SECTION VI
ASSESSMENT OF AIR POLLUTION DAMAGE TO MAN-MADE MATERIALS

OVERVIEW OF THE PROBLEM

Air pollution has a variety of effects on materials--the corrosion of metals, the deterioration of materials and paints, and the fading of dyes. There have been a number of attempts at estimating the resultant economic losses due to those detrimental effects of air pollution.

INDIVIDUAL STUDIES

Robbins - Electrical Contacts

It appears that the first materials effects study of major significance was performed by Robbins (1970) of Stanford Research Institute. The study intended to determine whether or not air pollution creates problems of economic significance in the operation of electrical contacts, and if so, 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 investigated were: '(a) the direct cost associated with the plating of contacts with precious metals; and (b) the indirect cost associated with the preventive measures of air conditioning and air puriffcatfon.

The types of contacts that are normally plated are used in switches, relays, connectors, potentiometers, and commutators, which are used mostly in the electronics and communications industries. More money is spent combatfng the effects of sulfur dioxide (SO_2) and hydrogen sulfide (H_2S) air pollution on low-voltage electrical contacts than all the other air pollution effects on electrical devices combined. The effects of organic gases and particulates are of less importance. Organic gases form "frictional" polymers on sliding contacts whereas particulate pollutants are a problem due to the fact that the materials are excellent absorbers of moisture and corrosive agents.

It was estimated that $20 million is spent annually on plating contacts with precious metals because of air pollution, and $25 million is spent annually on air conditioning and purification which act to-prevent corrosion by maintaining clean air. Another $4 million is expended annually for washing insulators, $5 million for research and development expenditures by firms that might be affected by air pollution, and as estimated $10 million for losses due to failures. This totals approximately $65 million annually.

The most important conclusion drawn from this study was the fact that the air pollution problem, with respect to electrical contacts, was not as serious as originally estimated. It was also concluded that the cost of $65 million is unnecessarily high because two or more individually preventive measures are being applied simultaneously to minimize losses. It is believed that losses will decrease as cheaper substitutes, more resistant to air pollution, are used in electrical contacts.

ITT - Electrical Components

In a similar survey, ITT Electra-Physics Laboratories (1971) assessed the economic impact of air pollution on electronic components. Information concerning pollutant-material damage mechanisms was acquired by surveying the literature. Interviews with manufacturers and users of electrical and electronic components provided information on actual experience. The electronic component categories studied were: semiconductor devices, integrated circuits, television picture tubes, connectors, transformers, relays, receiving tubes, and crystals. Total damage costs for these receptors summed to $15.5 million. This included $2.36 million for preventive costs which included filtering air, etc., and another $13.2 million for maintenance costs which were the costs of cleaning, repairing, replacing and in any way restoring a piece of otherwise defective equipment. Costs that were estimated for various electronic devices in the Robbins (1970) study were not assessed in the ITT study.

As in the Robbins study, the cost of $15.5 million estimates the cost of two or more individually effective counter-measures that are being applied simultaneously to minimize losses. As expected, the data were very sketchy, and extrapolations from individual cases to the nation are questionable at best. Attempts to correlate statistically equipment failures and pollutant levels were less than successful. While the literature reviews indicated that sulfur dioxide should be expected to account for most of the damage to electrical components , interviews with manufacturers revealed that particulate matter was perhaps responsible for most of the electronic component and equipment malfunctions currently experienced.

Salmon - General Materials

The most comprehensive survey of the economic effects of air pollution on materials was undertaken by Richard L. Salmon (1970) of Midwest Research Institute. The objectives of the study were: (1) to identify the materials, air pollutants, and environmental factors that should be studied in order to assess the economic damage to materials caused by air pollution; (2) to analyze systematically the physical and chemical interactions among the variables identified in (1) for the purpose of determining cause-effect relationships; (3) to determine, where possible, the pollutant dose-response relationship for materials that are significant because of their relative economic value, and indicate how this may be done where such relationships are presently defined; and (4) to translate the pollutant and dose-response relationship into a pollutant and dose-cost-damage function.

Information was gathered through literature searches, and by personal, mail, and telephone interviews. Economic losses of materials were attributed either to damaged properties or to reduced 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 "percent condition" approach was adequate, with economic damage considered to be 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% 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 dollar production volume times a weighted average economic life of the material (based on usage), times a weighted average factor for the percent of the material that is exposed to air pollution. The in-place or as-used value of the material was determined by including a labor factor. The rate of economic loss Was calculated as the product of the -economic value of material exposed to air pollutioh times a value of interaction. The value of fnteraction'was calculated by estimating the difference between the rate of material deterioration in a polluted environment compared to 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 9. The total value of materials exposed to air pollution and values of interact& between the various materials and pollutants have been combined to produce a single figure representing the extent of economic damage attributable to air pollutants.

To interpret the results in Table 9, it must be realized that the individual material loss estimates were made to determine relative importance rather than actual value. However, the sum of the economic losses, $3.8 bfllfon in 1968, appears tenable. Such a calculation procedure is valid only within narrowly circumscribed limits. The difficulties lie in the problems inherent in the technical coefficients approach--the substftution problem in particular. The study concluded that ff it is assumed that'this list of materials represents only 40% of the total value of materials exposed to air pollution, and that damage functions for the other 60% are similar, the total loss due to chemical attack on materials by air pollution is estimated at $9.5 billion.

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

1. Sulfur oxides: metals, cotton, finishes, coatings, building stone, paints, paper, and leather.
2. Ozone: rubber, dyes and paints,
3. Nitrogen oxides: dyes and paints.
4. Carbon dioxide: building stone.
5. Partfculates: stone, clay, and glass

Table 9. RANKING OF MATERIAL ECONOMIC LOSSES CAUSED BY DETERIORATION

Rank	Material	Economic loss, $ million
1	Paint	1,195.0
2	Zinc	-778.0
3	Fibers	358.0
4	Cement and concrete	316.0
5	Nickel	260.0
6	Rubber	194.0
7	Tin	144.0
8	Plastics	126.0
9	Aluminum	114.0
10	Copper	110.0
11	Carbon steel	53.8
12	Building brick	24.2
13	Paper	22.1
14	Leather	20.6
15	Wood	17.6
16	Building stone	17.6
17	Brass and bronze	13.4
18	Magnesium	13.0
19	Alloy steel	8.7
20	Bituminous materials	2.2
21	Gray iron	1.9
22	Stainless steel	1.6
23	Clay pipe	1.4
24	Malleable iron	0.9
25	Chromium	0.8
26	Silver	0.7
27	Gold	0.6
28	Glass	0.3
29	Lead	0.2
30	Molybdenum	0.1
31	Refractory ceramincs	0.02
32	Carbon and graphite	0.003
Total (Approximate)		3,800.0

It was concluded that organic pollutants (hydrocarbons and aldehydes) are not damaging to materials except, to some extent, to elastomers. Much information was available on the effects of air pollutants on metals and rubber. There was some information on fibers such as cotton and nylon and little on paints, paper and leather. Virtually no information existed on plastics, wood, wool, and concrete. There exist direct quantitative correlations of damage with specific pollutants (dose-response) only for zinc and SO_2, several varieties of rubber and O_3, and for cotton and SO_2. In summary, the major informational shortages concert the effects of air pollution on concrete, paints, fibers, and plastics.

