 15	0 52	0 68	0 68	0 13	0 20	0 20	0 03	0 05	0 05	0 00	0 02	0 02	0 18	0 32	0 32	0 14	0 25	0 25	0 13	0 20	0 20
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 02	0 03	0 03	0 01	0 02	0 02	0 07	0 09	0 09	0 02	0 03	0 03	0 00	0 01	0 01	0 00	0 00	0 00	0 02	0 04	0 04	0 02	0 03	0 03	0 02	0 03	0 03
	acetaldehyde	oral cancer	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
	benzene	leukemia	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
	1,3-butadiene	cancer all sites	0 02	0 02	0 02	0 01	0 01	0 01	0 05	0 05	0 05	0 02	0 02	0 02	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01
	formaldehyde	oral cancer	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
Sub-total for VOC emissions			0 59	0 88	0 88	0 38	0 59	0 59	2 14	2 75	2 75	0 54	0 80	0 80	0 12	0 21	0 21	0 02	0 09	0 09	0 70	1 26	1 26	0 55	0 99	0 99	0 54	0 82	0 82
VOCs, NOx	O3	asthma attacks	0 02	0 02	0 02	0 01	0 01	0 01	0 04	0 04	0 04	0 02	0 02	0 02	0 01	0 01	0 01	0 00	0 00	0 00	0 02	0 03	0 03	0 02	0 02	0 02	0 02	0 02	0 02
		lower resp illness	0 07	0 07	0 07	0 04	0 05	0 05	0 16	0 17	0 17	0 06	0 06	0 06	0 03	0 03	0 03	0 00	0 01	0 01	0 10	0 10	0 10	0 08	0 08	0 08	0 06	0 07	0 07
		upper resp illness	0 02	0 02	0 02	0 01	0 01	0 01	0 05	0 05	0 05	0 02	0 02	0 02	0 01	0 01	0 01	0 00	0 00	0 00	0 03	0 03	0 03	0 02	0 03	0 03	0 02	0 02	0 02
		eye irritation	0 07	0 07	0 07	0 04	0 05	0 05	0 16	0 17	0 17	0 06	0 07	0 07	0 03	0 03	0 03	0 00	0 01	0 01	0 10	0 11	0 11	0 08	0 09	0 09	0 06	0 07	0 07
Subtotal mortality effects			7 41	8 75	9 62	4 85	7 06	7 56	17 27	19 83	21 85	6 63	8 30	9 05	21 42	21 57	22 25	2 94	3 19	3 62	42 69	46 03	51 43	35 08	37 66	41 90	9 14	10 89	11 95
Subtotal cancer effects			0 03	0 03	0 03	0 02	0 02	0 02	0 10	0 10	0 10	0 03	0 03	0 03	0 08	0 08	0 08	0 01	0 01	0 01	0 14	0 14	0 14	0 12	0 12	0 12	0 04	0 04	0 04
Subtotal chronic morbidity effects			2 47	2 91	3 22	1 63	2 35	2 53	5 56	6 41	7 11	2 21	2 76	3 03	7 57	7 62	7 86	1 04	1 12	1 27	15 06	16 16	18 06	12 38	13 23	14 72	3 11	3 69	4 06
Subtotal acute morbidity effects			1 85	1 94	1 98	1 15	1 27	1 29	4 55	4 71	4 81	1 64	1 73	1 77	1 68	1 69	1 73	0 23	0 25	0 27	4 61	4 80	5 06	3 71	3 86	4 06	1 82	1 92	1 97
Subtotal ambient PM10			9 79	11 64	12 86	6 45	9 49	10 19	22 05	25 59	28 41	8 76	11 06	12 11	30 09	30 30	31 25	4 13	4 47	5 08	59 91	64 52	72 08	49 23	52 80	58 73	12 33	14 75	16 23
Subtotal ambient O3			0 17	0 19	0 19	0 11	0 12	0 12	0 41	0 43	0 43	0 15	0 17	0 17	0 07	0 07	0 07	0 01	0 01	0 01	0 25	0 27	0 27	0 20	0 22	0 22	0 16	0 17	0 17
Subtotal ambient NO2			0 83	0 83	0 83	0 51	0 51	0 51	1 54	1 54	1 54	0 72	0 72	0 72	0 55	0 55	0 55	0 08	0 08	0 08	2 21	2 22	2 22	1 75	1 75	1 75	0 81	0 81	0 81
Subtotal ambient CO			0 96	0 96	0 96	0 57	0 57	0 57	3 42	3 42	3 42	0 85	0 85	0 85	0 04	0 04	0 04	0 01	0 01	0 01	0 13	0 13	0 13	0 10	0 10	0 10	0 79	0 79	0 79
Total all emissions, pollutants, effects			11 77	13 64	14 85	7 65	10 70	11 40	27 48	31 05	33 87	10 50	12 82	13 87	30 75	30 97	31 91	4 23	4 57	5 18	62 51	67 13	74 70	51 28	54 87	60 81	14 10	16 53	18 02

TABLE 11-A 54 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $/1000 VMT (PHOENIX MSA 1990) (UPPER BOUND)

	Ambient		LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
Emission	pollutant	Health effect	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	5 41	5 41	5 41	3 19	3 19	3 19	26 58	26 58	26 58	4 91	4 91	4 91	0.20	0.20	0.20	0 03	0 03	0 03	0 99	0 99	0 99	0 78	0 78	0 78	4 55	4 55	4 55
		hospitalization	0.21	0.21	0.21	0 13	0 13	0 13	1 05	1 05	1 05	0 19	0 19	0 19	0 01	0 01	0 01	0 00	0 00	0 00	0 04	0 04	0 04	0 03	0 03	0 03	0 18	0 18	0 18
		headaches	2.65	2.65	2 65	1 56	1.56	1 56	13 03	13 03	13 03	2 40	2 40	2.40	0 10	0 10	0 10	0 01	0.01	0 01	0 49	0 49	0 49	0 38	0 38	0 38	2.22	2.22	2.22
NOx	NO2	sore throat	2 40	2.40	2 40	1 48	1 48	1 48	6.22	6.22	6.22	2 12	2 12	2 12	1 37	1 37	1.37	0 19	0 19	0 19	8 93	8 93	8 93	6 96	6 96	6 96	2 54	2 54	2.54
		excess phlegm	1.05	1 05	1 05	0 65	0 65	0 65	2 73	2.73	2 73	0 93	0 93	0 93	0 60	0 60	0 60	0 09	0 09	0 09	3 92	3 92	3 92	3 06	3 06	3 06	1 12	1 12	1 12
		eye irritation	0 97	0 97	0 97	0 60	0 60	0 60	2 51	2.51	2.51	0.85	0.85	0.85	0 55	0.55	0.55	0.08	0.08	0 08	3 60	3 60	3 60	2.80	2.80	2.80	1 02	1 02	1 02
NOx, NH3	nitrate PM10	mortality	75.81	75.81	75.81	46 67	46 67	46 67	196 34	196.34	196 34	66 94	66 94	66 94	43 16	43 16	43 16	6 15	6 15	6 15	281 82	281 82	281.82	219 73	219 73	219 73	80 36	80 37	80 37
		chronic illness	50.27	50.27	50.27	30.87	30.87	30.87	129 71	129 71	129 71	44 39	44 39	44 39	28 61	28 61	28 61	4 07	4 07	4 07	186.21	186 21	186.21	145.20	145.20	145 20	53 29	53.29	53.29
		asthma attacks	0 04	0 04	0 04	0 02	0 02	0 02	0 09	0 09	0 09	0.03	0.03	0 03	0 02	0 02	0 02	0 00	0 00	0.00	0 14	0 14	0 14	0 11	0 11	0 11	0 04	0 04	0 04
		RRAD	1 58	1 58	1 58	0 97	0 97	0 97	4 10	4.10	4 10	1 40	1 40	1 40	0 90	0 90	0 90	0 13	0 13	0 13	5.88	5.88	5.88	4 59	4 59	4 59	1 68	1 68	1 68
Total for NOxand NH3emissions			132.12	132.12	132 12	81.26	81.26	81.26	341 70	341 71	341.71	116 66	116.66	116.66	75.21	75.21	75.21	10 71	10 71	10.71	490 49	490 50	490 50	382.44	382 44	382.44	140 05	140 06	140.06
PM2.5	PM2.5	mortality	14 71	14 72	69.88	12 68	12.69	44 68	95 00	95 01	223 09	15 11	15 12	62.90	189 83	189 83	232 72	24 56	24 57	52 38	521 51	521 53	864.32	419 55	419 56	688 59	50.81	50.82	117 96
		chronic illness	9 76	9 76	46 15	8 40	8 40	29 49	62.82	62.82	147 19	10 02	10 02	41 56	125 93	125 93	154 18	16.27	16.27	34 59	344 53	344 54	570 94	277.26	277.26	454 98	33 63	33 63	78 08
		asthma attacks	0 01	0 01	0 03	0 01	0 01	0 02	0 05	0 05	0 11	0 01	0 01	0 03	0 09	0 09	0 11	0.01	0 01	0 03	0 25	0.25	0 42	0.20	0.20	0 33	0 02	0 02	0 06
		RRAD	0 31	0 31	1 46	0 26	0 26	0 93	1 98	1 98	4 66	0 32	0 32	1 31	3 97	3 97	4 86	0 51	0 51	1 09	10 88	10 88	18 02	8 75	8 75	14 36	1 06	1 06	2 46
		lung cancer	0 18	0 18	0 18	0 15	0 15	0 15	1 14	1 14	1 14	0 18	0 18	0 18	0 96	0 96	0 96	0 12	0 12	0 12	2.66	2.66	2 66	2 14	2 14	2 14	0 35	0.35	0 35
Coarse PM10	coarse PM10	mortality	0 94	0 94	13 94	0 68	0 68	8.21	4 91	4 91	35.06	0 90	0 90	12 17	2 40	2 40	12 49	0 31	0.31	6.85	5 43	5 43	86 20	4 42	4 42	67 90	1.21	1.21	17 08
		chronic illness	0 62	0 62	9 18	0 45	0 45	5 41	3.25	3.25	23 09	0 60	0 60	8 02	1 59	1 59	8.23	0.20	0.20	4 51	3 58	3 58	56.83	2 91	2 91	44 71	0.80	0.80	11 26
		asthma attacks	0 00	0 00	0 01	0 00	0 00	0 00	0.00	0.00	0.02	0 00	0.00	0 01	0 00	0 00	0 01	0.00	0 00	0 00	0 00	0 00	0 04	0 00	0 00	0 03	0 00	0 00	0 01
		RRAD	0 02	0 02	0 29	0 01	0 01	0 17	0 10	0 10	0 73	0 02	0 02	0 25	0 05	0 05	0 26	0 01	0 01	0 14	0 11	0 11	1 80	0 09	0 09	1 42	0 03	0 03	0 36
Total for direct PM10emissions			26.54	26 55	141 11	22 64	22.65	89.07	169 25	169 27	435 09	27 15	27 17	126 43	324 81	324.81	413.83	42.00	42.00	99 72	888 95	888 98	1,601 32	715.33	715.35	1,274.45	87 91	87 92	227 61
SOx, NH3	sulfate PM10	mortality	7 99	8.29	8.29	5 16	5 70	5 70	21.23	21.80	21.80	7 15	7 55	7 55	44.82	44.85	44.85	6 67	6 73	6 73	116 84	117 62	117 62	94 40	95 00	95 00	14 86	15 27	15 27
