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HEALTH COSTS OF AIR POLLUTION DAMAGES
A Study of Hospitalization Costs

Health Effects Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

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HEALTH COSTS OF AIR POLLUTION DAMAGES

A Study of Hospitalization Costs

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FOREWORD

The many benefits of our modern, developing, industrial society are accompanied by certain hazards. Careful assessment of the relative risk of existing and new man-made environmental hazards is necessary for the establishment of sound regulatory policy. These regulations serve to enhance the quality of our environment in order to promote the public health and welfare and the productive capacity of our Nation's population.

The Health Effects Research Laboratory, Research Triangle Park, conducts a coordinated environmental health research program in toxicology, epidemiology, and clinical studies using human volunteer subjects. These studies address problems in air pollution, non-ionizing radiation, environmental carcinogenesis and the toxicology of pesticides as well as other chemical pollutants. The Laboratory develops and revises air quality criteria documents on pollutants for which national ambient air quality standards exist or are proposed, provides the data for registration of new pesticides or proposed suspension of those already in use, conducts research on hazardous and toxic materials, and is preparing the health basis for non-ionizing radiation standards. Direct support to the regulatory function of the Agency is provided in the form of expert testimony and preparation of affidavits as well as expert advice to the Administrator to assure the adequacy of health care and surveillance of persons having suffered imminent and substantial endangerment of their health.

The results of this study show that the hospitalization incidence rate and cost of certain pollutant related diseases were significantly greater among populations residing in the more polluted areas of Pittsburgh. Although the hospitalization costs associated with air pollutants in Pittsburgh were nearly 10 million dollars in 1972, the total health costs resulting from air pollution exposure in the Pittsburgh area would be much greater when non-hospitalization costs are also included.

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ABSTRACT

An investigation of the hospitalization costs of exposure to air pollution in Allegheny County, Pennsylvania was conducted to determine whether persons exposed to air pollution incurred higher incidences of hospitalization or additional costs for treatment. A hospitalization data-base comprising 37,818 total admissions for respiratory, suspect circulatory diseases, and control diseases was tested in a cross-section type analysis for relationships between rates of hospitalization, length of stay, and levels of air quality in the neighborhoods of patients' residence. Air quality was identified using data from 49 monitoring stations. Corrections were made in the analysis for race, age, sex, smoking habits, neighborhood median income, and type of occupation.

Respiratory and suspect circulatory system disease showed statistically significant increased hospitalization rates and lengths of stay for those exposed to higher levels of SO_2 and particulates compared to those from neighborhoods meeting air quality standards. At average costs per day for hospitalization in this area in 1972, the total increased costs of hospitalization for the 1.6 million persons in the County was estimated at $9.8 million dollars ($9.1 million for increased hospitalization rates and $0.7 million for increased length of stay).

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ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance provided during the course of the study by members of the Environmental Protection Agency staff. Dr. Donald G. Gillette, Criteria and Special Studies Office, Environmental Protection Agency served as Project Officer and provided guidance and direction. Dr. Fred Abel, now with the Energy Research and Development Administration, initiated the study and identified several of its methodological concepts. Mr. T. E. Waddell of EPA's Office of Planning and Review, served as project coordinator and assisted in development of the hospital data base.

We also wish to recognize the cooperation and help extended by the representatives of the hospitals contacted during the study.

SECTION 1

INTRODUCTION

Air pollution damage to human health has been investigated by Ridker,[1] Lave and Seskin,[2] and Park.[3] These, and other studies, have been reviewed and assessed by Waddell.[4] Sterling et al. studied hospitalization rate and length of stay as related to daily air pollution.[17,18,19] Hospitalization costs, however, have not been estimated. Outpatient medical costs for treatment of respiratory diseases were studied by Jacksch and Stoevener.[5] They found that, while air pollution may have affected the frequency of outpatient visits, it appeared not to have affected costs per contact with the medical system.

This study attempted to determine whether persons exposed to air pollution incurred higher incidences of hospitalization or additional costs for treatment. The objectives were to develop an air quality data base and a hospitalization data base which could be merged with population data for analysis; and to estimate by appropriate methods the effects of exposure to pollutants on rates of hospitalization, length of stay in the hospital, and associated costs. Three classes of diseases were studied: respiratory diseases, heart diseases, and control diseases.

SECTION 2

CONCLUSIONS

The results of this study of the hospitalization costs of exposure to levels of SO_2 and particulates in excess of prescribed standards indicate that, in 1972, subpopulations of Allegheny County, Pennsylvania so exposed incurred significantly greater hospitalization costs. Compared to subpopulations of the county living in clean-air neighborhoods, subpopulations living in polluted-air neighborhoods incurred increased rates of hospitalization and increased length of stay for treatment. For the 1.6 million persons in the county, the conservatively estimated cost of increased rates of hospitalization was $9.1 million dollars; the cost of increased length of stay, $0.7 million. These add to a total cost of $9.8 million dollars for the year.

The cost estimates were obtained through a comprehensive analysis of hospitalizations, air-quality and population data. All hospitals within the county were included in the development of the hospitalization data base.

Both respiratory diseases and circulatory system diseases suspected of being affected by exposure to these pollutants were studied. Non-suspect circulatory system diseases were utilized as controls.

Air quality was measured by: 1) the Huey Plate Sulfation Rate method, with the results reported as SO_2 based on calibrations made on-site; and 2) by the Coefficient of Haze with results reported as $\mu g/m^3$ suspended particulates also based on calibrations made on-site.

Estimated hospitalization rates were corrected for differences in age, sex, and race distributions among the six different air-quality subpopulations of the county. Effects of other factors were assessed and distinguished from air-quality effects. For hospitalization rates, these included the subpopulation median income, fraction below poverty-level income, fraction married, and the fraction employed in heavy industry. For length of stay, the effects of the patients' smoking habits, occupation, and type of hospitalization insurance were considered, along with the median income of his area of residence and the percent occupancy of the hospital.

These cost estimates should relate directly to the cost benefits of clean air in Allegheny County.

SECTION 3

RECOMMENDATIONS

The hospitalization costs of air pollution found in this study are of sufficient magnitude to merit continued investigation. The study should be repeated, applying the methodology in another geographical area, to confirm the findings prior to their extrapolation nationwide.

The possibility of developing a suitable data base to estimate hospitalization costs of exposure to other types of air-pollution involving photochemical smog should be investigated.

The findings presented herein are based on the experience of the population for an entire year. Further analysis of this data base should be made to assess the effects of seasonal variations.

The present data base should be examined for selected smaller groups of diseases to more closely identify costs with specific diseases.

The costs developed herein should be compared with estimated control costs for the county, to develop cost-benefit information.

SECTION 4

EXPERIMENTAL PROCEDURES

TECHNCIAL APPROACH

A general concept of excess risk of health costs under exposure to pollutants was defined by the equation:

$$\text{Health Costs} = \sum_{ij} p_i c_{ij} r_{ij} \qquad (4\text{-}1)$$

where p_i is the number of persons in the subpopulation exposed to pollutant level i, c_{ij} is the type j cost to a person in subpopulation i, and r_{ij} is the extra risk to subpopulation i of incurring the cost of type j. Each term of the health cost equation accounts for the added health costs of selected illnesses when a specified subpopulation is exposed to air pollution at a specified level.

The exposure levels, i, may be defined as the separate levels of each pollutant or as the combination of levels of several pollutants to which subpopulations are exposed. Either current air-quality standards or other candidate values might be used to specify clean air if the relationships between air-quality, c, and r proved to be sufficiently firm.

Under this study, only hospitalization costs were estimated, but other types of costs can be accomodated by the health costs model.

Before these cost elements could be estimated, it was necessary to establish that c and r were related to the levels of pollutants. The conceptual health costs model had to be verified; verification of the model required suitable data to test appropriate hypotheses.

Two hypotheses to be tested were:

Ho_1: Increased concentrations of air pollution result in no increase in the cost of hospital service per patient admitted and treated.

Ho_2: Increased concentrations of air pollution result in no increase in the rates of admissions to hospitals for treatment of selected illnesses.

The first hypothesis is for c, the second for r.

The Study Area

Allegheny County, Pennsylvania was selected as the study area. There were forty-nine locations for measuring sulfur dioxide and twenty-one locations for measuring atmospheric suspended particulates. These locations had been chosen for various reasons as sites of opportunity: for their proximity to emissions sources, for the varied topography, or for "background" measurement. Sulfur dioxide was monitored by the Huey Plate Sulfation Rate Method and reported as SO_2 ppm, the latter being obtained using a regression equation based on simultaneous measurements at representative locations during the study period by both the Huey Plate Method and the Environmental Protection Agency's standard method for SO_2.[6,7,8] Particulates were measured as the Coefficient of Haze (COH) or Soiling Index, using modified Unico Model 2800 instruments, and converted to $\mu g/m^3$ of total suspended particulates (TSP), using conversion factors determined at the sampling sites. The data exhibited, in 1972, neighborhoods that met air quality standards and neighborhoods that did not. The monthly average temperature was below 50°F for six months of 1972, and above 50°F for the remainder of the year.

The county lies in the central portion of the Pittsburgh, Pa SMSA for which census data are available, providing socio-economic characteristics of the population by census tract.[9] It had 28 hospitals, 26 of which maintained patient records by consistent entries, and two of which maintained equivalent records providing corresponding information without revealing any individual's identity.[11]

Air Quality Data Base

To assess the impact of ambient concentrations of these two pollutants upon the hospitalization costs to the population of the county it was necessary to assign particular quantitative values to the air-quality of each of the 498 census tracts therein. The values assigned had to be based upon existing measurements at nearby locations. Several techniques for assigning values, i.e., interpolation or extrapolation, were considered (Section 5). After trying a second order response surface fitted to the existing data, an interative, weighted average analysis technique, similar to procedures used in objective analyses of meteorological data was finally adopted. A few selected values assigned to census tracts are listed in Table I.

