EPA-AP-85

COST OF AIR POLLUTION DAMAGE:

a status report

U. S. ENVIRONMENTAL PROTECTION AGENCY

COST OF AIR POLLUTION DAMAGE:
a status report

Larry B. Barrett
and
Thomas E. Waddell
National Environmental Research Center

ENVIRONMENTAL PROTECTION AGENCY
National Environmental Research Center
Research Triangle Park, North Carolina
February 1973

The AP series of reports is issued by the Environmental Protection Agency to report the results of scientific and engineering studies, and information of general interest in the field of air pollution. Information reported in this series includes coverage of intramural activities and of cooperative studies conducted in conjunction with state and local agencies, research institutes, and industrial organizations. Copies of AP reports are available free of charge to Federal employees, current contractors and grantees, and nonprofit organizations - as supplies permit - from the Air Pollution Technical Information Center, Environmental Protection Agency, Research Triangle Park, North Carolina 27711, or from the Superintendent of Documents.

Publication No. AP-85

PREFACE

This report was conceived and undertaken in order to: (1) survey estimates made to date of the cost of air-pollution-induced damage; and (2) develop, on the basis of (1), an estimate of the national annual cost of damage from air pollution.

Fulfillment of these purposes entailed a survey of the literature on reported studies, as well as a review of unpublished and ongoing studies. The survey presents for the first time an opportunity to review critically and to compare the many fragmented studies on the cost of air pollution.

Those studies that survived critical review were amalgamated and a national estimate of the cost of damage was prepared. A by-product of this process was the identification of information shortages. Although the suggestion of further research topics was not the purpose of this report, such needs may now be more readily apparent.

The authors acknowledge that the scarcity of work in several effects areas necessitated assumptions that may have weakened the conclusions. These qualifications have been evaluated in each section of the report. While recognizing these limitations, the authors believe that the damage estimates presented are reasonable. The reader is cautioned against accepting the values as conclusive; they are reasoned, national estimates.

ACKNOWLEDGMENTS

The authors wish to acknowledge the continual encouragement provided by Paul H. Gerhardt and Paul A. Kenline over the course of the project. To a large measure, the impetus for this study came from Paul Gerhardt. A special thanks also goes to Brian W. Peckham for his counsel.

LIST OF TABLES

Table

1 Effects of Pollutants by Type of Receptor. 5
2 Resource Costs of Diseases Associated with Air Pollution . . . 9
3 Annual Health Costs of Air Pollution 11
4 Economic Value of Materials Exposed to Air Pollution 18
5 Summary and Rankings of Damage Factors 20
6 Estimated Costs of Air-Pollution-Resistant Materials 22
7 Costs of Shortened Service Life of Rubber Products 23
8 Estimated Costs of Dye Fading in Textiles. 25
9 Summary of Data from Mellon Institute Study on Soiling 34
10 Summary of Data from Beaver Report on Soiling. 35
11 Relationship of Cleaning and Maintenance Operations to Air Particulate Levels. 41
12 Cost of Cleaning Up after Boiler Malfunction 46
13 Amount of Money Respondents Would Pay Annually to Reduce Air Pollution in Morgantown, West Virginia 47
14 National Costs of Pollution Damage, by Pollutants, 1968. . . . 59
15 National Costs of Pollution Damage, by Source and Effect, 1968 60
16 Estimates of Nationwide emissions, 1968 61

LIST OF FIGURES

Figure

1 Total Benefits and Costs of Pollution Abatement. 3
2 Marginal Benefits and Costs of Pollution Abatement 3

CONTENTS

ABSTRACT vii
SUMMARY AND CONCLUSIONS. viii
CHAPTER 1. INTRODUCTION 1
PURPOSE. 1
BACKGROUND 1
Economics of Air Pollution 1
Functions for Cost of Pollution. 3
SCOPE. 4
METHOD 6
CHAPTER 2. HUMAN HEALTH EFFECTS 7
INDIVIDUAL STUDIES 7
Ridker - Morbidity and Mortality, Respiratory Diseases . . . 7
Lave-Seskin - Heart Disease and Cancer of Stomach, Esophagus, and Bladder 8
Riggan - Human Health and Motor Vehicle Pollution. 11
NATIONAL ESTIMATE. 12
CHAPTER 3. EFFECTS ON MATERIALS 13
INDIVIDUAL STUDIES 13
Uhlig - Corrosion of Metals. 13
Rust-Oleum Corporation - Corrosion of Metals 13
Hudson Painting and Decorating Company - Painting. 14
Stanford Research Institute - Electrical Contacts. 15
Midwest Research Institute - General Materials 16
Haynie - Corrosion of Galvanized Materials 21
Battelle-Columbus Laboratories - Rubber Products 21
Salvin - Textiles. 23
NATIONAL ESTIMATE. 25
CHAPTER 4. EFFECTS ON VEGETATION. 27
INDIVIDUAL STUDIES 27
Middleton and Paulus - Crop Survey 27
Lacasse, Weidensaul, and Carrol - Pennsylvania Plant Survey 27
Stanford Research Institute - Nationwide Survey. 29
NATIONAL ESTIMATE. 30
CHAPTER 5. SOILING. 33
INDIVIDUAL STUDIES 33

Mellon Institute - Pittsburgh Smoke Nuisance 33
Beaver Report - London Smog Episode. 34
Michelson and Tourin - Household Costs 35
Ridker - Urban Soiling 37
Ando - Costs of Air Pollution in Japan 38
Booz-Allen and Hamilton - Philadelphia Survey. 39
CONCLUSIONS. 42
CHAPTER 6. ANIMAL HEALTH EFFECTS. 43
CHAPTER 7. EFFECTS ON AESTHETIC PROPERTIES. 45
INDIVIDUAL STUDIES 45
Ridker - Soot Incident Survey. 45
Lawyer - Morgantown Study. 46
Williams and Bunyard - St. Louis Opinion Survey. 47
Medalia and Finkner - Clarkston, Washington, Study. 47
Williams and Edmisten - Nashville Perception Interviews. . . 48
Current Efforts. 48
CONCLUSIONS. 49
CHAPTER 8. EFFECTS ON RESIDENTIAL PROPERTY VALUES 51
INDIVIDUAL STUDIES 51
Ridker and Henning - Housing Market Indicators 51
Crocker and Anderson - Three-City Comparison 52
Zerbe - Toronto Study. 53
Peckham - Delaware Valley Study. 53
NATIONAL ESTIMATES 53
CHAPTER 9. LITIGATION 57
CHAPTER 10. COST OF AIR POLLUTION BY CATEGORIES 59
SOURCE EMISSIONS 59
ASSIGNMENT OF COSTS. 61
CHAPTER 11. DISCUSSION. 63
DAMAGE ESTIMATES 63
INFORMATION GAPS AND DATA LIMITATIONS. 64
REFERENCES 69

ABSTRACT

Published and unpublished estimates of the cost of air pollution damage are reviewed and national total estimates are given. In addition, cost estimates are developed for air pollution effects on human health, vegetation, materials, and residential property values. Estimates of the cost of air pollution damage to animals and to aesthetic aspects of the environment are not derived. Although discussed at length, the cost of soiling from air pollution is not estimated.

The total national cost in 1968 of damage resulting from air pollution was $16.1 billion, which includes $5.2 billion for residential property, $4.7 billion for materials, $6.1 billion for health, and $0.1 billion for vegetation. The cost for each effect is distributed among the several pollutants considered responsible for that effect according to their relative emissions. The same cost is distributed among the sources by their relative emissions. No cost function relations could be developed for various levels of pollution. As a consequence, the pivotal functions of marginal benefit are precluded. The $16.1 billion figure is considered to be a reasonable, conservative estimate.

SUMMARY AND CONCLUSIONS

Relatively few studies on the costs of air pollution damage have been conducted, and, of the approximately 36 studies extant, about one-third have not yet been published. In the studies conducted to date, air pollution damage to human health, vegetation, materials, and residential property values has been examined and costs for this damage have been derived.

The national cost of air pollution damage for 1968 totaled $16.1 billion, which includes $5.2 billion for residential property, $4.7 billion for materials, $6.1 billion for health, and $0.1 billion for vegetation. The cost of damage from soiling was excluded from this national estimate to avoid counting twice the costs of damage to property and materials.

The cost of each effect was distributed among the several pollutants considered responsible for that effect in proportion to the relative emissions of those pollutants from all sources. The same cost was distributed among air pollution sources according to their relative emissions.

The national total cost of air pollution for 1968 may be considered a function of the pollution levels in that year. No cost relations, however, could be developed for various levels of pollution. As a consequence, pivotal functions that are of marginal benefit are precluded.

Considering all factors, a $16.1 billion national cost of air pollution in 1968 is believed to be a reasonable, conservative estimate.

The subject of assessing the costs of air pollution would benefit from further study. The scope of estimates should be broadened to include more pollutants and more effects. Furthermore, costs should be related to specific pollutants or pollutant synergisms, rather than to broad pollutant categories, and to specific sources or source categories. Functions for the total cost of pollution require the application of more sophisticated estimation procedures than those used to date.

COST OF AIR POLLUTION DAMAGE:
a status report

CHAPTER 1. INTRODUCTION

PURPOSE

The study reported here was designed to survey the literature on estimation of costs associated with pollution damages and to provide for the first time a comparison of the many fragmented studies on air pollution costs. In addition, the study was designed to review work still in progress and those cost estimates completed but as yet unpublished.

Another purpose of the study was the development of estimates of the national total annual cost of air pollution. Cost-of-pollution studies that survived critical review were used in estimating these national costs. A by-product of this process has been the identification of deficiencies in data. Although it was not the purpose of this report to suggest further research topics, such needs have become readily apparent as a result of this survey.

BACKGROUND

Economics of Air Pollution[1,2]

Air pollution has a multitude of effects on man and his behavior, on his property, and on his environment. Normally, these effects have some economic value or cost, such as increased human morbidity, reduced property values, and diminished agricultural output.

The effects of air pollution typically occur external to the emitter. If these effects cost society but not the emitters, the tendency will exist to produce more pollution than is economically efficient. It may be shown by well-established economic principles that pollution should be reduced to the level at which marginal savings effected by pollution abatement equal the marginal cost of that abatement. In other words,

savings in the cost of pollution are equivalent to the benefits that accrue from pollution reduction. Accordingly, additional or marginal savings in the cost of pollution are marginal benefits.

Consider that the total cost of abatement rises as collection of pollutants increases, as shown by the total cost of abatement (TCA) curve in Figure 1. Consider also that the total cost of abatement rises at an increasing rate for equal incremental reductions in pollution. It can be said, then, that the marginal cost of pollution abatement rises as pollution falls. This is shown by the marginal cost of abatement (MCA) curve in Figure 2. This curve is the slope, or first derivative, of TCA for each level of pollutant collection.

Total savings in the cost of pollution, or total benefits, are considered to rise, but at a decreasing rate as abatement or collection increases. Figure 1 shows the total benefits of pollution abatement (TBA) and Figure 2 depicts the marginal benefits (MBA). If society were collecting an amount, OB, of its pollutants (Figure 1), an incentive to increase collections would exist, because, as may be seen from Figure 2, the additional benefit from collections, P_2, exceeds the additional cost, P_1. The most efficient level of collections is at OA (Figure 1), where the slopes of TBP and TCA are equal, or, in terms of Figure 2, where MBA equals MCA.

At the optimum level of pollution control, the total benefits exceed the total costs. One might wish to infer from this simple observation that there ought to be additional collections. It must be realized, however, that beyond a certain point the marginal costs of additional collection will exceed the marginal benefits and thus result in a reduction of net benefits.

The foregoing demonstration supports the need for two types of functional relations in analyzing the economics of pollution control. One function would seek to identify the costs of abatement for each level of pollution. A second function would relate the benefits derived from pollution reduction, or their parent, the cost of pollution, to each level of pollution. Total costs of abatement are addressed, at least partially, in annual reports to Congress.[3,4] Only the second, the cost-of-pollution function, is considered in this report.

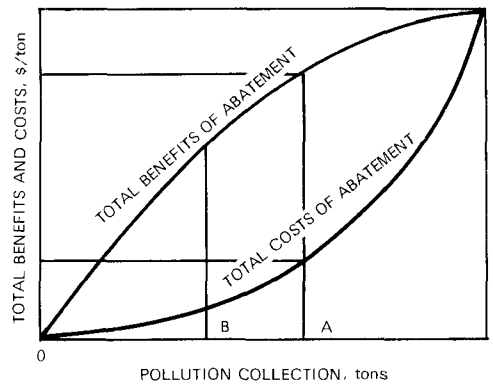

Figure 1. Total benefits and costs of pollution abatement.

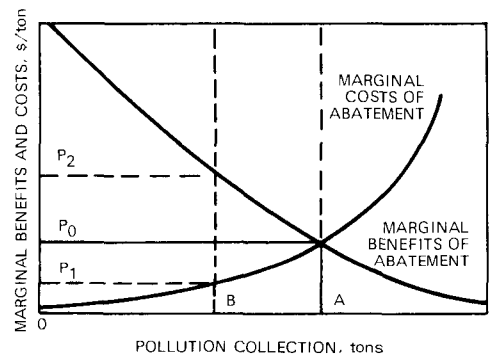

Figure 2. Marginal benefits and costs of pollution abatement.

Functions for Cost of Pollution

Ideally, cost-of-pollution functions should be constructed for each economic effect, for each pollutant, and for each emitter. Determination of economic effects should include direct and indirect effects.[5] Direct economic effects, such as vegetation damage, are the immediate result of pollution. Pollution costs are readily measured for many direct effects as the product of the number of units damaged and the price per unit.

Indirect effects of pollution, which are induced by the direct effects, include economic loss both to individuals and to market values. For example, a person is affected indirectly by pollution when he accepts a different job with a lower income in a cleaner city, an occurrence that is not uncommon. Van Arsdol,[6] for example, reports that Los Angeles populations are shifting away from sites seriously affected by air pollution.

Indirect market effects result from the accumulation of individual effects. As will be seen later, residential property value studies build on the market-price differentials associated with demands by the population for relocation away from pollution.

Calculation of the costs related to each type of pollution effect could result in some duplication in counting. It is conceivable, for example, that the costs of pollution measured by residential property price differentials might include some of the direct pollution costs of materials damage and soiling. As pointed out by Ridker,[7] however, no *a priori* way exists for discriminating among the various economic measurements of the cost of air pollution; therefore, both direct and indirect effects should be studied.

All pollutants or groups of pollutants that produce economic consequences should be included in the derivation of functional cost-of-pollution relationships for each type of pollutant effect. Table 1 lists effects of specific pollutants according to categories of receptors affected. Cost-of-pollution functions should be derived for each emitter in order to represent better the true balance of marginal costs and benefits of pollution control. Certainly, one of the costs of control is the expense of determining the cost-of-pollution functions; since the cost of obtaining information usually exceeds the gains associated with knowing these functions, emitters are seldom the smallest optimum air pollution control unit. Instead, aggregations by industry, region, or nation are the rule.

SCOPE

Eight measures of air pollution effects are discussed in this report; however, only four were used to estimate pollution costs: human health, materials, vegetation, and residential property. The others, which include soiling, animal health, aesthetic values, and litigations, were excluded because available data were inadequate for a cost determination.