		chronic illness	5 30	5.30	5 30	3 42	3 42	3 42	14 04	14 04	14 04	4 74	4 75	4 75	29 73	29 73	29 73	4 42	4 42	4 42	77 09	77 10	77 10	62 30	62.31	62 31	9 83	9 83	9 83
		asthma attacks	0 00	0 00	0 00	0.00	0 00	0 00	0 01	0.01	0 01	0 00	0 00	0 00	0 02	0 02	0 02	0 00	0.00	0 00	0 06	0 06	0.06	0 05	0 05	0 05	0.01	0 01	0 01
		RRAD	0 17	0 17	0 17	0 11	0 12	0 12	0 44	0 45	0 45	0 15	0 16	0 16	0 94	0 94	0 94	0 14	0 14	0 14	2 44	2 45	2 45	1 97	1 98	1 98	0 31	0 32	0 32
Total for SOxand NH3emissions			13 46	13 77	13.77	8 69	9.24	9.24	35 72	36 30	36.30	12.05	12.45	12.45	75.51	75.54	75.54	11.23	11.29	11.29	196.42	197 23	197.23	158 71	159.34	159 34	25.00	25 42	25 42
VOCs	organic PM10	mortality	5 02	5 94	5 94	3.23	3.88	3.88	30 07	31 98	31 98	4 73	5.57	5 57	1 03	1 31	1 31	0 18	0.39	0 39	10 03	11 77	11 77	7 76	9 14	9 14	5 00	5 88	5 88
	(SOA)	chronic illness	3 33	3 94	3 94	2 14	2 57	2.57	19 93	21 19	21 19	3 14	3 69	3 69	0 68	0.87	0.87	0 12	0.26	0.26	6 64	7 78	7 78	5 14	6 05	6 05	3 31	3 90	3 90
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 02	0.02	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 10	0 12	0 12	0 07	0 08	0 08	0 63	0 67	0 67	0 10	0 12	0 12	0 02	0 03	0 03	0 00	0 01	0 01	0.21	0.25	0.25	0 16	0 19	0 19	0 10	0 12	0 12
	acetaldehyde	oral cancer	0 01	0 01	0 01	0 01	0 01	0 01	0 04	0 04	0 04	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01
	benzene	leukemia	0 09	0 09	0 09	0 06	0 06	0 06	0 35	0 35	0.35	0 08	0 08	0 08	0 01	0 01	0 01	0 00	0 01	0 01	0 03	0 03	0 03	0 03	0 03	0 03	0 08	0 08	0 08
	1,3-butadiene	cancer all sites	0 30	0 30	0 30	0.20	0.20	0.20	1 17	1 17	1 17	0 28	0 28	0 28	0 03	0 03	0 03	0 01	0 02	0 02	0 07	0 07	0 07	0 06	0 06	0 06	0 26	0 26	0 26
	fomaldehyde	oral cancer	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
Sub-total for VOC emissions			8.87	10 41	10 41	5 70	6.80	6.80	52.22	55 42	55 42	8.34	9 75	9 75	1 78	2.25	2.25	0.30	0 69	0.69	17 00	19 91	19 91	13 16	15 48	15 48	8 76	10.25	10.25
VOCs, NOx	O3	asthma attacks	0 31	0 32	0 32	0 19	0 20	0 20	1 00	1 02	1 02	0 28	0 28	0 28	0 10	0 10	0 10	0 01	0 02	0 02	0 59	0 60	0 60	0 46	0 47	0 47	0 29	0 30	0 30
		lower resp illness	0 58	0 59	0 59	0 36	0 38	0 38	1 88	1 91	1 91	0 52	0 53	0 53	0 19	0 19	0 19	0 03	0 03	0 03	1 11	1 13	1 13	0 86	0 88	0 88	0 55	0 57	0 57
		upper resp illness	0 18	0 18	0 18	0 11	0 11	0 11	0 57	0 58	0 58	0 16	0 16	0 16	0 06	0 06	0 06	0 01	0 01	0 01	0 34	0 34	0 34	0 26	0 27	0 27	0 17	0 17	0 17
		eye irritation	0 43	0 44	0 44	0 27	0 28	0 28	1 41	1 44	1 44	0 38	0 39	0 39	0 14	0 14	0 14	0 02	0 02	0 02	0 83	0 85	0 85	0 65	0 66	0 66	0 40	0 41	0 41
Subtotal mortality effects			109 88	111 11	179.27	71 60	72.81	112.34	374 13	376 62	534.85	99 75	100 99	160 03	281 44	281 74	334 73	37 90	38 17	72 53	936 62	939 16	1,362.82	746 64	748.64	1,081 14	156 78	158 09	241 11
Subtotal cancer effects			0 58	0 58	0 58	0 41	0 41	0 41	2 71	2 71	2 71	0.55	0 55	0 55	1 00	1 00	1 00	0 13	0 16	0 16	2 77	2 77	2 77	2.23	2.23	2.23	0 70	0 70	0 70
Subtotal chronic morbidity effects			69.28	69 90	114.84	45.27	45 71	71 75	229 75	231 02	335.23	62.89	63 45	102 40	186 54	186 73	221 63	25.08	25.22	47.85	618 04	619 21	898.86	492.81	493 73	713 24	100 86	101 46	156 36
Subtotal acute morbidity effects			11 01	11 07	12 53	6.82	6.87	7.71	37.83	37 96	41 33	9.86	9 92	11 18	9 12	9 14	10.27	1 25	1 27	2 00	39.80	39 91	48 95	31.39	31 48	38.57	11 75	11.82	13.58
Subtotal ambient PM10			176 16	178 03	292 58	115.29	116 96	183 38	585 86	589 67	855 49	159 93	161 75	261 01	474 75	475 24	564 26	63.88	64 30	122 02	1,576 31	1,580 06	2,292 40	1,256 73	1,259 69	1,818 80	256 70	258 63	398 32
Subtotal ambient O3			1 49	1 53	1 53	0 94	0 97	0 97	4.87	4 94	4 94	1 34	1 37	1 37	0 48	0.50	0 50	0 07	0 08	0 08	2.86	2 92	2 92	2.24	2 28	2 28	1 42	1 45	1 45
Subtotal ambient NO2			4 42	4 42	4 42	2 72	2 72	2 72	11 46	11 46	11 46	3 90	3 90	3 90	2 52	2 52	2 52	0 36	0 36	0.36	16 44	16 44	16 44	12.82	12.82	12.82	4 68	4 68	4 68
Subtotal ambient CO			8.28	8.28	8.28	4.88	4.88	4.88	40 66	40 66	40 66	7 51	7.51	7 51	0 31	0.31	0.31	0 04	0 04	0.04	1.52	1 52	1 52	1 19	1.19	1 19	6.95	6 95	6 95
Total all emissions, pollutants, effects			190 76	192.66	307.22	124 10	125.80	192 22	644 42	648 31	914.12	173 05	174.91	274.17	478 10	478 61	567 63	64.36	64.81	122.53	1,597 24	1,601 05	2,313.39	1,273 07	1,276 08	1,835 19	270 10	272.06	411 75

TABLE 11-A 55 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH FFFECT, $/1000 VMT (ST LOUIS MSA 1990) (LOWER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	017	017	017	026	026	026	067	067	067	019	019	019	001	001	001	000	000	000	003	003	003	002	002	002	018	018	018
		hospitalization	003	003	003	004	004	004	011	011	011	003	003	003	000	000	000	000	000	000	000	000	000	000	000	000	003	003	003
		headaches	016	016	016	024	025	025	062	063	063	018	018	018	000	000	000	000	000	000	002	003	003	002	002	002	017	017	017
NOx	NO2	sore throat	024	026	026	037	041	041	069	077	077	027	029	029	014	014	014	005	006	006	087	091	091	068	072	072	030	033	033
		excess phlegm	011	012	012	017	018	018	031	034	034	012	013	013	006	006	006	002	003	003	039	041	041	031	032	032	013	015	015
		eye irritation	010	011	011	015	017	017	028	031	031	011	012	012	006	006	006	002	002	002	035	037	037	028	029	029	012	013	013
NOx, NH3	nitrate PM10	mortality	123	133	133	189	207	207	354	386	386	138	150	150	069	071	071	025	030	030	442	463	463	347	364	364	153	165	165
		chronic illness	021	023	023	033	036	036	062	068	068	024	026	026	012	012	012	004	005	005	077	081	081	060	063	063	027	029	029
		asthma attacks	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
		RRAD	006	006	006	009	010	010	017	018	018	007	007	007	003	003	003	001	001	001	021	022	022	017	017	017	007	008	008
Total for NOxand NH3emissions			195	211	211	300	329	329	562	615	615	218	237	237	109	113	113	039	047	047	701	736	736	551	578	578	243	263	263
PM2.5	PM2.5	mortality	024	034	041	052	074	084	156	188	213	031	044	051	310	313	318	100	106	115	854	889	955	703	731	782	081	094	105
		chronic illness	005	007	009	010	016	018	031	040	045	006	009	011	062	062	063	020	022	023	174	182	195	143	150	159	016	020	022
		asthma attacks	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	001	001	001	001	001	001	000	000	000
		RRAD	001	002	002	002	004	004	007	009	010	001	002	002	015	015	015	005	005	005	041	042	045	033	035	037	004	004	005
		lung cancer	001	001	001	001	001	001	005	005	005	001	001	001	006	006	006	002	002	002	015	015	015	013	013	013	002	002	002
Coarse PM10	coarse PM10	mortality	008	012	047	014	022	073	040	054	182	009	014	054	020	021	048	006	009	053	044	058	401	037	048	316	011	017	073
		chronic illness	002	003	009	003	005	015	008	012	036	002	003	011	004	004	010	001	002	010	009	013	078	008	010	061	002	004	014
		asthma attacks	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
		RRAD	000	001	002	001	001	003	002	003	009	000	001	003	001	001	002	000	000	003	002	003	019	002	002	015	001	001	004
Total for direct PM10emissions			041	059	111	084	124	198	249	311	500	051	074	132	417	422	463	134	147	212	1140	1204	1711	939	989	1384	117	142	225