Table I. 1972 annual average concentrations of SO_2 and particulates at five selected census tracts in Allegheny County, Pa.

Census Tract	UTM Coordinates Easting	UTM Coordinates Northing	SO_2 $\mu g/m^3$	Particulates ($\mu g/m^3$)
101	548.6	4476.7	85.8	87.9
1604	587.9	4474.3	141	84.9
2003	579.3	4478.3	40.6	74.9
4980	597.2	4464.4	155	88.5
5514	597.8	4466.2	97.9	124.7

Census tracts were sorted into three SO_2 and three particulate levels to establish subpopulations for comparison. Level 1 tracts met the standard. Level 2 tracts exceeded the standard enough to have a possible effect. Level 3 tracts exceeded the bound of Level 2. Class levels were:

SO_2 $\mu g/m^3$	SO_2 ppb	level	Particulates $\mu g/m^3$	Particulates level
<80	30	1 (low)	<76	1 (low)
80 - 99.3	30 - 37.2	2 (medium)	76 - 115	2 (medium)
>99.3	>37.2	3 (high)	>115	3 (high)

Hospitalization Data Base

Three classes of diseases were considered: respiratory diseases, suspect circulatory diseases, and control circulatory diseases. All diseases were identified by the ICDA-8 Code.[11] Respiratory diseases included in the data base were ICDA-8 numbers 462 through 515.9, except 508.1 (polyp of vocal cords or larynx). Suspect circulatory system diseases were Nos. 410-414.9; 427-429.9; 435; 435.9; and 436.9.[12] These are the ischemic heart diseases, the symptomatic heart diseases, transient cerebral ischemia, and acute cerebrovascular disease. Control circulatory system diseases were Nos. 390-404; 420-426; 430-434.9; 436; 437-448; 450-458.9; and 580-480.5. These are rheumatic fever, chronic rheumatic heart diseases, hypertensive diseases, certain cerebrovascular diseases; diseases of arteries, arterioles, and capillaries, and diseases of veins. The last category identified nephritis and nephrosis. There are only a few cases of these diseases, and they were included in the control diseases.*

Records (with case history but without names) were obtained from the twenty-eight hospitals in Allegheny County. The total number of records was 37,818, which included all cases treated in 1972.* Table II shows the breakdown of these into the three classes under study. It also shows the number of records from each of two files, the first a data base from HUP**, the second an equivalent data base compiled by two hospitals not in the HUP file.

Table II. Total 1972 hospitalizations in Allegheny County hospitals for diseases under study.

	Number of Hospitalizations		
Disease Class	HUP* Hospitals	Non-HUP Hospitals	Total
Respiratory	11,550		11,550
Suspect Circulatory	21,133	30	21,163
Controls	5,049	56	5,105
Total			37,818

*Hospital Utilization Project, Pittsburgh, Pa.

Population Data Base

The population base was developed from 1970 Census data. Table III shows the race-age-sex distribution of the population. Here the population is further classified according to the pollutant levels in their neighborhoods of residence. Six SO_2-particulate classifications are shown. These are identified by letters. For example, there was 72,260 white males age 1-44 in the high SO_2-medium particulates neighborhoods (HM).

The Census data were the source of additional population characteristics utilized in this study. For each of the 498 census tracts of Allegheny County, the median income, the fraction of the population with income below poverty

*A breakdown of all diseases by diagnosis and number of cases is included in the Appendix.

**Hospital Utilization Project.[10]

Table III. 1970 Population data base (in thousands of persons).

Stratum			Pollutant Classification*						
Race	Sex	Age	LL	LM	ML	MC	HL	HM	Total
White	Male	1 to 44	45.566	125.707	20.293	179.964	2.015	72.260	445.80
White	Male	45 to 64	16.042	49.282	5.444	69.628	0.920	29.607	170.92
White	Male	65 to 74	3.097	11.011	0.964	18.059	0.258	7.740	41.73
White	Male	75 or Older	2.110	6.231	0.620	10.317	0.140	4.680	24.20
White	Female	1 to 44	46.941	130.084	20.635	189.213	2.013	76.186	465.07
White	Female	45 to 64	16.971	54.675	5.628	81.353	0.973	34.082	193.68
White	Female	65 to 74	3.829	14.621	1.290	26.160	0.372	10.799	57.07
White	Female	75 or Older	3.524	10.248	0.821	16.993	0.245	6.758	38.59
Black & Other	Male	1 to 44	0.941	5.974	0.441	27.647	0.177	12.352	47.53
Black & Other	Male	45 to 64	0.261	1.473	0.084	8.541	0.023	3.241	13.62
Black & Other	Male	65 to 74	0.145	0.477	0.009	2.880	0.001	1.329	4.84
Black & Other	Male	75 or Older	0.112	0.221	0.021	1.304	0.014	0.560	2.23
Black & Other	Female	1 to 44	1.034	6.455	0.378	32.055	0.136	14.640	54.70
Black & Other	Female	45 to 64	0.307	1.616	0.073	10.049	0.044	3.904	15.99
Black & Other	Female	65 to 74	0.125	0.451	0.030	3.069	0.011	1.451	5.14
Black & Other	Female	75 or Older	0.178	0.236	0.015	1.427	0.001	0.772	2.63
TOTAL			141.183	418.852	56.746	679.259	7.343	280.370	1583.75

*The SO_2 level is indicated by the first letter; the particulates level, by the second: L = low, M = medium; H = high; C = combined M + H. There were no LH or HH census tracts. MC = MM + MH.

level, the fraction married (and maintaining a home together) and the fraction employed in heavy occupations were considered. Heavy occupations were Bureau of Census classes: 5 (Craftsmen and Kindred Workers); 6 (Operatives, except Transport); 7 (Transport Equipment Operatives); and 8 (Laborers, except Farm). The remaining classes, including unemployed, retired, and housewives, were considered to be light occupations.

Sample Selection

Additional information was required for each patient in the data base to locate his census tract of residence. This was obtained for all respiratory disease cases. It was obtained for a sample of the circulatory system disease and control disease cases. The sampling procedure was developed to limit the probability of error in assessing differences in rates of hospitalization between neighborhoods of differing air quality. Sample sizes sufficient to assess differences in the rates of hospitalization were considered adequate to assess the differences in length of stay. Random sampling within the strata defined by race, sex, and age was employed. Sample allocation to strata was proportional to the number of cases in each stratum. A 100 percent sample was utilized for respiratory disease cases and also for all three types of illnesses in two hospitals that were not included in the HUP data base.

Cases so selected were assigned to the proper census tract (or identified as living outside the county) with the help of the hospitals. This assignment identified the pollutant exposure level for each case. Considerable hand effort was required to resolve some 1800 addresses properly. Some cases were lost from the sample because hospitals could not locate their records. The final data base is shown in Table IV. There were 15,833 hospitalizations of which 12,420 were from Allegheny County. Set 1 comprises the 26 HUP hospitals; set 2 the two non-HUP hospitals which were completely enumerated.

This data base is believed to be the best ever used for the purpose of estimating hospitalization costs associated with air pollution. The details of the sample design are given in the next section.

Table IV. Final data base, hospitalizations of Allegheny County Residents in 1972, by hospital-set and sampling stratum.

Stratum	Respiratory Disease			Heart Disease				Control Diseases					
Race-Sex	Both Sets			Set 1			Set 2	Set 1			Set 2		
Age	I.C.	O.C.	Unk.	I.C.	O.C.	Unk.	I.C.*	I.C.	O.C.	Unk.	I.C.	O.C.	Unk.
W Males													
1-44	1489	457	80	103	39	12	1	24	10	2	6	1	0
45-65	1325	353	36	542	235	60	3	144	60	14	9	1	1
65-74	716	145	43	265	55	19	5	115	22	9	4	0	0
75+	654	85	31	242	34	16	2	107	19	6	1	0	0
W Females													
1-44	1437	427	78	33	9	2	0	17	18	4	3	1	0
45-64	1060	270	46	280	65	16	2	128	37	4	8	2	1
65-74	575	94	22	258	48	19	4	124	21	4	3	1	0
75+	504	65	28	367	32	16	4	163	27	6	7	1	0
NW Males													
1-44	451	21	24	10	1	0	1	3	2	1	0	0	0
45-64	202	3	12	46	2	0	4	19	2	3	0	0	0
65-74	102	2	6	28	1	2	0	14	1	0	2	0	0
75+	52	2	3	20	0	1	2	7	0	0	1	0	0
NW Females													
1-44	373	12	30	13	0	0	0	8	0	1	1	0	0
45-64	128	6	8	42	0	1	1	22	0	2	0	0	0
65-74	42	4	9	30	1	1	1	12	0	3	1	0	0
75+	34	2	2	30	1	0	0	10	3	0	2	0	0
Subtotal	9,144	1,948	458	2,311	523	165	30	917	222	59	48	7	1
Total		11,550			2,999		30		1,198			56	

W - White; NW - Nonwhite; I.C. - In County; O.C. - Outside County; Unk. - Unknown; *No O.C.s or Unk.s in Set 2.

Sample Design

For determining sample size requirements, a simplified analysis scheme based on random samples and the normal approximation was employed. The normal approximation to the true distribution of the test statistics should be adequate for the large sample sizes considered.

Null (H_0) and alternative (H_a) hypotheses were written as:

$$H_0 : D(ii'j) = 0, \text{ and}$$

$$H_a : D(ii'j) = D_0, \text{ where}$$

D(ii'j) = the difference between the hospitalizations for disease class j per 1000 persons at risk in subpopulations i and i'. This difference is defined by:

$$D(ii'j) = N(ij)/X(i) - N(i'j)/X(i'), \text{ where}$$

N(ij) = the number of 1972 hospitalizations from subpopulation i for condition j,
N(i'j)= the number for subpopulation i',
X(i) = the number of persons, in thousands, for subpopulation i,
X(i') = the number of persons, in thousands, in subpopulation i'.