The Salmon (1970) study is useful in summarizing the effects of air pollution on materials and lays the groundwork for more intensive studies. Some of the data used,, such as that for formulating interaction and corrosion rates, is of questionable validity, and particularly in a quantitative analysis such as was used here, the results are only as good as the data used. Another problem exists because no clear distinction was made between the stock and flow of materials. There is very likely a mixture of the two, resulting in potential discounting problems, Also, only the direct effects were investigated; the "value" of service was not assessed. As Salmon cautioned in his report, the economic loss from material deterioration indicated susceptibility to economic loss or potential loss. The results could not be interpreted as actually incurred economic loss. A primary purpose of the study was the ranking of materials indicating relative measures of air pollution-induced damage. This study should be very useful for setting research priorities.

Mueller and Stickney - Rubber Products

The Battelle Memorial Institute study by Mueller and Stickney (1970) 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 and makes an estimate of the yearly cost of this pollution. Costs are measured as: (1) the increased costs at the manufacturers' level to provide products that are resistant to atmospheric pollutants (these are normally passed on to the consumer); and (2) the direct costs to the consumer fn the form of shortened useful life of the product. The combined costs at the consumer level are used in estimating the total cost of pollution.

One phase of the study was a review of the literature for technical information. In the second phase questionnaires were sent to 60 rubber products firms to determine the cost-of atmospheric pollution at the manufacturing level. Of the thirty which were returned, only about a third provided complete information.

To estimate the cost of atmospheric pollution at the rubber product manufacturer's level, two independent calculations were made. One was based on the information derived by questionnaires sent to the industry, whereas the second calculation was based on the total of individual compounding costs.

Extrapolatfon of the results recorded by individual firms to the industry as a whole show a yearly cost of $54.0 million due to the detrioration of rubber products caused by air pollution. To calculate the added cost at .the manufacturer's level, it was necessary to add individually estimated costs for resistant polymers, antioronants, waxes, protective finishes, and wrapping. These estimated costs are listed in Table 10.

Table 10. ESTIMATED COSTS OF AIR POLLUTION RESISTANT MATERIALS

Preventive measure	$ million
Resistant polymers	20.6
Antiozonants	34.1
Waxes (50% of total)	5.0
Protective finishes	?
Wrappings	?
Research for compounding	?
Total	59.7

It can be seen that the two figures of $54.8 million and $59.7 million compare favorably. These are costs at the manufacturer's level. Since industry estimates suggest that an average retail price is three times the manufacturing cost, the compounding cost would be approximately $160-180 million at the retail level. Information on the cost of early replacement of rubber products is summarized in Table 11.

Table 11. COSTS OF SHORTENED LIFE OF RUBBER PRODUCTS

Rubber product	$ million
Tires	37.0
Innertubes	-
Footwear	
Mechanical goods	29.7
'Medical 'goods	100.5
Belting	22.5
Hoses	36.0
Total	225.7

The total annual cost-of pollution, as it affects the rubber industry, is approximated.as the sum of $170 million (the middle of the range $160-180 million) and $225.7, or about $395 million. The first cost is that added at the manufacturer's level, which is passed on to the consumer in the form of an increased price for the product. The second costs is for the early replacement of rubber products because of a shortened service life, a cost which must be borne directly by the consumer. Another cost considered is the labor cost connected.with the early replacement of damaged rubber products. Mueller and Stickney conservatively estimate this labor cost to be $75 million annually.

In conclusion, almost all damage to rubber is caused by ozone. Very little is known-about effects of other- pollutant? 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.

The Mueller-Sticltney study lacks detail in that it deals mostly with gross figures. Early replacement and associated labor costs of rubber products were "ballpark estimates" at best. Also, the logic of the assumption that retail costs are three times the manufacturers' cost can be questioned, Theoretically, the pollution cost at the retail level should only reflect the incremental pollution-related costs at the manufacturing level. It is not clear that the additional cost imposed by air pollution necessarily result in an increase in overhead and marketing costs or any other costs comprising the factor of "three times." Nonetheless, given the lack of better information, the estimate of $475 million annual cost determined by Battel le is considered acceptable in this report.

Spence and Haynie - Paints

Recent work by Spence and Haynie (1972) Investigated the deterioration of exterior paints by: (1) particulate matter primarily; and (2) the interaction of particulate matter and sulfur oxides. The associated potential economic loss to manufacturers and consumers because of this deterioratlon was then estimated. Their initial review of the literature made themacutely aware of the almost total lack of Information on dose-response relationships with respect to air pollution damage to paints. This informational gap confirms the findings of the Salmon (1970) study mentioned earller. That study concluded that sulfur dioxide and particulate matter play an Important role in the chemical deterioration of modern-day exterior paints. These pollutants serve to promote the chemical deterioration of exterior paints.

Spence and Haynie referred to the soiling studies by Michelson and Tourin (1967 and 1968) and Booz, Allen and Hamilton (1970) in order to derive information on the frequency of house repainting as a function of suspended particulate concentrations. The results of Michelson and Tourin are summarlzed in Table 12, and Booz-Allen in Table 13. In Table 12, it is shown that the maintenance intervals of the years between repaintings were observed to decrease as the particulate concentrations increased. While there appears to be a positive relationship between frequency of repainting and particulate concentrations, the questionable data generated in the Michelson and Tourin study (see Section IX) make use of it questionable.

Table 12. INTERVAL FOR EXTERIOR REPAINTING AS A FUNCTION OF PARTICULATE CONCENTRATIONS*

City	Particulate concentration, $\mu g/m^3$	Maintenance interval, year	Maintenance frequency, number/year[a]
Steubenville	235	0.88	1.14
Uniontown	115	1.89	0.53
Suftland	85	2.93	0.34
Rockville	75	3.62	0.28
Fairfax	60	3.90	0.26

'Reciprocal of maintenance interval in years

* Source: J. W. Spence and F. H. Haynie. Paint Technology and Air Pollution: A Survey and Economic Assessment. Environmental Protection Agency Publication No. AP-103, Research Triangle Park, N. C. (February 1972).