SOx, NH3	sulfate PM10	mortality	032	334	334	053	645	645	087	1068	1068	037	401	401	183	294	294	068	304	304	486	1496	1496	402	1204	1204	064	460	460
		chronic illness	007	094	094	011	179	179	019	303	303	008	112	112	038	071	071	014	083	083	104	394	394	086	316	316	014	127	127
		asthma attacks	000	000	000	000	000	000	000	001	001	000	000	000	000	000	000	000	000	000	000	001	001	000	001	001	000	000	000
		RRAD	002	016	016	002	030	030	004	050	050	002	019	019	009	014	014	003	014	014	023	071	071	019	057	057	003	022	022
Total for SOxand NH3emissions			041	444	444	066	855	855	110	1422	1422	046	533	533	230	379	379	085	402	402	613	1962	1962	507	1577	1577	081	610	610
VOCs	organic PM10 (SOA)	mortality	011	018	018	018	035	035	053	077	077	012	022	022	002	004	004	001	005	005	020	048	048	016	037	037	013	023	023
		chronic illness	002	004	004	004	007	007	011	016	016	002	004	004	000	001	001	000	001	001	004	010	010	003	008	008	003	005	005
		asthma attacks	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
		RRAD	000	001	001	001	002	002	003	004	004	001	001	001	000	000	000	000	000	000	001	002	002	001	002	002	001	001	001
	acetaldehyde	oral cancer	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
	benzene	leukemia	000	000	000	001	001	001	001	001	001	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
	1,3-butadiene	cancer all sites	001	001	001	002	002	002	005	005	005	001	001	001	000	000	000	000	000	000	000	000	000	000	000	000	001	001	001
	fomaldehyde	oral cancer	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
Sub-total for VOC emissions			015	024	024	025	046	046	072	103	103	017	029	029	003	005	005	001	007	007	026	061	061	020	047	047	018	031	031
VOCs, NOx	O3	asthma attacks	001	001	001	001	002	002	003	004	004	001	001	001	000	000	000	000	000	000	002	002	002	001	002	002	001	001	001
		lower resp illness	003	003	003	005	006	006	010	014	014	003	004	004	001	001	001	000	001	001	006	008	008	005	006	006	003	004	004
		upper resp illness	001	001	001	001	002	002	003	004	004	001	001	001	000	000	000	000	000	000	002	002	002	002	002	002	001	001	001
		eye irritation	003	003	003	005	006	006	009	014	014	003	004	004	001	001	001	000	001	001	006	008	008	005	006	006	003	004	004
Subtotal mortality effects			215	549	590	352	1010	1070	757	1841	1993	247	650	696	584	704	736	200	455	507	1849	2957	3366	1507	2386	2704	340	778	845
Subtotal cancer effects			002	002	002	004	004	004	011	011	011	003	003	003	006	006	006	002	002	002	016	016	016	013	013	013	004	004	004
Subtotal chronic morbidity effects			037	131	139	061	243	255	130	438	467	042	156	165	116	151	158	040	113	123	368	679	757	300	547	608	061	185	197
Subtotal acute morbidity effects			080	101	104	125	167	170	260	335	343	090	116	119	056	063	065	020	035	037	269	334	354	214	266	281	099	127	131
Subtotal ambient PM10			245	689	741	403	1275	1350	859	2302	2491	281	817	875	733	894	934	251	591	656	2319	3792	4299	1891	3058	3453	400	983	1066
Subtotal ambient O3			007	009	009	012	015	015	024	035	035	008	010	010	003	003	003	001	002	002	016	020	020	013	016	016	009	011	011
Subtotal ambient NO2			045	049	049	069	076	076	129	142	142	050	055	055	025	026	026	009	011	011	161	169	169	126	133	133	056	061	061
Subtotal ambient CO			036	036	036	055	055	055	139	140	140	040	040	040	001	001	001	000	000	000	006	006	006	004	005	005	038	038	038
Total all emissions, pollutants, effects			334	783	835	542	1424	1499	1158	2625	2814	382	924	982	762	924	965	261	605	670	2502	3987	4494	2034	3212	3607	504	1093	1176

TABLE 11-A 56 COST OF AIR POI LUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLF EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFFCT, $/1000 VMT (ST LOUIS MSA 1990) (UPPER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	2.20	2.20	2.20	3.38	3.38	3.38	10.32	10.32	10.32	2.51	2.51	2.51	0.06	0.06	0.06	0.02	0.02	0.02	0.40	0.41	0.41	0.31	0.32	0.32	2.35	2.35	2.35
		hospitalization	0.09	0.09	0.09	0.13	0.13	0.13	0.41	0.41	0.41	0.10	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.01	0.01	0.01	0.09	0.09	0.09
		headaches	1.00	1.00	1.00	1.54	1.54	1.54	4.71	4.71	4.71	1.14	1.14	1.14	0.03	0.03	0.03	0.01	0.01	0.01	0.18	0.19	0.19	0.14	0.15	0.15	1.07	1.07	1.07
NOx	NO2	sore throat	1.22	1.27	1.27	1.87	1.97	1.97	4.31	4.48	4.48	1.38	1.44	1.44	0.59	0.60	0.60	0.21	0.24	0.24	5.33	5.45	5.45	4.14	4.23	4.23	1.58	1.64	1.64
		excess phlegm	0.55	0.57	0.57	0.84	0.88	0.88	1.93	2.01	2.01	0.62	0.65	0.65	0.26	0.27	0.27	0.09	0.11	0.11	2.39	2.45	2.45	1.86	1.90	1.90	0.71	0.74	0.74
		eye irritation	0.50	0.52	0.52	0.76	0.80	0.80	1.76	1.83	1.83	0.56	0.59	0.59	0.24	0.25	0.25	0.09	0.10	0.10	2.17	2.22	2.22	1.69	1.73	1.73	0.64	0.67	0.67
NOx, NH3	nitrate PM10	mortality	33.00	34.44	34.44	50.45	53.08	53.08	115.46	120.21	120.21	37.20	38.91	38.91	15.97	16.32	16.32	5.63	6.41	6.41	142.71	145.87	145.87	110.87	113.38	113.38	42.64	44.40	44.40
		chronic illness	8.99	9.42	9.42	13.77	14.56	14.56	31.43	32.86	32.86	10.14	10.66	10.66	4.34	4.45	4.45	1.54	1.77	1.77	38.96	39.91	39.91	30.27	31.02	31.02	11.63	12.16	12.16
		asthma attacks	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.03	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.04	0.03	0.03	0.03	0.01	0.01	0.01
		RRAD	0.52	0.55	0.55	0.80	0.84	0.84	1.85	1.92	1.92	0.59	0.62	0.62	0.25	0.26	0.26	0.09	0.10	0.10	2.29	2.34	2.34	1.78	1.82	1.82	0.68	0.70	0.70
Total for NOxand NH3emissions			44.78	46.79	46.79	68.50	72.15	72.15	156.76	163.34	163.34	50.50	52.86	52.86	21.66	22.15	22.15	7.65	8.72	8.72	193.90	198.27	198.27	150.63	154.10	154.10	57.89	60.33	60.33
PM2.5	PM2.5	mortality	5.96	6.89	32.89	12.73	14.57	51.98	54.19	57.21	151.79	7.79	8.91	37.82	76.46	76.75	96.95	24.43	25.07	57.58	292.07	295.07	548.59	234.93	237.29	434.88	24.59	25.80	67.14
		chronic illness	1.69	2.00	9.39	3.63	4.23	14.87	15.42	16.42	43.30	2.21	2.58	10.81	21.69	21.79	27.53	6.96	7.17	16.41	83.68	84.66	156.80	67.28	68.05	124.27	7.03	7.43	19.20
		asthma attacks	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.02	0.04	0.00	0.00	0.01	0.02	0.02	0.03	0.01	0.01	0.02	0.08	0.08	0.14	0.06	0.06	0.11	0.01	0.01	0.02
		RRAD	0.09	0.11	0.52	0.20	0.23	0.82	0.86	0.91	2.41	0.12	0.14	0.60	1.20	1.21	1.53	0.39	0.40	0.91	4.65	4.70	8.71	3.74	3.77	6.90	0.39	0.41	1.06
		lung cancer	0.13	0.13	0.13	0.27	0.27	0.27	1.17	1.17	1.17	0.17	0.17	0.17	0.76	0.76	0.76	0.24	0.24	0.24	2.97	2.97	2.97	2.39	2.39	2.39	0.33	0.33	0.33
Coarse PM10	coarse PM10	mortality	0.38	0.46	6.99	0.68	0.83	10.21	2.80	3.08	26.79	0.46	0.56	7.82	0.97	1.00	6.06	0.30	0.36	8.51	3.04	3.30	66.92	2.48	2.68	52.27	0.61	0.72	11.11
		chronic illness	0.11	0.14	1.99	0.19	0.24	2.90	0.80	0.89	7.61	0.13	0.17	2.22	0.27	0.28	1.72	0.09	0.11	2.42	0.87	0.96	19.00	0.71	0.78	14.84	0.17	0.21	3.16
		asthma attacks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.00
		RRAD	0.01	0.01	0.11	0.01	0.01	0.16	0.04	0.05	0.42	0.01	0.01	0.12	0.02	0.02	0.10	0.00	0.01	0.13	0.05	0.05	1.06	0.04	0.04	0.83	0.01	0.01	0.18
Total for direct PM10emissions			8.37	9.73	52.02	17.71	20.40	81.24	75.30	79.74	233.55	10.90	12.54	59.58	101.39	101.82	134.67	32.43	33.37	86.23	387.41	391.78	804.21	311.61	315.07	636.51	33.13	34.91	102.19