Table 1. EFFECTS OF POLLUTANTS BY TYPE OF RECEPTOR

Pollutant	Receptor				
	Human health	Materials	Aesthetic properties	Vegetation	Animals
Particulate matter	x	x[a]	x[a]	x	x
Sulfur oxides	x	x	x	x	x
Oxidants	x	x	x	x	-
Carbon monoxide	x	-	-	-	-
Hydrocarbons	x	-	x	x	-
Nitrogen oxides	x	x	x	x	-
Fluorides	x	-	-	x	x
Lead	x	-	-	x	x
Polycyclic organic matter	x	-	-	-	x
Odors (including hydrogen sulfide)	x	x	x	-	-
Asbestos	x	-	-	-	-
Beryllium	x	-	-	x	x
Hydrogen chloride	x	x	-	x	-
Chlorine	x	x	-	x	x
Arsenic	x	-	-	x	x
Cadmium	x	-	-	-	x
Vanadium	x	-	-	-	-
Nickel	x	-	-	-	-
Manganese	x	-	-	-	-
Zinc	x	-	-	-	x
Copper	x	-	-	-	-
Barium	x	-	-	-	-
Boron	x	-	-	-	-
Mercury	x	x	-	x	x
Selenium	x	-	-	-	x
Chromium	x	x	-	-	-
Pesticides	x	-	-	x	x
Radioactive substances	x	-	-	-	x
Aeroallergens	x	-	-	-	-

[a]Includes soiling by particulate matter.

Six of the eight criteria can be considered indices of direct effects of air pollution: human health, deterioration of materials, soiling, vegetation damage, animal health, and aesthetic properties.

The cost of direct effects is determined by multiplying the extent of effects in a particular category times the economic value of that category. Two measures by which indirect effects may be estimated are differential residential property values and litigation. Residential property value studies concentrate on market dislocations, and litigation studies examine individual reparations.

Air pollution is believed to have pervasive effects - which may transcend other effects combined - in the biosphere and on geophysical processes. These effects of air pollution are not without some economic value, but until ecological relationships can be more clearly identified, economic analysis is premature.

Because data on the cost of damage resulting from specific pollutants are limited, presentation is restricted to the major pollutants: sulfur oxides, particulate matter, oxidants, carbon monoxide, and nitrogen oxides. Furthermore, since specific cost-of-pollution functions are not available for any emitters, only the broad aggregations are considered; namely, fuel combustion in stationary sources, transportation, industrial processes, solid-waste disposal, and miscellaneous sources.

METHOD

The study reported here proceeded in two general steps. First, what should be known about the costs of pollution was defined. Second, a survey of the literature was made to ascertain what is known. As a result, areas that have not been investigated can be identified, although such an identification is not explicitly made here.

What should be determined with respect to costs arising from air pollution damage has been described under "Background." What is already known is given in the remaining chapters, which present results of the literature search for each of the principal measures or economic effects of air pollution. Limitations of the report are described in the preceding section, "Scope."

Studies on the costs of air pollution are reviewed critically for the utility of their objectives, fulfillment of these objectives, and the analytical methods used. Where necessary, and where feasible, the results are adjusted to allow annual cost comparisons for 1968. The eight chapters in which measures of economic effects are discussed have been made as mutually exclusive as possible in order to minimize counting the same cost twice. Some overlapping is inevitable, however. Mitigating this are omissions, which weigh in favor of conservative damage estimates.

CHAPTER 2. HUMAN HEALTH EFFECTS

INDIVIDUAL STUDIES

It is not uncommon to see references that cite the health effects of air pollution separate from the economic effects. One inference from this division is that the effects of air pollution on health transcend economic values. In fact, however, economic values can be attached to health effects even though they are not easily measured. The separation may have been influenced largely by the absence of cost estimates for health relative to other types of damages.

As of 1970, only two studies estimating the health costs resulting from air pollution had been published.[8,9] In addition to these studies, there is a report internal to the National Environmental Research Center of the Environmental Protection Agency that deals with health effects from motor vehicle pollution.[10] The first two studies attempt to measure the cost of air pollution in terms of costs of health for the nation. The third study is restricted to an assessment of Federal revenues and expenditures growing out of morbidity and mortality related to automobile pollution.

All the studies follow the same general method: (1) an estimate is made of the total dollar value associated with health losses; (2) a coefficient is determined for the share of this value attributable to air pollution; and (3) total health losses are multiplied by the coefficient to determine the value of health losses associated with air pollution.

The proportion of health losses associated with air pollution is determined to be a constant in all the studies. Thus the cost-of-pollution function for health may be taken to be linear.

Ridker - Morbidity and Mortality, Respiratory Diseases

The earliest published attempt at estimating the cost of damages to health from air pollution is that of Ridker,[8] who estimated the total national cost of morbidity and mortality for diseases associated with the respiratory system. The diseases considered, chosen partly on the basis of crude empirical determinations and partly on reasonable hypotheses, were cancer of the respiratory system, chronic and acute bronchitis, pneumonia, emphysema, asthma, and the common cold.

The cost estimates for each disease included - where possible - the costs of treatment, absenteeism, premature death, and premature burial. Treatment costs were estimated for each disease using per capita values of drug manufacturers' shipments. Absenteeism costs were the product of days lost for each disease times the average annual earnings of those suffering from that disease. The costs of premature death were the 1958 value of future earnings lost. Discount rates of 5 and 10 percent were applied to expected lifetime earnings from full-time employment. Costs of premature burial represented the difference between the present cost of burial and the present value of future expected burial costs discounted at rates of 5 and 10 percent. The total costs for 1958 yielded a total economic loss from these diseases of $1.990 billion at a discount rate of 5 percent. Table 2 presents the results of this study.

Ridker estimated that 18 to 20 percent of the approximately $2 billion in national health costs results from air pollution. His coefficients of 0.18 and 0.20 are taken from two studies relating, in one case, respiratory mortality rates and, in the other, lung cancer mortality rates to urban and rural areas. The coefficients are corrected for age, sex, race, smoking habits, and the proportion of population in the United States that is urban. Thus the damage to health from air pollution in 1958 had an economic value of $360 to $400 million.

Ridker considered the estimate to be quite conservative. For one thing, he recognized the absence of expenditures made to avoid air pollution, such as moving costs and possible reduced earnings of those who migrate to areas of lower pollution because of their health. He did not take into account the full value of housewives' services lost because of death or illness related to air pollution. No attempt was made to include the psychic costs associated with death or illness. Data limitations prevented estimation of the full costs of some of the diseases considered and also prevented consideration of certain diseases.

Ridker was unable to relate morbidity and mortality to specific types of pollution, and therefore did not attempt to construct individual damage functions.

Lave-Seskin - Heart Disease and Cancer of Stomach, Esophagus, and Bladder

The Lave-Seskin study[9] expanded the number of diseases covered by Ridker. In particular it included air pollution damages to health in

Table 2. RESOURCE COSTS OF DISEASES ASSOCIATED WITH AIR POLLUTION[8]

Type of cost	Costs[a] associated with selected diseases, 10^6							
	Cancer of the respiratory system	Chronic bronchitis	Acute bronchitis	Common cold	Pneumonia	Emphysema	Asthma	Total
Premature death	518	18.0	6.0	na[b]	329	62	59	992.0
Premature burial	15	0.7	0.2	na	13	2	2	32.9
Treatment	35	89.0	na	200	73	na	138	535.0
Absenteeism	112	52.0	na	131	75	na	60	430.0
Total	680	159.7	6.2	331	490	64	259	1,989.9

[a]Using a discount rate of 5 percent.
[b]Not available.

the form of heart disease and of cancer of the stomach, esophagus, and bladder.

Health costs from all causes have been estimated by Rice,[11] who included the costs of premature death, treatment, and absenteeism. These costs were broken down by major disease category except for costs of some types of treatments and of expenditures for items such as drugs, eyeglasses, and school health services. Lave and Seskin considered only those costs given by disease category. The cost of premature death was calculated as foregone earnings discounted at 6 percent. All costs were computed on the basis of 1963 data.

Lave and Seskin consider the evidence relating air pollution and health to be quite good in the case of bronchitis and lung cancer, and, although evidence correlating air pollution with heart disease and nonrespiratory cancers is not as good, they believe that a consideration of all factors suggests causality for these diseases as well.

Approximately half the foregone income and current medical expenses associated with bronchitis morbidity and mortality are ascribed to air pollution. The coefficient for lung cancer that is attributable to air pollution is 0.25. In the other categories, air pollution is responsible for 15 percent of the damages associated with nonrespiratory lung cancers, 25 percent of all respiratory diseases other than bronchitis, and 10 percent of the cardiovascular disease. These coefficients were estimated by regressions that were run on data from published epidemiological studies in which morbidity rates were expressed as functions of air pollution and selected socioeconomic variables.

The total annual cost for increases in human morbidity and mortality caused by air pollution is $2.08 billion for 1963; stated inversely, a 50 percent reduction in air pollution would result in an annual savings of $2.08 billion. The index that Lave and Seskin prefer is that air pollution damage amounts to 4.5 percent of all the economic damage associated with morbidity and mortality. Table 3 summarizes their results.

Lave and Seskin consider their estimate to be conservative on several grounds. They argue that, for conceptual meaning, the willingness of an individual to pay for improved health or longevity, given a certain level of income and wealth, is the true measure of health costs

Table 3. ANNUAL HEALTH COSTS OF AIR POLLUTION[9]

Disease	$ billion
Respiratory	
Bronchitis	0.500
Other	0.722
Subtotal	1.222
Cancer	
Lung	0.033
Other	0.357
Subtotal	0.390
Cardiovascular	0.468
Total	2.080

attributable to air pollution. They consider the sum of foregone income and current expenditures that result from morbidity and mortality from air pollution to be a gross underestimate of willingness to pay. Some health costs may have been overlooked, so that the estimate may be even more conservative. Finally, the exclusion of some treatment costs results in an underestimate of true damage costs.

If one accepts with Ridker the inclusion of premature burial costs in damage estimates, then their absence from the Lave-Seskin estimate further corroborates the conservative nature of that estimate. Yet Lave and Seskin suffer from the same difficulties as Ridker in deriving meaningful estimates. They assume linear relationships between air pollution and health even though it is not possible to relate health costs to levels of pollution or to sources of pollution. The result of their efforts, then, is another gross estimate that can only be suggestive of the direction air quality management programs should take, but not of the level of effort required.

Riggan - Human Health and Motor Vehicle Pollution

The objective of the two previous studies was to quantify the effects of air pollution on human health and to estimate the economic benefits that would result from abatement. Riggan[10] set a more limited objective of investigating the effects of motor vehicle pollution on human health. He made a study of the effects of automobile pollutants and their derivatives on lung cancer, bronchitis, heart disease, and motor vehicle accidents. Although some estimates were generated, they are too preliminary for reporting here.

NATIONAL ESTIMATE

Lave and Seskin calculated the national cost of air pollution damage to health as $2.08 billion for 1963. This represents a savings that would result from a 50 percent abatement of air pollution. Under their assumption that the functional relationship of pollution and mortality is linear, a 100 percent reduction in air pollution would result in a savings of $4.16 billion in that year. This amount includes the discounted 1963 value of future earnings lost because of mortality and the costs of treatment, prevention, and morbidity. Because an approach based on discounted, future earnings lost places value only on those people in the working force, homemakers who do not work for an income, as well as retired individuals over 65, are not valued. Thus, the estimate of $4.16 billion surely is an understatement of the true cost of deaths and illnesses caused by air pollution.

The authors believe that some caveats should be mentioned. Lave and Seskin seem to have a stronger faith in the magnitude, sign, and statistical significance of their regression coefficients than their analysis would seem to support. Their many statements about the causes of these "effects" are not as justified as the authors seem to conclude. Yet in fairness, despite the authors' questionable data, analysis, and extended discussion of their results, their final cost estimate is believed to be reasonable.

A national economic estimate of health losses from air pollution may be calculated for 1968. The 1963 loss of $4.16 billion amounted to 0.70 percent of the 1963 Gross National Product (GNP) of the United States, which was $590.5 billion.[12] Assuming that the economic loss was the same percentage of the 1968 GNP, which was $865.7 billion,[13] the cost of air pollution effects on health in 1968 was $6.06 billion.

CHAPTER 3. EFFECTS ON MATERIALS

INDIVIDUAL STUDIES

Air pollution has a variety of effects on materials, including corrosion of metals, deterioration of materials and paints, and fading of dyes. Several attempts have been made to estimate the economic losses attributable to the detrimental effects of air pollution on materials. The resulting reports are listed and discussed in the following paragraphs.

Uhlig - Corrosion of Metals

The first serious attempt at estimating economic losses resulting from corrosion of metals was made by Uhlig in 1950.[14] He distinguished between two types of losses: (1) direct losses resulting from the cost of protecting or replacing corroded equipment or parts; and (2) indirect losses resulting from shutdown, over-design, loss of product, inefficiency, explosion, and contamination. The total corrosion bill was estimated to be $5.4 billion. In Uhlig's study, air pollution was merely implicated as a causal agent of corrosion.

Rust-Oleum Corporation - Corrosion of Metals

The Rust-Oleum Corporation[15] updated the Uhlig information and estimated the rust bill for the United States as $7.5 billion in 1958. According to this study, rusting is not so great a problem in rural as in urban atmospheres because industrial fumes and acids are not present in rural areas to any appreciable extent. Corrosion in industrial atmospheres was associated mainly with the sulfur-containing gases, which become dissolved in water to form acid mists that act as electrolytes. Chlorides were also blamed as a corrosive agent in many industrial environments.

The data employed in constructing the estimates were acquired from exposed metal plates placed in cities that have had a population of 10,000 people or more for the past 25 years. Some of the costs making up the $7.5 billion estimate included, among others, $500 million annually for corrosion to railroads and $1.25 billion to homeowners

for corrosion damage. The estimate encompassed all types of corrosion, and to determine the portion attributed to SO_x in particular would necessitate a number of weak assumptions. The study dealt with gross estimates only and gave no justification or basis for these estimates.

Hudson Painting and Decorating Company - Painting

The Hudson Painting and Decorating Company estimated, in 1967, the increased costs of painting resulting from air pollution damage to paint in New York.[16] Using as a starting point the sum grossed through the sale of paint and allied materials manufactured in New York and New Jersey in 1963, they arrived at an amount attributable to air pollution effects through the assumptions and calculated sums given below:

		$ billion
1.	Sum grossed through the sale of paint and allied materials manufactured in New York and New Jersey in 1963.	0.238
2.	Assumptions and resultant sums:	
	a. That two-thirds of this dollar volume was for metropolitan New York.	0.158
	b. That 1967 prices had increased 10 percent over 1963 prices and that materials were sold to the contractor at a 20 percent markup.	0.209
	c. That the cost of labor was three times the material cost and that the common method of pricing a paint job was to double the labor cost.	1.254
	d. That contractors do one-third of the painting done.	0.418
	e. That 15 percent is deducted for any overstatement.	0.350
	f. That about one-third of the cost of painting is assumed to be attributable to air pollution damage.	0.150

The assumptions as presented here are speculative, and the use of data such as these yields results of questionable value.

Stanford Research Institute - Electrical Contacts

The objective of the Stanford Research Institute study[17] was to determine whether air pollution creates problems of economic significance in the operation of electrical contacts; and, if it does, to study the cause-and-effect relationships. Information was compiled by searching the literature as well as by consulting manufacturers through letters, telephone calls, and on-site visits. The major costs that were investigated were: (1) the direct cost of plating contacts with precious metals and (2) the indirect cost associated with air-conditioning and purification.