Table 13. FREQUENCY FOR EXTERIOR WALL PAINTING IN PHILADELPHIA AS A FUNCTION OF PARTICULATE CONCENTRATION*

Particulate concentration ranges, $\mu g/m^3$	Mean annual frequency	Standard error of mean
<75	0.28	0.016
75-100	0.35	0.053
100-125	0.35	0.041
>125	0.29	0.055

* Source: J. W. Spence and F. H. Haynie. Paint Technology and Air Pollution: A Survey and Economic Assessment. Environmental Protection Agency Publication No. AP-103, Research Traingle Park, N. C. (February 1972).

Many of the analytical and statistical problems encountered in the Michelson studies were minimized in the Booz, Allen, and Hamilton study in Philadelphia. Table 13 shows their maintenance frequencies for exterior wall painting by mean annual particulate concentrations. Spence and Haynie suggest that the fact that the proportion of households with incomes less than $6000 increased with pollution level is a factor that tends to counteract the effect of suspended particulates on paint life. And it is this confounding factor that partially explains 'why no statistically significant difference in painting frequency as a function of particulate level was detected.[86]

Table 14 outlines the method used by Spence and Haynie to establish their estimate of the potential annual consumer cost for repainting that can be attributed to pollutant damage in urban areas. Estimates of losses are developed for four paint classes: coil coating, automotive refinishing, maintenance, and household. Expected service lives were best "guesstimates" except for household, where expected service lives for rural and urban'areas were estimated from the Michelson and Booz-Allen studies. Estimates of the distribution of paint in rural versus urban areas were also best judgments of the authors. Labor factors were estimated from best available information concerning professional painting costs. The total value lost at the retail level is estimated as $704 million. Household paints, with, a value 'loss of $450 million, represent over 75% of the total estimate.

The authors readily admit that these calculations result in only a rough approximation, and that more information on dose-response, expected service life, maintenance frequency, and labor factors, must be obtained if more reliable economic assessment is to be made. Given the lack of better information, the figure of $0.7 billion will be taken as more defensible than the estimate for paint damage of $1.195 billion generated in the Salmon study.

Fink - Corrosion

A recently completed study by Fink, Buttner, and Boyd (1971) attempted to develop a more realistic assessment of the added cost of corrosion damage to the nation resulting from the exposure of metallic systems and structures to polluted atmospheres. In the approach used, applicable national shipment/

Table 14. ECONOMIC ASSESSMENT OF AIR POLLUTION DETERIORATION OF EXTERIOR PAINTS*

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11	Column 12
Exterior paint classes	Value at manufacturer's level, $ million	Area	Expected service life, years	Maintenance frequency,[a] per year	Estimated distribution of paint, % population	Paint consumed in urban areas,[b] %	Value of paint exposed in urban areas, $ million	Service life,[c] % loss	Loss at manufacturer's level? $ million	Labor factor	Loss at consumer's level? $ million
Coil coating	40	Rural urban	20 15	0.05 0.07	30 70	77	31	25	a	2	16
Automotive refinishing	150	Rural urban	5 4	0.2 0.25	30 70	74	111	20	22	4	88
Maintenance	100	Rural Urban	5 4	0.2 0.25	30 70	74	74	20	15	4	60
Household	485	Rural Urban	6 3	0.17 0.33	40 60	74	359	50	180	3	540
Total	775						575		225		704

Notes:

[a] Maintenance frequency is the reciprocal of expected service (Column 4).

[b] Calculation of % coil coatings consumed in urban areas (Column 7):

Rural Areas: $\frac{\text{Col. 5}}{0.05} \times \frac{\text{Col. 6}}{.30} = 0.015$

urban Areas: $0.07 \times .70 = \frac{0.049}{0.064}$

$\frac{0.049}{0.064} \times 100 = 77\%$

[c] Calculation of % service life loss for coil coating (Column 9):

Rural Areas: 20 years

Urban Areas: 15 Years

% Service Life loss: $\frac{20 - 15}{20} \times 100 = 25$

* Source: J. W. Spence and F. H. Haynie. Paint Technology and Air Pollution: A Survey and Economic Assessment. Environmental Protection Agency Publication No. AP-103, Research Triangle Park, N.C. (February 1972).

value data from the U.S. Department of Commerce were employed to compute average pollution costs on a national basis. Of these data, individual corrosion costs were calculated for nine major categories that survived the screening process (see Table 15). These categories were regarded as the most sensitive to and most damaged by air pollution corrosion. The total of these individual estimates was $1.45 billion.

Two calculations were considered by Fink et. al. for assuming up the economic marginal cost of corrosion caused by air pollutionover the typical cost in clean air service. The first calculation estimated the extra amount of protection and maintenance expense required in polluted atmospheres to prevent serious corrosion attack. The second calculation estimated the cost due.to the shortened life of the structural system caused by corrosion from polluted air. Thus, costs associated with corrosion include both maintenance costs (i.e., painting) and early replacement costs.

The general approach compared maintenance painting costs in clean and polluted air. The steps followed were: (1) the total amount of each item in use was established; (2) this amount was converted into exposed surface area; (3) the portion of this area exposed to polluted air was estimated; (4) the annual extra cost of protection by paint, per unit area, was calculated for each system; and (5) the area and annual cost figures were combined to obtain the total national loss for each item.

As shown in Table 15, the top four structural systems are primarily constructed of galvanized steel. Based on this corrosion study, the accelerated corrosion of zinc by sulfur dioxide accounts for more than 90% of the national economic burden imposed by air pollution corrosion.

The Fink, et. al. corrosion study makes a systematic and.reasonable estimate of the costs of corrosion to materials and the costs of related losses. Yet, several criticisms can be levied against this study. The first criticism relates to the problem that typifies most materials studies: no attempt is made to relate material damage to actual levels of air quality. Material losses are identified with "clean" or "polluted" areas which are not defined according to the severity or kind of air pollution. As a general rule, any study of air pollution damage should attempt in its analysis to relate damages to actual

Table 15. ANNUAL COST OF CORROSION BY AIR POLLUTION DAMAGE OF EXTERNAL METAL STRUCTURES, 1970"

Structural System	Useful life, years	Cost basis	cost, $ million	Percent of total
Outdoor metal work	45	Maintenance	914.0	63.0
Chain link fencing	30/20	Maintenance	166.0	11.5
Pole line hardware	30	Replacement	161.0	11.1
Galvanized wire and rope	20	Replacement	112.0	7.7
Steel storage tanks	50/11	Maintenance	46.3	3.2
Bridges	30	Maintenance	30.4	2.1
Street light fixtures	20	Maintenance	11.9	0.8
Power transformers	30	Maintenance	7.5	0.5
Transmission towers	30	Maintenance	1.5	0.1
Total			1,450.0	100.0

*Source: F.W. Fink, F.H. Buttner and W.K. Boyd. Technical Economic Evaluation of Air Pollution Corrosion Costs in Metals in the United States. Final Report from Battelle Memorial Institute, Columbus, Ohio, to the EPA, Research Triangle Park, N.C. February 1971.

levels of air quality, or at least to sound proxy for air quality. The use of "clean" and "polluted" as measures of the severity of air pollution, without further definition, is not acceptable. Another problem in the Fink corrosion study is the fact that the role of relative humidity in the corrosion and deterioration of materials is not considered in the analysis. Such an important parameter cannot be ignored.