SOx, NH3	sulfate PM10	mortality	3.72	24.32	24.32	5.98	44.69	44.69	14.07	81.28	81.28	4.26	28.77	28.77	20.92	28.78	28.78	7.73	24.24	24.24	77.15	145.52	145.52	62.28	116.62	116.62	8.55	35.25	35.25
		chronic illness	1.11	8.40	8.40	1.80	15.40	15.40	4.23	28.02	28.02	1.28	9.94	9.94	6.26	9.06	9.06	2.33	8.18	8.18	23.37	47.45	47.45	18.85	38.00	38.00	2.58	12.01	12.01
		asthma attacks	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.02	0.02	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.02	0.04	0.04	0.02	0.03	0.03	0.00	0.01	0.01
		RRAD	0.06	0.37	0.37	0.09	0.69	0.69	0.22	1.25	1.25	0.07	0.44	0.44	0.33	0.45	0.45	0.12	0.37	0.37	1.22	2.27	2.27	0.98	1.82	1.82	0.13	0.54	0.54
Total for SOxand NH3emissions			4.89	33.10	33.10	7.88	60.79	60.79	18.52	110.57	110.57	5.61	39.16	39.16	27.52	38.30	38.30	10.18	32.80	32.80	101.76	195.28	195.28	82.13	156.47	156.47	11.27	47.82	47.82
VOCs	organic PM10 (SOA)	mortality	1.96	2.65	2.65	3.30	4.83	4.83	14.10	16.30	16.30	2.35	3.22	3.22	0.37	0.57	0.57	0.16	0.57	0.57	5.25	7.77	7.77	4.04	6.01	6.01	2.48	3.42	3.42
		chronic illness	0.55	0.76	0.76	0.94	1.39	1.39	3.98	4.64	4.64	0.67	0.92	0.92	0.11	0.16	0.16	0.05	0.17	0.17	1.50	2.24	2.24	1.16	1.73	1.73	0.70	0.98	0.98
		asthma attacks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		RRAD	0.03	0.04	0.04	0.05	0.08	0.08	0.22	0.26	0.26	0.04	0.05	0.05	0.01	0.01	0.01	0.00	0.01	0.01	0.08	0.12	0.12	0.06	0.09	0.09	0.04	0.05	0.05
	acetaldehyde	oral cancer	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.03	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
	benzene	leukemia	0.06	0.06	0.06	0.11	0.11	0.11	0.30	0.30	0.30	0.08	0.08	0.08	0.01	0.01	0.01	0.00	0.02	0.02	0.04	0.04	0.04	0.03	0.03	0.03	0.07	0.07	0.07
	1,3-butadiene	cancer all sites	0.22	0.22	0.22	0.37	0.37	0.37	1.02	1.02	1.02	0.26	0.26	0.26	0.02	0.02	0.02	0.01	0.04	0.04	0.07	0.07	0.07	0.06	0.06	0.06	0.24	0.24	0.24
	fomaldehyde	oral cancer	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sub-total for VOC emissions			2.83	3.75	3.75	4.79	6.79	6.79	19.67	22.56	22.56	3.40	4.54	4.54	0.52	0.77	0.77	0.22	0.80	0.80	6.95	10.24	10.24	5.36	7.93	7.93	3.54	4.79	4.79
VOCs, NOx	O3	asthma attacks	0.13	0.14	0.14	0.21	0.23	0.23	0.53	0.61	0.61	0.15	0.16	0.16	0.04	0.04	0.04	0.01	0.02	0.02	0.33	0.36	0.36	0.26	0.28	0.28	0.16	0.17	0.17
		lower resp illness	0.24	0.26	0.26	0.39	0.43	0.43	0.99	1.14	1.14	0.28	0.31	0.31	0.07	0.08	0.08	0.03	0.04	0.04	0.63	0.68	0.68	0.49	0.53	0.53	0.30	0.32	0.32
		upper resp illness	0.07	0.08	0.08	0.12	0.13	0.13	0.30	0.35	0.35	0.09	0.09	0.09	0.02	0.02	0.02	0.01	0.01	0.01	0.19	0.21	0.21	0.15	0.16	0.16	0.09	0.10	0.10
		eye irritation	0.17	0.18	0.18	0.27	0.30	0.30	0.69	0.79	0.79	0.19	0.21	0.21	0.05	0.05	0.05	0.02	0.03	0.03	0.43	0.47	0.47	0.34	0.37	0.37	0.20	0.22	0.22
Subtotal mortality effects			47.22	70.97	103.48	76.52	121.38	168.17	210.94	288.40	406.69	54.58	82.88	119.05	114.75	123.47	148.73	38.28	56.68	97.34	520.63	597.92	915.06	414.92	476.30	723.47	81.22	111.95	163.67
Subtotal cancer effects			0.42	0.42	0.42	0.77	0.77	0.77	2.53	2.53	2.53	0.51	0.51	0.51	0.79	0.79	0.79	0.26	0.30	0.30	3.09	3.09	3.09	2.48	2.48	2.48	0.65	0.65	0.65
Subtotal chronic morbidity effects			12.46	20.72	29.97	20.32	35.82	49.12	55.85	82.82	116.43	14.43	24.27	34.55	32.68	35.75	42.93	10.95	17.39	28.94	148.38	175.21	265.39	118.26	139.57	209.86	22.11	32.80	47.52
Subtotal acute morbidity effects			4.69	5.21	5.74	7.31	8.31	9.06	18.86	20.79	22.69	5.34	5.97	6.55	3.14	3.32	3.73	1.08	1.45	2.11	20.11	21.68	26.79	15.79	17.03	21.02	6.11	6.78	7.61
Subtotal ambient PM10			58.32	90.71	133.00	94.92	155.98	216.82	260.89	366.53	520.33	67.50	106.08	153.12	149.96	161.89	194.74	50.07	75.19	128.05	680.00	785.33	1,197.76	541.96	625.61	947.05	102.58	144.47	211.76
Subtotal ambient O3			0.61	0.67	0.67	0.99	1.10	1.10	2.50	2.89	2.89	0.70	0.77	0.77	0.19	0.20	0.20	0.07	0.10	0.10	1.58	1.72	1.72	1.23	1.34	1.34	0.74	0.81	0.81
Subtotal ambient NO2			2.26	2.36	2.36	3.47	3.65	3.65	8.00	8.32	8.32	2.55	2.67	2.67	1.10	1.12	1.12	0.39	0.44	0.44	9.90	10.12	10.12	7.69	7.86	7.86	2.93	3.05	3.05
Subtotal ambient CO			3.28	3.29	3.29	5.05	5.06	5.06	15.43	15.44	15.44	3.75	3.76	3.76	0.09	0.09	0.09	0.03	0.03	0.03	0.60	0.61	0.61	0.47	0.48	0.48	3.51	3.51	3.51
Total all emissions, pollutants, effects			64.78	97.32	139.61	104.93	166.28	227.12	288.19	394.54	548.34	74.86	113.63	160.66	151.36	163.33	196.18	50.57	75.81	128.68	692.20	797.90	1,210.32	551.44	635.39	956.83	110.09	152.18	219.46

TABLE 11-A 57 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $/1000 VMT (SPOKANE MSA 1990) (LOWER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	0 67	0 67	0 67	0 57	0 58	0 58	2 14	2 17	2 17	0 65	0 67	0 67	0 02	0 02	0 02	0 00	0 01	0 01	0 10	0 13	0 13	0 07	0 10	0 10	0 61	0 62	0 62
		hospitalization	0 11	0 11	0 11	0 09	0 09	0 09	0 34	0 34	0 34	0 10	0 11	0 11	0 00	0 00	0 00	0 00	0 00	0 00	0 02	0 02	0 02	0 01	0 02	0 02	0 10	0 10	0 10
		headaches	0 64	0 65	0 65	0 55	0 56	0 56	2 07	2 09	2 09	0 63	0 64	0 64	0 02	0 02	0 02	0 00	0 01	0 01	0 09	0 12	0 12	0 07	0 09	0 09	0 59	0 60	0 60
NOx	NO2	sore throat	0 37	0 37	0 37	0 33	0 34	0 34	1 02	1 02	1 02	0 37	0 37	0 37	0 20	0 20	0 20	0 04	0 04	0 04	1 35	1 35	1 35	1 03	1 03	1 03	0 42	0 42	0 42
		excess phlegm	0 17	0 17	0 17	0 15	0 15	0 15	0 46	0 46	0 46	0 17	0 17	0 17	0 09	0 09	0 09	0 02	0 02	0 02	0 60	0 60	0 60	0 46	0 46	0 46	0 19	0 19	0 19
		eye irritation	0 15	0 15	0 15	0 14	0 14	0 14	0 42	0 42	0 42	0 15	0 15	0 15	0 08	0 08	0 08	0 02	0 02	0 02	0 55	0 55	0 55	0 42	0 42	0 42	0 17	0 17	0 17
NOx, NH3	nitrate PM10	mortality	2 59	2 59	2 59	2 32	2 32	2 32	7 06	7 07	7 07	2 56	2 56	2 56	1 41	1 41	1 41	0 29	0 29	0 29	9 32	9 33	9 33	7 12	7 12	7 12	2 91	2 91	2 91
		chronic illness	1 00	1 00	1 00	0 89	0 90	0 90	2 72	2 73	2 73	0 99	0 99	0 99	0 54	0 54	0 54	0 11	0 11	0 11	3 59	3 60	3 60	2 75	2 75	2 75	1 12	1 12	1 12
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 00	0 00	0 00
		RRAD	0 12	0 12	0 12	0 10	0 10	0 10	0 32	0 32	0 32	0 11	0 12	0 12	0 06	0 06	0 06	0 01	0 01	0 01	0 42	0 42	0 42	0 32	0 32	0 32	0 13	0 13	0 13
Total for NOx and NH3 emissions			4 39	4 40	4 40	3 94	3 94	3 94	12 00	12 02	12 02	4 35	4 36	4 36	2 39	2 39	2 39	0 50	0 50	0 50	15 84	15 85	15 85	12 10	12 11	12 11	4 95	4 95	4 95
PM2.5	PM2.5	mortality	0 45	0 50	0 69	0 56	0 66	0 81	2 77	2 91	3 50	0 51	0 58	0 76	5 73	5 73	5 88	1 08	1 09	1 23	16 34	16 53	18 12	12 98	13 12	14 34	1 47	1 54	1 81
		chronic illness	0 17	0 19	0 27	0 22	0 25	0 31	1 07	1 12	1 35	0 20	0 22	0 29	2 21	2 21	2 27	0 42	0 42	0 47	6 30	6 38	6 99	5 01	5 06	5 53	0 57	0 60	0 70
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 02	0 02	0 02	0 02	0 02	0 02	0 00	0 00	0 00
		RRAD	0 02	0 02	0 03	0 03	0 03	0 04	0 12	0 13	0 16	0 02	0 03	0 03	0 26	0 26	0 26	0 05	0 05	0 06	0 73	0 74	0 81	0 58	0 59	0 64	0 07	0 07	0 08
		lung cancer	0 01	0 01	0 01	0 01	0 01	0 01	0 06	0 06	0 06	0 01	0 01	0 01	0 07	0 07	0 07	0 01	0 01	0 01	0 19	0 19	0 19	0 15	0 15	0 15	0 02	0 02	0 02
Coarse PM10	coarse PM10	mortality	0 14	0 17	1 20	0 15	0 19	1 02	0 72	0 78	3 96	0 15	0 18	1 18	0 36	0 37	1 17	0 07	0 08	0 79	0 85	0 93	9 48	0 69	0 75	7 27	0 19	0 23	1 65
