SECTION IX

ASSESSMENT OF THE EFFECTS OF SOILING

OVERVIEW OF THE PROBLEM

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. But the effects of air pollution in most cases are so much more gradual as to be unnoticed. Yet the costs of dealing with these effects may involve considerable extra expense of which the household is usually unaware. In urban areas some families spend very little as a result of air pollution, but many spend hundreds of dollars more each year than they would need to if the air were clean.

INDIVIDUAL STUDIES

Mel 1 on Institute- Pittsburgh Nuisance

The best known of the early studies of economic losses due to air pollution is the Mellon Institute Study of the Pittsburgh smoke nuisance reported by O'Connor (1913). The purpose of the study was to assess the economic cost of the smoke nuisance to the populace in the city of Pittsburgh. The cost estimates were based upon literature searches, observations, and informal surveys. The damage 'estimates obviously included some direct costs as well as some adjustment costs. The costs reflect losses due to soiling, corrosion, and the obstruction of sunlight by particulates. Questionable statistical techniques were used in averaging damage costs, in estimating the number of units (i.e., stores) affected, and in arriving at the percentage damage due to air pollution.

Beaver Report - London Smog Episode

The next major attempt to estimate soiling costs was an outgrowth of the Mellon study. As a result of the London "smog" episode in 1952, a committee was appointed in 1953 to examine the nature, causes, and effects of air pollution and the efficacy of preventive measures. The report to Parliament was released by Hugh Beaver (1954).

Much 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, however, "black" areas were compared with "clean" areas, whereas in the Mellon study, Pittsburgh was compared with different cities. Costs were assessed in the Beaver study by estimating the proportion of the total expenditure on a specific item that is attributable to air-pollution. The necessary proportional estimates were obtained from additional estimates of the amount and frequency of expenditures in polluted versus non-polluted areas, as determined by interviews with local authorities. The polluted areas in the study were assumed to contain one-half of the total population as thus one-half of all other items, i.e., painting of buildings, etc.

It is evident that this method resulted in extremely crude lump sum figures with only simple correlation with pollutant level. Where little or no information was available, the investigators did not hesitate to use pure guesswork. It should be noted that the investigator recognized that his results did little more than suggest a broad order of magnitude.

Michelson and Tourin - Household Costs

In recent years, several attempts have been made to identify the costs of soiling due to air pollution. For the most part, these studies have worked with the household as the primary unit of investigation in an attempt to measure pollution-related cleaning and maintenance costs.

In the area of evaluating household costs of soiling, the work of Irving Michelson has received the most attention.[118] Michelson's method of study is based upon the hypothesis that if air pollution causes meaningful soiling, the intensity of soiling should be reflected in a shorter time interval between successive cleaning and maintenance operations in areas with higher levels of pollution. If the relationship between particulate level and the frequency of cleaning and/or maintenance operations could be established, soiling costs could be calculated by applying a cost factor for each operation studied.

To test this theory, Michelson and Tourin (1966) conducted a survey by mailed questionnaire in the towns of Steubenville and Uniontown in the Upper Ohio River Valley. These towns have annual average particulate levels of 235 $\mu g/m^3$ and 115 $\mu g/m^3$, respectively. A high response'rate was achieved through a large publicity campaign, and a positive relationship was found to exist between the cleaning frequency of the home and of personal care items and the particulate level.

Cost comparisons were made within two income groups (less than $8000 and more than $8,000), and the total costs were calculated on the basis of the number of families and persons in each income group in each city. The differences in frequencies were calculated and then converted into dollar differences by applying local market prices for the various household services used in the survey. The resulting figures showed that the economic cost of air pollution for Steubenville was $3.1 million, or $84 per capita higher than in Unlontown.

In an attempt to validate this study, a subsequent survey by Michelson and Tourin (1967) was conducted in three suburban cities of the Washington, D.C. area, The Washington area was chosen for the validating study because it was thought to offer a severe test to the method. First, the absolute levels of suspended particulate in the D.C. area were very much lower. Second, the difference in the levels of suspended particulates of the paired cities was so much smaller in the Washington area as compared to the paired cities of the Upper Ohio River Valley. Finally, the character of the two areas was very different as far as industrial mix and population characteristics.

Again, Michelson found a positive relationship between the frequency of cleaning and maintenance operations and the level of suspended particulates. Although the findings of the Washington, D.C. study would seem to support the findings of the Ohio study, there appear to be not only major differences between the two studies but also inherent problems within each that throw some doubt upon his conclusion. For example, income level was the only controlling factor in the analysis. Furthermore, 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 group in his estimate of total and per capita soiling costs. In summary, the principal weakness was the lack of statistically reliable techniques.

Since these two major studies, Michelson and Tourin (1968) have applied their method of estimating the total extra household costs resulting from air pollution in Connecticut. In this study, no household survey was performed to measure the frequency of cleaning and maintenance operations. Instead, the frequencies were taken from the Upper Ohio River Valley and Washington, D.C. area studies. Because these frequencies were not alike, some kind of "averaging" was done. The local costs of the operations were investigated, and the demographic figures from census materials were used to arrive at a total damage estimate for the state of Connecticut. The usefulness of this method without adequate verification is questionable.

Ridker - Urban Soiling

Ronald Ridker also did research in identifying the soiling costs of air pollution."' In 1965, Ridker 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 the apparently adequate collection of data, the results of the analysis were inconclusive. Although there appeared to be some detailed problems and errors in the analysis, the principal problem involved the use of time spent in routine household cleaning, which may very well be an inappropriate estimate of these costs. The relative frequency with which these tasks are performed may be a more appropriate measure.