Data collected from the sample were to be used to estimate D(ii'j) by $\hat{D}(ii'j)$, which may be expressed by:

$$\hat{D}(ii'j) = N(+j)\hat{p}(ij)/X(i) - N(+j)\hat{p}(i'j)/X(i'),$$

where $\hat{p}(ij)$ is the sample estimate of p(ij) and

$$p(ij) = N(ij)/N(+j).$$

Assuming that the normal approximation is valid, the statistical test may be written as:

$$\text{Reject } H_0 \text{ if } \hat{D}(ii'j)/(V[D(ii'j)])^{0.5} \geq Z$$

$$\text{Accept } H_0 \text{ otherwise.}$$

The term $V[\hat{D}(ii'j)]$ is the variance of $\hat{D}(ii'j)$. The value of Z is chosen to control the probability, α, of rejecting the null hypothesis when it is true. This value may be obtained from a standard normal probability table as the value of the normal deviate corresponding to α. To determine sample size, another value of Z is similarily chosen to control the probability, β, of accepting the null hypothesis when the alternative is true.

To determine the required minimum sample sizes, values α_0 and β_0 were chosen along with a particular alternative hypothesis (specified by the value of D_0) and then the number of hospitalizations, n, was calculated so that $\alpha \leq \alpha_0$ and $\beta \leq \beta_0$ for the selected D_0. Certain additional notations and assumptions were required to develop the computations. Let $\lambda(i)$ be the proportion of the population belonging to subpopulation i, i.e.,

$$X(i) = \lambda(i)X(+).$$

The term $\lambda(i')$ is similarly defined for subpopulation i'. It was assumed that subpopulations considered do not overlap, i.e., no person can be a member of both subpopulations i and i'. Further, let the hospitalization rates for condition j and population i be

$$R(ij) = N(ij)/X(i),$$

recalling that X(i) is expressed in thousands of persons. Let the rate for the overall population of Allegheny County for condition j be

$$R(.j) = N(+j)/X(+).$$

Note that R(.j) can be determined for each j on the basis of data already available.

It was assumed that the estimates $\hat{p}(ij)$ and $\hat{p}(i'j)$ are subject to binomial variation and therefore, after some simplification:

$$V[\hat{D}(ii'j)] = n^{-1}[R(.j]^2\{p(ij)[1-p(ij)]/\lambda^2(i) + p(i'j)[1-p(i'j)]/\lambda^2(i') + 2\,p(ij)\,p(i'j)/[\lambda(i)\lambda(i')]\}.$$

The sample size required for particular selected values α_0, β_0, and D_0 were stated approximately [if n is shown to be large] as

$$n \geq D_0^{-2}\left\{Z(\alpha_0)\sqrt{V[\hat{D}(ii'j)|H_0]} + Z(\beta_0)\sqrt{V[\hat{D}(ii'j)|H_a]}\right\}^2$$

where $Z(\alpha_0)$ and $Z(\beta_0)$ are the normal deviates corresponding to α_0 and β_0 respectively and $V[\hat{D}(ii'j)|H_0]$ and $V[\hat{D}(ii'j)|H_a]$ are the variances of $\hat{D}(ii'j)$ given the null or the alternative hypothesis, respectively.

In order to compute values for the variances, realistic assumptions had to be made about the respective values of p(ij) and p(i'j) associated with a particular rate difference, D_0. A reasonable, but now always true, assumption is that the hospitalization rate for persons not in subpopulation i and i' is the same as the overall hospitalization rate R(.j) for condition j. Under this assumption p(ij) and p(i'j) may be expressed in terms of R(.j), $\lambda(i)$, $\lambda(i')$, and D_0 as

$$p(ij) = \lambda(i) + \frac{D_0 \lambda(i) \lambda(i')}{R(.j)[\lambda(i) + \lambda(i')]},$$

and

$$p(i'j) = \lambda(i') - \frac{D_0 \lambda(i) \lambda(i')}{R(.j)[\lambda(i) + \lambda(i')]}.$$

In light of the preceding discussion and the stated assumptions, sample size requirements were determined as a function of the parameter R(.j), D_0, $\lambda(i)$, $\lambda(i')$, α_0, and β_0. Recall that these parameters have been defined as follows:

R(.j) = county-wide hospitalization rate for condition j expressed in hospitalizations per thousand persons at risk;

D_0 = the hypothesized difference between hospitalization rates for subpopulation i and i' under the alternative hypothesis;

$\lambda(i)$ = proportion of the county population belonging to subpopulation i [$\lambda(i')$ is similarly defined for subpopulation i'];

α_0 = the specified probability of rejecting the null hypothesis (the hypothesis of no difference) when it is true; and

β_0 = the specified probability of accepting the null hypothesis when the alternative is true.

Table V shows sample size requirements for some possible values of these parameters.

The examples presented in Table V were chosen to illustrate sample size requirements for some possible hypotheses. The values of $\lambda(i)$ and $\lambda(i')$ in examples 1 through 7 correspond to those appropriate for the total population residing in the high pollution area and the total population residing in the low pollution area. The values of $\lambda(i)$ and $\lambda(i')$ in example 8 correspond to those appropriate for males 65 and over residing in high pollution and low pollution areas, respectively; this subpopulation was chosen since it illustrates sample size requirements for some of the smaller subpopulations that might have been considered in the study. It may be noted that larger overall sample sizes are required if attention is to be focused on small subpopulations. The values of R(.j) correspond to those for circulatory diseases possibly pollutant-related,

Table V. Sample size requirements for specified hypotheses.

					Estimated Minimum Sample, n			
					$\alpha_0 = 0.05$		$\alpha_0 = 0.01$	
Example	R(.j)	D_0	$\lambda(i)$	$\lambda(i')$	$\beta_0 = 0.1$	$\beta_0 = 0.05$	$\beta_0 = 0.05$	$\beta_0 = 0.01$
Suspect Circulatory Diseases								
1	13.2	0.3	0.248	0.341	115,919	145,292	212,369	292,262
2	13.2	1.	0.248	0.341	10,471	13,130	19,178	26,413
3	13.2	2.	0.248	0.341	2,629	3,298	4,814	6,635
4	13.2	3.	0.248	0.341	1,172	1,469	2,144	2,957
5	13.2	5.	0.248	0.341	424	532	775	1,071
Control Diseases								
6	3.2	1.	0.248	0.341	622	781	1,138	1,571
7	3.2	0.5	0.248	0.341	2,487	3,123	4,553	6,282
Control Diseases, males $\geq$ 65								
8	3.2	2.	0.012	0.013	3,555	4,462	6,511	8,975

R(.j) County-wide hospitalization rate per 1000

D_0 Hypothesized difference in hospitalization rates for subpopulations i and i'

$\lambda(i)$ Estimated fraction of population in high pollutant areas, based on preliminary air quality analysis

$\lambda(i')$ Estimated fraction of population of low pollutant areas, based on preliminary air quality analysis

α_0 Risk of claiming a difference > 0 when it's really 0

β_0 Risk of claiming a difference = 0 when it's really D_0.

and control diseases, respectively. The values of D_0 are what appeared at first consideration to be reasonable candidates for specifying the alternative hypotheses; other values might have been considered.

This analysis permitted some tentative conclusions to be drawn about sample size requirements.

1. Enumeration of all respiratory disease cases in the file would be necessary to permit meaningful comparisons to be made between small subpopulations such as males over 65 residing in different areas.

2. A sample of 3000 circulatory diseases suspected of association with air pollution should provide good control of the α and β risks for a D_0 of 3, and fairly good control for a D_0 of 2. Assuming similar types of comparisons are to be made for control diseases, and considering the lower R(.j) value for this category, a D_0 slightly less than 1 should be controlled ($\alpha_0 = 0.01$, $\beta_0 = 0.05$) with a sample size of about 1200. The total for both categories 4200, was attainable within the budget for data acquisition.

3. A supplemental sample of hospital records from peripheral counties might do more to reduce total errors in subsequent estimates than heavier sampling in the 28 Allegheny County hospitals. The seventeen hospitals in the neighboring counties (Beaver, Butler, Washington, and Westmoreland) were contacted. Fourteen of these were in the HUP data base. Beaver County records showed only a few patients from Allegheny County. Butler County record librarians found essentially no Allegheny cases. Washington and Westmoreland County hospital librarians reported essentially no cases from Allegheny County.

<u>Other Possible Analyses</u>

The analyses discussed in considering sample size requirements were based on a simple comparison of rates. Control diseases have been included in the study to test the hypothesis

$$H_0 : D(ii'j) = D(ii'j');$$

i.e., the differences between subpopulations i and i' are the same for condition j, say pollutant related circulatory system diseases, as they are for condition j', control diseases.

Drawing Conclusions from the Proposed Analyses

The methods described above permit the analyst to decide, within controlled error levels, whether subpopulation hospitalization rates for various conditions are similar or different. Since the study is primarily addressed at determining the relation to air pollution, one may wish to assert that any detected differences among subpopulations are directly attributable to the level of air pollution experienced by these populations. Such an assertion or conclusion may not be based solely on the statistical tests discussed above since the subpopulations may possess a number of other known or unknown characteristics, which were in no way experimentally controlled to allow the difference to be associated solely with the pollutant level.