		chronic illness	0 06	0 06	0 46	0 06	0 07	0 39	0 28	0 30	1 53	0 06	0 07	0 46	0 14	0 14	0 45	0 03	0 03	0 31	0 33	0 36	3 66	0 26	0 29	2 81	0 07	0 09	0 64
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 00	0 00	0 01	0 00	0 00	0 00
		RRAD	0 01	0 01	0 05	0 01	0 01	0 05	0 03	0 03	0 18	0 01	0 01	0 05	0 02	0 02	0 05	0 00	0 00	0 04	0 04	0 04	0 43	0 03	0 03	0 33	0 01	0 01	0 07
Total for direct PM10 emissions			0 85	0 97	2 72	1 04	1 23	2 63	5 06	5 34	10 75	0 96	1 10	2 79	8 79	8 80	10 17	1 66	1 69	2 91	24 81	25 20	39 72	19 73	20 02	31 10	2 40	2 56	4 97
SOx, NH3	sulfate PM10	mortality	0 56	0 73	0 73	0 53	0 97	0 97	1 43	1 87	1 87	0 56	0 82	0 82	3 13	3 14	3 14	0 69	0 73	0 73	8 58	9 19	9 19	6 85	7 30	7 30	1 04	1 32	1 32
		chronic illness	0 21	0 28	0 28	0 20	0 37	0 37	0 55	0 72	0 72	0 22	0 31	0 31	1 21	1 21	1 21	0 26	0 28	0 28	3 31	3 54	3 54	2 64	2 82	2 82	0 40	0 51	0 51
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 01	0 01	0 01	0 00	0 00	0 00
		RRAD	0 03	0 03	0 03	0 02	0 04	0 04	0 06	0 08	0 08	0 03	0 04	0 04	0 14	0 14	0 14	0 03	0 03	0 03	0 39	0 41	0 41	0 31	0 33	0 33	0 05	0 06	0 06
Total for SOx and NH3 emissions			0 80	1 05	1 05	0 75	1 38	1 38	2 05	2 68	2 68	0 80	1 17	1 17	4 48	4 50	4 50	0 98	1 04	1 04	12 28	13 15	13 15	9 80	10 46	10 46	1 49	1 88	1 88
VOCs	organic PM10 (SOA)	mortality	0 20	0 34	0 34	0 19	0 34	0 34	0 88	1 28	1 28	0 20	0 35	0 35	0 04	0 08	0 08	0 01	0 05	0 05	0 38	0 69	0 69	0 29	0 53	0 53	0 21	0 37	0 37
		chronic illness	0 08	0 13	0 13	0 07	0 13	0 13	0 34	0 49	0 49	0 08	0 14	0 14	0 01	0 03	0 03	0 00	0 02	0 02	0 15	0 27	0 27	0 11	0 20	0 20	0 08	0 14	0 14
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 01	0 02	0 02	0 01	0 02	0 02	0 04	0 06	0 06	0 01	0 02	0 02	0 00	0 00	0 00	0 00	0 00	0 00	0 02	0 03	0 03	0 01	0 02	0 02	0 01	0 02	0 02
	acetaldehyde	oral cancer	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
	benzene	leukemia	0 01	0 01	0 01	0 00	0 00	0 00	0 02	0 02	0 02	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
	1 3-butadiene	cancer all sites	0 02	0 02	0 02	0 02	0 02	0 02	0 06	0 06	0 06	0 02	0 02	0 02	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
	formaldehyde	oral cancer	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
Sub-total for VOC emissions			0 31	0 51	0 51	0 30	0 50	0 50	1 34	1 91	1 91	0 32	0 53	0 53	0 06	0 11	0 11	0 01	0 07	0 07	0 56	1 00	1 00	0 42	0 77	0 77	0 32	0 54	0 54
VOCs, NOx	O3	asthma attacks	0 01	0 01	0 01	0 01	0 01	0 01	0 02	0 02	0 02	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 02	0 02	0 02	0 01	0 01	0 01	0 01	0 01	0 01
		lower resp illness	0 02	0 03	0 03	0 02	0 02	0 02	0 07	0 07	0 07	0 02	0 03	0 03	0 01	0 01	0 01	0 00	0 00	0 00	0 06	0 06	0 06	0 05	0 05	0 05	0 03	0 03	0 03
		upper resp illness	0 01	0 01	0 01	0 01	0 01	0 01	0 02	0 02	0 02	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 02	0 02	0 02	0 01	0 01	0 01	0 01	0 01	0 01
		eye irritation	0 02	0 02	0 02	0 02	0 02	0 02	0 05	0 06	0 06	0 02	0 02	0 02	0 01	0 01	0 01	0 00	0 00	0 00	0 05	0 05	0 05	0 03	0 04	0 04	0 02	0 02	0 02
Subtotal mortality effects			4 59	5 01	6 23	4 32	5 06	6 04	15 01	16 08	19 85	4 64	5 15	6 34	10 69	10 75	11 70	2 15	2 25	3 10	35 57	36 80	46 93	28 00	28 93	36 66	6 44	6 99	8 67
Subtotal cancer effects			0 03	0 03	0 03	0 03	0 03	0 03	0 14	0 14	0 14	0 03	0 03	0 03	0 07	0 07	0 07	0 01	0 02	0 02	0 20	0 20	0 20	0 16	0 16	0 16	0 04	0 04	0 04
Subtotal chronic morbidity effects			1 52	1 67	2 14	1 45	1 73	2 10	4 96	5 37	6 82	1 54	1 73	2 19	4 12	4 14	4 50	0 83	0 87	1 19	13 68	14 15	18 06	10 77	11 12	14 11	2 25	2 46	3 11
Subtotal acute morbidity effects			1 67	1 71	1 76	1 48	1 54	1 58	5 05	5 14	5 31	1 66	1 70	1 75	0 91	0 92	0 96	0 19	0 19	0 23	4 38	4 48	4 95	3 39	3 46	3 82	1 79	1 83	1 91
Subtotal ambient PM10			5 64	6 21	7 97	5 39	6 42	7 82	18 48	19 98	25 39	5 72	6 44	8 13	15 34	15 43	16 79	3 08	3 22	4 44	50 98	52 70	67 22	40 14	41 44	52 51	8 37	9 14	11 55
Subtotal ambient O3			0 05	0 06	0 06	0 05	0 05	0 05	0 16	0 17	0 17	0 05	0 06	0 06	0 02	0 02	0 02	0 00	0 01	0 01	0 14	0 15	0 15	0 11	0 11	0 11	0 06	0 06	0 06
Subtotal ambient NO2			0 69	0 69	0 69	0 62	0 62	0 62	1 89	1 89	1 89	0 68	0 69	0 69	0 38	0 38	0 38	0 08	0 08	0 08	2 50	2 50	2 50	1 91	1 91	1 91	0 78	0 78	0 78
Subtotal ambient CO			1 41	1 43	1 43	1 20	1 24	1 24	4 55	4 60	4 60	1 39	1 41	1 41	0 04	0 04	0 04	0 01	0 01	0 01	0 20	0 27	0 27	0 16	0 21	0 21	1 29	1 32	1 32
Total all emissions, pollutants, effects			7 82	8 42	10 17	7 28	8 36	9 76	25 16	26 72	32 13	7 87	8 62	10 31	15 79	15 87	17 24	3 17	3 33	4 54	53 83	55 62	70 14	42 31	43 67	54 75	10 52	11 32	13 74

TABLE 11-A 58 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $/1000 VMT (SPOKANE MSA 1990) (UPPER BOUND)

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	8 50	8 51	8 51	7 19	7 22	7 22	37 14	37 19	37 19	8 45	8 47	8 47	0 22	0 22	0 22	0 04	0 05	0 05	1 65	1 70	1 70	1 25	1 30	1 30	7 90	7 92	7 92
		hospitalization	0 34	0 34	0 34	0 28	0 29	0 29	1 47	1 47	1 47	0 33	0 34	0 34	0 01	0 01	0 01	0 00	0 00	0 00	0 07	0 07	0 07	0 05	0 05	0 05	0 31	0 31	0 31
		headaches	3 97	3 98	3 98	3 36	3 38	3 38	17 39	17 41	17 41	3 95	3 96	3 96	0 10	0 10	0 10	0 02	0 02	0 02	0 77	0 80	0 80	0 59	0 61	0 61	3 69	3 70	3 70
NOx	NO2	sore throat	1 94	1 94	1 94	1 73	1 73	1 73	7 17	7 17	7 17	1 94	1 94	1 94	0 91	0 91	0 91	0 19	0 19	0 19	9 43	9 43	9 43	7 12	7 12	7 12	2 34	2 34	2 34
		excess phlegm	*0 87*	*0 87*	*0 87*	0 77	0 77	0 77	3 20	3 20	3 20	*0 87*	*0 87*	*0 87*	0 41	0 41	0 41	0 08	0 08	0 08	4 21	4 21	4 21	3 18	3 18	3 18	1 04	1 04	1 04
		eye irritation	0 79	0 79	0 79	0 70	0 70	0 70	2 91	2 91	2 91	0 79	0 79	0 79	0 37	0 37	0 37	0 08	0 08	0 08	3 83	3 83	3 83	2 89	2 89	2 89	0 95	0 95	0 95
NOx, NH3	nitrate PM10	mortality	53 98	53 99	53 99	47 86	47 87	47 87	198 83	198 85	198 85	53 89	53 90	53 90	25 34	25 34	25 34	5 23	5 23	5 23	261 54	261 56	261 56	197 52	197 54	197 54	64 93	64 94	64 94
		chronic illness	19 93	19 94	19 94	17 66	17 67	17 67	73 37	73 38	73 38	19 91	19 91	19 91	9 35	9 35	9 35	1 93	1 93	1 93	96 54	96 55	96 55	72 91	72 92	72 92	23 99	24 00	24 00
		asthma attacks	0 03	0 03	0 03	0 02	0 02	0 02	0 10	0 10	0 10	0 03	0 03	0 03	0 01	0 01	0 01	0 00	0 00	0 00	0 13	0 13	0 13	0 09	0 09	0 09	0 03	0 03	0 03
		RRAD	0 90	0 90	0 90	0 79	0 79	0 79	3 30	3 30	3 30	0 89	0 89	0 89	0 42	0 42	0 42	0 09	0 09	0 09	4 34	4 34	4 34	3 28	3 28	3 28	1 08	1 08	1 08
Total for NOx and NH3 emissions			78 44	78 45	78 45	69 54	69 55	69 55	288 88	288 91	288 91	78 31	78 32	78 32	36 81	36 82	36 82	7 60	7 60	7 60	380 01	380 04	380 04	287 00	287 02	287 02	94 36	94 38	94 38
PM2.5	PM2 5	mortality	8 74	8 88	50 81	10 92	11 16	44 65	85 24	85 58	214 94	10 29	10 46	50 94	112 22	112 23	144 81	21 02	21 05	50 15	495 52	495 99	842 55	384 07	384 43	648 86	39 09	39 28	96 93
		chronic illness	3 22	3 28	18 76	4 03	4 12	16 48	31 45	31 58	79 31	3 80	3 86	18 81	41 41	41 41	53 44	7 76	7 77	18 51	182 96	183 13	311 22	141 81	141 94	239 69	14 44	14 51	35 84