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

The Michelson and Ridker soiling studies have indicated several major problem'areas with regard to evaluating household soiling costs due to air pollution:

1. Isolation of costs due to air pollution from those due to 'other variables.
'2. Sample selection and bias.
3. Development of a survey technique that will provide reliable answers.
4. Inclusion of all household tasks whose costs are influenced by soiling damage from air pollution.

Booz, Allen and Hamilton - Phildelphia Survey

The Booz, Allen and Hamilton, Inc. (1970) residential soiling study in Philadelphia was expected to improve upon and extend the methodologies already developed. A questionnaire consisting of two sections 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 1800 personal interviews were conducted in the Philadelphia region.

Booz-Allen employed rigorous statistical survey techniques from the outset of the project.. These techniques were employed because of the belief that other, perhaps more dominant, non-pollution variables explain differences in the frequencies of many residential cleaning and maintenance operations to a far greater degree than the variations in the annual air particulate levels. Therefore, the survey techniques included: (1) a probability sample within. several zones of the Philadelphia area; (2) group-depth interviews leading to pre-estimates of attitudes toward cleaning and the best ways'of phrasing survey questions; (3) personally administered questionnaires, rather than mail or telephohe surveys; (4) a factor analysis of the questionnaire respondents to separate the population into attitude groups in order to better explain why people clean; (5) collection of demographic data on each respondent and his residence; and (6) the use of qualified interviews coding, and keypunching operations.

The study of residential household soiling costs made an attempt to discern between cleaning necessitated by pollution and cleaning by habit or other factors. 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 established through a factor analysis.

From the study of 27 cleaning and maintenance operations, results indicated that the range of annual air particulate levels experienced In the Philadelphla area (approximately 50 to 150 μg/m^3) 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 shown in Table 18, 11 were detennlned to be somewhat sensitive to air particulate levels. 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 house--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. The material costs of these do-it-yourself operations were considered only when such costs were considered to be non-trivial, such as the cost of painting.

They concluded that some low-cost cleaning and maintenance operations appear to be sensitive to air particulate levels, but more importantly, the high cost operations are unaffected by variations in air particulate levels in the Philadelphia area. Another finding of interest indicated that a higher proportion of residents of high-pollution areas believed their neighborhoods were dirtier than did residents of low-pollution areas.

On a smaller scale, an attempt was made 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 the poor return in the sample, the results have proved inconclusive. Also, because of contractual arrangements, cleaning functions are performed at the stores at regular intervals, whether "needed" or not.

Table 18. RELATIONSHIP OF CLEANING AND MAINTENANCE OPERATIONS TO AIR PARTICULATE LEVELS

	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

The data collected in the Booz-Allen study are extensive, but the analysis performed was of a very limited nature. Some of the conclusions are believed to be unwarranted. For example, great care was taken to collect demographic and social motivation data because these variables were assumed to be perhaps more important than the air pollution variable. Yet, the analysis of these data shows that no more than one variable was considered in the attempts to identify the soiling damage functions, In all likelihood, the within-zone variability of these factors would so increase the maintenance frequency scatter that it would be impossible to see any statistically significant effects of pollution levels. It is this author's opinion that such is the case with the activity of painting ouside walls. Booz-Allen concluded that this activity was not sensitive to differences in particulate levels because the frequencies between zones were not statistically significant. These data warrant further analysis to account for some of the confounding factors considered.

The Booz-Allen report has been criticized on several grounds: (1) statements concerning the statistical significance of operations have not been adequately justified in many instances; (2) the sensitivity or insensitivity of the cleaning and maintenance operations is not fully explained; and (3) accepted economic principles justify including with the cost of materials some imputed values for homemakers' time spent in cleaning and maintenance operations.

CONCLUSIONS

In conclusion, the Michelson, Ridker, and Booz-Allen studies dealt mainly with the estimation of household cleaning and maintenance costs. Except for Michelson, the evidence to date indicates air pollution does not have significant economic effects in terms of household maintenance and cleaning operations. A cost estimate will not be derived for this category in this report because: (1) the Michelson estimates do not appear to be acceptable for the purpose of extrapolation; and (2) those soiling costs associated with painting have already been estimated by Spence and Haynie (1972).

Yet, intuitively, other than what is implicitly measured in property value differentials, it is difficult to conclude that there are not significant soiling-related costs. Some of the significant costs that perhaps deserve attention include: commercial cleaning and maintenance costs; individual adjustments such as laundering, dry cleaning, and hair and facial care; car washing; and costs to quasipublic properties, which might Include cleaning and maintenance costs of buildings and monuments and washing of street 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 will not be estimated in this report.

SECTION X
EFFECTS OF AIR POLLUTION ON ANIMALS

OVERVIEW OF THE PROBLEM

Generaly speaking, air pollutants enter the bodies of domestic animals and wildlife via inhalation or ingestion of contaminated vegetation. Lillie[121] and Stokinger and Coffin[122] provide good reviews of the effects of air pollution on animal organisms. Fluorine by-products, lead, and arsenic are the major offending constituents in industrial pollution. Dusts, ammonia, hydrogen sulfide, and sulfur and nitrogen oxides cause less of a problem. Pollution of agricultural origin is oftentimes linked to the misuse of pesticides. Urban air pollution has been implicated as a causal factor in the poor health of zoo animals. While no empirical studies to estimate air pollution damages to animals have been attempted, a brief survey of the literature will, hopefully, place this problem in perspective.