Gillette - SO, Effects on General Materials

Gillette (1973), employing basically the same general approach as that used by Battelle, attempted to rectify in his assessment of materials damages, some of the problems in the Fink study. Gillette's study, being somewhat broader than that of Battelle, was designed to assess the economic damages from sulfur oxides (SO,) to man-made materials. Where Fink assumes that about 80% of materials are located in "polluted areas," Gillette assumes that materials are distributed according to human population. Information on population distributions, coupled with sulfur dioxide data for about 150 SMSA's for the years 1968-1972, provided a basis for estimating materials populations-at-risk.

Gillette then integrated measures of the average annual relative humidity by SMSA into his analysis. This consideration of relative humidity is important because the corrosion damage-function shows relative humidity to be more important than sulfur dioxide in causing corrosion. Using the best available damage function data for corrosion and paint deterioration, Gillette estimated economic losses for the inclusive years. Gillette estimated for 1970 that SO, damage (where sulfur dioxide acts as a surrogate for all sulfur damaging compounds in the atmosphere) to metals and paints was approximately $.4 billion. Gillette concluded from his analysis of available dose-response data on the effects of SO, on susceptible materials that SO, effects on textiles, building materials, leather and paper products, and dye fading are probably negligible from an economic standpoint. Gillette based this conclusion on the following considerations: (1) many materials are exposed primarily to indoor environments where the exposure is to much lower levels of air pollutants than exposure outdoors; (2) current SO_2 levels are generally lower than several years ago, presumably because of the substitution of cleaner fuels; and (3) the use-life of many materials is quite short.

Gillette's study, while a substantial improvement upon earlier efforts to assess materials losses due to air pollution, is not necessarily a definitive statement of the effects of sulfur oxides and derivatives on man-made materials. For example, it is difficult to say to what extent SO_2 is a good surrogate for all atmospheric sulfur-damaging compounds. It is possible that atmospheric sulfates are significant in the deterioration of materials, and thus, should have been accounted for in a more explicit manner in Gillette's analysis, Also, it appears that in some cases, tenuous conclusions were drawn where informational gaps existed. For example, some of the assumptions made concerning the paint damage function were based on very "soft" information. Yet even with these caveats, the estimate of SO_x-caused material losses developed by Gillette i's believed to be more realistic and more defensible than estimates of losses developed in other materials studies.'

Salvin - Dye Fading

Victor S. Salvin (1970) of the Unitersity of North Carolina conducted a study of the economic effects of air pollution on textile fibers and dyes. The objectives of his study were: (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 assess the economic effects of air pollution on textile fibers and dyes.

The status of the problem was discussed with manufacturing and industrial representatives as to the prevalence, mechanisms, preventative measures, and research costs. The suppliers of dyes were contacted for costs of dyes and dyeing processes (preventative measures). A technology committee of each industry served as a clearinghouse for information. The production figures for each industry, the awareness of the industry, and actions by major manufacturers in offering goods of increased performance were documented. The costs in this case are those of research, quality control, more expensive dyes and textiles, and the associated, more costly production techniques. The additional annual replacement costs of air pollution-damaged textile and fiber products were also estimated. Preliminary economic costs of the fading of dyes on textiles due to air pollutants are shown in Table 16.

Table 16. 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

The costs of fading of dyed fabrics by oxides of nitrogen (NO,) and ozone (O_3) generally are based on: the increased cost of dyes more resistant to fading; the cost of inhibitors for cheaper dyes; the cost of research; the cost of quality control related to the use of more expensive dyes; and, the costs to consumers and sellers with respect to any reduction in product-life

As weak as this information is, it appears as if this is the only information of its type available There are little or no supporting economic data and none that would contribute to the construction of-any damage function. Given the serious concern over the validity of many of the assumptions made in his study, it is believed that the estimate of $206 million is a very rough approximation of the actual damage of air pollution on textile and fiber products. The conservative nature of this estimate of corroborated by the absence of data in Salvin's study on the effects of sulfur and nitrogen oxides and acids and other particulate matter on the deterioration of textile fibers and dyes.[87] These effects are assumed to be measured in the "fibers" category in-Table 9.

NATIONAL ESTIMATES OF MATERIALS LOSSES

The eight studies reviewed in this report offer substantial evidence on which a reasonable national gross damage estimate can be based. A total of $1.8 billion is derived if the following are summed: $.5 billion (rounded off) from the Mueller and Stickney elastomer study; $.4 billion from the Gillette SO, study; $.2 billion from the dye-fading study; and $.7 billion from the Spence-Haynie paint study. In summing these, it is assumed: (1) that the Gillette study is more defensible than the corrosion study by Fink, et. al.; (2) that the Gillette study does not significantly overlap with the Spence-Haynie study that focuses primarily on the effects of particulates on painting rates; and (3) that the Gillette study adequately accounts for damages to electrical contacts and components. Then if the materials analyzed in these studies--zinc, paints, synthetic and natural rubber, carbon and alloy steel, fibers, cement and concrete, plastics, building brick, paper, leather, wood, and building stone--are subtracted from the Salmon study, in addition to the metal categories of aluminum, copper, stainless steel and lead which were regarded by Fink, et. al. as not significantly affected by air pollution, the total remainder in the Salmon study becomes about $.4 billion. Adding $.4 billion to the $1.8 billion derived earlier, the total gross damage estimate for material losses in 1970 due to air pollution is approximated at $2.2 billion.

The Salmon study develops estimates of losses for the various material receptor categories, but where more indepth research was done, it is believed that those estimates should be given priority. It should be reasonable to assume that this national estimate of materials losses is representative only insofar as it falls within an estimated range. Given the lack of more objective evidence, the percent variation expressed with the property value estimate will also be applied to the materials receptor. By applying that same variation (about 43%), a range of $1.3-3.1 billion is generated, with a "best" estimate of $2.2 billion. Given the nature of the studies reviewed, this estimate should be viewed not as the "true" cost of material damage, but indicative of the general magnitude of damage'in 1970.