		asthma attacks	0 00	0 00	0 02	0 01	0 01	0 02	0 04	0 04	0 10	0 00	0 01	0 02	0 05	0 05	0 07	0 01	0 01	0 02	0 24	0 24	0 40	0 18	0 18	0 31	0 02	0 02	0 05
		RRAD	0 15	0 15	0 84	0 18	0 19	0 74	1 42	1 42	3 57	0 17	0 17	0 84	1 86	1 86	2 41	0 35	0 35	0 83	8 22	8 23	13 97	6 37	6 38	10 76	0 65	0 65	1 61
		lung cancer	0 18	0 18	0 18	0 22	0 22	0 22	1 73	1 73	1 73	0 21	0 21	0 21	0 84	0 84	0 84	0 16	0 16	0 16	3 70	3 70	3 70	2 87	2 87	2 87	0 41	0 41	0 41
Coarse PM10	coarse PM10	mortality	0 56	0 57	11 24	0 58	0 60	9 12	4 41	4 43	37 35	0 61	0 62	10 93	1 41	1 41	9 71	0 27	0 28	7 68	5 16	5 20	93 51	4 04	4 07	71 45	0 87	0 89	15 59
		chronic illness	0 21	0 21	4 15	0 21	0 22	3 37	1 63	1 64	13 78	0 22	0 23	4 03	0 52	0 52	3 58	0 10	0 10	2 83	1 91	1 92	34 51	1 49	1 50	26 37	0 32	0 33	5 76
		asthma attacks	0 00	0 00	0 01	0 00	0 00	0 00	0 00	0 00	0 02	0 00	0 00	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 04	0 00	0 00	0 03	0 00	0 00	0 01
		RRAD	0 01	0 01	0 19	0 01	0 01	0 15	0 07	0 07	0 62	0 01	0 01	0 18	0 02	0 02	0 16	0 00	0 00	0 13	0 09	0 09	1 55	0 07	0 07	1 19	0 01	0 01	0 26
Total for direct PM10 emissions			13 06	13 26	86 19	16 17	16 52	74 75	125 98	126 49	351 41	15 31	15 56	85 98	158 34	158 36	215 01	29 67	29 72	80 32	697 79	698 49	1,301 46	540 91	541 44	1,001 53	55 82	56 10	156 46
SOx, NH3	sulfate PM10	mortality	4 72	4 93	4 93	4 42	4 96	4 96	19 05	19 59	19 59	4 80	5 11	5 11	26 50	26 51	26 51	5 76	5 81	5 81	112 28	113 02	113 02	87 30	87 85	87 85	11 16	11 49	11 49
		chronic illness	1 74	1 82	1 82	1 63	1 83	1 83	7 03	7 23	7 23	1 77	1 89	1 89	9 78	9 78	9 78	2 12	2 14	2 14	41 44	41 71	41 71	32 22	32 42	32 42	4 12	4 24	4 24
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 05	0 05	0 05	0 04	0 04	0 04	0 01	0 01	0 01
		RRAD	0 08	0 08	0 08	0 07	0 08	0 08	0 32	0 33	0 33	0 08	0 08	0 08	0 44	0 44	0 44	0 10	0 10	0 10	1 86	1 88	1 88	1 45	1 46	1 46	0 19	0 19	0 19
Total for SOx and NH3 emissions			6 54	6 84	6 84	6 13	6 87	6 87	26 41	27 15	27 15	6 66	7 09	7 09	36 73	36 75	36 75	7 98	8 05	8 05	155 63	156 66	156 66	121 01	121 78	121 78	15 47	15 93	15 93
VOCs	organic PM10 (SOA)	mortality	2 90	3 67	3 67	2 84	3 59	3 59	20 70	22 84	22 84	3 10	3 88	3 88	0 57	0 77	0 77	0 14	0 35	0 35	8 90	10 56	10 56	6 68	7 96	7 96	3 37	4 19	4 19
		chronic illness	1 07	1 36	1 36	1 05	1 33	1 33	7 64	8 43	8 43	1 14	1 43	1 43	0 21	0 29	0 29	0 05	0 13	0 13	3 28	3 89	3 89	2 46	2 94	2 94	1 24	1 55	1 55
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0 05	0 06	0 06	0 05	0 06	0 06	0 34	0 38	0 38	0 05	0 06	0 06	0 01	0 01	0 01	0 00	0 01	0 01	0 15	0 18	0 18	0 11	0 13	0 13	0 06	0 07	0 07
	acetaldehyde	oral cancer	0 01	0 01	0 01	0 01	0 01	0 01	0 05	0 05	0 05	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01
	benzene	leukemia	0 09	0 09	0 09	0 09	0 09	0 09	0 42	0 42	0 42	0 09	0 09	0 09	0 01	0 01	0 01	0 00	0 01	0 01	0 04	0 04	0 04	0 04	0 04	0 04	0 09	0 09	0 09
	1,3-butadiene	cancer all sites	0 31	0 31	0 31	0 30	0 30	0 30	1 42	1 42	1 42	0 32	0 32	0 32	0 03	0 03	0 03	0 01	0 03	0 03	0 12	0 12	0 12	0 09	0 09	0 09	0 30	0 30	0 30
	fomaldehyde	oral cancer	0 00	0 00	0 00	0 00	0 00	0 00	0 02	0 02	0 02	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
Sub-total for VOC emissions			4 44	5 51	5 51	4 34	5 39	5 39	30 60	33 55	33 55	4 72	5 81	5 81	0 83	1 12	1 12	0 21	0 53	0 53	12 50	14 80	14 80	9 39	11 16	11 16	5 08	6 22	6 22
VOCs, NOx	O3	asthma attacks	0 11	0 12	0 12	0 10	0 11	0 11	0 45	0 46	0 46	0 11	0 12	0 12	0 04	0 04	0 04	0 01	0 01	0 01	0 39	0 39	0 39	0 29	0 30	0 30	0 13	0 13	0 13
		lower resp illness	0 21	0 22	0 22	0 19	0 20	0 20	0 83	0 85	0 85	0 21	0 22	0 22	0 07	0 07	0 07	0 02	0 02	0 02	0 72	0 73	0 73	0 55	0 55	0 55	0 24	0 25	0 25
		upper resp illness	0 06	0 07	0 07	0 06	0 06	0 06	0 25	0 26	0 26	0 06	0 07	0 07	0 02	0 02	0 02	0 00	0 01	0 01	0 22	0 22	0 22	0 17	0 17	0 17	0 07	0 08	0 08
		eye irritation	0 11	0 11	0 11	0 10	0 11	0 11	0 44	0 45	0 45	0 11	0 12	0 12	0 04	0 04	0 04	0 01	0 01	0 01	0 38	0 39	0 39	0 29	0 29	0 29	0 13	0 13	0 13
Subtotal mortality effects			79 39	80 55	133 15	73 81	75 40	117 40	365 38	368 47	530 74	81 14	82 44	133 23	166 26	166 49	207 37	32 46	32 77	69 27	885 04	888 03	1,322 90	680 86	683 14	1,014 96	127 33	128 71	201 08
Subtotal cancer effects			0 59	0 59	0 59	0 63	0 63	0 63	3 63	3 63	3 63	0 64	0 64	0 64	0 88	0 88	0 88	0 17	0 20	0 20	3 87	3 87	3 87	3 00	3 00	3 00	0 82	0 82	0 82
Subtotal chronic morbidity effects			26 18	26 60	46 02	24 59	25 16	40 67	121 12	122 25	182 13	26 84	27 32	46 08	61 27	61 35	76 44	11 96	12 07	25 54	326 12	327 20	487 88	250 89	251 72	374 33	44 12	44 62	71 39
Subtotal acute morbidity effects			9 62	9 66	10 56	8 44	8 50	9 21	39 73	39 85	42 62	9 62	9 67	10 54	4 81	4 82	5 52	0 96	0 97	1 60	35 10	35 20	42 62	26 73	26 80	32 46	10 94	10 99	12 22
Subtotal ambient PM10			98 46	100 04	172 97	92 57	94 73	152 96	456 69	460 92	685 84	100 98	102 76	173 18	230 98	231 31	287 96	45 09	45 51	96 11	1,228 30	1,232 36	1,835 33	944 98	948 08	1,408 17	166 00	167 88	268 25
Subtotal ambient O3			0 50	0 52	0 52	0 46	0 47	0 47	1 97	2 02	2 02	0 50	0 52	0 52	0 17	0 18	0 18	0 04	0 04	0 04	1 71	1 73	1 73	1 30	1 31	1 31	0 57	0 58	0 58
Subtotal ambient NO2			3 60	3 60	3 60	3 20	3 20	3 20	13 28	13 28	13 28	3 60	3 60	3 60	1 69	1 69	1 69	0 35	0 35	0 35	17 47	17 47	17 47	13 19	13 19	13 19	4 33	4 33	4 33
Subtotal ambient CO			12 80	12 83	12 83	10 83	10 88	10 88	56 01	56 07	56 07	12 74	12 77	12 77	0 33	0 33	0 33	0 07	0 07	0 07	2 48	2 57	2 57	1 89	1 95	1 95	11 90	11 93	11 93
Total all emissions, pollutants, effects			115 78	117 40	190 33	107 46	109 68	167 91	529 85	534 19	759 11	118 25	120 07	190 49	233 22	233 55	290 20	45 55	46 01	96 61	1,250 13	1,254 29	1,857 26	961 48	964 67	1,424 76	183 21	185 14	285 50

TABLE 11-A 59 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $/1000 VMT (WASHINGTON D C MSA 1990) (LOWER E

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	0.22	0.22	0.22	0.32	0.32	0.32	1.04	1.04	1.04	0.24	0.24	0.24	0.01	0.01	0.01	0.00	0.00	0.00	0.04	0.04	0.04	0.03	0.03	0.03	0.23	0.23	0.23
		hospitalization	0.03	0.03	0.03	0.05	0.05	0.05	0.16	0.16	0.16	0.04	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.04	0.04	0.04
		headaches	0.26	0.26	0.26	0.39	0.39	0.39	1.27	1.27	1.27	0.30	0.30	0.30	0.01	0.01	0.01	0.00	0.00	0.00	0.05	0.05	0.05	0.04	0.04	0.04	0.28	0.28	0.28
NOx	NO2	sore throat	0.31	0.31	0.31	0.46	0.46	0.46	1.10	1.10	1.10	0.35	0.35	0.35	0.18	0.18	0.18	0.06	0.06	0.06	1.37	1.37	1.37	1.02	1.02	1.02	0.39	0.39	0.39
		excess phlegm	0.14	0.14	0.14	0.20	0.20	0.20	0.49	0.49	0.49	0.15	0.15	0.15	0.08	0.08	0.08	0.03	0.03	0.03	0.61	0.61	0.61	0.45	0.45	0.45	0.17	0.17	0.17
		eye irritation	0.13	0.13	0.13	0.19	0.19	0.19	0.45	0.45	0.45	0.14	0.14	0.14	0.07	0.07	0.07	0.02	0.02	0.02	0.55	0.56	0.56	0.41	0.41	0.41	0.16	0.16	0.16
NOx, NH3	nitrate PM10	mortality	2.38	2.39	2.39	3.50	3.52	3.52	8.45	8.47	8.47	2.66	2.67	2.67	1.37	1.37	1.37	0.46	0.47	0.47	10.54	10.57	10.57	7.82	7.85	7.85	2.99	3.00	3.00
		chronic illness	0.38	0.38	0.38	0.55	0.56	0.56	1.33	1.34	1.34	0.42	0.42	0.42	0.22	0.22	0.22	0.07	0.07	0.07	1.67	1.67	1.67	1.24	1.24	1.24	0.47	0.48	0.48