The types of contacts usually plated are switches, relays, connectors, potentiometers, and commutators that are used mainly in the electronics and communications industries. More money is spent combatting the effects of SO_2 and H_2S air pollution on low-voltage electrical contacts than is spent combatting all other air pollution effects on electrical devices combined. Organic gases form "frictional" polymers on sliding contacts, whereas particulate pollutants are a problem because particulate matter is an excellent adsorber of H_2O and corrosive agents. The effects of organic gases and particulates are of less importance, however, than the effects of SO_2 and H_2S.

It was estimated in this study that $20 million is spent on plating contacts with precious metals to prevent air pollution corrosion and $25 million is spent annually on air-conditioning and purification. Another $4 million is spent annually for washing insulators; $5 million is spent for research and development by firms whose products might be affected by air pollution; and an estimated $10 million is spent because of equipment failures. The total annual expenditure is approximately $65 million.

The most important conclusion drawn from this study is that the damage to electrical contacts from air pollution is not as serious as originally thought. In addition, the estimated annual cost of $65 million was concluded to be unnecessarily high because two or more individually effective countermeasures are being applied simultaneously to minimize losses. Furthermore, losses will decrease as cheaper materials that are more resistant to air pollution are used in electrical contacts.

A critical review of the study has shown that the assumptions on which estimates of expenditures for air-conditioning and purification

were based were somewhat questionable, but they were perhaps the best that could be made.

Midwest Research Institute - General Materials

The most comprehensive survey of the economic effects of air pollution on materials was undertaken by Salmon of Midwest Research Institute.[18] The objectives of the study were: (1) to identify the materials, air pollutants, and environmental parameters that should be studied in order to assess the economic value of air pollution damage to materials; (2) to analyze systematically the physical and chemical interactions among the variables identified in (1) above for the purpose of determining cause-effect relationships; (3) to determine, where possible, the pollutant-dosage/material-response relationship for materials that are significant because of their relative economic value, and to indicate how this may be done where such relationships are presently defined; and (4) to translate the pollutant-dosage/material-response relationship into a pollutant-dosage/monetary-loss function.

Information was gathered through literature searches, and by personal, mail, and telephone interviews. Economic losses from damage to materials were attributed either to damaged properties or to impaired serviceability. The basic problem was to determine the extent of economic damage associated with a given level of physical or functional damage. This problem was approached in different ways, depending on the material and its application. In some cases a "percentage condition" approach was adequate, with economic damage considered to have been incurred at the same rate as the physical damage. The replacement of damaged materials was also included in this category, with replacement presumably occurring at the 100 percent damage (or zero percent condition) level. In other cases, a cost-of-prevention or cost-of-restoration basis proved more suitable.

The economic value of material exposed to air pollution was calculated as the product of the annual production volume in dollars, times a weighted average economic life of the material (based on usage), times a weighted average factor for the percentage of the material that is exposed to air pollution. The in-place or as-used value of the material was estimated by inclusion of a labor factor. The rate of economic loss was calculated as the product of the economic value of material exposed to air pollution times a value of interaction; the

latter was calculated by estimating the difference between the rate of material deterioration in a polluted environment and that in an unpolluted environment. The interaction value is expressed as dollars lost per year. The results of the operations described are presented in Table 4. The total value of materials exposed to air pollution and values of interaction between the various materials and pollutants have been combined to produce a single figure - a damage factor - that represents the extent of economic damage attributable to air pollutants. These damage factors are summarized and ranked in Table 5.

To interpret the results in Table 5, it is imperative that one realize that the individual material loss estimates were made to determine relative importance rather than actual value. The sum, however, of the economic losses - $3.8 billion in 1968 - appears to be a reasonable estimate. If it is assumed that this list of materials represents only 40 percent of the total value of materials exposed to air pollution, and that damage functions for the other 60 percent are similar, then the total loss resulting from the chemical attack of materials by air pollution is estimated at $9.5 billion.

The pollutants, in decreasing order of economic importance, and the materials they damage are as follows:

1. SO_x: metals, cotton, finishes, coatings, building stone, paints, paper, and leather.

2. O_3: rubber, dyes, and paints.

3. NO_x: dyes and paints.

4. CO_2: building stone.

5. Particulate matter: stone, clay, and glass.

The study concluded that organic pollutants (hydrocarbons and aldehydes) are not damaging to materials, except for elastomers, which they damage to some extent. Much information was available on the effects of air pollutants on metals and rubber. Some information was available on fibers such as cotton and nylon, but little was available on paints, paper, and leather. Virtually no information existed on plastics, wool, wood, and concrete. Direct quantitative correlations of damage with specific pollutants have been made (dose-response) only

Table 4. ECONOMIC VALUE OF MATERIALS EXPOSED TO AIR POLLUTION[18]

Rank	Material	Annual production, $ billion	Economic life, yr	Exposure index	Labor content factor	In-place material exposed to air pollution, $ billion
1	Cement and concrete	6.081	40	0.5	2.6	316.21
2	Copper	2.041	22	0.5	2.4	54.88
3	Aluminum	3.380	16	0.5	2.0	54.08
4	Brass and bronze	0.600	40	0.6	2.3	33.12
5	Flat glass	0.592	30	0.7	2.3	28.59
6	Zinc	0.540	36	0.6	2.3	26.83
7	Building brick	0.375	40	0.7	2.3	24.15
8	Paint	2.587	4	0.7	3.3	23.90
9	Bituminous materials	1.106	10	0.7	2.9	22.45
10	Stainless steel	1.000	15	0.6	2.1	18.90
11	Wood	10.875	30	0.03	1.8	17.61
12	Synthetic rubber	6.660	3	0.7	1.0	14.00
13	Carbon steel	13.000	18	0.02	2.3	10.76
14	Nickel	0.646	14	0.5	2.3	10.40
15	Building stone	0.095	50	0.7	2.3	7.65
16	Paper	20.927	3	0.06	2.0	7.53
17	Magnesium	0.590	12	0.4	2.3	6.5
18	Gold	0.124	39	0.6	2.0	5.80
19	Tin	0.506	13	0.4	2.1	5.53
20	Leather	5.146	5	0.2	1.0	5.15
21	Gray iron	3.216	20	0.03	2.0	3.86
22	Cotton (fiber)	3.336	6	0.1	1.9	3.80
23	Wool (fiber)	1.085	6	0.2	1.9	2.48
24	Urea and melamine (plastic)	0.420	27	0.2	1.0	2.27
25	Alloy steel	2.160	21	0.02	2.4	2.18
26	Lead	0.728	5	0.3	2.0	2.18
27	Phenolics (plastic)	0.366	27	0.2	1.0	1.98
28	Refractory ceramics	0.700	6	0.2	2.3	1.93
29	Polyvinyl chloride (plastic)	0.700	11	0.2	1.0	1.54

Table 4 (continued). ECONOMIC VALUE OF MATERIALS EXPOSED TO AIR POLLUTION[18]

Rank	Material	Annual production, $ billion	Economic life, yr	Exposure index[a]	Labor content factor	In-place material exposed to air pollution, $ billion
30	Clay pipe	0.103	50	0.1	2.8	1.44
31	Polyesters (plastic)	0.228	30	0.2	1.0	1.37
32	Polyethylene (plastic)	0.975	6	0.2	1.0	1.17
33	Chromium	0.113	10	0.4	2.4	1.08
34	Acrylics (plastic)	0.278	12	0.3	1.0	1.00
35	Nylon (fiber)	0.830	6	0.1	1.9	0.95
36	Polystyrene (plastic)	0.850	6	0.2	1.0	0.85
37	Cellulose esters (fiber)	0.717	6	0.1	1.9	0.82
38	Polypropylene (plastic)	0.403	8	0.2	1.0	0.64
39	Acrylonitrile-butadiene-styrene (plastic)	0.278	11	0.2	1.0	0.61
40	Malleable iron	0.486	20	0.03	2.0	0.58
41	Silver	0.105	6	0.3	3.0	0.57
42	Natural rubber	1.790	6	0.05	1.0	0.54
43	Molybdenum	0.238	37	0.02	2.9	0.51
44	Epoxies (plastic)	0.147	16	0.2	1.0	0.47
45	Cellulosics (plastic)	0.228	7	0.2	1.0	0.40
46	Rayon (fiber)	0.288	6	0.1	1.9	0.33
47	Carbon and graphite	0.339	12	0.02	2.4	0.3
48	Acrylics (fiber)	0.170	6	0.1	1.9	0.19
49	Acetate (fiber)	0.165	6	0.1	1.9	0.19
50	Nylons (plastic)	0.106	8	0.2	1.0	0.17
51	Polyester (fiber)	0.136	6	0.1	1.9	0.16
52	Acetate (plastic)	0.058	10	0.2	1.0	0.12
53	Polyolefins (fiber)	0.036	6	0.1	1.9	0.04

[a]The exposure index is the estimated fraction of material that is exposed directly to a polluted atmosphere.

Table 5. SUMMARY AND RANKINGS OF DAMAGE FACTORS[18]

Rank	Material	Value of interaction $/yr	In-place value of materials exposed, $ billion	Economic loss, $ million
1	Paint	0.50×10^{-1}	23.9	1195.0
2	Zinc	0.29×10^{-1}	26.83	778.0
3	Cement and concrete materials	0.10×10^{-2}	316.21	316.0
4	Nickel	0.25×10^{-1}	10.40	260.0
5	Cotton (fiber)	0.40×10^{-1}	3.80	152.0
6	Tin	0.26×10^{-1}	5.53	144.0
7	Synthetic rubber	0.10×10^{0}	14.00	140.0
8	Aluminum	0.21×10^{-2}	54.08	114.0
9	Copper	0.20×10^{-2}	54.88	110.0
10	Wool (fiber)	0.40×10^{-1}	2.48	99.2
11	Natural rubber	0.10×10^{0}	0.54	54.0
12	Carbon steel	0.50×10^{-2}	10.76	53.8
13	Nylon (fiber)	0.40×10^{-1}	0.95	38.0
14	Cellulose ester (fiber)	0.40×10^{-1}	0.82	32.8
15	Building brick	0.10×10^{-2}	24.15	24.2
16	Urea and melamine (plastic)	0.10×10^{-1}	2.27	22.7
17	Paper	0.30×10^{-2}	7.53	22.6
18	Leather	0.40×10^{-2}	5.15	20.6
19	Phenolics (plastic)	0.10×10^{-1}	1.98	19.8
20	Wood	0.10×10^{-2}	17.61	17.6
21	Building stone	0.23×10^{-2}	7.65	17.6
22	Polyvinyl chloride (plastic)	0.10×10^{-1}	1.54	15.4
23	Brass and bronze	0.42×10^{-3}	33.12	13.9
24	Polyesters (plastic)	0.10×10^{-1}	1.37	13.7
25	Rayon (fiber)	0.40×10^{-1}	0.33	13.2
26	Magnesium	0.20×10^{-2}	6.50	13.0
27	Polyethylene (plastic)	0.10×10^{-1}	1.17	11.7
28	Acrylics (plastic)	0.10×10^{-1}	1.00	10.0
29	Alloy steel	0.40×10^{-2}	2.18	8.7
30	Polystyrene (plastic)	0.10×10^{-1}	0.85	8.5
31	Acrylics (fiber)	0.40×10^{-1}	0.19	7.6
32	Acetate (fiber)	0.40×10^{-1}	0.19	7.6
33	Polyesters (fiber)	0.40×10^{-1}	0.16	6.4
34	Polypropylene (plastic)	0.10×10^{-1}	0.64	6.4
35	Acrylonitrile-butadiene-styrene (plastic)	0.10×10^{-1}	0.61	6.1
36	Epoxies (plastic)	0.10×10^{-1}	0.47	4.7
37	Cellulosics (plastic)	0.10×10^{-1}	0.40	4.0
38	Bituminous materials	0.10×10^{-3}	22.45	2.2
39	Gray iron	0.50×10^{-3}	3.86	1.9
40	Nylon (plastic)	0.10×10^{-1}	0.17	1.7
41	Polyolefins (fiber)	0.40×10^{-1}	0.04	1.6
42	Stainless steel	0.85×10^{-4}	18.90	1.6
43	Clay pipe	0.10×10^{-2}	1.44	1.4
44	Acetate (plastic)	0.10×10^{-1}	0.12	1.2
45	Malleable iron	0.16×10^{-2}	0.58	0.9
46	Chromium	0.75×10^{-3}	1.08	0.8
47	Silver	0.12×10^{-2}	0.57	0.7
48	Gold	0.10×10^{-3}	5.80	0.6
49	Flat glass	0.10×10^{-4}	28.59	0.3
50	Lead	0.11×10^{-3}	2.18	0.2
51	Molybdenum	0.25×10^{-3}	0.51	0.1
52	Refractory ceramics	0.10×10^{-4}	1.93	0.02
53	Carbon and graphite	0.10×10^{-5}	0.30	0.00
Total				3800.00

for zinc and SO_2, several varieties of rubber and O_3, and for cotton and SO_2. In summary, major information shortages exist concerning air pollution effects on concrete, paints, fibers, and plastics.

This effort is a landmark in summarizing the effects of air pollution on materials and lays the groundwork for more intensive studies. Some of the data, such as those used in formulating interaction and corrosion rates, are of questionable validity; and in a quantitative analysis, such as that used here, results are only as good as the data used. Only the direct effects were investigated; the "value" of service was not assessed. As Salmon cautioned in his report, deterioration of materials indicated susceptibility to economic loss, or potential loss. The results could not be interpreted as economic loss actually incurred. A primary purpose of the study was the ranking of materials to indicate relative measures of air-pollution-induced damage.

Haynie - Corrosion of Galvanized Materials

On the basis of work done by Midwest Research Institute on zinc, Haynie[19] has suggested that the annual cost of the corrosion of galvanized steel, including prevention costs, is $4.5 billion. This estimate is the total of several costs: (1) costs of coil coating for corrosion prevention, (2) costs of substituting aluminum sheet for steel because of corrosion, and (3) replacement costs. By taking different fractions for various product forms, different economic lives, and different "in-place" to zinc ratios and combining them correctly, the extreme values were calculated. The minimum annual value is $1.4 billion and the maximum is $13 billion. Because of the lack of evidence for most of the assumptions used in estimating the many different fractional parts, the minimum value of $1.4 billion probably reflects the most defensible estimate.

Battelle Columbus Laboratories* - Rubber Products

The Battelle study,[20] entitled, "Survey and Economic Assessment of the Effects of Air Pollution on Elastomers," correlates technical information relating to the effects of air pollution on rubber products with an estimation of the yearly cost of this pollution damage. Costs measured are: (1) increased expenditures required at the manufacturers'

---

*Formerly the Battelle Memorial Institute.

level to provide products that are resistant to atmospheric pollutants (these costs are normally passed on to the consumer) and (2) direct economic loss on the part of the consumer in the form of shortened useful life of products. The combined costs to the consumer were used in estimating the total cost of pollution.

The literature was reviewed for technical information and questionnaires were sent to industry to determine the cost of atmospheric pollution at the manufacturing level. Sixty questionnaires were sent to firms representing the broad spectrum of the rubber industry; 30 were returned, and many of them had unanswered questions.

In estimating the cost of atmospheric pollution at the rubber product manufacturers' level, two independent calculations were made. One was based on the information supplied from the questionnaires sent to industry, whereas the second calculation was based on the total of individual compounding costs.