SECTION VII
ASSESSMENT OF AIR POLLUTION DAMAGE TO VEGETATION

OVERVIEW OF PLANT SURVEYS

Damage to vegetation as a result of air contamination 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 an air pollution problem more commonly associated with urban expansion. The continued commercial and noncommercial production of crops and forests in many areas has been jeopardized and in some locations discontinued.

In general, air pollution adversely affects plants in one of two ways. Either the quantity of output or yield'is reduced or the quality of the product is lowered. The biological response of a plant to a fumigation by air pollution is a function of a complex mix of biological, environmental, and climatic factors. Such factors include, among others: level and duration of pollution exposure, age of plant, genetic sensitivity of the plant, light, relative humidity, soil moisture and fertility, and general health of the plant. Given this kind of information, one could construct a reasonable, physical dose-response relationship--the physical damage function. The translation of this function into an economic damage function is fraught with another complex set of variables. Important aspects that one must consider here include: time and growing season, market value of the plant affected, the aesthetic value that might be attached to the plant, the nature of the harvesting and culturing costs for the particular affected crop, the adaptability of the site for growing a different crop, and the value of the site for alternative uses.

Two general approaches have been used to assess the amount of economic loss resulting from plant damage by air pollution. One general approach has been to survey air pollution losses on a statewide basis by using the existing manpower of county agricultural agents and commissioners at the local level. From these local estimates of damage, extrapolations can be made to the national level to arrive at a crude estimate of gross damages. Another general approach is one of incorporating data on pollutant emissions, crop statistics, and meteorological parameters into a predictive model of plant losses. Such models that incorporate damage factors are then subject to continual refine: ment as: (1) greater knowledge about dose-response relationships is gained; and (2) the true situation at the local level is better defined.

The'major strengths in using statewide surveys are: (1) an existinq manpower can be utilized for achieving continual coverage over an area; (2) agents at the local level have an established rapport with growers in that area;' are familiar with any crop peculiarities, and are probably knowledgeable of any sources of pollution in the locale; and (3) a field coordinator supplies expertise to the reporters and provides some degree of standardization in reporting losses. One problem arises all too often: unjustifiable conclusions can be made on one-year estimates when several years are needed'to make accurate assessments of damages.

INDIVIDUAL STUDIES

Middleton and Paulus - California, 1955

The use of manpower at the local level was first used in a California survey performed in 1949. A second survey in 1955, as reported by Middleton and Paulus (1956), was designed to determine 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 - Pennsylvania, 1969 and 1970

A similar program was established in 1969 in Pennsylvania and reported by Lacasse-Weidensaul-Carrol (1970). As in California, a training course was held to teach trained observers how to identify and evaluate air pollution damage to plants. The objectives of the survey were: (1) to estimate objectively the total cost of agricultural losses due to 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; and (4) to provide a base for estimatinq the nationwide impact of air polluti on on vegetation and for guiding research efforts.

A professional plant pathologist was enlisted to coordinate the field survey. He assisted reporters 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 noncommercial plants were studied. Past episodes also were investigated for purposes of detecting possible trends. Estimates of losses were based on the amount of plant damaqe, crop value, and production costs incurred by harvest time. Direct losses to producers or growers included only production costs. Indirect losses included profit losses, costs of.reforestation, grower relocation costs, and substitution of lower-value crops for higher-value crops. Costs associated with the destruction of aesthetic values, erosion, and resultant stream silting, damage to watershed retention capacity, and farm abandonment, were not considered.

Ninety-two field investigations were made as part of the Pennsylvania study. The amount of direct losses uncovered in the survey were estimated at more than $3.5 million. The air pollutants, by decreasing importance, were: oxidants, sulfur oxides, lead, hydrogen chloride, particulates, herbicides, and ethylene. The crops most affected, in decreasing order of importance, were: vegetables, fruits, agronomic crops, lawns, shrubs, woody ornamentals, timber, and commercial flowers. Indlrect losses were estimated at $8 million, of which $7 million reflects profit losses, $0.5 million for reforestation of land, and $0.5 million for grower relocation costs. In total, air pollution losses in Pennsylvania for 1969 were estimated at approximately $11 million.

The major criticisms of the effort In Pennsylvania'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, at what price they should be valued. The economics of assessing losses is somewhat questionable in that grower profit losses were not included as direct costs, and it was not clear as to what constituted an annual cost and what did not. Also, the translation of physical injury into economic loss is somewhat subjective and has not been standardized.

Lacasse (1971) made an attempt in 1970 to again survey Pennsylvania. In using the same concepts of what constituted a "cost" and what did not as in the previous year's survey, Lacasse estimated direct losses to be $218,630 and indirect losses of $4,000. In explaining the low estimate of losses, Lacasse explains that "...the reason for the lack of widespread air pollution injury to vegatation during the 1970 growing season may have been due to fewer inversions and to no unfavorable growing conditions when air stagnation did occur."[88]

Feliciano - New Jersey, 1971

Similar surveys have also been made in New Jersey and in the New England states. In general, these surveys suffer from many of the same deficiencies as the Pennsylvania survey. Feliciano (1972) reported that losses to agriculture in New Jersey due to air pollution were estimated at $1.19 million in 1971. As in the Pennsylvania surveys, profit losses were not included. A total of 315 reported air pollution incidences were investigated and documented during the period of the New Jersey survey. A "rule of thumb" evaluation method developed by Millecan (1971) was used for estimating losses. As Feliciano describes it, "Where visual inspection of the overall leaf surface of the plants indicated 1 to 5 percent injury, a 1 percent loss was applied for that crop. A leaf surface injury ranging from 6 to 10 percent was given a 2 percent loss; 11 to 15 percent injury, a 4 percent loss; and 16 to 20 percent injury, an 8 percent loss."[89] Estimates of losses were based on the crop value of the acreage affected.

The damaging pollutants listed by decreasing importance were: peroxyacyl nitrates (PAN); hydrochloric acid mist and chlorine gas; ethylene; sulfur dioxide; ammonia; fluoride; and particulates. The first two accounted for 80% of the total incidences reported. Vegetables and field crops experienced about 85% of the total economic loss reported. Damage was reported in 16 of the 21 counties in New Jersey.

Pell - New Jersey, 1972

To obtain a better understanding of the year-to-year variation in plant losses caused by air pollution, Pell (1973) continued the work initiated by Feliciano in 1971. Pell estimated that direct losses of agronomic crops and ornamental plantings for the 1972-73 growing season were approximately $130,000. As in the study by Feliciano, costs associated with crop substitution and yield reductions, were not accounted for. The damaging pollutants, listed by decreasing importance, were: oxidants, 47% of crop losses; hydrogen fluoride, 16%; ethylene, 16%; sulfur dioxide, 4%; and anhydrous ammonia, 1%. Surprisingly, the damage reported in Pell's survey was only 11% of that reported in Feliciano's 1971-72 survey in New Jersey. The significant year-to-year variation is attributed to altered environmental conditions rather than to decreased air pollution concentrations. For example, it is believed that the unusual rainfall patterns in 1972 placed the plants under water stress and thereby protected them from air pollution injury.