DOMESTIC ANIMALS

Some of the odlest documented cases of the deleterious effects of air pollution have been associated with the Meuse Valley disasters, notably in 1897, 1902, and 1911. Vegetation and cattle were known to suffer from adverse atmospheric conditions, locally called "fog disease."[123] In actuality, the cattle had been stricken with asthma and emphysema.[124] An analysis of data collected in Donora, Pennsylvania, has shown that a positive correlation exists between the smog and the health of small domestic animals--dogs, cats, poultry, and rabbits.[125]

Fluoride poisoning of cattle grazing in the vicinities of aluminum reduction and phosphate fertilizer plants has demanded 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. Chronic fluorosis is typified by severe dental malformations and bone lesions. Acute fluorosis often results in stiffness, anorexia, weakness, convulsions, and cardiac failure.[126] Cattle with fluorosis often show a reduction in milk production and conceive poorly.[127] Middleton[128] reported that registered steers in Polk County, Florida, once valued at $3,000 a head, were sold for as little as $50 or were slaughtered because they were crippled and made helpless by eating fluoride-poisoned grass.

Losses to livestock have been known to occur in the vicinity of lead smelters and refineries.[129] Molybdenum dust, scattered from the chimney of the neighboring molybdenum-smelting factory, also has allegedly caused damage to livestock. The cattle developed diarrhea and malnutrition. Also, decreases in production and in the rate of conception were found.[130] Animals also have been damaged by the effluents of a copper smelter. The-high copper and arsenic output that deposited on plants and-grass caused numerous cases of poisoning and even the death of domestic animals such as cattle, horses, sheep and poultry.[131]

WILDLIFE

A number of general conclusions have been drawn regarding air pollution effects on wildlife. From field investigations, the economic poisons--insecticides, herbicides, chlorinated hydrocarbons, organic phosphates, etc.--appear to outweigh by far all other types of air pollutants as hazards to wildlife. Wildlife is chiefly affected by ingestion of the "fallout" of the air pollutant.

The relative susceptibility of various species to specific air pollutants is far from clear, but it would appear that the mammals are considerably more susceptible than birds.[132] Yet air pollution has been implicated as the causal agent of primary lung cancer in birds in the Philadelphia zoo. Synder[133] has focused attention on the. possibility that the amount of carcinogens in the atmosphere is increasing, because water fowl that were kept outdoors the year round were those animals most affected. It has also been reported that lead poisoning of zoo animals has become a significant problem at the Staten Island Zoo. The major source of the lead appears to come from atmospheric contamination.[134]

CONCLUSIONS

The damage to animals caused by air pollution has generally been localized and its economic consequence has probably been relatively unimportant; but the social consequences of this pollution are potentially more severe. Though indirect, the risk to the food cycle, especially when pesticides are implicated, could be serious; and it may be true that the economic importance of heavy metals and other toxic substances may lie in their impact on animals. In general, little is known about the effects of urban'air pollutants on domestic animals and zoo animals. The pollutant burden in these animals might offer an area of fruitful research.

Tolerance limits, much less damage functions, have not been developed for domestic animals exposed to air pollutants except for fluoride with cattle, swine; and poultry, and ammonia and carbon monoxide with poultry. In general, air pollution does not appear to constitute a major potent1al health hazard to domestic animals. However, the cadmium content of milk throughout the United States has revealed levels higher than safe limits.[135] This finding, coupled with evidence that other edible tissues of animals show increasing concentrations of air toxicants, indicates the importance of the potential impact that air pollution could have on the food chain.

SECTION XI

EFFECTS OF AIR POLLUTION ON THE NATURAL ENVIRONMENT

OVERVIEW OF THE PROBLEM

The general effects of air pollution on the natural environment or biosphere, have yet to be clearly delineated, let alone evaluated in economic terms. Nevertheless, it is useful to mention some of the more pronounced effects that air pollution may have, thereby providing a perspective of economic dimension. The impacts of air pollution on the natural order of things are important because again, we are dealing with the problem of scarcity--the scarcity of natural resources.

Damage studies typically examine specific types of pollution effects and attempt to isolate the damages of air pollution on a very limited basis. However, the effects and damages associated with air pollution are likely to have repurcussions beyond the simple effect investigated. Thus, there is a need to trace out the interdependent effects of air pollution, and it is this broader approach that recognizes the effects of air pollution as inherently related to other aspects of man's activities and his natural environment. Such a study is relevant, because it forces an examination of the global and other less quantifiable aspects of air pollution effects. Increasingly, air pollution is being considered a global problem not because of its individually minor effects, but because of its collectively major effects.

When we talk about the natural environment or ecology, we are concerned with the relation of living things to their environment and to each other. Over time, the environment is altered, naturally and by man. The so-called ecological balance, then, is a transitory, everchanging state of relationships of living things to each other and to their environment. We can conclude, then, that it is not conceivable that there is, ever has been, or ever will be, an ideal, all-inclusive ecological balance.[136] The economist, then, is interested in what way major perturbations of this changing ecological balance impact upon man and his welfare.