Analysis of the industry questionnaire and some extrapolation of results revealed that the yearly cost for rubber products of $50.7 million represents the added yearly cost of compounding new or improved products. To calculate the added cost at the manufacturers' level, it was necessary to add individually, where available, the estimated costs of resistant polymers, antiozonants, waxes, protective finishes, and wrappings. Estimated costs are given in Table 6. The two figures of $50.7 million and $56.4 million, which are costs at the manufacturers' level, compare favorably. Industry estimates suggest that an average retail price is three times the manufacturing cost. If this is true, then at the retail level the cost of compounding would be approximately $150 million to $170 million.

Table 6. ESTIMATED COSTS OF AIR POLLUTION RESISTANT MATERIALS

	$ million
Resistant polymers	$17.31
Antiozonants	34.00
Waxes (50% of total)	5.00
Protective finishes	?
Wrappings	?
Research for compounding	?
Total (approximate)	$56.40

The information in Table 7 summarizes the cost of early replacement of rubber products (shortened service life). The total annual cost of air pollution as it affects the rubber industry is estimated to be $150 million to $170 million plus $216.7 million, or approximately $380 million. The first is the added cost at the manufacturers' level that is passed on to the consumer in the form of an increased price for the product. The second cost is for the early replacement of rubber products because of shortened service life, a cost that must be borne directly by the consumer.

Table 7. COSTS OF SHORTENED SERVICE LIFE OF RUBBER PRODUCTS

	$ million
Tires	$ 32.2
Innertubes	-
Footwear	-
Mechanical goods	27.6
Medical goods	100.5
Belting	21.9
Hoses	34.5
Total	$216.7

Finally, it was determined that almost all damage to rubber is done by ozone. Very little is known about the effects of other pollutants on elastomers. Virtually no information is available on the damage threshold for rubber, so that few or no data are available for the construction of a meaningful damage function.

This study is deficient because it deals only with gross figures. Labor costs in connection with the early replacement of rubber products, not considered in this report, would add substantially to any estimate of losses. Although an estimated annual cost of almost $400 million was presented, this figure has no sound basis.

Salvin - Textiles

Victor S. Salvin, of the University of North Carolina, is engaged in a study of economic losses resulting from air pollution damage to textiles.[21] The objectives of the study are: (1) to conduct a comprehensive survey to identify and document known and suspected air-pollution-induced effects on various textiles and dyes and (2) to survey the

economic losses resulting from air pollution effects on textile fibers and dyes.

Aspects of the problem to be discussed with manufacturing and industrial representatives are: (1) extent and mechanisms of air pollution damage, (2) preventative measures required, and (3) research costs. The costs of dyes and dyeing processes (preventative measures) will be obtained from the suppliers of dyes. Each industry will have a technology committee that will serve as a clearinghouse for information. Production figures for each industry, awareness in each industry of the aspects of air pollution damage that affect it, and actions by major manufacturers in offering goods with increased performance potential will be documented. The costs in this case will be those associated with research, quality control, the use of expensive dyes and textiles, and the use of associated costly new procedures. Consumer awareness of air pollution effects will be assessed through direct interviews and the use of questionnaires. The annual cost of air pollution damage to textile fibers and dyes will be estimated. This economic analysis will not only include estimates of costs resulting from damage but also the costs of steps taken to mitigate or eliminate damage, such as (1) substituting more costly materials, (2) using additional protection, (3) using more expensive production techniques, (4) initiating closer quality control, (5) conducting relevant research and development, (6) conducting environmental testing, and (7) providing consumer sales services.

Preliminary estimates of the costs of the fading of dyes on textiles caused by air pollutants are given in Table 8. These numbers are tentative and qualified, inasmuch as the final figures will be based upon more complete production data and remedial processing costs. This is the only information of its type available. There are few or no supporting economic data and none that would contribute to the construction of any damage function. Other preliminary estimates from Salvin[22] indicate that the total economic loss caused by air pollution damage to textiles and fibers is estimated to be $2 billion annually. Included in this figure are: (1) $300 million to $400 million for the shortened useful life of cotton and nylon resulting from the disintegration of the fibers, (2) $800 million for the cost of extra laundering and dry cleaning (this is considered in the section on soiling), (3) $350 million for the fading of fabrics, and (4) the remainder for the discoloration of white fabrics.

Table 8. ESTIMATED COSTS OF DYE FADING IN TEXTILES

Pollutant	Effect	$ million
NO_x	Fading on acetate and triacetate	$ 72.800
	Fading on viscose rayon	21.600
	Fading on cotton	22.050
	Yellowing of white acetate-nylon-Spandex	5.650
	Subtotal	$122.100
O_3	Fading on acetate and triacetate	24.985
	Fading on nylon carpets	41.500
	Fading on permanent-press garments	17.050
	Subtotal	83.535
	Total	$206.000

NATIONAL ESTIMATE

The Midwest Research Institute report offers evidence on which a reasonable national estimate can be based. These data generally will be used except for those cases in which more intensive analyses have been made, such as costs of air pollution effects on galvanized steel and elastomers. Thus, to prevent any double counting, the material loss values of zinc, synthetic and natural rubber, and carbon and alloy steel were omitted from Table 5 in order to obtain an estimate of material loss for categories other than galvanized steel and rubber.

The $9.5 billion estimate is not used because of the lack of any data that would suggest a similar response to air pollution of those materials not included as compared to those included in the $3.8 billion figure. The assumption is made as well that those materials represented in Table 5 are the ones most affected physically, and thus economically, by air pollution. For consistency with other estimates, the conservative figure of $3.8 billion is considered only in the national estimate.

If the above materials are omitted from the value in Table 5, the economic loss then becomes $2.766 billion. If Haynie's value of $1.400 billion for the cost of corrosion of galvanized steel is considered, plus the Battelle estimate of $0.380 billion for effects on elastomers, plus the Salvin estimate of $0.206 billion lost because of the fading of

dyes-which was not considered in the Midwest study-then the total cost of materials is estimated at $4.752 billion annually.

In all probability, the property-value approach includes implicitly some portion of the material costs estimated here. It is assumed, however, that those material costs contained in the differential property-value approach are not a large proportion of the total costs of air pollution damage to materials.

CHAPTER 4. EFFECTS ON VEGETATION

Damage to vegetation as a result of air contaminants has been recorded in the United States since the turn of the century. What was once a problem associated only with point sources has evolved into a widespread problem generated by urban expansion. The problem is severe enough that commercial and non-commercial production of crops and forests in many areas has been jeopardized and in some cases discontinued.

Several approaches have been used to assess the economic losses resulting from air pollution damage to plants. One approach has been to survey air-pollution-induced vegetation losses on a statewide basis by using existing manpower at the local level, such as county agricultural agents and commissioners. From these estimates of damage at the local level, extrapolations can be made that provide an estimate of gross national damages. Another approach is that of incorporating data on pollutant emissions, crop statistics, and meteorological parameters into a predictive model of plant losses; this model is subject to continual refinement as the true situation at the local level is better defined.

INDIVIDUAL STUDIES

Middleton and Paulus - Crop Survey

Economic assessment by manpower at the local level was first done in the California survey made in 1949. A somewhat similar survey in 1955, reported by Middleton and Paulus,[23] was designed to show the location of injury, the crops injured, and the toxicant responsible for the damage. Specialists in agriculture throughout the state were trained as crop survey reporters. The survey covered four categories of crops: field, flower, fruit, and vegetable.

Lacasse, Weidensaul, and Carrol - Pennsylvania Plant Survey

A program similar to that in California was established in Pennsylvania in 1969, where a training course for county extension agents, university extension specialists, and state forestry extension personnel was held to teach them how to identify and evaluate air pollution damage to plants.[24] The objectives for the survey were: (1) to estimate scientifically the total cost of agricultural losses resulting from air

pollution in Pennsylvania, (2) to determine the relative importance of the various pollutants in Pennsylvania, (3) to survey the extent of the air pollution problem in Pennsylvania, (4) to provide a basis for estimating the nationwide impact of air pollution on vegetation, and (5) to provide a basis for guiding research efforts.

A professional plant pathologist was enlisted to coordinate the field survey. He assisted reporting personnel in the detection and evaluation of air pollution damage to crops and performed independent field surveys in areas where sources of pollution were located. Commercial and non-commercial plants were studied. Past air pollution episodes were investigated for purposes of detecting possible trends. Estimates of losses were based on crop value and production costs incurred by harvest time. Direct losses to producers or growers included only production costs, whereas indirect losses included profit losses, costs of reforestation, grower relocation costs, and the cost of substituting lower-value crops for higher-value crops. Costs associated with destruction of aesthetic values, erosion and resultant stream silting, damage to watershed retention capacity, and farm abandonment were not considered.

Of the 92 field investigations made, 60 revealed damage that was attributable to air pollution. Damage resulting from pollution was observed in 23 counties, most of which were located in southeastern and western Pennsylvania. Direct losses uncovered in the survey exceeded $3.5 million. The air pollutants responsible for the damage, in order of decreasing importance, were: oxidants, sulfur oxides, lead, hydrogen chloride, particulates, herbicides, and ethylene. The vegetation most affected, also in order of decreasing importance, was: vegetables, fruits, agronomic crops, lawns, shrubs, woody ornamentals, timber, and commercial flowers. Indirect losses were estimated at $8 million, of which $7 million reflects profit losses, $0.5 million reflects reforestation costs, and the remainder reflects costs for grower relocation. In summary, economic losses in Pennsylvania from air pollution damage amount to approximately $11 million annually.

The major criticisms of the Pennsylvania effort reflect the state of the art. Little is known of the extent to which home garden plantings and flowers are being affected by air pollution and, if they are affected, the value that should be assigned to these losses. The method used in assessing losses is somewhat questionable because grower profit losses

are not included as direct costs. Also, methods of translating physical injury into economic loss have not been standardized.

The major strengths in such an approach are that: (1) existing manpower can be utilized for achieving continual coverage over an area; (2) agents at the local level have rapport with growers in that area; are familiar with crop peculiarities; and are probably knowledgeable about local sources of pollution in the area; and (3) a field coordinator supplies expertise to the reporting personnel and provides some degree of standardization in reporting losses.

Because of the successful first year's attempt in Pennsylvania and the inherent advantages in such an approach, a similar statewide survey was initiated in California in the summer of 1970. The added data from other states will make possible more realistic estimates of losses.

Stanford Research Institute - Nationwide Survey

Another major survey of plant damage, "Economic Impact of Air Pollutants on Plants,"[25] has been undertaken by H. M. Benedict of Stanford Research Institute(SRI). This study, initiated in 1969, will develop an estimate of the annual economic losses to agriculture, in all regions of the United States, that result from damage to vegetation by air pollutants. Special emphasis will be placed on those losses ascribable to automotive emissions or to pollutants arising as a result of automotive emissions.

SRI will: (1) develop a method for assessing agricultural losses caused by air pollutants, based on established evaluation methods now used to assess agricultural losses from natural causes such as plant pathogens or insects; (2) determine the type and general extent of air pollution injury to agricultural crops of major importance and the symptoms of such injury; (3) locate the principal sources or areas of pollution and estimate the economic value of plant damages, placing special emphasis on the economic loss attributable to specific automotive emissions; (4) consider the possible influence of meteorological conditions affecting the exposure of vegetation to air pollutants in various geographical regions; and (5) estimate the yearly dollar losses to agriculture that result from damage to vegetation by air pollutants.

SRI reviewed the literature to obtain information on the concentration and duration of fumigations necessary to affect plants and the nature

of the effects produced. Counties to be surveyed were identified by locating potential sources of air pollution throughout the United States. The economic value of agricultural production in each of these counties was estimated. Theoretical consideration was given to possible models for estimating losses resulting from other factors such as disease, insects, and weeds. The major pollutants that have been identified by SRI as causing 90 percent of the damage to plants are ozone, peroxyacetyl nitrate, ethylene, nitrogen oxides, sulfur oxides, and fluorides.

Emissions in standard metropolitan statistical areas were estimated from known fuel consumption. Crop production and emissions were estimated for the 500 most important counties in the country. In the initial phases of the study, estimates have been confined to losses caused by the direct effects of major pollutants on yield, quality, and marketability. Preliminary estimates indicate that these direct effects amount annually to about $70 million nationwide. Hydrocarbons have been associated with losses of about $64 million, sulfur oxides with losses of about $4 million, and fluorides with losses of about $2 million. If it is true that this reflects 90 percent of plant losses, then the total direct loss of selected crops approaches $80 million annually.

The major benefit from the SRI study will be the accumulation of good background data for the development of predictive models for use in estimating losses. The basic assumptions made of the extent to which crops are exposed to pollution as well as the general severity of damage to plants at varying emission levels are not altogether realistic as given in this study, but perhaps they are the most reasonable possible at this time. Also, this study considers observable, direct effects only. Home plantings and flowers, which some experts believe comprise the largest portion of plant losses caused by air pollution, have again been largely ignored.

NATIONAL ESTIMATE

The preliminary estimate of direct losses in Pennsylvania by the SRI survey amounts to about $4.9 million (for oxidants only). This compares with the estimate of the statewide survey in Pennsylvania of about $9.0 million (profit losses added). If it is assumed that the Lacasse-Weidensaul-Carroll estimate for losses in Pennsylvania is more

defensible than that made by SRI, then by substituting the former estimate into the SRI model, a realistic estimate of direct annual losses for the nation, based on these two studies, might be approximately $120 million for 1968.

It should be noted that this estimate represents those losses caused by the visible, direct effects of the major pollutants on agronomic, field, horticultural field, and forest crops only. Losses of ornamental plantings, flowers, and gardens are assumed to be implicit in the property-value estimate of air pollution costs. Also ignored, because of the lack of meaningful data, are losses resulting from indirect effects of air pollution on agriculture, such as grower relocation, the denudation of land and resultant erosion, and lost productivity.

CHAPTER 5. SOILING

Individuals, households, and commercial establishments are affected by air pollution in many ways, only a few of which are obvious. When dust particles fall, the need to dust window sills and furniture is distressingly obvious. The effects of air pollution in most cases, however, are gradual enough to go unnoticed. Yet dealing with these effects may involve considerable extra expense, of which the household is usually unaware. Some families in urban areas spend very little as a result of air pollution, but many spend hundreds of dollars more each year than they would need to spend if the air were clean. The costs associated with soiling of materials are discussed under the following reviews of studies of soiling from air pollution.

INDIVIDUAL STUDIES

Mellon Institute - Pittsburgh Smoke Nuisance

Surely the best known of the early studies of economic losses resulting from air pollution is the Mellon Institute Study of the Pittsburgh smoke nuisance in 1913.[26] The purpose of the study was to assess the economic cost of the smoke nuisance to the populace of the city of Pittsburgh. The cost estimates were based upon literature searches, observations, and informal surveys. The estimated annual cost (1913), shown in Table 9, was more than $9.9 million, or $20 per capita.

The damage estimates obviously included some direct costs as well as some adjustment costs. The costs involve losses resulting from soiling by particulate matter as well as corrosion, depending on the damage category, and the obstruction of sunlight by particulate matter.

No attempt was made to measure the extra cost of cleaning the interior of public buildings and of cleaning and maintaining the exteriors of buildings, nor costs of health, agricultural, and aesthetic properties. Questionable statistical techniques were used in averaging damage costs, in estimating the number of units affected (for example, stores), and in arriving at the percentage damage cause by air pollution. As Kneese has said, "Perhaps one can be forgiven for suspecting that this information is somewhat dated."[27]

Table 9. SUMMARY OF DATA FROM MELLON INSTITUTE STUDY ON SOILING[26]

Cost	$/yr
Cost to the smoke emitter resulting from imperfect combustion	$1,520,740
Cost to the individual	
Laundry	1,500,000
Dry cleaning	750,000
Cost to the household	
Exterior painting	330,000
Sheet metal work	1,008,000
Cleaning and renewing wallpaper	550,000
Cleaning and renewing lace curtains	360,000
Artificial lighting	84,000
Cost to wholesale retail stores	
Damage to merchandise	1,650,000
Extra precautions	450,000
Inside maintenance	750,000
Artificial lighting	650,000
Department stores	175,000
Cost to quasi-public buildings (inside maintenance and artificial lighting)	
Office buildings	90,000
Hotels	22,000
Hospitals	55,000
Total	$9,944,740[a]

[a]$20 per capita in 1913.