Naegele - New England, 1971-72

Naegle, et. al. (1972) reported on a field survey of agricultural losses in the New England region caused by air pollution. Some 83 investigations were made in 40 counties of the six New England states. Direct economic losses for the 1971-72 season were estimated at approximately $1.1 million'. Estimates of economic losses were based on grower costs, crop value at the time of harvest, and the possibility of crop recovery following the pollution incident. Here, direct losses also include grower profit losses. It was determined that fruits, vegetables, and agronomic crops suffered the greatest losses, and that over 90% of the damage could be attributed to oxidant air pollution.

Millecan - California, 1970

An approach similar to that used in Pennsylvania, New Jersey, and New England was employed by Millecan (1971) to survey and assess the air pollution damage to California vegetation in 1970. Because of foreknowledge of the distribution of air pollution problems, efforts were concentrated in the Los Angeles Basin, San Joaquin Valley, and the San Francisco Bay Area. Estimates of losses were confined to 15 of the 58 counties in the state. Plant injury from air pollution was observed in 22 counties. Ventura County, with a loss of almost $11 million, experienced the greatest economic'crop loss for any one county. Losses of citrus production in the Los Angeles Air Basin accounted for over $19 million of the total monetary loss of almost $26 million. The monetary loss estimate does not include losses attributed to reduction in crop yield or growth except for losses of citrus and grapes. Nor were monetary losses to native vegetation including forests or to landscape plantings estimated.

As expected, photochemical smog accounted for most of the economic losses. Photochemical smog is composed of oxidant-type pollutants like ozone and PAN that are derived from the interaction of nitrogen oxides and hydrocarbons in the presence of sunlight. Analysis of field reports showed that six pollutants accounted for the following percentages of plant injury: ozone, 50%; PAN, 18%; fluorides, 15%; ethylene, 14%; sulfur dioxide, 2%; and particulates; 1%.

Benedict - Nationwide Survey, 1969 and 1971

A major study to estimate plant losses caused by air pollution was undertaken by H. M. Benedict (1971) of Stanford Research Institute (SRI) in 1969. SRI has developed an estimate of the annual economic losses to agriculture in all regions of the United States resulting from damage to vegetation by air pollutants. Special emphasis was placed on those losses ascribable to automotive emissions.

Their work progressed in the following manner: First, counties were selected in the United States were the major air pollutants--oxidants (ozone, PAN, and oxides of nitrogen), sulfur dioxide, and fluorides--were likely to reach plant-damaging concentrations. This selection was based on fuel consumption and the existence of large single-source emitters. Second, relative potential severity classes of the pollution in each county were then estimated, based on emissions area, and potential pollution episode days. Third, crop value estimates were completed for these counties. 'This necessitated calculating the dollar value of grass hay produced and of pastures. Fourth, estimates of the potential annual value of forests and the annual maintenance costs of ornamental plantings were completed and apportioned by area and population. Fifth, a continuing literature review provided information on the relative sensitivity of different plant species to the selected pollutants, so the percentage loss that might be expected to crops and ornamental plantings in the most severely polluted counties could be determined. Sixth, tables were then prepared showing the percentage loss that might be expected to crops and ornamentals in counties and in the different pollution classes described in the second step above. And seventh, these factors were then applied to the value of the crops, forests, and ornamentals grown in the polluted counties , and the dollar loss value for each crop in each county was recorded. From this, state, regional, and national estimates were obtained.

Thus, dollar loss estimates for agricultural crops and ornamentals were determined using the following equation:

DOLLAR LOSS = (Plant Value) x (Plant Sensitivity) x (Pollution Potential)

When the loss factors for the various pollution intensities in the 551 selected counties were applied to the determined crop and ornamental values, the total annual dollar loss to crops in the United States for 1964, as shown in Table 17, was calculated to be about $85.5 million, and the loss to ornamentals. about $46 million.

The significant weaknesses in the study seem to be: (1) given the paucity of knowledge in the literature on pollutant-yield relationships, many of the damage factors were probably "best guesses" and thus are subject to refinement. The same can be said of the determination of relative sensitivity; (2) the systematic application of factors to determine crop and ornamental plant values, especially the latter, does not allow for individual variation, thus one would expect a great deal of variation in error in any particular county estimate; and (3) ornamentals were under-valued in that only replacement costs were used as a proxy for aesthetic values. Also, the values of recreational areas were not assessed. A major benefit from this study is the accumulation of good background data for the development of more sophisticated predictive models for estimating losses when better data on dose-response becomes available.

Table 17. PLANT LOSSES DUE TO AIR POLLUTION
($ million)

	Oxidants	SO_2	Fluorides	Total
Crops	78	3.3	4.3	85.6
Ornamentals	43	3	0.2	46.2
Total	121	6.3	4.5	131.8

NATIONAL ESTIMATE OF PLANT DAMAGES

The loss estimate of $132 million generated in the SRI study for 1964 is the most defensible of those reviewed. Also, the SRI estimates are consistent with the individual estimates for California, Pennsylvania and elsewhere. Because the SRI study attempted to grapple with losses of ornamentals, the state estimates generated by the predictive model are consistenly higher than those developed through statewide surveys. But even then, the SRI estimate still reflects a lower bound of the true plant-associated losses due to air pollution. This is so because the losses resulting from reduction in yield are largely ignored. Also ignored are costs associated with grower relocation, crop substitution, losses in productivity, and denudation of land and resultant erosion. Due to the lack of adequate knowledge on many aspects of air pollution effects on plants, there are many inadequacies inherent in all reported efforts to estimate plant losses due to air pollution. Although all estimates have their shortcomings, the studies discussed above represent the current state of the art,

By updating the 1964 estimate of $132 million to 1970, the estimated cost of air pollution damage to vegetation is estimated to he approximately $150 million., This is based on the assumption that the same percentage value of crops are lost in 1970 as was lost in 1964.[90] Implicit in this assumption is that the value of ornamental plantings has increased the same as cash crops. By rounding this estimate off to $0.2 billion and then assuming that $0.2 billion is representative of a range, a range of 50 percent or $0.1-0.3 billion will be assumed, with a "best" estimate of $0.2 billion for 1970.[91]

SECTION VIII

ASSESSMENT OF THE EFFECTS ON AIR POLLUTION ON AESTHETIC PROPERTIES

OVERVIEW OF THE PROBLEM

This very nondescript receptor category is concerned mostly with the organoleptic aspects of air pollution--those pertaining to siqht and smell. Given the level of public esposure, it can be considered public knowledge that air pollution restrains progress toward an environment congenial to aesthetic and other socially conditioned needs. Peckham's[92] review of the literature has provided a good starting place in understanding the seriousness of this aspect of the air pollution problem.