The inability to conclude causation even though association has been proven (with possible error) is a weakness of all observational studies and particularly of most studies involving human populations.[2] Many previous health studies, however, have been made which, collectively, help to establish that the respiratory diseases under study increase in prevalence or incidence among populations exposed to SO_2 and particulate air contamination. Additional studies are showing the biological impact of such exposure on living tissues. Given these findings, this study is concerned only with estimation of those increases in hospitalization rates for these diseases that may be occurring among exposed subpopulations and the translation of such increases to costs. For this purpose, it is necessary only to prove association, which is being done through application of statistical tests.

Lesser evidence supports the effects on circulatory system diseases and to that extent this study itself is a source of further evidence, and employs controls as a necessary element of the methodology.

Drawing the Sample

The previous section described the sizing of the samples, based upon the need for precision in comparisons of different subpopulations. A sample size of 3000 pollutant-suspect circulatory diseases and 1200 control diseases was selected. Respiratory diseases were not to be sampled. Instead, all cases were being utilized for analysis.

A proportionate stratified random sample of the required size was selected. Race, sex, and age were used to identify the strata. Samples were drawn separately for the population-suspect-circulatory diseases and the control diseases. Table VI shows the numbers prescribed for the strata, and the total number of cases from which they were drawn. These numbers provided weighting factors equal to the ratio: total numbers in stratum/number in stratum sample.

The selection process began by reading a record from the computer tape. Records on the tape were rank-ordered by hospital, which were coded by number. Each record was read, screened, and discarded if the patient was less than a year old. If retained, it was then categorized by identifying its stratum. The stratum was checked to see if its quota of the sample had been filled. If not, a random number, R(0-1), was generated and subtracted from the ratio A/B, which equaled the number of samples yet to be drawn from the stratum divided by the number of records in the stratum remaining unconsidered. If the differences were greater than or equal to zero, the record was taken into the sample, and the elements of the ratio reduced by one. If the differences were less than zero, the record was discarded and the stratum count reduced by one. Accepted records were printed onto forms by computer, with space for hospitals to record additional data.

This procedure resulted in the selection of 3000 circulatory disease records and 1198 controls, as shown in Table VI.

Table VI. Proportionate stratified random sample of cases of hospitalization for circulatory system and control diseases.

	Circulatory System Diseases			
	Pollution Suspect		Control	
Stratum	Population	Sample	Population	Sample
W Males under 45	1085	154	150	36
W Males 45 to 64	5894	837	919	218
W Males 65 to 74	2387	339	617	146
W Males 75 and over	2057	292	556	132
W Females under 45	315	45	163	39
W Females 45 to 64	2556	363	718	169
W Females 65 to 74	2292	325	627	149
W Females 75 and over	2933	415	824	196
NW Males under 45	79	11	25	6
NW Males 45 to 64	342	48	103	24
NW Males 65 to 74	217	31	65	15
NW Males 75 and over	147	21	28	7
NW Females under 45	89	13	36	9
NW Females 45 to 64	300	43	100	24
NW Females 65 to 74	222	32	62	15
NW Females 75 and over	218	31	56	13
Total	21,133	3,000	3,049	1,198

W - White

NW - Non White

This table includes population and sample sizes for Set 1 (HUP) hopsitals. Refer to Table IV for population and sample sizes for the totally enumerated cases and Set 2 (non-HUP) hospitals for all three types of illnesses.

SECTION 5

OBJECTIVE ANALYSIS OF AIR QUALITY BY CENSUS TRACT IN ALLEGHENY COUNTY PENNSYLVANIA

In order to assess the impact of the ambient concentrations of particulate and SO_2 upon the hospitalizations of the population of Allegheny County, Pennsylvania, it was necessary to assign quantitative values to the air quality in each particular area. The values assigned should be based upon the existing measurements at nearby monitoring sites. Several available techniques for assigning values were tested. In one attempt, a second-order response surface was fitted to the existing data, but the error at points of measurement was large. Three separate surfaces were then fitted to data from three parts of the county with some success. When the three analyses were combined, however, extreme gradients of concentrations occurred at the boundaries of the areas, making the total analysis unacceptable. An iterative, weighted average analysis technique, similar to procedures used in objective analyses of meteorological data, was finally adopted.

In Allegheny County, SO_2 is measured at 49 locations and atmospheric particulates are measured at 21 locations. The locations were chosen for various reasons: proximity to emissions sources, varied topography, or "background concentrations area". As a result, air monitoring sites are distributed rather inhomogeneously about the county. Some are rather tightly clustered and others are rather remote. The following technique was employed to develop SO_2 and particulates levels for each census tract using the air quality data base. As a preliminary to application of the technique, the locations of all monitoring stations, and the centroid of all county census tracts were identified by their Universal Transverse Mercater (UTM) coordinates.

METHODOLOGY

The analysis technique assumes that the contribution of an observed pollutant concentration to the estimated pollutant concentration within a census tract decreases as a function of the distance between the two locations, until the separation exceeds a specified distance, R, called the radius of influence of the observed pollutant concentration. Thus, all observations within a radius R of a given location (census tract) are accorded a weight in computing the interpolated pollutant concentration for that location. The computation begins by determining the distances, r_{ij}, between a particular census tract (the centroid of which is identified by coordinates x_i, y_i) and measurement site j (located at coordinates x_j, y_j, $j = 1,2..., n$). The following relationship is applied:

$$r_{ij}^2 = (x_i - x_j)^2 + (y_i - y_j)^2 \quad (5\text{-}1)$$

The weighted average of sufficiently nearby measured pollutant concentrations is then calculated to give the estimated pollutant concentration for the census tract, $\hat{\phi}_i$

$$\hat{\phi}_i = \frac{\sum_j W_{ij} \phi_j}{\sum_j W_{ij}} \quad (5\text{-}2)$$

where W_{ij} is a weight function dependent upon r_{ij} and R.

There are many possible choices of function form for W_{ij}. The form used by Cressman,[15]

$$W_{ij} = \frac{R^2 - r_{ij}^2}{R^2 + r_{ij}^2} \quad , \quad r_{ij} < R \quad (5\text{-}3)$$

$$W_{ij} = 0 \quad , \quad r_{ij} \geq R \quad (5\text{-}4)$$

was chosen based upon successes in previous interpolations of atmospheric variables. This function, normalized to the interval (0,1), is shown in Figure 1.

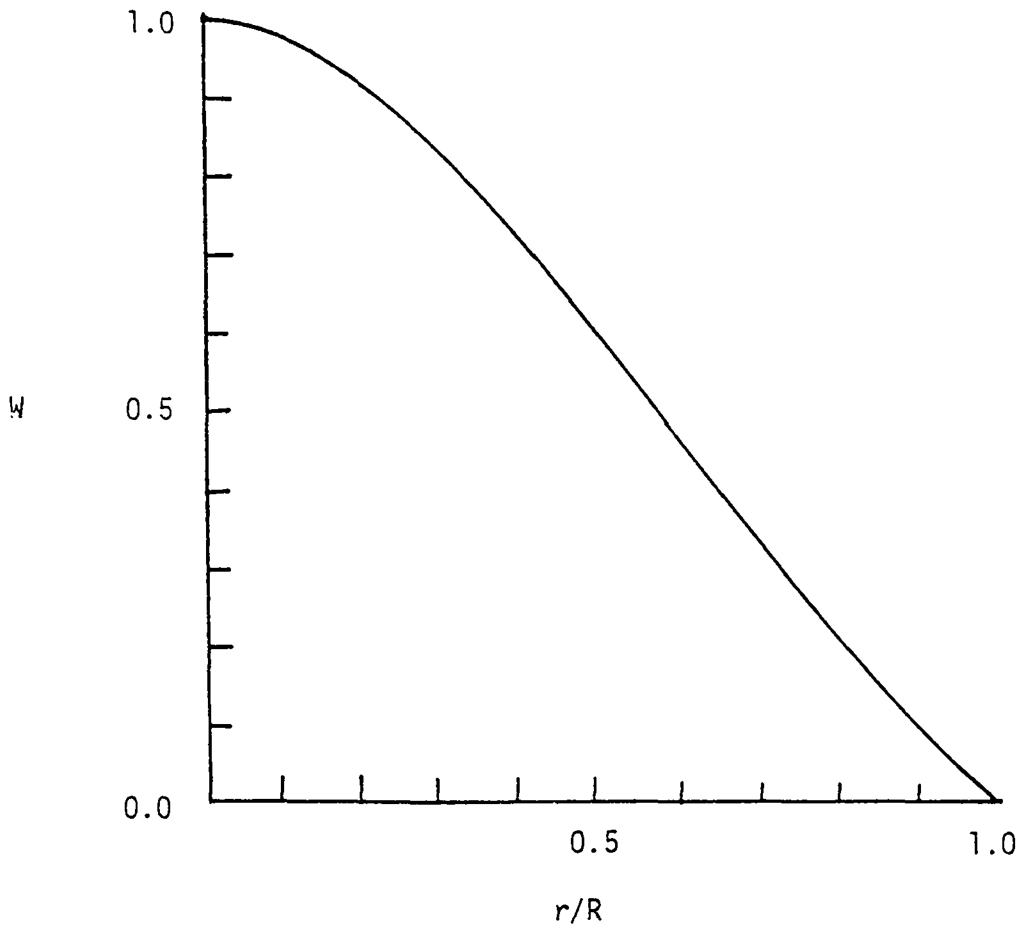

Figure 1. Cressman weight function, W, as a function of relative distance, r/R.

If R is large, many observations will be included in the estimate of $\hat{\phi}_i$. Even if several observations are very near the census track, $\hat{\phi}_i$ tends toward an average value in R. In the resulting analysis, maxima and minima values are reduced, the mean of the estimated values, $\hat{\phi}_i$'s, is nearly equal to the mean of the observed values, ϕ_j's, but the variance of $\hat{\phi}_i$'s is much smaller than the variance of ϕ_j's.