Environmental problems normally arise because the natural assimilative capacity of the environment is exceeded. Bower and Spofford state, "The natural environment has a capacity to assimilate, in some degree, all forms and types of residuals through the mechanisms of transport, transformation, and storage. In effect, the environment acts as a buffer between the discharger and the receptor, that is, it dissipates, absorbs, dilutes, and degrades or modifies residuals. However, the capacity of the environment to assimilate residuals varies from place to place and from time to time, depending both upon local conditions and upon the stochastic nature of some component of the environment, such as stream flow, temperature, and sunlight."[137]

Actually, little is known about the ultimate fate of pollutants once they are emitted into the atmosphere. Some of the pollution undoubtedly moves into the upper atmosphere where it can remain for long periods of time, but most is probably washed out. The continual deposition of pollution on the earth's surface may be creating irreversible imbalances by affecting the nutritional content of the soil as well as the delicate balance of soil microbes and other organisms important in food chains.[138] When we examine the details of food cycles, we see that the living and nonliving elements in nature are found together in the ecosystem through which energy cascades and matter cycles.[139]

Intuitively, scientists feel that air pollution should have some bio-climatic effects. Will the discharge of CO_2 and heat into the atmosphere create the infamous "greenhouse effect" and cause the polar ice caps to melt, or does the slight increase in the earth's temperatures indicate that the discharge of particulates into the atmosphere causes a reflection of solar rays resulting in cooler temperatures? Indeed, little is known about the impact of man's activities on the geophysical and biological world.

Aspects of global ecology enter also into the accumulation of toxic substances. Woodwel[140] argues that there are global, long-term ecological processes that concentrate toxic substances, sometimes hundreds of thousands of times, above levels in the environment. These processes include not only patterns of air and water circulation, but also a complex series of biological mechanisms. Over the past decade, detailed studies of the distribution of botti radioactive debris and pesticides have revealed patterns that have surprised even biologists long familiar with the unpredictability of nature. Yet as Moriarity points out, there is little evidence to suggest that pollutants do concentrate along the food chain.[141]

Climatic effects have also been associated with air pollution. Scientists have shown measurable'and distinct differences between the climate in the city'and that in its environs.'[142] Air pollution is recognized as a significant causal-factor. In the city, temperature and humidity are generally higher, precipitation and cloud cover are more frequent, and fog is more common. In extrapolating such findings, we should obviously be concerned with any major changes in the global climate. Weather has a tremendous effect on many animal populations. If an entire area warms or cools significantly, the reproduction, growth, and survival of organisms in that area' could be affected.[143] It has been reported that in the Northeastern United States, rainfall shows higher acid content than heretofore.[144] This has been blamed by scientists on air pollution. Oxides of sulfur and nitrogen are believed to be converting to strong acids, thus, increasing rainfall acidity 10 to 100 times. Some fear has been expressed that this could prove to be a water supply contaminant. Sweden is experiencing a similar problem, and Brohult has concluded that the acid rain is leaching nutrients that are essential for forest growth from the forest soils.[145]

CONCLUSIONS

There is much to learn about the effects of pollution as it intervenes into the life processes of the food web, productivity, populations, distributions, and the mechanisms of reinoculation. As Porter argues, "As we lengthen and elaborate the chain of technology that intervenes between us and the natural world, we forget that we become steadily more vulnerable to even the slightest failure to that chain."[146] Many of these consequences of air pollution are not without some economic value. While macro-economic analysis might be premature in many areas where the human and natural ecological relationships are not clearly defined, micro-economic analysis can aid in the identification of those possibilities that are economically feasible, resulting in a more efficient allocation of research efforts.

Even though the effects of pollution on ecological systems are not known, nor the probability of catastrophic events, it is obvious that people are concerned and are willing to spend money to reduce these effects and probabilities. The amount people are willing to pay to avoid ecological risk is probably very large in the aggregate and should be included in any estimate of the benefits to society from reducing pollution. However, given the paucity of such information, no numbers are currently available.

SECTION XII
ESTIMATION AND ALLOCATION OF NATIONAL GROSS DAMAGES

GROSS DAMAGE ESTIMATION

Methods and studies have been examined in this report to determine the economic value of the damages of air pollution. It is concluded from this review of the six measurement methods that can be used to estimate costs of pollution, only two have been used successfully in developing defensible damage estimates--the market study approach employing the property value method and the technical coefficients approach.

The property value method provides a national estimate of air pollution damages ranging from $3.4 to $8.4 billion with a "best" estimate of $5.9 billion for 1970. Anderson and Crocker argue that the property value estimate can, with great confidence, be considered a lower bound of the economic value of the negative effects of air pollution. As argued earlier in this report, it is assumed here that property value, or site value differentials measure primarily aesthetic and soiling costs.

Studies of the costs of air pollution associated with human health, materials and vegetation were also reviewed. These studies have used the technical coefficients approach. The damages from air pollution determined in this manner sum to $3.0 to $11.0 billion, with a "best" estimate of $7.0 billion. These national damage estimates for 1970 are summarized in Table 19. Estimates were not generated in this report for the other effects--animals and environmental risk--because of data limitations.

The problem now is to try to understand how the estimates of $5.9 billion and $7.0 billion relate to each other. The best that can be done is to make inteiligent, intuitive interpretations. The components of the latter cost estimate have been fairly well defined; the former, much less so, In theory, the housing market estimator should capitalize all of the economic costs associated with polluted air. In the real world, however, this is unlikely because the property market is less than perfect. This is because some losses are probably capitalized in durable resources that are immobile, and some of the effects are perhaps So insidious as to go unnoticed by consumers.