One possible effect of air pollution is the deterioration of materials with historic or artistic significance, such as paintings, statuary, and rare books. Air pollution that reduces visibilfty and obscures vistas can also have a depressing psychological effect on individuals. Noxious odors represent another series of effects that are considered here to be aesthetic effects of air pollution.

Aesthetic effects also belong to the calculus of pollution damages because of values that could be attached to 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 due significantly to air pollution.[93] Part of this expenditure represents what the library was willing to pay to avoid book losses from air pollution.

In general, man wants an environment congenial to his aesthetic and phychological needs. Yet air pollution restrains progress toward such an environment. Odors from various,industrial sources deprive many of the full enjoyment of their property. Particulates dangerously diminish visibility. Oxides of sulfur accelerate the decay of honored works of art and statuary. Emissions from automotive combustion.and their resultant atmospheric interactions injure the trees that adorn our urban arteries and often cause watering of eyes, thereby diminishing our quality of life.

ODORS

Odors have historically generated a high level of public concern. This is clear from opinion surveys. For example, in the St. Louis survey,[94] 926 out of 1361 complaints received during the 1958-1962 period pertained to odors. In an opinion survey taken in Clarkston, Washington,[95] 91% of the respondents made a similar identification of air pollution with odors.

Regardless of the area they cover, odors can deprive people of the full use and enjoyment of their property. A survey of the court records might be a good way to determine the seriousness of this deprivation. For example, 31 homeowners brougkt suit against the Weyerhauser Company to recover damages caused by odors emitted from the' company's kraft pulp mill in Elkton, Maryland.[96] The testimony was convincing enough in that the court awarded the plaintiffs the amount of about $18,000. In another case, plaintiffs were awarded over $35,000 as a result of a suit filed against an industrial concern for emanating odorous pollutants that resulted in hospitalization costs, loss in earning, and the loss of enjoyment of their properties.[97] Other similar judgments are extensively recorded in the legal records. Yet some decisions from recent cases seem to indicate that the rights of individuals to odor-free air have not been well established. For example, a recent ruling by the United States District Court in Cincinnati ruled that odors from a dump site are not illegal.[98] A suit had been brought by 22 property owners who complained that odors from the disposal site fouled their air and deprived them of their rights to clean air and the free use of their property. The judge ruled that the United States Constitution does not guarantee citizens the right of protection of their environment. A similar ruling was made in a Michigan court case where the plaintiff claimed that hog odors from a neighbor's farm had an "adverse effect" on her sick husband.[99]

Not surprisingly, the major obstacle to initiating action against odor problems begins with measurement. As reported by Dravnieks, "Odor dimensions are intensity, detectability, acceptability, and quality (character). Human response to odors is not linearly related to the concentrations of odorants in air and relates to the chemistry of odorants in a complex way. The response is influenced by criteria which the individuals, use to interpret odor sensations and by the form of response expected or accessible, especially in community setting."[100] Methods for evaluating odor problems have been developed by Copley International Corporation.[101] These are to be field tested in selected metropolitan areas throughout the country. Copley found that people were generally unaware of any adverse economic effects of odors pollution, or they did not believe such effects existed.[102] It is likely that people are generally unwilling to admit these kinds of effects do exist.

VISIBILITY

Air pollution not only affects the olfactory senses but also the sense of sight. Serious hazards to transportation are created by visibility-reducing air pollutants; they cloud the landscape with haze and smog and discolor the sky. The visibility-restricting air pollutants are particulates and nitrogen dioxide.

Particulates in the atmosphere can affect visibility in two ways--either by absorption or by scattering of light. The nature and magnitude of the effect are functions of the chemical composition of the particle, particulate size, shape, and concentration. Particulates also exert an indirect effect upon visibility by facilitating the formation of fogs and by slowing their dissipation, making travel difficult and hazardous.

Poor visibility can also result in accidents and disruptions in transportation. It has been estimated that adverse effects of air pollution on air travel cost from $40 to $80 million annually.[103] The Civil Aeronautics Board, in reviewing 1962 aircraft accidents in the United States, found at least six to be directly due to what they called "obstruction to vision" caused by smoke, haze, dust, and sand.[104] Delays in the movement of air traffic are quite common at major commercial airports during times of poor visibility.

As Peckham has said, "People want safe and dependable transport. They want to be able to travel without extraordinary risk or delay. Furthermore, most people also want access to pleasing scenery and bright, clear weather with sunshine. Air pollution can often defeat these wants by depressing visibility, blocking sunshine, and intensifying fog. This seems clear from the evidence. What is not so clear, however, is the monetary magnitude of the injuries suffered."[105]

Vars and Sorenson (1972) attempted to measure externalities associated with the visibility-reducing air pollution generated by open field burning in Oregon's Willamette Valley, Utilizing a market study approach, they constructed a theoretical model to explain the relationship between air quality and consumer behavior, or more specifically, the consumption of recreation-related activities. The consumer was viewed in the model as literally producing consumption activities by combining market commodities and time in different combinations so as to create an activity he then consumes. While the theory was straightforward, albeit complex, it was not amenable to empirical analysis. There was not only the problem of the lack of a priori information about the comsumption activity production functions, but also a second difficulty arising from the lack of a priori information on what activities would be affected negatively by a deterioration in air quality and which activities would be affected positively, as they perform the role of substitutes.

These empirical problems led to a redesign in research plan. The subsequent investigation employed multiple regression analysis in examining the determinants of the following recreation activities: (1) swimming pool use; (2) golf course attendance; (3) number of visitors at the state Capitol; and (4) the number of overnight campers at a selected state park. By hypothesis, participation in these activities should be affected by, among other things, air quality. It was predicted that all but the number of visitors at the state Capitol would be negatively affected by aworsening in air quality. Attendance or use was treated as the dependent variable, while the independent variables included minimum daylight visibility, high temperature, and day of the week. Data recorded between July 15 and September 30, 1970 on the participation in these activities were analyzed.

The results showed no significant relationships between rounds of golf, indoor swimming pool attendance in Eugene, Oregon, and minimum visibility. On the other hand, the hypothesized relationships between minimum visibility and attendance at outdoor swimning pools in both cities were positive. Statistically, the relationships were significantly different from'zero at the 95 and 99% levels of significance. Overall, the hypothesis that air quality affects the extent to which individuals undertake (consume> outdoor recreational activities, was supported. In addition, the evidence supports the hypothesis that consumers , in fact, do engage in activity substitution under variations in air quality.