If R is small, the variance of $\hat{\phi}_i$'s will be more nearly equal to the variance of the ϕ_j's. However, if R is too small there may be some locations which do not have r_{ij}'s less than R. Thus no interpolation is possible.

A three-step iterative procedure was adopted to analyze the entire area of Allegheny County, maintaining the spatial variability of the measurements. On the first iteration, a large value of R, R(1), was used so that at least three observations were included in each interpolation. On the second iteration, a smaller value, R(2) was used. R(2) depended upon the average density of observation over the analysis area. The results of the first iteration were also incorporated into the second analysis by a preassigned weight. Finally, R(3), a very small value, was used with the previous iteration to help regain the observed values within the analysis field.

Letting ν indicate the iteration, $W_{ij}(\nu)$ denotes the Cressman weight function using $R(\nu)$. The expression for $\hat{\phi}_i$ can be generalized to:

$$\hat{\phi}_i(\nu+1) = \frac{\overline{W}\,\phi_i\;(\nu) + \sum_{j=1}^{n} W_{ij}(\nu)\;\phi_j}{\overline{W} + \sum_{j=1}^{n} W_{ij}(\nu)} \tag{5-5}$$

where $\hat{\phi}_i(0) = 0$, and $\overline{W}$ is a small positive constant.

On the first iteration, equation 5-5 estimates a $\hat{\phi}_i$ for each census tract. In the next iteration, if there are no observations within distance R(2) of a census tract, the first interpolated value is retained. Otherwise, the new interpolation will depend primarily upon nearby observations but, for continuity, will weakly incorporate the first estimate, using a multiplier $\overline{W}$. In this study, $\overline{W} = 0.05$, gave satisfactory results.

ANALYSIS APPROACH

The computations were carried out using census tract and monitoring station locations mapped into the square grid centered on the city of Pittsburgh and normalized by the grid length, 2 km. The average concentration of SO_2 and of particulate measurements for 1972 from each monitoring site were used as inputs for the analyses. Two interpolations were done for each pollutant. The first analysis used the concentration, C, as the dependent variable ϕ_j. The second used the natural logarithm of the concentration as that variable, i.e., $\phi_i = \ln C$. The census tract values of concentration were obtained by exponentiating the results.

The spatial representations were examined for continuity and agreement with observed values. In both cases, the analysis using the logarithms showed a more pronounced peak near the monitoring stations with little gradient in other areas. The analyses using observed concentrations showed a smoother transition with increasing distance from a monitoring station. Reasoning that over a year's time, with many different wind and dispersion conditions, a smooth transition between data points would be more likely, the analysis using the observed data was accepted as preferred.

The scan radii, R, were different for the particulate estimations and the SO_2 estimations, because of the different data density. Table VII shows the $R(\nu)$'s which were used. The greatest difference is in R(2) which was due to the difference in number of observations available. Letting A be the overall area of the Allegheny County interpolation grid (3600 km^2) and N the number of observations, then

$$R(2) \approx (A/N)^{1/2}.$$

Table VII. Scan radius (km) by iteration and pollutant.

ν	Particulates	Sulfur Dioxide
1	30.0	24.0
2	13.0	5.0
3	1.6	1.6

Figure 2 shows approximate contours of levels of SO_2 drawn on a map of Allegheny County, using the estimated levels by census tracts. Figure 3 shows approximate contours of levels of particulates. The effects of uneven terrain and known emission sources are quite evident. A complete listing of the estimated air quality by census tract is given in the Appendix.

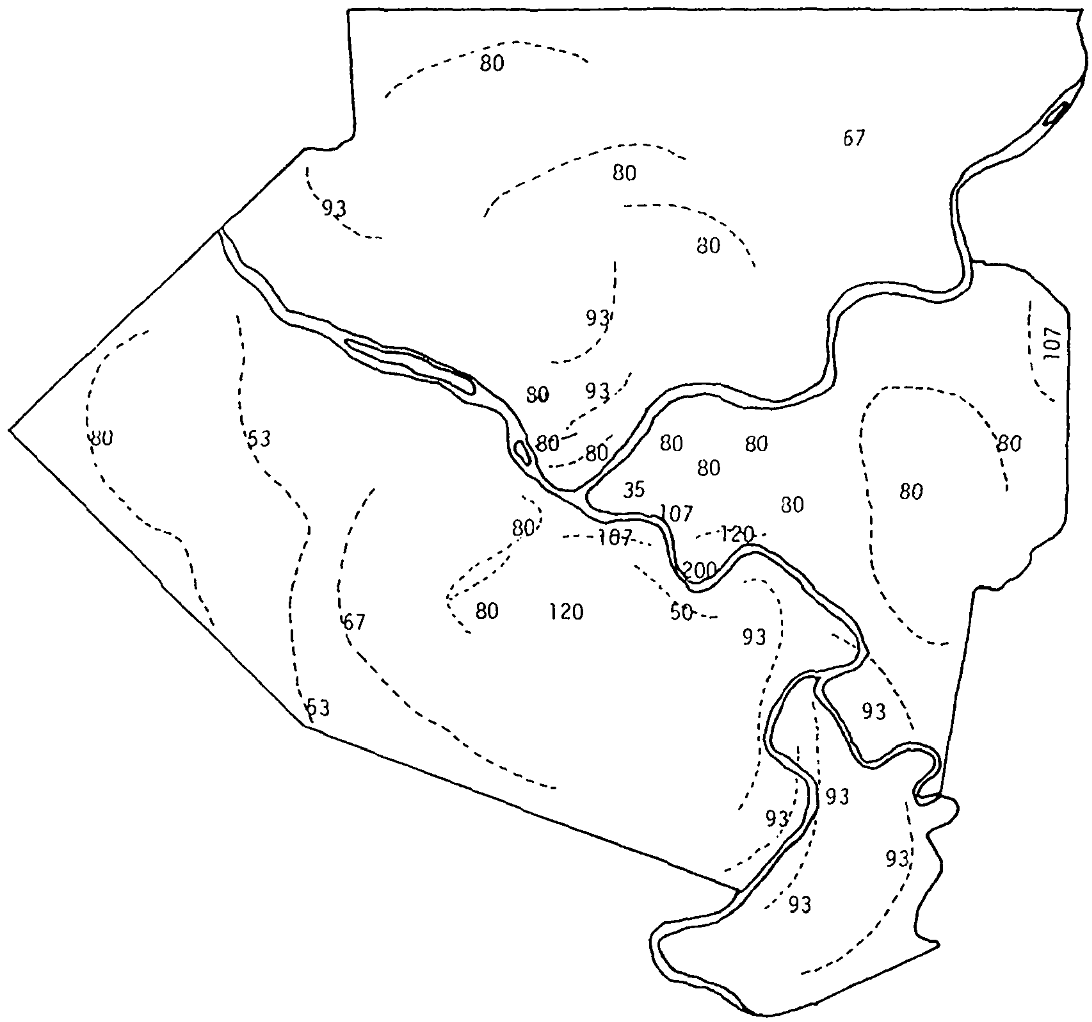

Figure 2. SO_2 levels (1972 yearly average), Allegheny County, Pa., $\mu g/m^3$.

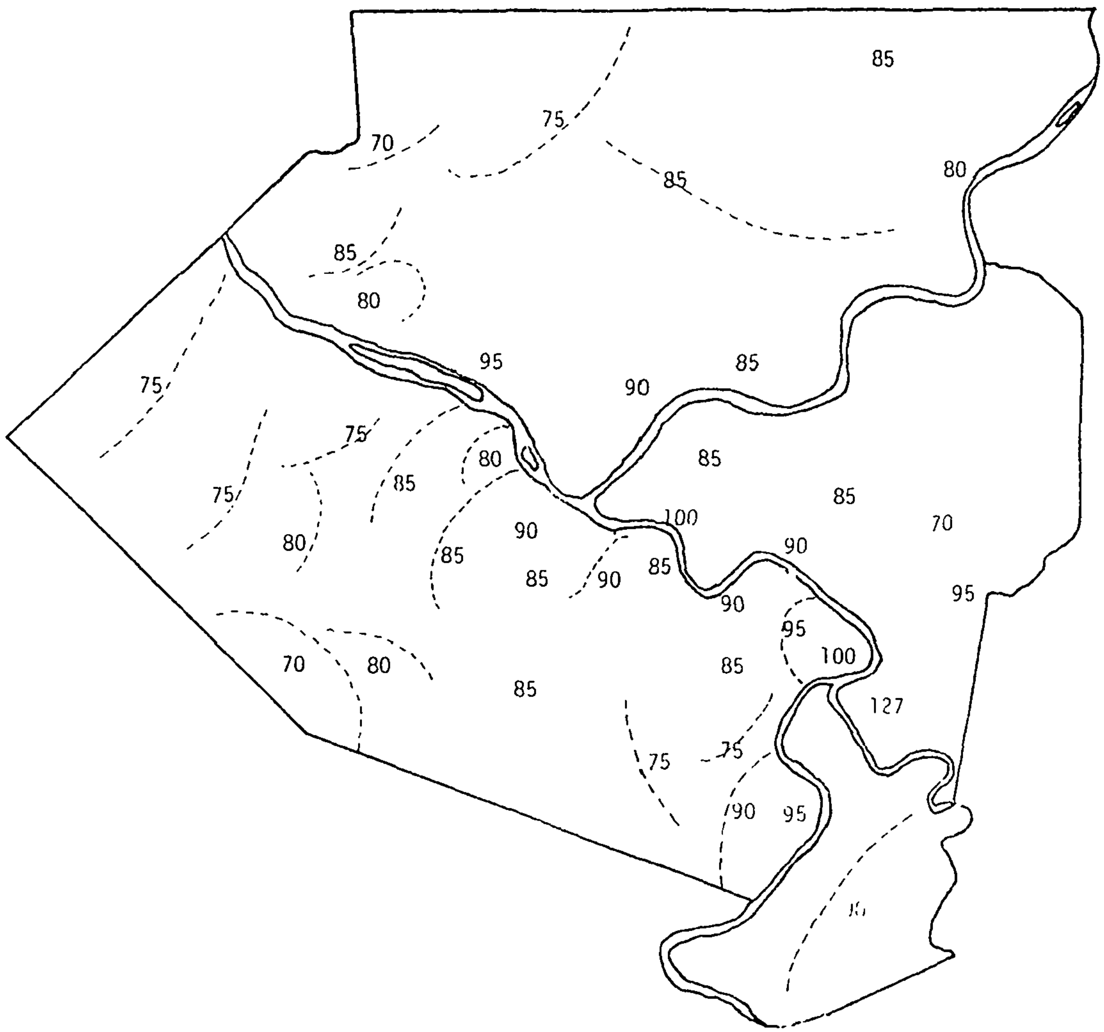

Figure 3. Particulates levels (1972 yearly average), Allegheny County, Pa., μm/g³.