Beaver Report - London Smog Episode

The next major attempt to estimate soiling costs was an outgrowth of the Mellon Study. In 1953, as a result of the London smog episode of 1952, a committee was appointed to examine the nature, causes, and effects of air pollution and the efficacy of preventive measures. The report of this committee to Parliament was released in 1954.[28]

Many of the data were secured through literature searches and informal surveys. The actual method used to make the estimates was similar to that used in the Mellon Study. In the Beaver Report,[28] however, "black" areas were compared with "clean" areas, whereas in the

Mellon Study, Pittsburgh was compared with different cities. Costs were assessed by estimating the proportion of the total expenditure for specific items damaged by air pollution. The necessary proportional estimates were obtained from additional estimates of the amount and frequency of expenditures in polluted as compared with nonpolluted areas, as determined by interviews with local authorities. The polluted areas used in the study were assumed to account for half of all other items, such as painting of buildings.

The net results of the study are given in Table 10.

Table 10. SUMMARY OF DATA FROM BEAVER REPORT ON SOILING[26]

Cost	$ million/yr
Direct	
Laundering	[illegible]
Painting and decorating	
Soiling and depreciation of buildings (other than houses)	56
Corrosion of metals	70
Damage to textiles and other goods	147
Indirect - loss of efficiency	280
Total	707
Cost/person	$/yr
Nonpolluted areas	14
Polluted areas	28

It is evident that this method of estimation resulted in extremely crude sums that do not reflect variation with pollutant level or type of pollutant. Where little or no information was available, the authors did not hesitate to use pure guesswork. They recognized, however, that their results did little more than suggest broad orders of magnitude.

Michelson and Tourin - Household Costs

In recent years, several attempts[29-31] have been made to identify the costs of soiling from air pollution. For the most part, these studies have dealt with the household as the primary unit of investigation in an attempt to measure pollution-related cleaning and maintenance costs in certain localities. The review by Jones[32] is particularly helpful in evaluating the Michelson-Tourin study.

In the evaluation of household costs resulting from soiling caused by air pollution, the work of Michelson and Tourin has received the most attention. Their method of study is based upon the theory that if air pollution causes significant soiling, the extent of damage by soiling may be reflected in shortened time intervals between successive cleaning and maintenance operations in areas with higher levels of pollution. If this relationship could be established, then by using the cost of each operation studied and the damage functions relating particulate level and costs, the costs of soiling in a polluted environment could be calculated.

To test this theory, Michelson and Tourin conducted a survey by mailed questionnaire in the towns of Steubenville and Uniontown in the Upper Ohio River Valley.[29] These towns have annual average particulate matter concentrations of 235 $\mu g/m^3$ and 115 $\mu g/m^3$, respectively. A good rate of response to the questionnaire was achieved through a large publicity campaign. A positive relationship was found to exist between the frequency of cleaning of the house and personal care items and levels of particulate pollution.

Cost comparisons were made between two income groups (less than $8,000 and more than $8,000), and total costs were calculated on the basis of the number of families and persons in each income group in each city. The differences in frequency of cleaning were calculated and then converted into dollar differences by applying local market prices for the various household services covered by the survey. The resulting figures showed that the economic loss associated with air pollution in Steubenville was $3.1 million, or $84 per capita, more than in Uniontown.

In an attempt to validate this study, a subsequent survey was conducted in three suburban cities of the Washington, D. C., area.[30] The Washington area was chosen for the validation study because it was thought to offer a severe test to the methodology. First, the absolute levels of suspended particulate matter in the D. C. area were much lower than those of Steubenville and Uniontown. Second, the difference in the levels of suspended particulate matter was much smaller in the paired cities in the Washington area than in the paired cities in the Upper Ohio River Valley. Finally, the two areas had very different industrial and population characteristics.

Michelson and Tourin again found a positive relationship between the frequency of performance of cleaning and maintenance operations and the level of suspended particulate matter in the ambient air. Although the findings of the second study would seem to support the findings of the first, major differences between the two studies and inherent problems within each throw a great deal of doubt upon this conclusion. For example, although income level was the only controlling factor in the analysis, only the responses of the above-average income group were analyzed in the Washington study. Once the relationship was found to exist in that income group, it was assumed to exist for the below-average income group. Also, within each study there are considerable problems with the sample survey design, the data, and the analysis. The chief problem, however, is the lack of statistically reliable techniques that would allow a certain degree of confidence in the results.

Since these two major studies, Michelson and Tourin have applied their methodology in other sections of the country. In 1968, they completed a study of the total extra household costs resulting from air pollution in Connecticut.[32] In these studies, no household survey was performed to measure the frequency of cleaning and maintenance operations. Instead, the frequencies found in the Upper Ohio River Valley and Washington area studies were used. Because these frequencies were not alike, some kind of averaging must have been done. The local costs of the operation were investigated, and the demographic figures from census materials were used to come up with a total damage estimate for the state of Connecticut. Such a use of the methodology without adequate verification is highly questionable.

Ridker - Urban Soiling

Ridker conducted research to identify costs associated with soiling caused by air pollution.[33] In 1965, he conducted a study in high-, medium-, and low-pollution zones of Philadelphia to determine whether family behavior and expenditures were affected by air pollution. Despite an apparently adequate collection of data, the results of the analysis were inconclusive. Although many detailed problems and errors were apparent in the analysis, the principal problem involved the use of time expended in routine household cleaning as a basis for cost estimates. The relative frequency with which these tasks are performed may be a more appropriate measure than the time spent performing them.

Ridker also conducted a time-series analysis of a pollution episode in Syracuse.[34] A questionnaire was developed and administered through personal interviews. Although the results of this household survey were much better than the cross-sectional analysis made in Philadelphia, the approach was obviously limited to the episode-type situation and could not be put to widespread use.

The Ridker study, along with the Michelson and Tourin studies, called attention to major problem areas with regard to evaluating household expenditures resulting from soiling caused by air pollution:

1. Isolation of economic losses resulting from air pollution from those resulting from other causes.
2. Sample selection and bias.
3. Development of a survey technique that will provide reliable answers.
4. Inclusion of all household tasks or services whose costs are influenced by soiling damage from air pollution.

Ando - Costs of Air Pollution in Japan

Itaru Ando attempted in his report, "Social Expenditures for Public Hazards and Their Apportionment,"[35] to study the causes of public hazards, to review the present status of social expenditures, and to investigate the shares of expenses allotted to reduce hazards produced by air pollution.

Ando took the following steps in isolating the effects of air pollution: (1) examined the fact that public hazards have increased rapidly for the last 20 years; (2) reviewed the growth of economic complexes; (3) discussed the direct losses caused by public hazards and the problem of representing these in economic units; (4) used dustfall and SO_2 as representative indices of air pollution; and (5) patterned cost estimates after the Mellon Study of 1913.

Ando estimated that direct losses to Kawasaki City from air pollution damages were nearly $5 million, or approximately $19 per household. Health expenditures accounted for $1.1 million; damage to residential property and household goods accounted for $2 million; damage to merchandise accounted for $0.05 million; and other damage accounted for $1.66 million. Average household costs attributable to air pollution were $38.89 in Osaka and $28 in Sapporo City.

The scope of this study goes beyond that of other studies because the author relates public hazards to industrial development. Commenting that it is impossible to enrich the national life without industrial development, he states that the residents and businessmen in an area must bear expenses in proportion to their restored profits. A weak point of the study is that the author patterned his cost estimates after those of the Mellon Study.

Booz-Allen and Hamilton - Philadelphia Survey

The current Booz-Allen and Hamilton, Inc., study in Philadelphia[36] is expected to improve upon and extend the methodologies already developed. The objectives of the Philadelphia community study are: (1) to determine the impact of various air quality standards and regulation schemes on the region by using a benefit-cost approach and (2) to extend existing knowledge of how to assess damages resulting from air pollution.

A questionnaire consisting of two parts was developed to determine the frequency of cleaning. The first section included questions regarding cleaning operations and the second consisted of a set of self-referent statements designed to determine cleaning attitudes. A total of 1,800 personal interviews were conducted in the Philadelphia Air Quality Control Region.

An attempt was made on a smaller scale to determine the costs of soiling borne by commercial establishments because of particulate pollution. A sample survey of 138 stores was conducted, and various cleaning operations were investigated. Because of sample size, the results have proved inconclusive thus far.

Rigorous statistical survey research techniques were employed from the beginning of the project because of the initial belief that many, perhaps more, dominant, non-pollution-related variables explain differences in residential cleaning frequencies and maintenance operations to a far greater degree than the variations in the annual air particulate level measurements in the Philadelphia area. Therefore, the survey techniques included: (1) a probability sample within several zones of the Philadelphia area; (2) group interviews leading to preliminary estimates of attitudes toward cleaning and the best ways of phrasing survey questions; (3) personally administered questionnaires, rather

than mail or telephone surveys; (4) a factor analysis of the questionnaire respondents to separate the population into attitude groups in order to explain better why people clean; (5) collection of demographic data on each respondent and his residence; and (6) the use of qualified interviewers to perform coding and key-punch operations.

The study of residential household soiling costs made an attempt to discern between cleaning necessitated by pollution and cleaning performed out of habit or for other reasons. Before any relationship could be established between the frequency of these cleaning operations and the level of particulate pollution, other socioeconomic variables that may contribute to the frequency were identified and the degree of their interaction was established through a factor analysis.

From the study of 27 cleaning and maintenance operations, preliminary results indicate that the range of annual air particulate levels experienced in the Philadelphia area (approximately 50 to 150 micrograms per cubic meter) had no statistically significant differential effect on the residential cleaning and maintenance costs for over 1,500,000 households in the area. These operations included painting, cleaning, and washing. Of the 27 operations studied, 11 were determined to be somewhat sensitive to air particulate levels. These are shown in Table 11. Each of the sensitive operations is a low-cost, do-it-yourself item, and many are associated with being able to see out of the houses - washing windows, cleaning screens, and cleaning venetian blinds. It must be pointed out that these do-it-yourself operations were considered to be free of labor cost and the material costs were considered only when these were non-trivial, such as for painting. Theories on various methods of imputing labor costs to household member operations were not applied partly because these costs are not direct costs.

The preliminary conclusion of the study is that some low-cost cleaning and maintenance operations appear to be sensitive to air particulate levels, but, more important, that the high-cost operations are unaffected by variations in air particulate levels in the Philadelphia area. Another finding of interest is that a higher proportion of residents of high pollution areas believed their neighborhoods were dirtier than residents of low pollution areas believed theirs to be.

The Booz-Allen report has been criticized on several grounds. First, statements concerning the statistical significance of operations have

Table 11. RELATIONSHIP OF CLEANING AND MAINTENANCE OPERATIONS TO AIR PARTICULATE LEVELS[36]

	Relationship	
	Sensitive	Insensitive
Inside		
Clean and oil air conditioners		x
Clean furnace		x
Clean venetian blinds and shades	x	
Dry-clean carpeting		x
Dry-clean draperies		x
Paint walls and ceilings		x
Replace air conditioner filter	x	
Replace furnace filter		x
Shampoo carpeting		x
Shampoo furniture		x
Wallpaper walls		x
Wash floor surfaces	x	
Wash walls		x
Wash windows (inside)	x	
Wax floor surfaces	x	
Outside		
Clean and repair awnings		x
Clean and repair screens	x	
Clean and repair storm windows	x	
Clean gutters	x	
Clean outdoor furniture	x	
Maintain driveways and walks	x	
Maintain shrubs, flowers, etc.		x
Paint outside trim		x
Paint outside walls		x
Wash automobiles		x
Wash windows	x	
Wax automobiles		x

not been adequately justified in many instances. Second, the report does not fully explain the sensitivity or insensitivity of the cleaning and maintenance operations. Third, accepted economic principles justify including with the cost of materials some imputed value for homemakers' time spent in cleaning and maintenance operations. This study should

provide guidelines for improving the methodology used in estimating costs and applying such methodology to other regions.

CONCLUSIONS

In conclusion, the Michelson and Tourin and Ridker studies dealt mainly with the estimation of household cleaning and maintenance costs. Except for the Michelson and Tourin study, however, the evidence to date indicates that air pollution does not have significant economic effects in terms of household maintenance and cleaning operations. Yet, there are other costs associated with pollution soiling that deserve attention if not estimation. Some of these costs are: commercial cleaning and maintenance costs; individual adjustments such as laundering, dry cleaning and hair and facial care; car washing; and costs to quasi-public properties, which might include cleaning and maintenance costs of buildings and monuments and washing of street-lighting luminaries. The magnitude of soiling costs associated with specific effects undoubtedly runs into the millions of dollars annually, but because of the lack of data, these soiling costs are not estimated in this report.

CHAPTER 6. ANIMAL HEALTH EFFECTS

Air pollution has many effects on animals. Some of the oldest documented cases of the deleterious effects of air pollution have been associated with the Meuse Valley disasters, notably those of 1897, 1902, and 1911. It is evident from reports of those disasters that vegetation was damaged and that cattle suffered from a malady, caused by the adverse atmospheric conditions, known locally as "fog disease."[37] In actuality, the cattle had been stricken with asthma and emphysema.[38]

Pollution of the air and damage to plants used as animal feed - and the resulting diseases of animals - are frequent in regions where metallurgical plants are located.[39] Fluorine by-products, lead, and molybdenum are the major offending constituents in industrial air pollution. Cement dust, sulfur dioxide, and arsenic are lesser problems. Pollution of agricultural, as opposed to industrial, origin is essentially linked to the misuse of pesticides.[40]

Fluoride poisoning of cattle grazing in the vicinities of aluminum reduction and phosphate fertilizer plants has received much attention in the literature. Fluorosis, a disease common to cattle, occurs when fluorine compounds are ingested for long periods of time. The animals eat contaminated fodder, grass, and hay, and also inhale quantities of fluorine. No adverse effects occur in dairy cattle when the fluorine content of the daily ration is less than 30 ppm, but 40 to 60 ppm will result in moderately adverse effects. Acute fluorosis results from ingestion of 250 ppm fluoride per day, a level that often results in stiffness, anorexia, weakness, convulsions, and cardiac failure.[41] Chronic fluorosis is typified by the ingestion of 60 to 100 ppm fluoride per dav and causes severe dental malformations and bone lesions. Cattle often produce less milk and conceive poorly as a result of fluorosis.[42]

Losses to livestock have been known to occur in the vicinity of lead refineries. Cattle raised in the area were estimated to have eaten 26 milligrams of lead in 100 grams of herbage. Near the plant they ate 0.07 to 0.16 percent lead by weight, which resulted in lead poisoning.[43] Molybdenum dust, scattered from the chimney of the neighboring molybdenum-smelting factory, also allegedly caused damage to livestock.