		asthma attacks	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
		RRAD	0.13	0.13	0.13	0.19	0.19	0.19	0.45	0.45	0.45	0.14	0.14	0.14	0.07	0.07	0.07	0.02	0.03	0.03	0.57	0.57	0.57	0.42	0.42	0.42	0.16	0.16	0.16
Total for NOx and NH3 emissions			3.47	3.48	3.48	5.09	5.12	5.12	12.27	12.31	12.31	3.87	3.88	3.88	1.99	1.99	1.99	0.67	0.68	0.68	15.31	15.36	15.36	11.36	11.40	11.40	4.35	4.37	4.37
PM2.5	PM2.5	mortality	0.47	0.50	0.56	0.97	1.05	1.13	3.67	3.77	4.04	0.60	0.64	0.71	6.07	6.08	6.12	1.86	1.87	1.95	19.97	20.13	20.85	15.56	15.67	16.20	1.56	1.61	1.71
		chronic illness	0.08	0.08	0.09	0.16	0.17	0.19	0.59	0.61	0.65	0.10	0.11	0.12	0.99	0.99	0.99	0.30	0.30	0.32	3.21	3.24	3.36	2.51	2.53	2.61	0.25	0.26	0.28
		asthma attacks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.00
		RRAD	0.03	0.03	0.03	0.05	0.06	0.06	0.20	0.20	0.22	0.03	0.03	0.04	0.32	0.32	0.33	0.10	0.10	0.10	1.06	1.07	1.11	0.83	0.83	0.86	0.08	0.09	0.09
		lung cancer	0.01	0.01	0.01	0.01	0.01	0.01	0.05	0.05	0.05	0.01	0.01	0.01	0.05	0.05	0.05	0.01	0.01	0.01	0.15	0.15	0.15	0.12	0.12	0.12	0.01	0.01	0.01
Coarse PM10	coarse PM10	mortality	0.15	0.16	0.46	0.26	0.28	0.68	0.95	0.98	2.28	0.18	0.19	0.52	0.39	0.39	0.62	0.12	0.12	0.47	1.04	1.08	4.59	0.82	0.86	3.44	0.22	0.23	0.71
		chronic illness	0.02	0.03	0.07	0.04	0.05	0.11	0.15	0.16	0.36	0.03	0.03	0.08	0.06	0.06	0.10	0.02	0.02	0.07	0.17	0.18	0.72	0.13	0.14	0.54	0.04	0.04	0.11
		asthma attacks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		RRAD	0.01	0.01	0.02	0.01	0.01	0.04	0.05	0.05	0.12	0.01	0.01	0.03	0.02	0.02	0.03	0.01	0.01	0.03	0.06	0.06	0.24	0.04	0.05	0.18	0.01	0.01	0.04
Total for direct PM10 emissions			0.77	0.81	1.24	1.50	1.63	2.22	5.65	5.82	7.73	0.96	1.02	1.50	7.91	7.91	8.25	2.42	2.44	2.95	25.68	25.93	31.04	20.03	20.21	23.97	2.19	2.26	2.94
SOx, NH3	sulfate PM10	mortality	0.82	1.09	1.09	1.26	1.87	1.87	2.65	3.65	3.65	0.93	1.27	1.27	4.64	4.73	4.73	1.63	1.85	1.85	14.57	15.88	15.88	11.41	12.39	12.39	1.60	1.98	1.98
		chronic illness	0.13	0.18	0.18	0.21	0.31	0.31	0.43	0.60	0.60	0.15	0.21	0.21	0.75	0.77	0.77	0.27	0.30	0.30	2.35	2.57	2.57	1.84	2.01	2.01	0.26	0.32	0.32
		asthma attacks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
		RRAD	0.04	0.06	0.06	0.07	0.10	0.10	0.14	0.19	0.19	0.05	0.07	0.07	0.25	0.25	0.25	0.09	0.10	0.10	0.78	0.84	0.84	0.61	0.66	0.66	0.09	0.10	0.10
Total for SOx and NH3 emissions			1.00	1.33	1.33	1.54	2.28	2.28	3.22	4.44	4.44	1.13	1.54	1.54	5.64	5.75	5.75	1.99	2.25	2.25	17.70	19.30	19.30	13.87	15.06	15.06	1.95	2.41	2.41
VOCs	organic PM10 (SOA)	mortality	0.20	0.32	0.32	0.32	0.55	0.55	1.24	1.73	1.73	0.23	0.38	0.38	0.04	0.08	0.08	0.02	0.09	0.09	0.47	1.00	1.00	0.35	0.73	0.73	0.24	0.41	0.41
		chronic illness	0.03	0.05	0.05	0.05	0.09	0.09	0.20	0.28	0.28	0.04	0.06	0.06	0.01	0.01	0.01	0.00	0.01	0.01	0.08	0.17	0.17	0.06	0.12	0.12	0.04	0.07	0.07
		asthma attacks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		RRAD	0.01	0.02	0.02	0.02	0.03	0.03	0.07	0.09	0.09	0.01	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.05	0.05	0.02	0.04	0.04	0.01	0.02	0.02
	acetaldehyde	oral cancer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	benzene	leukemia	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1,3-butadiene	cancer all sites	0.01	0.01	0.01	0.02	0.02	0.02	0.05	0.05	0.05	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	fomaldehyde	oral cancer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
Sub-total for VOC emissions			0.25	0.41	0.41	0.41	0.70	0.70	1.57	2.17	2.17	0.30	0.48	0.48	0.05	0.10	0.10	0.02	0.11	0.11	0.58	1.22	1.22	0.43	0.90	0.90	0.31	0.51	0.51
VOCs, NOx	O3	asthma attacks	0.01	0.01	0.01	0.02	0.02	0.02	0.05	0.06	0.06	0.01	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.03	0.02	0.03	0.03	0.01	0.02	0.02
		lower resp illness	0.05	0.05	0.05	0.08	0.08	0.08	0.20	0.22	0.22	0.06	0.06	0.06	0.02	0.02	0.02	0.01	0.01	0.01	0.12	0.13	0.13	0.09	0.10	0.10	0.06	0.06	0.06
		upper resp illness	0.01	0.02	0.02	0.02	0.03	0.03	0.06	0.07	0.07	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.04	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02
		eye irritation	0.05	0.06	0.06	0.08	0.09	0.09	0.22	0.24	0.24	0.06	0.06	0.06	0.02	0.02	0.02	0.01	0.01	0.01	0.12	0.14	0.14	0.09	0.11	0.11	0.06	0.07	0.07
Subtotal mortality effects			4.25	4.68	5.04	6.63	7.60	8.08	17.98	19.64	21.22	4.84	5.39	5.79	12.51	12.65	12.93	4.09	4.41	4.83	46.63	48.70	52.92	36.00	37.51	40.64	6.85	7.46	8.03
Subtotal cancer effects			0.02	0.02	0.02	0.03	0.03	0.03	0.11	0.11	0.11	0.02	0.02	0.02	0.05	0.05	0.05	0.01	0.02	0.02	0.16	0.16	0.16	0.12	0.12	0.12	0.03	0.03	0.03
Subtotal chronic morbidity effects			0.65	0.72	0.78	1.01	1.18	1.25	2.71	2.99	3.24	0.74	0.83	0.89	2.03	2.05	2.09	0.66	0.72	0.78	7.47	7.83	8.49	5.77	6.04	6.52	1.06	1.17	1.26
Subtotal acute morbidity effects			1.22	1.26	1.28	1.83	1.91	1.93	4.92	5.06	5.15	1.37	1.42	1.44	1.06	1.07	1.09	0.35	0.38	0.40	5.41	5.57	5.80	4.10	4.21	4.38	1.55	1.60	1.63
Subtotal ambient PM10			4.90	5.44	5.87	7.68	8.86	9.45	20.61	22.65	24.55	5.59	6.27	6.74	15.25	15.42	15.76	4.98	5.37	5.88	56.74	59.27	64.38	43.80	45.68	49.45	8.06	8.81	9.49
Subtotal ambient O3			0.13	0.14	0.14	0.20	0.22	0.22	0.53	0.58	0.58	0.15	0.16	0.16	0.04	0.05	0.05	0.02	0.02	0.02	0.31	0.35	0.35	0.23	0.26	0.26	0.15	0.17	0.17
Subtotal ambient NO2			0.58	0.58	0.58	0.85	0.85	0.85	2.03	2.04	2.04	0.64	0.65	0.65	0.33	0.33	0.33	0.11	0.11	0.11	2.53	2.54	2.54	1.88	1.89	1.89	0.72	0.72	0.72
Subtotal ambient CO			0.51	0.51	0.51	0.76	0.76	0.76	2.47	2.47	2.47	0.58	0.58	0.58	0.02	0.02	0.02	0.01	0.01	0.01	0.10	0.10	0.10	0.07	0.07	0.07	0.55	0.55	0.55
Total all emissions, pollutants, effects			6.13	6.68	7.11	9.50	10.71	11.30	25.71	27.80	29.71	6.97	7.67	8.14	15.65	15.82	16.16	5.12	5.52	6.03	59.68	62.26	67.37	45.99	47.90	51.67	9.49	10.26	10.95

TABLE 11-A 60 COST OF AIR POLLUTION ATTRIBUTABLE TO A 10% REDUCTION IN MOTOR VEHICLE EMISSIONS, BY EMISSION-POLLUTANT PATHWAY AND HEALTH EFFECT, $/1000 VMT (WASHINGTON D C MSA 1990) (UPPER B

Emission	Ambient pollutant	Health effect	LDGVs			LDGTs			HDGTs			*Total gasoline vehicles*			LDDVs			LDDTs			HDDVs			*Total diesel vehicles*			*Total all vehicles*		
			V	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*	*V*	*V+U*	*V+U+RD*
CO	CO	mortality	2 55	2.55	2 55	3 79	3 79	3 79	14 99	14 99	14 99	2 91	2 91	2 91	0 07	0 07	0 07	0 02	0 02	0 02	0 59	0 59	0 59	0 43	0 43	0 43	2 75	2 75	2 75
		hospitalization	0 10	0 10	0 10	0 15	0 15	0 15	0 59	0 59	0 59	0 11	0 11	0 11	0 00	0 00	0 00	0.00	0 00	0.00	0 02	0 02	0 02	0 02	0 02	0 02	0 11	0 11	0 11
		headaches	1 51	1 51	1 51	2.25	2.25	2.25	8 93	8 93	8 93	1 73	1 73	1 73	0 04	0 04	0 04	0 01	0 01	0 01	0 35	0 35	0 35	0.26	0.26	0.26	1 63	1 63	1.63
NOx	NO2	sore throat	1 64	1 65	1 65	2 40	2 40	2 40	7 12	7 13	7 13	1 84	1 84	1 84	0 81	0 81	0 81	0 27	0 27	0 27	8 82	8 84	8 84	6 47	6 49	6 49	2 13	2 14	2 14
		excess phlegm	0 73	0 73	0 73	1 06	1 06	1 06	3 15	3 15	3 15	0 81	0 82	0 82	0 36	0 36	0 36	0 12	0 12	0 12	3 91	3 92	3 92	2 87	2 87	2 87	0 95	0 95	0 95