SECTION 6

EFFECT OF AIR POLLUTION ON HOSPITALIZATION INCIDENCE RATES

The data were examined first by multiple regression analysis techniques to determine whether the relationship between hospitalization incidence rates (hospitalizations per year per 1000 persons) for respiratory and circulatory system diseases and the levels of pollution were statistically significant, and whether such a relationship was not significant in control disease data. Such effects were indeed established, except for the control diseases. Accordingly, the data were further analyzed by methods which utilized the sample design more fully in disclosing the nature of the effects.

A regression model was used in which the unit of observation was the census tract, and the population considered was that defined by the Census. Incidence rates data were merged with air-quality data and population data for the analysis. The rates (in hospitalizations per 1,000 population) were then examined for their relation to several factors, and treated simultaneously as independent variables. Air-quality variables were: the census tract SO_2 level (ppb), the particulates level ($\mu g/m^3$), and their product (interaction). Population characteristics included were: the census tract fraction males, fraction white race, fraction married (and living with spouse), fraction with income less than or equal to the poverty level (as defined by the Census, with consideration of the family status, etc.), the median income, the fraction employed in heavy industry, and the fractions in three age classes (65-74 years, 45-64, and 75 or over).

In development of the model, all variables were treated as continuous variables. The analysis imposed the assumption that the smoking habits of the population did not vary significantly with census tract pollutant level, since data for this characteristic of the population were not available. This assumption seems reasonable.

Three regression analyses were made, one for respiratory diseases, one for suspect circulatory system diseases, and one for control diseases. Ideally, the control diseases would reconfirm that the effects of air pollution are disease specific. Several additional benefits from the use of controls are discussed by MacMahon.[14]

RESULTS OF REGRESSION ANALYSIS

Of the 498 census tracts in the county, required Census data were complete for 493, and these were used in the analysis. The effects estimated by regression analysis are shown in Table VIII. Their significance is also indicated. All effects are listed. However, effects such as those of age are not unexpected and were estimated primarily to minimize their influence on the effects of pollutants.

Exposure to pollution appears not to have affected the incidence rates for control diseases judged by the large significance levels. Such exposure seems definitely to have increased incidence rates for respiratory diseases, judged by the low significance levels. The effects on incidence rates for circulatory diseases are positive (hospitalization rates increased with exposure to higher pollution levels); the significance levels are not quite so low as those for respiratory diseases, but are too low to be ignored. In comparison to control diseases, the evidence is strong that hospitalization rates for the circulatory system diseases under consideration here are increased by exposure to the higher pollutant levels. (It is certain that they did increase in Allegheny County in 1972).

The regression analysis was helpful in assessing several population characterisitcs as factors that might have affected incidence rates. According to the analysis, the fraction males was not a significant one. The effect of race, represented by the fraction white in the analysis, was significant: whites appear to have lower hospitalization rates for respiratory diseases and higher rates for suspect circulatory system diseases, compared to other races. Rates for control diseases do not appear to be race dependent. Married persons appear to incur lower rates of hospitalization for both respiratory and suspect circulatory system diseases, but not for the control diseases. Persons with incomes at or below poverty level showed significantly higher rates for respiratory and control diseases, but not for suspect circulatory diseases. Admission

Table VIII. Effects of exposure to air pollution, and other factors, on incidence of hospitalization.

	Control Diseases		Respiratory Diseases		Suspect Circulatory System Diseases	
	Effect	Significance*	Effect	Significance	Effect	Significance
Intercept	-8.7	0.41	-15.4	0.20	-41.8	0.13
SO_2 level*, ppb	-0.008	0.98	0.71	0.053	1.34	0.12
Particulates level, $\mu g/m^3$	0.012	0.92	0.27	0.049	0.58	0.069
SO_2 x Particulates	0.00009	0.98	-0.008	0.054	-0.015	0.12
Fraction males	5.97	0.38	-1.52	0.85	1.86	0.92
Fraction white	-1.39	0.20	-3.47	0.005	5.41	0.06
Fraction married	1.99	0.49	-10.8	0.001	-24.9	0.0013
Fraction $\leq$ poverty level income	74.1	0.005	92.1	0.002	35.4	0.42
Median income, $/yr	0.001	0.098	0.00002	0.79	0.00006	0.78
Fraction in heavy industry	6.2	0.019	8.6	0.005	6.95	0.32
Fraction age 65-74	1.01	0.915	-11.1	0.30	7.0	0.78
Fraction age 45-64	7.63	0.11	19.7	0.0003	37.4	0.003
Fraction age 75 or more	32.6	0.003	15.6	0.215	21.0	0.47

*The significance is the theoretical probability of obtaining an absolute value of t (t = estimate of effect ÷ standard error of the estimate) as large or larger than that exhibited by the data under the hypothesis of a zero effect.

rates appeared to increase with census tract median income only for control diseases. They also increased with percentage employed in heavy industry, except in the case of suspect circulatory diseases.

While the regression analysis serves to show that there are significant effects of air pollution on hospitalization incidence rates, the model is inadequate to provide estimates to those effects. As indicated in Table VIII, both SO_2 and particulates levels were entered into the calculations of the regression model in their basic units, so that the effects are per $\mu g/m^3$ for particulates and per ppb for SO_2. While the model could be used to estimate a hospitalization rate for each census tract, the errors of such estimates would be relatively large, and the distinction between populations exposed to prescribed air quality and polluted air would be affected. The population pollutant exposure experience breaks down into six of the nine possible combinations of "levels" of SO_2 and particulates. There were no census tracts with low SO_2 and high particulate levels, nor any with both pollutants at the high levels. Very little of the population experienced exposure to medium SO_2-high particulates, and therefore, this subpopulation was combined with the medium SO_2-medium particulates subpopulation to avoid inflated error estimates that were obtained using the small population separately. With six distinct pollutant-exposure levels, it is doubtful that three parameters in the regression model can provide the desired comparisons. To obviate these difficulties, the incidence rate data were analyzed as a proportionate stratified random sample.

ANALYSIS BASED ON THE SAMPLE DESIGN

In addition to the regression analysis discussed above, an analysis of hospitalization rates based on six levels or categories of exposure to air pollutants was conducted. Annual hospitalization rates per thousand persons were computed using the 1972 sample data on hospitalizations and 1970 Census base data. The link between the two data sets was achieved by identifying the residence of each patient by census tract. Air quality measures were assigned to census tracts as discussed in Section 5; then air quality measures were associated both with the hospitalization estimates and with the population base counts by age, sex, and race.

Ideally, both hospitalization and base data should be based on the same year. Since 1972 is only two years from 1970, it has been assumed that population changes and shifts occurring over that short period of time would not materially effect the results of the analysis.

Sixteen age-sex-race categories were utilized in stratifying the hospital cases prior to sample selection. These sixteen categories were collapsed to twelve in the analysis by combining the age classes "65 to 74" and "75 and older" into a single "65 and older" category. This was done primarily to eliminate all zero cells in the population data base. Population bases in thousands of persons are shown in Table IX.

Total hospitalizations were then estimated for each exposure level, and converted to rates per 1000 persons. These estimates are shown in Table X. Age-sex-race adjusted rates are shown at the bottom of Table X.

Part of the observed differences in hospitalization rates among the six areas might be attributed to factors other than air pollution. Due to differences in age, sex, and race distribution (Table XI), estimates of hospitalization rates for each area were also computed using the total SMSA population as a standardizing distribution. These adjusted rates are also shown in Table X, along with their standard errors. The final entries in Table X show the median pollutant level for both SO_2 and particulates, and the median family income.

Estimation Procedures

Standard estimation procedures for stratified samples were utilized in computing estimates of hospitalizations by pollutant exposure areas. Since the inferences drawn from the analysis are intended to extend beyond the finite list of 1972 hospitalizations in Allegheny County, no finite population correction factors were used in any of the variance estimates. This is not meant to suggest a claim of external validity to any particular population defined statewide or nationally. Ignoring the finite connection factors treats the occurrence of hospitalizations as a random process taking place under conditions defined in terms of the existing population characterized by age, race, sex, and residence in a defined air quality area.

Estimates of hospitalization rates, $\hat{R}_\alpha(dp)$, for disease d in pollutant level p were computed as a weighted average

$$\hat{R}_\alpha(dp) = \sum_{i=1}^{12} W_\alpha(pi)\,\hat{R}(dpi)$$

where

α = 1 or 2 for type of weighting distribution;

Table IX. Classification of Allegheny County Population according to exposure to pollutants, by race, sex, and age. (In thousands of persons).