The cattle experienced diarrhea, symptoms of malnutrition, decreased milk production, and decreased rate of conception.[44]

Animals also have been damaged by the effluents of a copper smelter. The high-copper- and arsenic-containing effluents that are deposited on plants and grass cause numerous cases of chronic poisoning and even death of domestic animals such as cattle, horses, sheep, and poultry.[45]

A number of general conclusions have been drawn regarding effects of air pollution on wildlife. From field investigations, the economic poisons (insecticides, herbicides, etc.), such as chlorinated hydrocarbons and organic phosphates, appear to outweigh by far all other types of air pollutants as hazards to wildlife health. The hazard to wildlife occurs chiefly from ingestion of the "fallout" of the air pollutant. Relative species susceptibility to specific air pollutants is far from clear, but it would appear that mammals are considerably more susceptible than birds.[46] Nevertheless, air pollution has been implicated as the causal agent of primary lung cancers in birds in the Philadelphia zoo. Waterfowl that were kept outdoors the year round were the animals most affected, which led Snyder[47] to suggest the possibility that the levels of carcinogens in the atmosphere are increasing.

No studies of the economic impact of air pollution on animals have been made. The damage to animals caused by air pollution has been localized and its economic consequences have been probably relatively unimportant; yet the social consequences of this pollution damage are potentially more severe. Though indirect, the risk to the food cycle, especially when pesticides are implicated, is serious, and it may indeed be true that the economic importance of heavy metal air pollutants lies in their effects on animals.

CHAPTER 7. EFFECTS ON AESTHETIC PROPERTIES

One possible effect of air pollution is the deterioration of materials with historic artistic significance, such as paintings, statuary, and rare books. In addition, air pollution can reduce visibility and obscure vistas and thus can have a depressing psychological effect on individuals. Noxious odors as well are considered here to have aesthetic effects.

The adverse aesthetic effects of air pollution belong in the calculus of air pollution damages because of values that can be attached to their prevention or avoidance. For example, the New York City Public Library spent $900,000 between 1952 and 1967 to microfilm books that were in an advanced state of deterioration largely as the result of air pollution.[48] Part of this expenditure represents what the library was willing to pay to avoid loss of its books. Presumably other examples could be found that indicate a willingness-to-pay for avoiding the adverse aesthetic effects caused by air pollution.

Studies of the costs of air pollution in terms of damage to aesthetic properties are discussed below.

INDIVIDUAL STUDIES

Ridker - Soot Incident Survey

Ridker[49] surveyed the residents near a power plant to determine the cost of cleaning up after malfunctioning boilers fumigated the neighborhood with unusually high amounts of soot. The 1965 survey not only determined costs of cleaning, but also attempted to estimate the willingness-to-pay costs. Table 12 records measured and willingness-to-pay costs provided by 10 respondents. The difference between respective measured and willingness-to-pay costs is termed the "psychic" cost, which refers to the loss beyond the direct, measured costs. These results indicate that the households generally were willing to pay at least the measured cost of pollution cleanup in order to prevent the need for cleanup. Usually they were willing to pay more than the measured cost. The results indicate that the residents were willing to

Table 12. COST OF CLEANING UP AFTER BOILER MALFUNCTION

Respondent	Measured costs, $	Willingness-to-pay costs, $	Psychic costs, $
1	9.45	10.00	0.55
2	43.75	50.00	6.25
3	45.61	45.61	0.00
4	19.78	25.00	5.22
5	15.67	25.00	9.33
6	25.32	30.00	4.68
7	13.59	25.00	11.41
8	12.95	20.00	7.05
9	4.25	4.25	-
10	8.79	8.79	-

pay, on the average, 27 percent above the measured cost of cleanup in order to avoid the occurrence of soiling from pollution.

These results must be qualified on several accounts. First, since the survey was constructed in only a few days, one must allow for the possibility of an incomplete questionnaire and an unreliable sample. Second, too few respondents provided willingness-to-pay costs for them to be representative of the psychic costs; only 122 residents of the nearly 3,500 residential units in the population were interviewed.

Lawyer - Morgantown Study

Another survey on willingness-to-pay was conducted in 1965 by Lawyer among 362 of the 6,424 families in Morgantown, West Virginia.[50] Table 13 shows the percentage respondents who would pay the indicated amount each year . . . "if all air pollution were reduced below the point where it was noticeable (or harmful)."[51]

The average amount respondents were willing to pay was calculated to be $16.46. The "zero or no response" category is not considered in the average because it is doubtful that people would be unwilling to pay anything at all and it is probable that most of the numbers reported

Table 13. AMOUNT OF MONEY RESPONDENTS WOULD PAY ANNUALLY TO REDUCE AIR POLLUTION IN MORGANTOWN, WEST VIRGINIA[51]

Amount, $	Respondents, %
Zero or no response	38.4
1 to 5	23.9
6 to 10	9.4
11 to 15	2.5
16 to 20	4.7
21 to 25	6.3
26 to 30	0.3
31 to 35	0.6
36 to 40	0.3
40	13.5
Total	99.9[a]

[a]Error resulted from rounding of figures.

indicate no response. The mark of the $1 to $5 class is taken to be $3.50 because it is assumed the class really extends to $5.99. The mark of each subsequent class is $5 higher than the previous mark. The highest class is assumed to have a mark of $40.

Williams and Bunyard - St. Louis Opinion Survey

An average payment of $16.46 per year per respondent is much higher than the willingness-to-pay costs determined in a study by Williams and Bunyard.[52] They reported that 66 percent of those interviewed in a 1963 survey of the St. Louis area were willing to pay $5 per year in higher living costs for clean air, and that 85 percent of those interviewed would pay $1 per year in higher taxes.

Medalia and Finkner - Clarkston, Washington, Study

One aspect of evaluating aesthetic damages from air pollution consists of examining individual and community perception of pollution in general and the perception of visibility and odors in particular. In

an investigation of the effects of smoke and odor from a pulp mill in Clarkston, Washington, Medalia and Finkner[53] interviewed 104 local residents. Of the persons queried, 91 percent perceived air pollution in the community as an odor problem, 74 percent perceived it as a visibility problem, and 62 percent saw it as a problem in nose-throat irritation. Concern with air pollution was found to be unrelated to the location of the respondent's residence, probably because of the pervasive nature of the pollution. Concern with air pollution was found to vary directly with social status and with factors such as civic pride, desire to eliminate the problem, length of residence, and occupational prestige of the household head.

Williams and Edmisten - Nashville Perception Interviews

A broader study by Williams and Edmisten[54] for Nashville, Tennessee, included an examination of individual perceptions of pollution. People in 3,032 dwelling units were interviewed to test the hypothesis that perception and concern for air pollution are directly related to neighborhood pollution levels. The hypothesis was found to be true. Furthermore, the higher the socio-economic status was, the greater the correlation between degree of concern and air pollution levels. They also found that citizens' perceptions of air pollution were influenced more by the frequency of high daily levels of pollution than by high monthly, seasonal, or average levels.

Current Efforts

Several studies are in progress that relate to the aesthetic effects of air pollution. These deal with either the problems of visibility or odors. A group at Oregon State University[55] is examining social and economic questions relating to the open burning of agricultural waste, which generates particulates that create a visibility problem. A series of interviews among residents in two cities of Oregon's Willamette Valley will provide some basis for evaluating the social aspects of the visibility problem. A team of economists is focusing on: (1) the estimation of a pollution production function for the Willamette Valley; (2) the estimation of the value of the right to burn grass seed fields in the Willamette Valley; and (3) the economic effects of air pollution (visibility reduction) on Oregon's tourist-related industries.

In another study, the Copley International Corporation[56] is examining social and economic factors surrounding the problem of odors. Some economic assessment of odor perception may result from this effort.

CONCLUSIONS

These studies have examined the factors influencing the perception of pollution. Once these factors are known, the economic value to the individual or community of reducing pollution can be estimated. One way to measure this value is to determine the individual's willingness to pay to reduce pollution. This has been done in two studies and may be repeated in two current projects. An alternative method of measuring the value is to estimate the expenditure required to prevent damages to aesthetic objects such as paintings, tapestries, and statuary.

CHAPTER 8.
EFFECTS ON RESIDENTIAL PROPERTY VALUES*

The value of residential property is contingent upon many factors. One factor believed to influence the value of property is the quality of air in a neighborhood. All other things considered, the value of property in areas with more air pollution can be expected to be lower than the value of property in neighborhoods with less air pollution. Measures of this relationship, obtained through standard multiple regression analysis, should yield rough estimates of air pollution damages to property.

INDIVIDUAL STUDIES

Ridker and Henning - Housing Market Indicators

Ridker and Henning made the first serious use of the housing market estimator as an index of the effect of air pollution on property values.[57] Using 1960 census data and pollution readings from the 1963-1964 interstate air pollution study, they explained over 90 percent of the variation in the median property values of the St. Louis Standard Metropolitan Statistical Area (SMSA) census tracts. The variables in their regressions were as follows:

1. MPV = median property value for census tract, St. Louis, Missouri, SMSA.
2. SUL = measure of annual geometric mean sulfation levels for February 20, 1963, to February 10, 1964, denominated in units of 0.25 mg SO_3/100 cm^2-day.
3. MNR = median number of rooms in tract.
4. PBR = percentage of homes recently built.
5. HPM = houses per mile.
6. TIZ = bus travel time to the St. Louis central business district.
7. HWA = accessibility of census tract to highways.

---

*This chapter was prepared in conjunction with Brian W. Peckham, formerly with U. S. DHEW, PHS, National Air Pollution Control Administration, Raleigh, N. C.

8. SCHI = school quality within census tract.

9. OCR = occupation ratio (ratio of craftsmen, foremen, operatives, and laborers to total work force).

10. PPU = population density in residential areas.

11. PNW = percentage non-white residents in a census tract.

12. RILL = dummy variable indicating whether census tract is in Illinois or Missouri, orthogonal to sulfation.

13. RMFI = median family income, orthogonal to MNR, HPM, and OCR.

Assuming that the observed sample was generated by a classical normal linear regression model, the construction of 95 percent asymptotic confidence intervals for the sample coefficient of SUL yields an interval estimate of 73 to 417 for the corresponding population coefficient. This is to say that there is a 0.95 probability that the slope of the population regression surface in the MPV-SUL plane lies in the closed interval [73,417] or that the mean of the marginal conditional probability distribution of the dependent variable MPV changes by an amount within [73,417] for every 0.25 mg SO_3/100 cm^2-day change in SUL. When a reduction in sulfation of this amount is experienced evenly over a city, other things being equal, the amount of increase in MPV will vary from census tract to census tract; it is a random variable with a probability distribution. The coefficient of SUL estimates the mean of this distribution and thereby serves to estimate also the minimum sum needed to persuade receptors to endure various levels of whatever pollution a sulfation index measures.

Crocker and Anderson - Three-City Comparison

At least three other studies have been made that are similar in method and results to that of Ridker and Henning.[57] Crocker and Anderson studied the covariation of sulfation, suspended particulates, and census-tract median property values in St. Louis, Washington, D.C., and Kansas City.[58] They obtained the highest precision by isolating these variables:

1. AMS = arithmetic mean sulfation rate.

2. SPT = annual arithmetic mean suspended particulates.

3. MFI - median family income.

4. DLP = percentage of dilapidated homes.

5. OLD = percentage of homes more than 20 years old in 1959.

6. DIS = distance to central city.

From their equations, Crocker and Anderson concluded that the pollution (AMS and SPT combined) elasticity of MPV lies between 0.1 and 0.2. For every change of 0.1 mg SO_3/100 cm^2-day in sulfation and of 10 mg/m^3-day in suspended particulates over a particular census tract, the best estimate of the change in that tract's MPV lies in the interval $300 to $700.

Zerbe - Toronto Study

Zerbe, using similar methods, reported for Toronto "that, other things being equal, for each increase in 1 mg SO_3/100 cm^2-day property values will fall by an amount between $800 and $1800 for each single-family detached dwelling, and that the best estimate is that the values will fall by about $966."[59]

Peckham - Delaware Valley Study

Finally, Peckham, of the Division of Economic Effects Research,* used the extensive sulfation data collected by the Division of Abatement† in the Delaware Valley to estimate property value differentials. Although this equation has not been purged of multicollinearity, non-normality of residuals, and the thousand other shocks that the regression is heir to, it does have the advantage of utilizing quite accurate sulfation data gathered from lead dioxide plates from 400 stations during January 1969.[60] It suggests that the mean of the marginal conditional probability distribution of MPV probably changes for every 0.5 mg SO_3/100 cm^2-day by some $663.

NATIONAL ESTIMATES

From these four studies have come four similar estimates of the marginal capitalized damage caused to residential property by that pollution that is measured by sulfation. From Ridker's study, it can be taken that the mean change in MPV per 0.25 mg SO_3/100 cm^2-day change in sulfation lies within [73,417] with a 0.95 probability, and that the best linear unbiased estimate of the mean change is $245, or about $100 per

*Now the Division of Ecological Research, National Environmental Research Center, North Carolina,

†Now the Applied Technology Division, Office of Air and Water Programs, EPA.

0.1 mg change. From Crocker and Anderson comes an estimate of $300 to $700 per 0.1 mg SO_3 and 10 mg/m^3-day change in suspended particulates. Note that because it derives from a curvilinear functional form this coefficient of damage applies only for marginal changes about existing pollution levels; it cannot be used to indicate the benefits of cumulative abatement. Both Zerbe's estimate of $966 per 1 mg SO_3 change and the $663 per 0.5 mg SO_3 estimate of Peckham seem close to that of Ridker and Henning, although somewhat below that of Crocker and Anderson. All four studies, however, agree that sulfation is inversely related to MPV and that the magnitude of the marginal capitalized sulfation damage for residential structures, for a marginal decrease of 0.1 mg SO_3/100 cm^2-day, probably lies in the range $100 to $300. This remarkable uniformity of results, for five major metropolitan areas, warrants some confidence in the worth of the housing market estimator for national pollution damages.

Given a marginal capitalized damage coefficient and the assumption that sulfation changes are always evenly distributed among census tracts (i.e., a 10 percent drop in the annual average sulfation rate for a city implies a 10 percent drop in the corresponding rates for each tract), estimates of sulfation damage to entire communities can be calculated by the following equation: Damage = (SUL coefficient) (number of marginal changes needed to reduce arithmetic annual mean sulfation rate for the SMSA to desired background) (number of housing units).

The damage given by this relation is total capitalized pollution damage, or the decrease in real property wealth caused by whatever pollution is measured by a sulfation index. Total annual damage, or the decrease in real property income as the result of pollution, is obtained by multiplying total capitalized damage by a discount rate reflecting the average return on capital. Clearly the total capitalized pollution damage depends on the choice of SUL coefficient, desired background sulfation rate, arithmetic annual mean sulfation rate of the SMSA, housing units over which aggregation occurs, and discount rate.

In this case these choices were made as follows:

1. The four studies taken together show that the magnitude of the marginal capitalized sulfation damage for residential structures, for 0.1 mg SO_3/100 cm^2-day, probably lies in the range of $100 to $300. A middle estimate of $200 is used here.

2. Selection of the desired background level at 0.1 mg SO_3/100 cm^2-day was guided by the annual sulfation averages that obtain in suburban or rural regions (Pensacola, Florida: 0.1 mg SO_3/100 cm^2-day;[61] Columbus, Georgia: 0.0666 mg SO_3/100 cm^2-day;[61] and Las Vegas, Nevada: 0.1410 mg SO_3/100 cm^2-day).[62]

3. Annual arithmetic mean sulfation rates were established for all SMSA's by either averaging the annual averages for all individual monitoring stations (in the case of Washington, D. C.,[63] Kansas City, and St. Louis[64,65]); or by averaging the monthly averages for a single SMSA[61,63] station; or by estimating, in the case of 164 SMSA's for which sulfation data were lacking, from a regression of annual SO_x emission data (supplied by the Division of Air Quality and Emissions Data, BCS, NAPCA)* on sulfation annual averages. Variations in emissions of SO_x were found to explain more than 40 percent of the variance of sulfation about its mean.