Sorenson's data on swimning pool attendance as calculated over the range of minimum visibilities in Eugene and Salen, imply that a 20% improvement in visibility associated with a ban on open field burning would increase the number of swim-days for residents by 60,000 to 90,000. Valued at an admission fee of $0.50, the value of this increase in swim-days amounts to a sum of $30,000 to $45,000. By assuming an elasticity of aggregate resident recreational activity with respect to <u>daylight</u> visibility of 0.1, and extrapolating to the entire Willamette Valley, estimates of increased recreational experiences are generated. Economic values were based on the range of values suggested by the Water Resources Council for the evaluation of outdoor recreation days.[106] Vars and Sorenson determined best estimates of the value of increases in Willamette Valley resident outdoor recreation activity, consequent to the three policies under investigation, to be: (1) $249,000 for a ban on open burning; (2) $111,000 for a policy allowing alternate year open burning, and (3) $160,000 for a policy allowing open burning once in three years.[107]

The second portion of the empirical research design consisted of a statistical analysis of data derived from interviewing 401 tourists travelling in Oregon during periods of reduced air quality. It was hoped that information on tourist perceptions and response to reduced visual range, could be secured. Yet, again, the lack of <u>a priori</u> information about the consumer activities production functions complicated the empirical problem. This sample population was divided into polluted and non-polluted areas, based on the hypothesis that recreation activities in the "clean" area would be substitutes for recreation activities in the "dirty" area because of the adverse aesthetic effects of poorer air quality. One particularly interesting aspect of this was the investigation of whether tourists were sufficiently "tracked" in their behavior or whether they were flexible to the extent that their plans were causually subject to change.

Data showed that of the 59 respondents who indicated that their plans had changed upon entering the state, only six associated that change with air pollution. Further analysis showed that tourists have fairly fixed plans about the path of their travels and the amount they will spend. Quite obviously these six responses cannot be viewed as statistically significant in relation to any of the hypotheses about behavior or perceptions of interest to this study.

Vars and Sorenson concluded that in terms of the hypothesis about the effects of air pollution that this research set out to examine, the findings must be viewed as negative. It is possible that the experience of most Americans has suggested that air pollution is more or less pervasive, and that they select among available recreational activities as if ai'r quality were constant.[108] In an indirect criticism of the market approach, Vars and Sorenson observe that it will be very difficult for social scientists to observe a clearly defined relationship between air pollution and the behavior of people, even though the behavior of people would be related implicitly to air pollution.

WORKS OF ART

Another kind of injury to aesthetic sensitivities occurs when air pollution accelerates the decay of stonework., Calcarous materials such as limestone, marble, lime plaster walls, and frescoes are subject to chemical assault by acids which are formed by the interaction of sulphur and nitrogen oxides and moisture. One such example of international significance is the damage that has occurred to the 14th century Giotto frescoes in the Scovegni Chapel at Padua, Italy.. These frescoes have been the object of special studies. By late 1960, these works had experienced severe deterioration and scaling of paint.[109]

The assualt of atmospheric pollutants on antiquities, metal, and stone artwork occurs all over the industrial world. In New York City, air pollution has contributed to the spoiling of the facade of City Hall, resulting in a $4 million expenditure for restoration."' And, officials of the Metropolitan Museum of Art have been forced to coat statuary with beeswax and to air condition exhibition areas. The Operating Administrator has explicitly stated: "The presence of various forms of sulphur in the air is particularly injurious to limestone and marble. There is an appreciable, visible etching on marble... I would say that all of the exposed stonework of ancient elements at the Cloisters has deteriorated since its erection in New York City...It is pointless to collect outstanding works of art, many over a thousand years of age, if one thousand years from now they are going to be so badly deteriorated as to be virtually worthless."[111]

In Spain, several Titians, Rubens, and other priceless works of the Italian, Flemish, and Dutch schools are reportedly in danger of serious damage due to the polluted air in the Prado Museum. Although experts have warned for 12 years that air pollution in Madrid was damaging the valuable canvasses, the Spanish government only recently ordered emergency measures, protect the 3,000 major paintings that are housed in the former palace. As a result of these kinds of dangers, it is hoped that preservatives can be applied to help retard decay in marble and limestone.[113]

ORNAMENTAL PLANTINGS

Another category of effects that should rightfully be classified as aesthetic include the destruction by air pollution of ornamental flowers, shrubs, and trees that normally provide, some sense of aesthetic enjoyment. These could be ornamental flowers and shrubs that surround our homes, trees that line our traffic arteries, or trees and other vegetation that normally grow in parks and other areas used for purposes of recreation. Heggestad has reported phytotoxic effects of common urban pollutants on lilacs, petunia, orchid, and gladioli.[114] Also, it has been reported that some 160,000 acres of ponderosa and jeffrey pine in Southern California are experiencing severe decline, and this has been attributed to the oxidant air pollution generated in the Los Angeles Basin.[115] This is significant in that a large part of the natural ecosystem is being affected and this area is one of very high recreational value.

CONCLUSIONS

As' Ayres has summarized, "The disutility arising from minor discomfort and essentially'aesthetic objections to air pollution is probably the most under-estimated an'd certainly the fastest-growing component of the total problem. This arises from two interrelated factors: (1) the rising level of education on the part of the population and even more rapid rate of increase in the means and possibilities of communications , all of which results in an explosive increase in the level of awareness and general perception of the pollution problem as compared with a few decades ago, and (2) the fact that comfort and aesthetic satisfaction are 'superior goods', as many economists have pointed out, and the demand for them grows nonlinearly with general prosperity and affluence, which are themselves rapidly increasing."[116]

Given that the aesthetic qualities of our environment do have some economic dimension, we are faced with the problem of measurement in quantifiable economic terms. S. V. Ciriacy-Wantrup makes a strong case for the use of the terminology, "extra-market" rather than "intangible" to describe those benefits that are not routinely valued in the market place. Further, he argues that attempts to quantify such values should be encouraged, and indeed, if the measurement of air pollution damages is to be realistic, these extra-market values must be assessed.[117] The SRI vegetation study estimated the value of ornamental plantings. Copley International Corporation (1971) made an attempt to estimate odor costs by analyzing property value differentials. Vars and Sorenson (1972) made an attempt to estimate the impact and value of air pollution as it affected recreation-related activities in Oregon. While none of these studies has been particularly successful in identifying the pollution exposure-receptor response relationship, progress is being made in understanding the value of social choices that man explicitly and implicitly makes every day. The major difficulty lies in isolating the incremental effect of changing air quality on man's aesthetic and psychological needs. Even though measurement is difficult, it is quite obvious that society is willing to expend significant resources to reduce aesthetic damages from pollution.