Table 19. NATIONAL ESTIMATES OF AIR POLLUTION DAMAGES (UNADJUSTED) 1970. ($ billion)

Effect	Range of Damages		
	Low	High	"Best" Estimate
Aesthetics and soiling[a]	3.4	8.4	5.9
Human Health[b]	1.6	7.6	4.6
Materials	1.3	3.1	2.2
Vegetation	0.1	0.3	0.2

[a]Property value estimator

[b]Does not include estimates of losses attributable to oxidant-related air pollutants because of data limitations.

Thus, what does the property value differential estimate? As discussed earlier, many authors agree that what are probably implicitly contained in this estimator are the aesthetic aspects of air pollution--costs associated with soiling, odors, visibility-restriction, "psychic" effects, and losses of plant ornamentals. If such is indeed true, then it would seem justifiable to add the property value differential estimate to the $7.0 billion estimate which is the sum of losses that, in general, do not significantly overlap with those losses capitalized in the residential property market. This would sum to a total of $12.9 billion.

At a minimum, there would be two areas of overlap: (1) the value of plant ornamental losses as estimated in the study by Benedict (1971). Yet even here this overlap is believed to be very small, since Benedict's estimate for ornamental losses included only replacement costs, not any "aesthetic" value--the true value that would normally exceed the replacement value; and (2) soiling costs associated with household painting thay may have been partially estimated by Spence and Haynie (1972). Even so, the total value of these two areas of overlap would be quite small in proportion to the whole.

The fact is: we have little idea as to the extent the various effects are capitalized into property values rather than being capitalized into other assets or registered as losses in consumer surplus. Because of this lack of knowledge, it seems reasonable to consider the estimates of $5.9 billion and $7.0 additive, with minor adjustments.

If one considers the areas of overlap mentioned above, two adjustements must be made. First, $50 million for ornamental losses as determined by Benedict (1971) must be subtracted from the property value estimate. Second, $540 million for residential painting as determined by Spence and Haynie (1972) must be subtracted from the estimate of materials losses. By making these adjustments, the possibility of double-counting losses for plant ornamentals and soiling that are implicit in the property value estimator, is minimized. The adjusted gross damage estimate for 1970 then becomes $12.3 billion. This estimate can be allocated as follows: Aesthetics and Soiling, $5.8 billion; Health, $4.6 billion; Materials, $1.7 billion; and Vegetation, $0.2 billion.

SOURCE EMISSIONS

Using the general approach of Barrett and Waddell (1973), it may be instructive to relate the cost of pollution for each effect to the specific pollutants . considered most responsible for that effect. EPA has estimated national emissions of principal pollutants by major source category for 1970. The principal pollutants are carbon manoxide (CO), particulates (part.), sulfur oxides (SO,), hydrocarbons (HC), and nitrogen oxides (NO,). National emissions of these pollutants were estimated to be 266 million tons in 1970 (see Table 20).

Approximately 54% of all national emissions come from transportation sources, including automobiles, trucks, buses, trains, aircraft, and other vessels. Fuel combustion in stationary sources such as public utility and industrial power plants, commercial and institutional boilers, and residential furnaces accounts for 17% of national emissions. Pollutants from industrial processes other than fuel comb&ion make up 14% of national emissions. Dumps and incinerators and related solid waste disposal practices generate some 4% of the

Table 20. ESTIMATES OF NATIONWIDE EMISSIONS, 1970*
(thousand tons/year)

Source Category	CO	Part.	SO_x	HC	NO_x	Total
Transportation	11.0	0.7	1.0	19.5	1.7	143.9
Fuel combusion in stationary sources	0.8	6.8	26.5	0.6	0.0	44.7
Industrial process losses	11.4	13.3	6.0	5.5	0.2	36.4
Solid waste disposal	7.2	1.4	0.1	2.0	0.4	11.1
Agricultural burning	13.8	2.4	Neg	2.8	0.3	19.3
Miscellaneous	4.5	1.5	0.3	4.5	0.2	11.0
Total	148.7	26.1	33.9	34.9	22.8	266.4

* Source: J.H. Cavender, D.S. Kircher, and A.J. Hoffman, Nationwide Air Pollutant Emission Trends 1940-1970, Publ. No. AP-115, Environmental Protection Agency, Research Triangle Park, January 1973.

national emissions, The remaining 15% derives from a variety of sources including prescriptive burning of agricultural and forest fuels, wild forest fires, structural fires, coal refuse burning, organic solvent evaporation, and gasoline marketing.

ASSIGNMENT OF DAMAGE COSTS BY POLLUTANT AND SOURCE

The national air pollution-related health costs for mortality and morbidity in 1970 were estimated to be $4.6 billion. Most health studies reviewed in this paper, related health effects with particulates, sulfur dioxide, and sulfur oxide pollutants. These pollutants have been studied most commonly because: (a) there is generally more information on dose-response for these pollutants than for any others; (b) more and better air quality data is generally available for these pollutants than for any others; and (c) often-times, particulates measurements seem to be a fairly good index of overall air quality. Thus, until better information is forthcoming, it is assumed that the health costs of air pollution stem from particulates and sulfur oxides and from the sources of these two pollutants shown in Table 20. Costs will be allocated in this report according to the relative sensitivity coefficients for these pollutants as determined by Lave and Seskin. In other words, the relative importance of particulates can be determined as being accountable for 59% of the total costs and SO, for the balance, or 41%.[147] Therefore, 59% or $2.7 billion of the $4.6 billion in health losses, is attributed to particulates and $1.9 billion, or 41% of the $4.6 billion, is estimated for the sulfur oxides-related health costs. Data deficiencies prohibit the estimation of the value of health effects associated with carbon monoxide, hydrocarbons, and oxides of nitrogen.