4. All estimates were calculated for the number of households in the SMSA as of January 1, 1969.[66]

5. As a reasonable approximation to an average return on all real property wealth in the economy, a 0.10 rate was uniformly used in all calculations.

The charge can reasonably be made that sulfation readings from single stations in large SMSA's do not give an accurate picture of pollution conditions throughout the entire SMSA. To take account of this source of bias, annual average sulfation data for the ten dirtiest of the larger SMSA's (Philadelphia; St. Louis; Detroit; Chicago; Newark; Cincinnati; Buffalo; Hammond-Gary-East Chicago, Indiana; Boston; and New York) were adjusted downward in all of the estimates by 28 percent, which is the average percentage difference between annual average sulfation for the SMSA and for six center-city stations in Washington, St. Louis, Philadelphia, and Kansas City.

Objections can also be raised to the lack of synchronism between pollution and the other variables in the original regression analyses of the relationship of sulfation to MPV. Given certain assumptions,

---

*Now part of Division of Atmospheric Surveillance and of Applied Technology Division, EPA.

this condition will probably make the ordinary least squares estimator of the coefficient for SUL or AMS asymptotically biased downward.

As a result of the calculations described above, and of assuming a marginal capitalized damage coefficient of $200 for each reduction of 0.1 mg SO_3/100 cm^2-day, the national annual estimate comes to $5.2 billion. This estimate, to repeat, spans all housing units within all SMSA's and assumes that pollution changes are spread evenly over all census tracts and that there is a negative linear relationship between sulfation and MPV. It indicates the approximate amount that residents of American cities would demand, under emitter liability, to forego asserting their rights to have pollution abated so that arithmetic mean sulfation rates in all SMSA's would be 0.1 mg SO_3/100 cm^2-day or lower.

CHAPTER 9. LITIGATION*

By 1969, after many attempts at estimating pollution costs, the realization came that personal opinion polls often did not yield truthful responses; that surveys of the technical coefficients of household production functions failed to pick up all the myriad actions taken in adjusting for pollution loadings; and that property-value studies were only as good as the data used in them, which were often not very good at all. The hope was that some new technique could be developed to circumvent the difficulties of the traditional estimators; specifically, that legal scholars could suggest some way of deriving information on air pollution damages from the decisions of the judicial system in adjudicating conflicts of interest over air resources.

As originally drawn up, a litigation survey conducted by Havighurst and his staff had two major objectives.[67] First, find and report in sufficient detail all litigation, at the original or appellate levels, that might bear on the problem of finding out how much air pollution damage costs and on the problem of finding out the extent to which the people of Philadelphia have returned to the courts for redress of these injuries. Second, using the information gathered from the study, evaluate the properties of judicial data as an estimator of damage functions.

Many hours were spent talking to lawyers, court clerks, state and local control officials, and anyone who might have knowledge of past or pending litigation relevant to the study. In all, three useful cases in Philadelphia were found. Havighurst concluded that citizens of urban areas are much less inclined to control pollution through private legal action than are citizens of rural areas. City dwellers apparently become conditioned to air pollution - over time they adapt to dirty windows and brown skies - and, in a dense industrial city, there is some difficulty in knowing just what sources are primarily responsible for the pollution. Because of the paucity of interesting cases in the

---

*This chapter was prepared in conjunction with Brian W. Peckham, formerly with U. S. DHEW, PHS, National Air Pollution Control Administration, Raleigh, N. C.

Philadelphia area the project was broadened to include the Berks County-Bethlehem region. Except for a few cases that turned up, this effort, too, proved unavailing.

It was obvious that no damage functions, or even many useful data, would emerge from the records of the few cases located. The most important thing, then, was to evaluate carefully the feasibility of this litigation technique as a means of measuring pollution damage.

To proceed on such an appraisal required a careful comparison of the type of damage information desired by economic analysts and the type yielded by the courts. Noting that most courts, in practice, make nuisance awards on the basis of the estimated decline in the market value of the injured property and on the basis of the court's allowance for special "discomfort and annoyance," Havighurst concluded that the economic usefulness of such awards depended on the similarity between the preferences of the market (as often estimated by real-estate appraisers in litigation of this type) and the preferences of those actually injured. The more these preferences coincided, whether resulting from the absence of consumer surplus enjoyed by the owner of injured property or from wide knowledge of the effects of the pollution nuisance, the stronger the case for disregarding the court's special annoyance allowance in deriving estimates of economic damage.

The final product of the project was a recommendation that litigation surveys of this type be continued. Despite the lack of success in the Philadelphia area, it was thought that a national survey, perhaps of cases involving odors, would turn up enough damage awards that some tentative functions might be drawn. Havighurst suggested, however, that legal records as they now stand are frequently unsatisfactory for this purpose because of a failure to itemize pollution injuries and to specify the ambient air quality involved in the nuisance conditions. He urged, therefore, that the help of state and local control agencies be enlisted to maintain a reporting network for air pollution litigation and to provide air quality data pertinent to pending cases.

CHAPTER 10.
COST OF AIR POLLUTION BY CATEGORIES

Past and current studies have been examined to determine the cost of air pollution to the people of the United States in terms of additional costs of health care and impairment of human resources, reduction in residential property values, degradation of materials, and damage to vegetation and agricultural productivity. A national cost estimate was not calculated for soiling and aesthetic effects in order to avoid counting twice those damages affecting property values. Estimates were not determined for other effects because of insufficient data.

The cost of air pollution for each category of economic loss is identified with the specific pollutants considered most responsible for that loss in Table 14 and in the following discussion. An attempt is also made to distribute the cost of the effects of air pollution among specific sources (Table 15).

Table 14. NATIONAL COSTS OF POLLUTION DAMAGE, BY POLLUTANTS, 1968
($ billion)

Effects (loss category)	SO_x	Part.	Oxidant	NO_x	Total
Residential property	2.808	2.392	-	-	5.200
Materials	2.202	0.691	1.127	0.732	4.752
Health	3.272	2.788	-	-	6.060
Vegetation	0.013	0.007	0.060	0.040	0.120
Total	8.295	5.878	1.187	0.772	16.132

SOURCE EMISSIONS

The Office of Air Programs, EPA, estimated national emissions of principal pollutants by major source category for 1968.[68] Table 16 presents their estimates. The principal pollutants are carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x), particulates (Part.), and sulfur oxides (SO_x). National emissions of these pollutants amounted to about 214 million tons in 1968. Forty-two percent of all national

Table 15. NATIONAL COSTS OF POLLUTION DAMAGE, BY SOURCE AND EFFECT, 1968

($ billion)

Effects	Stationary source fuel combustion	Transportation	Industrial processes	Solid waste	Miscellaneous	Total
Residential property	2.802	0.156	1.248	0.104	0.884	5.200
Materials	1.853	1.093	0.808	0.143	0.855	4.752
Health	3.281	0.197	1.458	0.119	1.005	6.060
Vegetation	0.047	0.028	0.020	0.004	0.021	0.120
Total	7.983	1.474	3.534	0.370	2.765	$16.132

Table 16. ESTIMATES OF NATIONWIDE EMISSIONS, 1968[68]
(10^6 tons/year)

Source category	CO	Part.	SO_X	HC	NO_X
Transportation	63.8	1.2	0.8	16.6	8.1
Fuel combustion in stationary sources	1.9	8.9	24.4	0.7	10.0
Industrial processes	9.7	7.5	7.3	4.6	0.2
Solid waste disposal	7.8	1.1	0.1	1.6	0.6
Miscellaneous	16.9	9.6	0.6	8.5	1.7
Total	100.1	28.3	33.2	32.0	20.6

emissions comes from transportation sources including automobiles, trucks, buses, trains, and aircraft. Fuel combustion in stationary sources such as public utility and industrial power plants, commercial boilers, and residential furnaces accounts for 22 percent of national emissions. Pollutants from industrial sources other than fuel combustion - namely, industrial processes - make up 14 percent of national emissions. Dumps and incinerators and related solid waste disposal practices generate 5 percent of the national emissions. The remaining 17 percent derives from a variety of sources including forest fires, agricultural burning, and coal refuse smoldering.

ASSIGNMENT OF COSTS

The national health costs of pollution in 1968 were estimated to be $6,060 million. Studies by Ridker and by Lave and Seskin related health effects to particulate and sulfur oxide pollutants. Until better evidence is forthcoming, it is assumed that the health costs of air pollution stem from particulates and sulfur oxides. Sources of these two pollutants are shown in Table 15 according to their relative emission levels. For example, 54 percent, or $3.272 billion of the $6.060 billion in health losses, is attributed to sulfur oxide pollution inasmuch as this pollutant amounts to about 54 percent of the national emissions of sulfur oxides and particulates combined.

The cost of air pollution damage reflected in residential property values amounted to $5.200 billion in 1968. Onus for this cost is attached principally to sulfur oxides and particulates, acting individually and synergistically. The costs of pollution damage to residential property are allocated in direct proportion to the emissions of these

two pollutants. The liability for these costs among sources is assigned according to each source's contribution of particulate plus sulfur oxide emissions to the national total of these two pollutants. For example, 24 percent, or $1.248 billion of the $5.200 billion in residential property losses, is assigned to industrial process sources because they account for 24 percent of the nation's sulfur oxides and particulate emissions.

In the case of materials, the Midwest Research Institute cost estimate of $2.766 billion is allocated in proportion to the pollutants emitted except for CO, which is omitted because there is no evidence that CO is damaging to materials. The corrosion of galvanized steel is attributed solely to SO_x. The fading of dyes and effects of pollution on elastomers are attributed to oxidants and nitrogen oxides. Because the formation of oxidants is directly related to the emission of hydrocarbons, the costs of fading and of elastomer deterioration are therefore allocated to oxidants and nitrogen oxides according to the relative emissions of hydrocarbons and nitrogen oxides respectively.

The two vegetation studies yielded basically the same results, which show that oxidants account for about 90 percent of observable direct crop losses. If this is true, then the portion of the estimated total loss of $120 million attributable to oxidants is approximately $100 million. This value is distributed according to relative emissions of hydrocarbons and nitrogen oxides, inasmuch as these pollutants are the raw materials from which the plant-damaging oxidants, PAN and O_3, are formed. Work by Waddell[69] indicates that SO_x accounts for direct damage assessed at approximately $13 million. The remainder of the pollution cost is allocated to particulates, which include dusts of fluoride, lead, and other pollutants that, if deposited on crops, would make them unmarketable. Carbon monoxide was not considered because evidence indicates that only extremely high levels - which are not found in ambient air - will noticeably damage plants.[70]

CHAPTER 11. DISCUSSION

DAMAGE ESTIMATES

The national total cost of damage from air pollution in the United States for 1968 is estimated to have been $16.1 billion. The cost was principally at the expense of residential property, materials, and health. Transportation, fuel combustion in stationary sources, and industrial processes were the most significant sources.

The magnitude of this estimate provides some indication of the possible benefits that could accrue from pollution reduction. Use of this figure, however, should be tempered by several qualifications. If optimum resource allocation is to be achieved, pollution control should proceed to the point at which marginal benefits equal marginal costs of control. The estimate given in this report of the total annual cost of pollution is for 1 year, 1968. Based on the methods used to determine total annual costs of pollution, it is possible to suggest the marginal benefits of abatement. Total annual costs of pollution were based on assumed and empirically determined proportional relationships between the cost and level of pollution. Therefore, it may be claimed, for example, that a 90 percent reduction in pollution would result in an equivalent reduction in cost. If the relationship between pollution and its cost is not proportional, then greater care should be exercised in interpreting and using the results.

The temptation will exist to use the $16.1 billion estimate of the total cost of pollution as the measure of total benefits to be received from controlling pollution. Yet, in fact, some of the pollution costs associated with the miscellaneous source category are not likely to become benefits instead of liabilities as a result of general pollution reduction, mainly because emissions from structural and forest fires, which account for about 50 percent of the miscellaneous pollution and about 8 percent of all pollution, are not normally controlled under traditional air quality management programs. If there were complete control of all pollutants considered here from all sources except structural and forest fires, and if the cost-of-pollution function is linear, then the total national benefit would be $14.8 billion.

The $16.1 billion estimate can be compared with those developed by others. A commonly cited figure for the cost of pollution damage is $11 billion for 1959, based on a $60 per capita cost for that year. This amount was extrapolated from results of the 1913 Mellon Institute Study on the basis of commodity price index and population.[30] More recently, Gerhardt[71] estimated the cost of pollution for 1968 to be within a range of $6.8 to $15.2 billion, with $8.1 billion the probable cost. Ridker[72] has suggested a total cost of pollution damage in 1970 of $7.3 to $8.9 billion. The basic procedure of the latter two efforts involved: (1) the identification of categories of air pollution damage, (2) an estimation of the total value of category regardless of the air pollution effects, (3) the assumption of an air pollution damage factor, (4) the application of this damage factor to the total value of the category, and (5) the summation of the estimates across all damage categories.

The principal difference between these national estimates is the determination of damage factors. The factors applied for national cost-of-pollution estimates for this study are thought to have been determined by more reliable and objective procedures than in the previous studies.

No comparative analysis of pollutants in terms of their effects has been made. We do not know, for example, whether a ton of SO_x pollution causes greater or lesser damage to vegetation than a ton of hydrocarbon emissions. Neither has there been any comprehensive regional analysis to examine location-related differences in pollutant effects within and between regions.

INFORMATION GAPS AND DATA LIMITATIONS

The objectives in identifying information deficiencies are to qualify the $16.1 billion estimate and to isolate those areas in which a greater research effort might be desirable. It is the authors' opinion that the estimate of $16.1 billion is realistically conservative and defensible. Many pollution effects were not costed simply because of data limitations. Other estimates were not possible because existing evidence is meager. Conservative figures were used generally throughout the estimation procedure.

With respect to health, $6.06 billion can be considered a conservative estimate for several reasons. First, Lave and Seskin did not

consider the indirect costs of some medical services because these could not be assigned readily to disease categories. Second, Lave and Seskin stated that people generally would be willing to pay more than the expenses of medical care and lost productivity that they incur. Finally, in all probability, health expenditures have increased proportionally more than the gross national product has from 1963 to 1968.

It is doubtful that the assumption of a straight-line functional relationship of mortality and pollution is accurate, but perhaps it is the best that can be derived at this time. Another problem in estimating health costs is determining what costs are appropriate measures of the economic impact of air pollution; e.g., should premature burial costs be considered as a cost of pollution? Furthermore, the functional relationship of health morbidity to air pollution levels and selected socioeconomic parameters might be somewhat spurious in that a more sophisticated statistical consideration should be given to this problem. Also, as in most economic assessments of pollution effects, great leaps are made in assigning the technical coefficients or damage factors. Lave and Seskin's work takes the first reasonable step in looking at the economic assessment of air-pollution-related health costs.

The property-value approach, with its sophisticated econometric handling of data, has provided the soundest basis for estimating pollution costs. Even though the assumption is made that some soiling, aesthetic, and plant effects are implicit in this approach, grave uncertainty exists as to what effects are actually being measured. One serious limitation has been the reliability of air quality data and the assumptions that have to be made in using them. What pollutants are actually being measured is uncertain. Nevertheless, the $5.2 billion estimate of losses in property value appears to be quite reasonable, even though all of its ramifications are not entirely understood.