Race	Sex	Age	POLLUTANT LEVELS* LL	LM	ML	MC	HL	HM	TOTAL
White	Male	1 to 44	45.566	125.707	20.293	179.964	2.015	72.260	445.80
White	Male	45 to 64	16.042	49.282	5.444	69.628	0.920	29.607	170.92
White	Male	65 or Older	5.207	17.332	1.584	28.976	0.398	12.429	65.93
White	Female	1 to 44	45.941	130.084	20.635	189.213	2.013	76.186	465.07
White	Female	45 to 64	16.971	54.675	5.628	81.353	0.973	34.082	193.68
White	Female	65 or Older	7.353	24.869	2.111	43.153	0.617	17.557	96.66
Black and Other	Male	1 to 44	0.941	5.974	0.441	27.647	0.177	12.352	47.53
Black and Other	Male	45 to 64	0.261	1.473	0.084	8.541	0.023	3.241	13.62
Black and Other	Male	65 or Older	0.257	0.698	0.030	4.184	0.015	1.889	7.07
Black and Other	Female	1 to 44	1.034	6.455	0.378	32.055	0.136	14.640	54.70
Black and Other	Female	45 to 64	0.307	1.616	0.073	10.049	0.044	3.904	15.99
Black and Other	Female	65 or Older	0.303	0.687	0.045	4.496	0.012	2.223	7.77
Total			141.183	418.852	56.746	679.259	7.343	280.370	1583.75

*The first letter represents the SO_2 level; the second, the particulates level. LL = low SO_2, low particulates. MC = medium SO_2, combined medium and high particulates, etc.

Table X. Estimated hospitalization rates, by level of population exposed to air pollution.

	LL	LM	ML	MC	HL	HM	Total
Subpopulation Exposed (1000's)	141.183	418.852	56.746	679.259	7.343	280.37	1583.75
Total Hospitalizations, 1972							
Respiratory Diseases	548 (22)**	2216 (42)	281 (17)	4191 (51)	78 (9)	1830 (39)	9144 (43)
Suspect Circ. Sys. Diseases*	951.5 (80)	4292 (155)	331.2 (48)	7276.9 (179)	119.9 (29)	3343.5 (58)	16315 (157.8)
Control Diseases	184.3 (27)	1015. (58)	76.7 (18)	1896.9 (70)	25.2 (10)	713.9 (50)	3913 (60)
Hospitalization Rates (per 1000)							
Respiratory Diseases	3.88 (0.16)	5.29 (0.10)	4.95 (0.29)	6.17 (0.08)	10.62 (1.20)	6.53 (0.14)	5.77 (0.03)
Suspect Circ. Sys. Diseases	6.74 (0.67)	10.25 (0.37)	5.84 (0.84)	10.72 (0.26)	16.32 (3.93)	11.93 (0.50)	10.30 (0.10)
Control Diseases	1.31 (0.19)	2.48 (0.14)	1.35 (0.32)	2.79 (0.10)	3.43 (1.37)	2.55 (0.18)	2.47 (0.02)
Hospitalization Rates (per 1000) (Age-Sex and Race Adjusted)							
Respiratory Diseases	4.20 (0.20)	5.67 (0.12)	5.98 (0.42)	5.95 (0.07)	9.82 (1.16)	6.19 (0.13)	5.77 (0.03)
Suspect Circ. Sys. Diseases	7.24 (0.64)	10.74 (0.41)	7.59 (0.12)	10.25 (0.26)	14.91 (4.13)	11.42 (0.48)	10.30 (0.10)
Control Diseases	1.56 (0.26)	2.50 (0.15)	2.28 (0.62)	2.67 (0.10)	3.73 (1.58)	2.38 (0.17)	2.47 (0.04)
Median SO_2 Level, $\mu g/m^3$	66	66	83	83.1	104.9	105.1	
Median Particulates Level, $\mu g/m^3$	64.4	84.6	72.7	85.3	73.5	87.3	
Median Family Income, $	7343	7096	7312	7107	7055	7358	

*The fractional values result from estimating, using the sample data.

**( ) denotes standard deviation of the value entered immediately above.

Table XI. Population distribution within defined areas.

Population Group	PERCENT OF TOTAL POPULATION BY POLLUTANT LEVEL						
	SO_2 ($\mu g/m^3$)						All Allegheny County
	<80		80 - 99.3		> 99.3		
	Particulates (Mg/m^3)						
	<76	≥76	<76	≥76	<76	≥76	
White Male							
1-44	32.3	30.0	35.8	26.5	27.4	25.8	28.1
45-64	11.4	11.8	9.6	10.3	12.5	10.6	10.8
65+	3.7	4.1	2.8	4.3	5.4	4.4	4.2
White Female							
1-44	33.2	31.1	35.4	27.9	27.4	27.2	29.4
45-64	12.0	13.1	9.9	12.0	13.3	12.2	12.2
65+	5.2	5.9	3.7	6.4	8.4	6.3	6.0
Non-White Male							
1-44	.7	1.4	.8	4.1	2.4	4.4	3.0
45-64	.2	.4	.1	1.3	.3	1.2	.9
65+	.2	.2	.1	.6	.2	.7	.4
Non-White Female							
1-44	.7	1.5	.7	4.7	1.9	5.2	3.5
45-64	.2	.4	.1	1.5	.6	1.4	1.0
65+	.2	.2	.1	.7	.2	.8	.5
White	97.8	96.0	98.1	87.2	94.5	86.4	90.7
Non-White	2.2	4.0	1.9	12.8	5.5	13.6	9.3
Males	48.4	47.9	49.1	47.0	48.3	47.0	47.4
Females	51.6	52.1	50.9	53.0	51.7	53.0	52.6
Persons aged 1-44	66.9	64.0	73.6	63.1	59.1	62.6	63.9
Persons aged 45-64	23.8	25.6	19.8	25.0	26.7	25.2	25.0
Persons aged 65+	9.3	10.4	6.6	11.9	14.2	12.2	11.1

d = 1, 2, or 3 for respiratory diseases, suspect circulatory diseases, or control diseases, respectively;

p = 1, 2, ---, 6 for the six defined pollutant levels as shown in Table IX;

i = 1, 2, ---, 12 for the 12 race-sex-age categories shown in Table IX;

$W_\alpha(pi)$ = weighting function for rates specific to pollutant level p and age-sex-race category i; and

$\hat{R}(dpi)$ = estimated hospitalization rate for disease d, air pollutant level p, and race-sex-age category i.

Race-sex-age specific estimates, $\hat{R}(dpi)$, were computed as

$$\hat{R}(dpi) = \{\sum_{h=1}^{2} \hat{P}(hdpi)\ N(hdi)\}/X(pi)$$

for i = 1, 2, 4, 5, 7, 8, 10, and 11 where

h = 1 or 2 for the sampled or enumerated hospitals, respectively;

$\hat{P}(hdpi)$ = proportion of studied hospitalization cases from hospital group h, disease d, and race-sex-age group i that are associated with pollutant p;

$N(hdi)$ = total number of 1972 hospitalizations from hospital group h, disease d, and race-sex-age group i, and

$X(pi)$ = 1970 Census population of pollutant level area p and race-sex-age group i.

For race-sex-age specific estimates involving over 65 (i.e., i = 3, 6, 9, and 12), estimates were computed as

$$\hat{R}(dpi) = \{\sum_{h=1}^{2} \sum_{j=1}^{2} \hat{P}(hdp(i,j))\ \ N(hd(i,j))\}/X(pi)$$

where the subscript j identifies the age groups 65-75 (j = 1) and 75 and over (j = 2) used as strata in the sample design and collapsed into a single age group (65 and over) for analysis purposes.

The weighting function $W_\alpha(pi)$ was computed in two ways depending on whether a standardizing race-sex-age distribution was employed. Non-standardized estimates (α = 1) were based on weights appropriate to the individual pollutant level defined areas, i.e.,

$$W_1(pi) = X(pi)/\sum_{i=1}^{12} X(pi).$$

Standardized estimates ($\alpha = 2$) were based on weights determined from the race-sex-age distribution of the entire county, i.e.,

$$W_2(pi) = \sum_{p=1}^{6} X(pi) / \sum_{p=1}^{6} \sum_{i=1}^{12} X(pi).$$

Variance estimates were computed for the rate estimates as:

$$var[\hat{R}_\alpha(dp)] = \sum_{i=1}^{12} W_\alpha^2(pi)\ var\ [\hat{R}(dpi)]$$

where

$$var[\hat{R}(dpi)] = \{\sum_h \sum_j var[\hat{P}(hdp(i,j))]\ N^2(hd(ij))\}/X^2(pi),$$

$$var[\hat{P}(hdp(i,j))] = \hat{P}(hdp(i,j))\ [1-\hat{P}(hdp(i,j))]/n(hd(i,j)),$$

and

$$n(hd(i,j)) = \text{sample size for stratum } hd(i,j).$$

The subscript j and the summation over j may be eliminated from the formulae for those race-sex-age categories whose age is under 65 (i.e., for i = 1, 2, 4, 5, 7, 8, 10, and 11).

Potential Biases

Some cases were lost from the sample because hospitals could not locate their records. Most of the hospitals felt that the patients involved were most likely from outside the county, therefore, they were omitted in the analysis of the data. The worst possible bias that these missing patients could introduced is the bias resulting from their having all belonged to a single air-quality subpopulation of Allegheny County. Although this was considered quite unlikely, its effect was examined. Table XII shows the increases in hospitalization rates that would result if all unclassified cases were added to cases from a single air-quality subpopulation. For example, the 458 unclassified cases out of 11,550 respiratory diseases cases, would increase the rate in the LL subpopulation from 3.88 to 7.12. If added to the HL subpopulation, the rate would increase from 10.62 to 72.99, which is unreasonably high.

Table XII. Effects of assigning all unclassified hospitalizations to a single air-quality subpopulation.