		eye irritation	0 66	0 67	0 67	0 97	0 97	0 97	2 88	2 88	2 88	0 74	0 75	0 75	0 33	0 33	0 33	0 11	0 11	0 11	3 57	3 58	3 58	2 62	2 62	2 62	0 86	0 87	0 87
NOx, NH3	nitrate PM10	mortality	42 53	42 61	42 61	62 31	62 48	62 48	186 50	186 81	186 81	47 72	47 82	47 82	20 88	20 91	20 91	7 03	7 10	7 10	231 58	232 00	232 00	169 87	170 18	170 18	55 56	55 67	55 67
		chronic illness	15 03	15 06	15 06	21 92	21 97	21 97	65 31	65 41	65 41	16 85	16 88	16 88	7 39	7 40	7 40	2 48	2 50	2 50	81 13	81 26	81 26	59 53	59 63	59 63	19 60	19 64	19 64
		asthma attacks	0 02	0 02	0 02	0 02	0 02	0 02	0 07	0 07	0 07	0 02	0 02	0 02	0 01	0 01	0 01	0 00	0 00	0 00	0 08	0 08	0 08	0 06	0 06	0 06	0 02	0 02	0 02
		RRAD	0 94	0 94	0 94	1 38	1 38	1 38	4 13	4 13	4 13	1 05	1 06	1 06	0 46	0 46	0 46	0 16	0 16	0 16	5 13	5 14	5 14	3 76	3 77	3 77	1 23	1 23	1 23
Total for NOxand NH3emissions			61 55	61 66	61 66	90.06	90.30	90.30	269 15	269 58	269 58	69.03	69 18	69 18	30.24	30.28	30.28	10 18	10.27	10.27	334 23	334 81	334.81	245 19	245 62	245 62	80.35	80.51	80 51
PM2.5	PM2 5	mortality	7 31	7 43	28 15	14.89	15 18	43 59	82 16	82 58	174 45	9 50	9 65	32 53	93 77	93 79	109.89	28 61	28 68	53 37	444 63	445 25	691 37	337 46	337 92	519 12	30 62	30.80	63 82
		chronic illness	2.58	2.62	9 81	5.23	5 32	15 18	28 67	28.80	60 66	3 34	3 39	11 34	33 09	33 10	38 68	10 05	10 07	18 63	154 37	154 55	240 04	117.28	117 42	180 36	10 69	10 74	22.23
		asthma attacks	0 00	0 00	0 01	0 01	0 01	0 02	0 03	0 03	0 06	0 00	0 00	0 01	0 03	0 03	0 04	0 01	0 01	0 02	0 16	0 16	0.25	0 12	0 12	0 19	0 01	0 01	0 02
		RRAD	0 16	0 16	0 63	0 33	0 34	0 97	1.82	1.83	3.89	0.21	0.21	0 73	2 08	2 08	2 44	0 64	0 64	1 19	9 90	9 91	15 42	7 51	7 52	11 57	0 68	0 68	1 42
		lung cancer	0 10	0 10	0 10	0.21	0.21	0.21	1 19	1 19	1 19	0 13	0 13	0 13	0 62	0 62	0 62	0 19	0 19	0 19	2 95	2 95	2 95	2.24	2.24	2.24	0 27	0 27	0 27
Coarse PM10	coarse PM10	mortality	0 47	0 47	5 52	0 79	0 80	7 72	4.25	4.27	26 64	0 56	0 57	6 15	1 19	1 19	5 11	0 36	0 36	6 37	4 63	4 67	64 69	3 56	3 59	47 78	0 76	0 77	8 83
		chronic illness	0 16	0 17	1 91	0 28	0 28	2 68	1 48	1 49	9 24	0 20	0 20	2 13	0 42	0 42	1 78	0 13	0 13	2.21	1 61	1 62	22 40	1 24	1 24	16 55	0 27	0 27	3 06
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 02	0 00	0 00	0 02	0 00	0 00	0 00
		RRAD	0 01	0 01	0 12	0 02	0 02	0 17	0 09	0 09	0 60	0 01	0 01	0 14	0 03	0 03	0 11	0 01	0 01	0 14	0 10	0 10	1 45	0 08	0 08	1 07	0 02	0 02	0 20
Total for direct PM10emissions			10.80	10 96	46.25	21 75	22 17	70.54	119 69	120.29	276.73	13 97	14 18	53 15	131 22	131 26	158 68	39 98	40 09	82.12	618 35	619 22	1,038 60	469 49	470 13	778 90	43 31	43.56	99.86
SOx, NH3	sulfate PM10	mortality	6 60	7 74	7 74	10 07	12.40	12 40	30 72	35 14	35 14	7 50	8 91	8 91	37 10	37 57	37 57	13 03	14 06	14 06	168 02	174 06	174 06	128.07	132 57	132 57	15.27	16.87	16 87
		chronic illness	2 33	2 69	2 69	3 54	4 29	4 29	10 72	12 13	12 13	2 64	3 09	3 09	13 09	13.24	13 24	4 57	4 90	4 90	58 25	60 13	60 13	44 44	45.85	45.85	5 34	5.85	5.85
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 06	0 06	0 06	0 05	0 05	0 05	0 01	0 01	0 01
		RRAD	0 15	0 17	0 17	0.22	0 27	0 27	0 68	0 77	0 77	0 17	0 19	0 19	0.82	0.83	0.83	0.29	0 31	0 31	3 74	3.86	3.86	2.85	2 94	2 94	0 34	0 37	0 37
Total for SOxand NH3emissions			9 08	10 61	10 61	13.84	16 96	16 96	42 14	48 05	48 05	10.32	12.20	12.20	51.02	51 66	51 66	17.89	19.28	19.28	230 08	238 12	238 12	175.41	181 41	181 41	20 95	23 10	23 10
VOCs	organic PM10 (SOA)	mortality	2.31	3 03	3.03	3 74	5 10	5 10	20 91	23 72	23 72	2 76	3 63	3 63	0 46	0 68	0 68	0 18	0 60	0 60	7 95	11 00	11 00	5 78	8 04	8 04	2 96	3 91	3 91
		chronic illness	0.81	1 06	1 06	1 32	1 79	1 79	7 38	8 36	8 36	0 98	1 27	1.27	0 16	0.24	0.24	0 07	0.21	0.21	2 78	3.84	3.84	2 02	2.80	2.80	1 04	1 37	1 37
		asthma attacks	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
		RRAD	0.05	0 07	0 07	0 08	0 11	0 11	0.46	0 52	0 52	0 06	0 08	0 08	0 01	0 01	0 01	0 00	0 01	0 01	0 18	0 24	0 24	0 13	0 18	0 18	0 07	0 09	0 09
	acetaldehyde	oral cancer	0 01	0 01	0 01	0 01	0 01	0 01	0 03	0 03	0 03	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01
	benzene	leukemia	0 05	0 05	0 05	0 09	0 09	0 09	0 31	0 31	0 31	0 06	0 06	0 06	0 01	0 01	0 01	0 00	0 01	0 01	0 04	0 04	0 04	0 03	0 03	0 03	0 06	0 06	0 06
	1 3-butadiene	cancer all sites	0 18	0 18	0 18	0 29	0 29	0 29	1 05	1 05	1 05	0 21	0 21	0 21	0 02	0 02	0 02	0 01	0 03	0 03	0 08	0 08	0 08	0 06	0 06	0 06	0 20	0 20	0 20
	fomaldehyde	oral cancer	0 00	0 00	0 00	0 00	0 00	0 00	0 01	0 01	0 01	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
Sub-total for VOC emissions			3 41	4 39	4 39	5 54	7 39	7 39	30 17	34 02	34 02	4 08	5 26	5 26	0 66	0 95	0 95	0 26	0 87	0 87	11 03	15 20	15 20	8 02	11 11	11 11	4 33	5 64	5 64
VOCs, NOx	O3	asthma attacks	0 21	0 22	0 22	0 33	0 35	0 35	1 10	1 13	1 13	0 24	0 26	0 26	0 06	0 06	0 06	0 02	0 03	0 03	0 63	0 66	0 66	0 47	0 49	0 49	0 26	0 27	0 27
		lower resp illness	0 40	0 42	0 42	0 62	0 65	0 65	2 06	2 12	2 12	0 46	0 48	0 48	0 12	0 12	0 12	0 04	0 05	0 05	1 19	1 24	1 24	0 87	0 91	0 91	0 49	0 51	0 51
		upper resp illness	0 12	0 13	0 13	0 19	0 20	0 20	0 63	0 64	0 64	0 14	0 15	0 15	0 04	0 04	0 04	0 01	0 02	0 02	0 36	0 38	0 38	0 27	0 28	0 28	0 15	0 15	0 15
		eye irritation	0 31	0 32	0 32	0 48	0 51	0 51	1 61	1 65	1 65	0 35	0 37	0 37	0 09	0 09	0 09	0 03	0 04	0 04	0 91	0 95	0 95	0 67	0 70	0 70	0 37	0 39	0 39
Subtotal mortality effects			61 76	63.82	89 59	95 60	99 76	135 09	339 53	347 52	461 75	70 95	73 48	101 93	153 45	154 21	174 23	49.24	50.83	81 53	857 41	867 56	1,173 71	645 17	652 73	878 12	107 92	110 76	151.86
Subtotal cancer effects			0 34	0 34	0 34	0 60	0 60	0 60	2 60	2 60	2 60	0 41	0 41	0 41	0 64	0 64	0 64	0 20	0 23	0 23	3 07	3 07	3 07	2 33	2 33	2 33	0 53	0 54	0 54
Subtotal chronic morbidity effects			20 92	21 60	30 54	32 28	33 65	45 90	113 57	116 19	155.80	24 01	24.84	34 72	54 16	54 40	61 34	17 29	17.81	28 45	298 13	301 40	407 68	224 51	226 94	305 19	36 93	37 87	52 15
Subtotal acute morbidity effects			7 02	7 12	7 70	10 52	10 70	11.50	35 37	35 71	38.31	7 96	8 07	8.72	5.30	5.33	5.79	1 73	1.80	2.50	39 13	39.50	46 45	29.08	29 36	34 48	9.32	9 44	10.37
Subtotal ambient PM10			81 57	84 35	119 64	126 37	131 99	180 36	446 60	457 38	613.82	93 72	97 13	136 10	211 62	212 63	240 05	67.81	69 95	111 99	1,177 27	1 190 90	1,610.28	886 06	896.20	1,204 96	144 74	148 58	204.89
Subtotal ambient O3			1 04	1 09	1 09	1 62	1 70	1 70	5 39	5 55	5 55	1 19	1.25	1.25	0 30	0 32	0 32	0 11	0 13	0 13	3 09	3.23	3.23	2 27	2 37	2 37	1 26	1 32	1 32
Subtotal ambient NO2			3 03	3 04	3 04	4 43	4 44	4 44	13 14	13 17	13 17	3 40	3 40	3 40	1 50	1 50	1 50	0 50	0 51	0 51	16.30	16 33	16 33	11 96	11 98	11 98	3 94	3 95	3 95
Subtotal ambient CO			4 16	4 16	4 16	6.20	6 20	6.20	24 52	24 52	24 52	4 75	4 75	4 75	0 11	0 11	0 11	0 04	0 04	0.04	0 96	0 96	0 96	0 71	0 71	0 71	4 49	4 49	4 49
Total all emissions, pollutants, effects			90 04	92.87	128 17	139.00	144.71	193.09	491 06	502 02	658 46	103 34	106.81	145 78	213 56	214 58	242.00	68.46	70 67	112 71	1,197 73	1,211 53	1,630 91	901.09	911.36	1,220 12	154 70	158 61	214 92