In the case of materials, pollution damages of $.7 billion to elastomers and dyes are attributed to oxidants and nitrogen oxides. The $.4 billion of damages to materials by sulfur oxides, estimated by Gillette, is identified as such. Because of the difficulty of separating the pollutant interactions, the remaining $.2 billion in the Spence-Haynie study (after adjusting for double-counting) will be equally divided in this attribution process between particulates and sulfur oxides. The remainder of the total materials cost estimate, 8.4 billion from the Salmon study, is allocated in proportion to the emissions of pollutants, except for carbon monoxide, which, according to present knowledge, is not damaging to materials.[148] Give that hydrocarbons and nitrogen oxides react in the presence of sunlight to form photochemical pollutants (oxidants), emissions of these two pollutants will be combined to represent damage from oxidant pollution and from nitrogen oxides.

Results of the model developed by Benedict (1971) which predicts air pollution damage to vegetation, indicate that over 90% of the observable damage can be attributed to oxidants, with a smaller part for sulfur oxides, and with a still smaller fraction attributable to fluorides. This assignment will allocate the total estimate of air pollution damage to vegetation of $.2 billion to oxidants. There should be a small portion allocated to SO,, but, because of its magnitude, it will not be displayed.

In considering the nature of the property value estimate, in that by assumption it measures aesthetic and soiling costs, it seems reasonable to assume that the total cost of $5.8 billion (adjusted for double-counting) can be allocated by evenly dividing the damage between particulates and sulfur oxides. Therefore, $2.9 billion in damage is associated with particulates and $2.9 billfon with sulfur oxides.[149]

Results of assignment by effect and by pollutant are given in Table 21. In like manner, assignment of air pollution damages is made by effect and by source according to the relative contribution of damaging pollutants. This relationship is shown in Table 22.

Table 21. NATIONAL COSTS OF AIR POLLUTION DAMAGE, BY POLLUTANT AND EFFECT, 1970
($ billion)

Effect	SO_x			Particulate			O_x			CO	Total		
	Low	High	Best	Low	High	Best	Low	High	Best	Best	Low	High	Best
[a]Aesthetics & soiling[b,c]	1.7	4.1	2.9	1.7	4.1	2.9	?	?	?	*	3.4	8.2	5.8
Human health	0.7	3.1	1.9	0.9	4.5	2.7	?	?	?	?	1.6	7.6	4.6
Materials[c]	0.4	0.8	0.6	0.1	0.3	0.2	0.5	1.3	0.9	*	1.0	2.4	1.7
Vegetation	*	*	*	*	*	*	0.1	0.3	0.2	*	0.1	0.3	0.2
Animals	?	?	?	?	?	?	?	?	?	*	?	?	?
Natural environment	?	?	?	?	?	?	?	?	?	?	?	?	?
Total	2.8	8.0	5.4	2.7	8.9	5.8	0.6	1.6	1.1		6.1	18.5	12.3

Notes:

[a]Also measures losses attributable to NO_x.

[b]Property value estimator

[c]Adjusted to minimize double-counting

?Unknown

*Negligible

Table 22. NATIONAL COSTS OF POLLUTION DAMAGE, BY SOURCE AND EFFECT, 1970

($ billion)

Effects	Transportation	Stationary source fuel combustion	Industrial processes	Solid Waste	Agricultura burning	Misc.	Total
Aesthetics & soiling	0.2	3.1	2.0	0.1	0.2	0.2	5.8
Human health	0.1	2.2	1.7	0.2	0.2	0.2	4.6
Materials	0.6	0.8	0.3	*	*	*	1.7
Vegetation	0.2	*	*	*	*	*	0.2
Total	1.1	6.1	4.0	0.3	0.4	0.4	12.3

*Negligible

SECTION XIII
DISCUSSION

SOME LIMITATIONS OF GROSS DAMAGE ESTIMATES

There will be a temptation to use the $12.3 billion estimate of the total cost of pollution as the measure of total benefits from pollution control. Yet, in fact, some of the pollution costs associated with the miscellaneous source category are not likely to become benefits resulting from general pollution reduction. This is because emissions from structural and wild forest fires are not normally controlled under traditionalair quality management programs.

Also, there has been no comparative analysis of poll'utants in terms of their relative severity, We do not know, for example, if a ton of SO, causes a greater or lesser effect on vegetation than a ton of NO_x emissions. This aspect should temper any use of the damage estimates as allocated according to pollutant.

There will also be the temptation to use the pollutant cost estimates as indicative of relative seriousness. While they may be indicative of a general magnitude of seriousness, it is necessary to point out that few studies have attempted to assess oxidant-type pollution effects on human health and aesthetics. While no cost is shown for oxidant effects on human health; it would be naieve to assume that there are no such effects.[150] The problem is this: research has not yet progressed to that point where specific effects can be, isolated and quantified, Because of this deficiency, the author has opted to conclude that instead of placing a zero cost in that particular cell,it would be more appropriate to indicate a-lack of knowledge.