The large number of variables that must be considered present a serious obstacle to the isolation of those parameters that are significant. Also, the application of different discount rates in the determination of total costs of pollution could change the relative cost estimates. The 10 percent rate of interest used in the residential property value to estimate results is an understatement of costs relative to health costs, in which a 6 percent interest rate was applied.

The $4.8 billion estimate of damage to materials represents a conservative loss figure despite the use of weak data. It is clear that little is known about air pollution effects on paints, concrete, and certain fibers. Although an argument can be made that the property-value approach implicitly contains some material deterioration costs, it is assumed here that these are insignificant with respect to the total impact of air pollution on materials.

Although vegetation losses resulting from air pollution are believed to be somewhat greater in magnitude than the suggested $0.1 billion, few data could be found to justify such an assumption. This figure is conservative in that costs associated with ornamental plantings are not included (these are considered part of the property-value estimate), and the effects that have been measured represent the observable direct effects only. Much remains to be learned about subtle, chronic, low-level-pollution growth effects. Also, no attempt has been made to quantify the effects of air pollution on the nutritional content of edible crops. Until some of these areas are investigated further, the vegetation-loss estimate must be used with an understanding of its deficiencies.

Conclusive evidence on the soiling costs attributable to air pollution is still lacking. As seen in the Booz-Allen study, the particulate pollution levels in Philadelphia have no statistically significant effect on residential cleaning and maintenance costs. Even if the household soiling costs are contained in the property-value estimates, there remain many soiling costs that cannot be totally ignored, as mentioned earlier in this report. In particular, little is understood of air-pollution-related costs of building maintenance and of losses associated with the soiling of artistic statuary and historical monuments.

In the area of aesthetics, little is known about what people would be willing to pay to preserve or achieve a given cleanliness of air. Such an approach is relevant in that air pollution perception is usually linked with visibility or odor problems. Yet, it is still largely unknown as to what is actually being measured in willingness-to-pay schemes. The lack of information suggests that virtually nothing is understood about the "psychic" costs people suffer as a result of the deterioration of artwork.

As suggested earlier, no known attempt has been made to investigate the economic effects of air pollution on animals, domestic and wild; however, the effects of the chlorinated hydrocarbons, in particular, pose a threat to the balance of animal and related populations.

REFERENCES

1. Kneese, Allen V. Air Pollution - General Background and Some Economic Aspects. In: The Economics of Air Pollution, Wolozin, H. (ed.). New York, W. W. Norton and Co., Inc., 1966. p. 23-29.

2. Kneese, Allen V. The Economics of Regional Water Quality Management. Baltimore, The Johns Hopkins University Press, 1964.

3. The Cost of Clean Air. Report of the Secretary of Health, Education, and Welfare to the Congress of the United States. Government Printing Office. Washington, D. C. First Report. June 1969.

4. The Cost of Clean Air. Report of the Secretary of Health, Education, and Welfare to the Congress of the United States. Government Printing Office. Washington, D. C. Second Report. March 1970.

5. Ridker, Ronald G. Economic Costs of Air Pollution. New York, Frederick A. Praeger, 1967. p. 12-29.

6. Van Arsdol, M. D., Jr. Social Organization and Air Pollution. Presented at 60th Annual Meeting, Air Pollution Control Assoc., Cleveland, Ohio. June 12-16, 1967.

7. Ridker, 1967. p. 12.

8. Ridker, 1967. p. 30-56.

9. Lave, L. B. and E. P. Seskin. Air Pollution and Human Health. Science 169(3947):723-733, August 21, 1970.

10. Riggan, Wilson B. Cost to the Federal Government of Health Effects Attributed to Pollution from Motor Vehicles. U.S.EPA, National Environmental Research Center. Research Triangle Park, N. C. Unpublished report.

11. Rice, Dorothy P. Estimating the Cost of Illness. U.S. Dept. of Health, Education, and Welfare. Washington, D. C. Health Economics Series, No. 6. 1966.

12. Statistical Abstract of the United States: 1968, 89th Ed. U.S. Dept of Commerce, Bureau of the Census. Washington, D. C. 1968. p. 312.

13. U.S. Dept. of Commerce. Survey of Current Business. 50:1, January 1970.

14. Uhlig, H. H. The Cost of Corrosion in the United States. Corrosion 51(1):29-33, 1950.

15. The Rust Index and What it Means. Rust-Oleum Corporation. Evanston, Illinois. 1964.

16. Private communication between Lee Brodsky, Hudson Painting and Decorating Company, New York, N. Y., and J. J. Schueneman, U.S. DHEW, PHS, National Air Pollution Control Administration, Durham, N. C. October 23, 1967.

17. Stanford Research Institute. Inquiry into the Economic Effects of Air Pollution on Electrical Contacts. U.S. DHEW, PHS, National Air Pollution Control Administration. Final Report, Contract No. PH-22-68-35. April 1970.

18. Salmon, R. Midwest Research Institute. Systems Analysis of the Effects of Air Pollution on Materials. U.S. DHEW, PHS, National Air Pollution Control Administration. Final Report, Contract No. CPA-22-69-113. January 1970.

19. Haynie, F. H. Estimation of Cost of Air Pollution as the Result of Corrosion of Galvanized Steel. U.S. EPA, National Environmental Research Center. Research Triangle Park, N. C. Unpublished Report.

20. Battelle-Columbus Laboratories. A Survey and Economic Assessment of the Effects of Air Pollution on Elastomers. U.S. DHEW, PHS, National Air Pollution Control Administration. Durham, N. C. Final Report, Contract No. CPA-22-69-146. June 1970.

21. Private communication between V. S. Salvin, University of North Carolina, Greensboro, N. C., and Thomas E. Waddell, U.S. DHEW, PHS, National Air Pollution Control Administration, Durham, N. C. Subject: Contract No., CPA-22-68-2, A Survey and Economic Assessment of the Effects of Air Pollution on Textile Fibers and Dyes. May 1970.

22. Salvin, W. S. Textile Pollution Loss is in Billions. Raleigh News and Observer, March 29, 1970, Section 4, p. 10.

23. Middleton, J. T. and A. O. Paulus. The Identification and Distribution of Air Pollution through Plant Response. AMA Arch. Ind. Health. 14:526-532, December 1956.

24. Lacasse, N. L., T. C. Weidensaul, and J. W. Carroll. Statewide Survey of Air Pollution Damage to Vegetation - 1969. Center for Air Environment Studies (CAES). State College, Penn. CAES Publication No. 148-70. January 1970.

25. Stanford Research Institute. Economic Impact of Air Pollutants on Plants. CRC-APRAC Project No. CAPCA-2-68. Palo Alto, Calif. Annual Report. August 1970.

26. O'Connor, J. J. The Economic Cost of the Smoke Nuisance to Pittsburgh. Mellon Institute. Pittsburgh, Pa. Smoke Investigation Bulletin No. 4. 1913.

27. Kneese, A. V. How Much is Air Pollution Costing Us in the United States. Proceedings of the Third National Conference on Air Pollution, Washington, D.C., December 12-14, 1966. p. 529.

28. Beaver, H. Committee on Air Pollution Report. Her Majesty's Stationery Office, London. 1954.

29. Michelson, I. and B. Tourin. Comparative Method for Studying Costs of Air Pollution. Public Health Reports. 81(6):505-511, June 1966.

30. Michelson, I. and B. Tourin. Report on the Validity of Extension of Economic Effects of Air Pollution Data from Upper Ohio River Valley to Washington, D. C., Area. Environmental Health and Safety Research Assoc., Hartford, Conn. August 1967.

31. Michelson, I. and B. Tourin. The Household Costs of Air Pollution in Connecticut. The Conn. State Dept. of Health and Environmental Health and Safety Research Assoc., Hartford, Conn. October 1968.

32. Jones, A. C. Studies to Determine the Costs of Soiling Due to Air Pollution: An Evaluation. In: Economics of Air and Water Pollution. Virginia Polytechnic Institute, Water Resources Center, Blacksburg, Va. April 1969,

33. Ridker, 1967. p. 73-89.

34. Ridker, 1967. p. 90-110.

35. Ando, Itara. Social Expenditures for Public Hazards and Its [sic] Apportionment. Economic Planning Agency. Tokyo, Japan. September 1967.

36. Private Communication between Booz-Allen and Hamilton, Inc., Washington, D.C., and Thomas E. Waddell, U.S. DHEW, PHS, National Air Pollution Control Association, Durham, N. C. Subject: Contract No. CPA-22-69-103, Survey to Determine Residential Soiling Costs of Particulate Air Pollution.

37. Rubay, M. About the Fog Observed in the Meuse Valley in December 1930 and Its Noxious Effects on Animals. Ann. Med. Veterinaire *77:97-110, March 1932. (Abstract)*

38. Firket, J. Comparative Pathology and Air Pollution. Seventh Lausanne Congr. Intern. Pathol. Com. 7(2):57-80, 1955. (Abstract)

39. Miessner, H. Damage to Animals Caused by Industry and Technology. Deut. Tieraerztl. Wochschr. 39:340-345, 1931. (Abstract)

40. Ferrando, R. and G. Milhad. The Biological Effects of Air Pollution on Animals. Rev. Med. Soc. 17(3):295-306, 1969. (Abstract)

41. Shupe, J. L. Levels of Toxicity to Animals Provide Sound Basis for Fluoride Standards. Environ. Sci. Technol. 3(8):721-726, August 1969.

42. Bohne, H. Industrial Smoke Damage from Fluoride. M. H. Deut. Landwirtsch. Ges. 77(17):575-578, 1962. (Abstract)

43. Iosif, C. Acute and Chronic Lead Poisoning in Cattle. Rec. Med. Vet. Ecole Alfort. 142(2):95-106, February 1966. (Abstract)

44. Ogura, Y. *Molybdenum Poisoning in Cattle Due to Air and Soil* Contamination as an Industrial Hazard. Tokyo National Institute Animal Health Bulletin. 50:24-29, 1965.

45. Bischoff, O. Poisoning of Domestic Animals through Copper and Arsenic Containing Fly Dust. Deut. Tieraerztl. Wochschr. 47:442-447, 1939.

46. Stokinger, H. E. Effect of Air Pollutants on Wildlife. Conn. Med. 27(8):487-492, August 1963.

47. Snyder, R. L. and H. L. Ratsliffe. Primary Lung Cancers in Birds and Mammals of the Philadelphia Zoo. Cancer Res. 26:514-518, March 1966.

48. Library Battles Decay of Rare Books. New York Times, February 20, 1967, p. 37.

49. Ridker, 1967. p. 90-114.

50. Lawyer, Robert E. An Air Pollution Public Opinion Survey for the City of Morgantown, West Virginia. Morgantown, Univ. of West Virginia. Unpublished Master's Thesis. 1966.

51. Lawyer, 1966. p. 24, 41.

52. Williams, J. D. and F. L. Bunyard. Interstate Air Pollution Study: Opinion Surveys and Air Quality Statistical Relationships. U.S. DHEW, PHS, National Center for Air Pollution Control. Cincinnati, Ohio. 1966.

53. Medalia, Nahum Z. and A. L. Finkner. Community Perception of Air Quality: An Opinion Survey in Clarkston, Washington. U.S. DHEW, Public Health Service. Cincinnati, Ohio. Publication No. 999-AP-10. June 1965.

54. Williams, J. D. and Norman G. Edmisten. An Air Resource Management Plan for the Nashville Metropolitan Area. U.S. DHEW, Public Health Service. Cincinnati, Ohio. Publication No. 999-AP-18. September 1965.

55. Private Communication between Robert Alexander, Oregon State University, Corvallis, Oregon, and Thomas E. Waddell, U.S. DHEW, PHS, National Air Pollution Control Administration, Durham, N. C. May 1969. Subject: Contract No. CPA-70-109, Social and Economic Effects of Changes in Air Quality.

56. Private Communication with David Flesh, Copley International Corporation, La Jolla, California. May 1970. Subject: Contract No. CPA-70-116, Social and Economic Impacts of Odors.

57. Ridker, Ronald G. and John Henning. The Determinants of Residential Property Values with Special Reference to Air Pollution. Rev. Econ. and Statistics. 49:246-257, May 1967.

58. Anderson, R. J., Jr., and T. D. Crocker. Air Pollution and Housing: Some Findings. Paper No. 264 . Presented at Institute for Research in the Behavioral, Economic, and Management Sciences, Krannert Graduate School of Industrial Administration, Purdue University, Lafayette, Indiana, December 1969.

59. Zerbe, R. O., Jr. The Economics of Air Pollution: A Cost-Benefit Approach. Report to the Ontario Department of Public Health. Toronto, Ontario, Canada. 1969. p. 54.

60. Huey, N., M. Wallar, and C. Robson. Field Evaluation of an Improved Sulfation Measurement System. Paper No. 69-133. Presented at 62nd Annual Meeting, Air Poll. Control Assoc., New York, N. Y., June 1969.

61. Interstate Effects Surveillance Project. U. S. DHEW, PHS, National Air Pollution Control Administration, Division of Abatement. Durham, N. C. Unpublished Report. 1968.

62. Air Quality Data from NASN and Contributing State and Local Networks, 1966. U.S. DHEW, PHS, National Air Pollution Control Administration. Durham, N. C. Publication No. APTD-68-9. 1968. p. 155.

63. Washington, D. C., Metropolitan Area Air Pollution Abatement Activity. U.S. DHEW, PHS, National Center for Air Pollution Control. Cincinnati, Ohio. November 1967. p. 37.

64. Interstate Air Pollution Study: Phase II, Air Quality Measurements. U.S. DHEW, PHS, National Center for Air Pollution Control. Cincinnati, Ohio. 1966.

65. Kansas City, Kansas-Missouri, Air Pollution Abatement Activity: Phase II, Pre-Conference Investigations. U.S. DHEW, PHS, National Center for Air Pollution Control. Cincinnati, Ohio. 1967.

66. Commercial Atlas and Marketing Guide, 100th Ed. Chicago, Rand McNally, 1969.

67. Havighurst, C. C. A Survey of Air Pollution Litigation in the Philadelphia Area. U.S. DHEW, PHS, National Air Pollution Control Administration. Durham, N. C. Final Report, Contract No. CPA-22-69-112. December 1969.

68. Nationwide Inventory of Air Pollutant Emissions, 1968. U.S. DHEW, PHS, EHS, National Air Pollution Control Administration. Raleigh, N. C. Publication No. AP-73. August 1970.

69. Waddell, Thomas E. Economic Effects of Sulfur Oxide Air Pollution from Point Sources on Vegetation and Environment. U.S. DHEW, PHS, EHS, National Air Pollution Control Administration. Raleigh, N.C. Unpublished Report. June 1970.

70. Air Quality Criteria for Carbon Monoxide. U.S. DHEW, PHS, EHS, National Air Pollution Control Administration, Washington, D.C. Publication No. AP-62. March 1970. p. 7-2.

71. Gerhardt, Paul H. An Approach to the Estimation of Economic Losses Due to Air Pollution. U.S. DHEW, PHS, CPEHS, National Air Pollution Control Administration. Raleigh, N. C. Unpublished Report. June 1969.

72. Ridker, Ronald G. The Problem of Estimating Total Costs of Air Pollution: Discussion and Illustration. Report to U.S. DHEW, PHS, National Center for Air Pollution Control. Cincinnati, Ohio. July 1966. p. 21.

☆U.S. G.P.O.: 1973—746-757-3807 Region No. 4