And there is another possibility: teh results of some of these studies are spurious because sulfation or particulate measurements. for example, are acting as /proxies for the presence of other environmental pollutants. This is a common problem in all non-laboratory studies. Research has shown that SO_x, NO_x, and HC all break down to the particulate state; thus, any individual particulate air quality measurement might also be representative of those pollutants that were originally emitted as gases. This possibility, then, complicates and raises serious questions of the validity of allocating costs by pollutant in the nice, neat way shown in Table 21. Also, these pollutants act synergistically to cause damage that perhaps would not occur when acting independently. So again, we have the problem of attaching weights to the different pollutants, which, by themselves are perhaps harmless, but which, in the presence of other pollutants, become harmful.

A problem of perhaps a different magnitude is whether or not damages will become benefits through the abatement of air pollution. In theory, the two should be the same. But, given the measurement problems that we either assume away or are somehow rationalized into nonsignificance, it is quite likely that damages estimated by some of the techniques discussed in Section III (especially the-technical coefficients approach) are not "true" damages. This is so partly because of the obvious fact that the world is not optimal except for air pollution, consumers do not have sufficient knowledge about how they are being affected by air pollution, and because no allowance is made for substitution possibilities and adjustments that would be expected under a different set of environmental conditions. Thus, it is possible that the control of air pollution will result in benefits not heretofore yet measured.

Another inconsistency may occur in estimating gross damages because of some double-counting. Property value estimates, along with estimates of pollution effects on health, materials, and vegetation, are included in the total damage estimate of $12.3 billion. There may be some significant overlap of property value effects with the other categories. Information is not sufficient to determine the extent of double-counting.

In summary, the major limitations of gross damage estimates are: (a) estimates are often based on questionable air quality monitoring techniques or incomplete air quality data; (b) synergistic actions between pollutants complicates the categorization of effects and pollutant cost; (c) weak assumptions are often made in extrapolating experimental data to the effects on the true population; (d) since some of the extra-market effects' are not amenable to quantitative assessment, they are lost in these estimates; (e) the confounding of effects prevents assignment of residual damages to specific pollutants or sources ; and (f) there may be some double-counting between property value effects and other effects.

COMPARISONS AMONG GROSS DAMAGE ESTIMATES

The $12.3 billion estimate can be compared with those developed by others. Perhaps the earliest cited figure for the costs of pollution is $11 billion in 1959 or $60 per capita, which was extrapolated from results of the 1913 Mellon Institute Study on the basis of the commidity price index and population.[151] Ridker (1966) has suggested a total cost of pollution in 1970 as falling between $7.3 billion and $8.9 billion. Gerhardt (1969) estimated the cost of pollution to be $8.1 billion for 1968 within a range of $6.8 to $15.2 billion. The basic procedure of the latter two efforts involved five steps: (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.

Recently, a $16.1 billion estimate for 1968 was generated by Barrett and Waddell (1973). It might be of value to mention how the Barrett-Waddell estimate of $16.1 billion for 1968 compares with the $12.3 billion estimate for 1970 developed in this paper. From a casual glance, one might' assume that damages have been reduced by approximately $4 billion between 1968 and 1970. This is not necessarily true. It is hoped that a brief discussion will put the differences between the two estimates in better perspective.

There are'several significant aspects that account for the differences between the two estimates. First, in the case of human health, the benefits of reducing pollution to the primary air quality standards for particulates and sulfur dioxide were estimated in this study, while Barrett and Waddell estimated the benefits of reducing pollution to zero, This would tend to result in a lower estimate for 1970.

Second, in the case of the property value estimator of aesthetic and soiling-related damages, there are two important things: (a) additional research showed that a marginal capitalized property value of $350 would be more accurate than the $200 value used in the earlier Barrett-Waddell study; and (b) levels of the air quality data for 1970 that were used were, in general, somewhat lower than those used for 1968. These tended to balance each other, thus resulting in no significant difference between the two property value estimates.

And third, in the case of materials damages, additional completed studies forced a lowering in this study of the economic losses associated with the corrosion of metals and those associated with painting. Also, a reevaluation of the available information suggested that there was no sound basis for estimating air pollution damages to certain materials such as cement and concrete, plastics, and wood; thus, estimates included for these damages in 1968 were dropped in this study. In addition to this fact, the lower SO_2 levels in 1970 resulted in a lower materials damage estimate for 1970. Implicit in all of these dollar values (as with that for vegetation losses), is the fact that inflation is another factor pushing air pollution damages higher in one year relative to the preceding one. The same can be said with respect to the increase in many instances of populations-at-risk. This would particularly be true in the area of health.

Thus, given that the bases for comparison of the two gross damage estimates are varied, it would be very difficult and probably not very meaningful to try to isolate what portion of the $3.8 billion difference could be attributed to the different assumptions made or different kinds of data used. Compared to the $16.1 billion estimate for 1968, the $12.3 billion estimated for 1970 in this paper is considered to be more refined and better specified--more refined in the sense that more logical and realistic assumptions are made and better specified in the sense that it is acknowledged that this is only the best estimate that falls within a specified range of $6.1 to $18.5 billion with some high degree of probability.

Most recently, Justice, et.al. (1973) have estimated that air pollution damages in 1970 ranged from $2.0 billion to $8.7 billion. While the range of damage estimates developed by Justice, et.al. overlap with the range developed in this report, there are significant differences between the two studies. The most significant difference pertains to health costs associated with air pollution, which Justice, et.al. estimate to range from $62 million to $311 million for 1970. This range is significantly lower than that reported in this report primarily because Justice, et.al. considered neither the additional work reported by Lave and Seskin after their Science article, nor the recent findings from EPA's CHESS program. Differences in other costs for specific effects rest largely on differences in the assumptions made, many of which that are suspect.[152]

The principal difference among all of the national damage estimates, including those reported in this study, is the determination of damage factors. The factors applied for national cost-of-pollution estimates for this study are believed to be determined by more reliable and objective procedures than in the previous studies.

SOME CONCLUDING REMARKS

It is the author's opinion that the estimate of $12.3 billion is a reasoned, defensible one. Many pollution effects were not costed simply because of data limitations. The estimate generated through the use of property value method is believed to be, at a minimum, the lower bound on the "true" economic damages resulting from air pollution. To minimize double-counting, potential areas of overlap in ornamental losses and household painting were accounted for. By accounting for this overlap, the separate estimates determined by the technical coefficients approach--health, materials, and vegetation--were made additive to the estimate for aesthetics and soiling determined via the property value approach. While acknowledging that there is room for argument, it is believed that the available evidence suggests that the two estimates should be added together. While some may exercise the option of using $7.0 billion as the gross damage estimate for 1970, it'is argued here that $12.3 billion is a sounder, more realistic estimate.

With respect to health, the estimates generated from Lave and Seskin (1973) and EPA can be considered a conservative measure of the real cost. It is argued that, in general, people are willing to pay more than the expenses of medical expenditures and lost productivity which they suffer, for air pollution abatement. While it is doubtful that the assumption of a straight-line functional relationship of mortality and'morbidity and pollution is accurate, it is perhaps the most reasonable stance that can be taken at this time. In summary, these two studies provide a basis for taking a significant step in attempting to assess the economic effects of air pollution on human health. Again, little is known about the effects of automobile-and-related pollution on human morbidity and longevity.

The estimate of economic costs associated with materials degradation also appears to be a reasonable approximation. It is quite obvious from the numerous studies that only little'dose-response information is available and in particular, little is known about air pollution effects on concrete and other building materials, paints, and some fibers.. Also, little is known about adjustment costs that can be related to the use of more resistent materials because of air pollution.

Although vegetation losses due to air pollution are believed to be somewhat greater in magnitude than the suggested $.2 billion, little empirical evidence could support such an assumption. The figure is conservative because the yield and growth effects on plants are not generally considered in this estimate. There is much to learn about subtle, chronic, low-level-pollution yield 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 can only be used with an understanding of its many deficiencies.

There is still a lack of conclusive evidence on the soiling costs attributable to air pollution. Although Booz-Allen concluded that no significant economic impact of particulate pollution differentials existed'with respect to residential cleaning and maintenance costs, the analysis in their study appears to be incomplete and warrants further work.

While the impact of air pollution on man's aesthetic values is believed to be considerable, because of data limitations, no direct estimates were generated. Quite obviously, man is bothered by poor visibility and noxious odors, but few attempts have been made to quantify these impacts. The lack of information suggests that only little is understood about the "psychic" costs people suffer as a result of a deteriorating air environment as well as the deleterious effects of air pollution on precious works of art.

As mentioned earlier, no known attempts have been made to investigate the economic effects of air pollution on animals, domestic or wild, even though pollutants such as chlorinated hydrocarbons, pose a threat to the balance of animal and related populations. It was also concluded that economic analysis of any long-run implications of perturbations to our ecosystem might be premature.

Obviously, of the different methods that might be used to estimate pollution costs, the technical coefficients approach has been the most popular. Why? Because of its simplicity in handling and translating from physical or biological damage to economic loss. Market studies, or more specifically, 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 often made that most aesthetic-related costs are implicitly measured in this approach, some uncertainty exists as to'what effects are actually measured.

It is likely that some combination of the different methods surveyed will ensure the most accurate assessment of the economic damages resulting from air pollution insults. The technical coefficients approach should prove valuable in understanding the basic cause-effect relationships affecting adjustments in the market place. The property value approach should be applied to rural areas and should be tested with other pollutant measurements. The public polling technique will be used in understanding the social, aesthetic, and psychological or "psychic" effects of adjustments that people experience. Different problems will require different handling.

In any attempt to determine a dose-response relationship, the large number of variables that must be considered presents a serious problem in the isolation of those parameters that are significant. Yet of course, excluded variables introduce a bias only to the extent they are not orthogonal to the included variables. Also, the application of different discount rates in the determination of total costs of pollution could change the relative cost estimates. The ten percent rate of interest used in the residential property value to estimate results is an understatement of costs relative to health costs which applied an eight percent interest rate.

RECOMMENDATIONS

Gross damage estimates are only the first step in providing information on the benefits of pollution abatement to policy-makers. Such estimates do point to the seriousness of air pollution problems. However, the U.S. Government and most individuals in the U.S. are already convinced that air pollution is indeed a serious problem.

Expansion and refinements in pollution effects studies should be undertaken. Such information on dose-response--damage functions--would provide a sounder basis for estimating benefits of abatement. However, the information which is generated should be over a range of realistic ambient air quality or control levels. Damage functions should be constructed on a pollutant-by-pollutant basis or group basis when pollutants act, or can be acted upon, together, and, most importantly, should be analyzed in a regional benefit, policy-making framework (see the example described in Section III).

Research should also be expanded in the area of the different methods that can be utilized in the assessment of the social cost of air pollution. It is likely that some combination of the different methods surveyed in this paper will ensure that most accurate assessment of the economic damages resulting from air pollution insults. Also, attempts should be made to understand and identify the economic and social significance of adjustments people make because of deteriorating environmental quality.