Item		Respiratory Diseases		Circulatory System Diseases		Control Diseases	
Total Sample		11550		2999		1198	
Number of Unclassified		458		165		248	
Estimated hospitalization rate per 1000 persons*							
Air quality	L, L	3.88	(7.12)	6.74	(7.90)	1.30	(3.06)
	L, M	5.29	(6.38)	10.25	(10.64)	2.43	(3.02)
	M, L	4.95	(13.02)	5.84	(8.75)	1.35	(5.72)
	M, C	6.17	(6.84)	10.71	(10.95)	2.79	(3.16)
	H, L	10.62	(72.99)	16.32	(38.79)	3.43	(3.72)
	H, M	6.53	(8.16)	11.93	(12.52)	2.55	(3.43)

*The first estimate is the rate without including unclassified hospitalizations; the second, in parentheses, is the rate obtained by adding all unclassifieds to the single air quality level.

A second potential bias could have resulted from persons in Allegheny County entering hospitals in neighboring counties, and thus not being included in the data. Hospitals in neighboring counties were contacted concerning this possibility; all indicated that to their knowledge, essentially no such cases had occurred. On the other hand, substantial numbers of persons in neighboring counties did enter Allegheny County hospitals, and the data analysis took this into account.

Effects on Hospital Use and Costs

The total number of excess hospitalizations for each of the three disease conditions was estimated by comparing the hospitalization rates in the area of the county meeting air quality standards (SO_2 <80 $\mu g/m^3$ and particulates <76 $\mu g/m^3$) with the remaining parts of the county. These comparisons are shown in Table XIII. The difference in rates is applied to the population residing in areas that did not comply with standards. Estimates of 3,000, 5,650, and 1,832 excess hospitalizations for respiratory, suspect circulatory, and control diseases associated with noncomplying areas are shown. Standard error estimates are given in parenthesis below each estimated number.

The cost of excess hospitalizations was calculated assuming that length of stay and cost per day did not vary with level of pollution. (These assumptions are not entirely correct; the costs of extra length of stay are estimated separately in Section 7.) Average lengths of stay and average cost per day were computed from data provided by 26 of the 28 hospitals in the study. Average lengths of stay were: 9.4 days for respiratory diseases; 13.7 days for suspect circulatory system diseases; and 15.4 days for control diseases. Corresponding average audited costs per day were: \$68.10, \$67.20, and \$71.30. These costs differ because of the slightly different distribution of the different diseases among the hospitals.

Using these length of stay and cost per day estimates, total excess hospital days and total excess costs were computed, and are given in Table XIII, along with their standard errors.

Table XIII. Estimated excess hospitalization rates, excess hospital days and excess hospital costs

Disease	HOSPITALIZATION RATES Air Pollutants At or Below Standards	Air Pollutants Above Standards	Excess Hospitalizations Per 1000 Persons 1 yr or older	Total Excess Hospitalizations	Total* Excess Hospital Days	Total* Excess Costs
Respiratory Diseases	3.88 (0.16)	5.96 (0.03)	2.08 (0.17)	3,000 (254)	28,205 (2,386)	$1,920,769 (162,490)
Suspect Circ. Sys. Diseases	6.74 (0.57)	10.65 (0.11)	3.91 (0.58)	5,640 (838)	77,274 (11,478)	5,192,823 (771,309)
Control Diseases	1.31 (0.19)	2.58 (0.03)	1.27 (0.20)	1,832 (300)	28,214 (4,615)	2,011,642 (329,119)
Total			7.26 (0.64)	10,472 (926)	133,693 (12,599)	9,125,241 (854,190)

*Based on a population of 1,442,570 persons 1 year old and over residing in those areas not meeting prescribed standards for air quality; assumed average lengths of stay equal to 9.4 days for respiratory diseases, 13.7 days for suspect circulatory diseases, and 15.4 days for control diseases; and assumed average costs per day of $68.10 for respiratory diseases; $67.20 for suspect circulatory diseases; and $71.30 for control diseases.

SECTION 7

EFFECT OF AIR POLLUTION ON LENGTH OF STAY IN THE HOSPITAL

ANALYSIS OF THE DATA

The data were examined by multiple regression analysis techniques to determine whether the relationship between the patient's length of stay and the level of pollution at his neighborhood residence was statistically significant. If so, then attendant costs could be estimated with justification. A regression model was used in which the unit of observation was the individual patient, and the population considered was the population of hospitalized persons. His length of stay was examined for its relation to several factors, treated simultaneously as independent variables. Personal characteristics included the patients sex, race, age, smoking habits, occupation, how his hospital bill was paid, and whether he had had surgery. His exposure to pollutants SO_2 and particulates was based upon the levels for his census tract. The hospital load, or percent occupancy, was taken from hospital records. The median income of his census tract was taken from census data.

In the development of the regression model, median income and hospital load were treated as continuous variables. The others were treated as class variables; differences between specific levels and the average over all levels were computed and tested for statistical significance.

The occupation effect was computed as half the difference in average length of stay between "light" occupations and "heavy" occupations. The rationale for this comparison was that the "light" occupations were less likely to impose additional pollutant burdens on the persons than the "heavy" occupations.

Smoking habits were defined using four codes: 0 = unknown (for those whose habits were not recorded); 1 = non-smokers (including those who had quit); 2 = light smokers (one pack or less a day); 3 = heavy smokers (more than a pack a day, or recorded as "heavy" smoker). The effects were computed by comparing, in sequence, the unknowns, the non-smokers, and the light smokers with the average over all four classes.

Four age classes were established: 1 = patients 1-44 years; 2 = 45-65; 3 = 65-74; and 4 = >74. Each of the first three classes were compared with the average of all classes. Patients less than one year old were excluded because of their limited exposure to air pollution.

Five payment classes were established: 1 = those using Medicare, Medicaid, or Government Insurance; 2 = Blue Cross or Commercial Insurance; 3 = Workmans Compensation or UMW Insurance; 4 = other types of insurance; 5 = selfpayment. Each of the first four classes were compared with the average of all classes.

Because pollutant levels for SO_2 were so often closely correlated with levels of particulates, four classes of air quality were established: 1 = low SO_2 and low particulates; 2 = low SO_2 and medium particulates; 3 = high, or medium SO_2 and low particulates; 4 = high or medium SO_2, and high or medium particulates. These classes covered all patient exposures. Each of the first three classes were compared with the average of all four.

The effect of sex was determined as half the difference between males and females (a negative effect thus would indicate a greater length of stay for females). The effect of race was calculated as half the difference between whites and other races.

Three analyses were made, one for respiratory diseases, one for suspect circulatory system diseases, and one for control diseases. Ideally, control diseases could reconfirm that the effects of air pollution are disease specific Several additional benefits from the use of controls are discussed by MacMahon.[14]

RESULTS

The effects estimated by regression analysis are shown in Table XIV. Their significance is also indicated. All effects are listed. However, effects such as those of age and smoking were not unexpected and were estimated primarily to minimize their influence on the effects of pollutants.

Exposure to air pollution appears not to have affected length of stay for control diseases. The comparisons for control diseases are not significant, judged by the large values in the significance column (0.50, 0.84, and 0.77). The comparisons for respiratory diseases, on the other hand, show that length of stay for pollutant levels 1 and 2 are significantly different from the average. The comparisons for suspect circulatory diseases show that length of stay for pollutant level 3 is very significant, greater than the average, and that length of stay for pollutant levels 1 and 2 is significant at a sufficient level to merit further study.

Table XIV. Effects of exposure to air pollution; and of other factors, on length of stay.

	Control Diseases		Respiratory Disease		Suspect Circulatory System Diseases	
	Effect	Significance*	Effect	Significance	Effect	Significance
Intercept	28.01	0.003	6.6	0.0001	11.8	0.0002
Sex 0.5 (males-females)	- 0.23	0.70	-0.2	0.015	- 0.17	0.39
Race 0.5 (whites-others)	0.21	0.83	-0.12	0.33	- 0.22	0.51
Surgery 0.5 (no surgery-surgery)	- 3.2	0.0001	-0.31	0.0002	- 0.29	0.15
Median Income, $ Δstay/Δ$	0.000	0.85	0.00004	0.07	- 0.0000	0.99
Occupation 0.5 (light-heavy)	- 1.0	0.34	0.05	0.71	0.04	0.92
Smoking: Unknown -avg.	0.15	0.89	-0.27	0.09	- 0.70	0.04
Nonsmokers - avg.	1.02	0.38	-0.69	0.0001	0.25	0.50
Light smokers - avg.	0.22	0.93	0.39	0.24	0.18	0.81
Pollutant exposure						
1-avg.	- 1.8	0.50	-0.63	0.030	- 1.16	0.11
2-avg.	0.32	0.84	0.39	0.033	- 0.69	0.14
3-avg.	1.0	0.77	-0.28	0.38	2.4	0.009
Age						
(1-44) - avg.	- 2.4	0.25	-4.29	0.0001	- 2.5	0.001
(45-64) - avg.	0.96	0.51	-0.02	0.89	- 0.14	0.77
(65-74) - avg.	- 0.19	0.90	1.82	0.0001	0.97	0.05
Payment class						
1 - avg.	2.3	0.54	0.12	0.77	1.25	0.34
2 - avg.	0.01	0.99	-0.43	0.29	1.54	0.20
3 - avg.	- 8.7	0.39	0.20	0.90	- 0.24	0.94
4 - avg.	8.6	0.32	0.70	0.19	- 6.99	0.05
Hospital % of occupancy Δstay/Δ%	- 0.16	0.11	0.05	0.0004	0.01	0.72
Number of Cases	951		8,993		2,312	

*The significance is the theoretical probability of obtaining an absolute value of t (t = estimate of effect ÷ standard error of the estimate) as large or larger than that exhibited by the data under the hypothesis of a zero effect.

Table XV shows the expected values of increased length of stay at each of the classes of pollutant levels studied along with the standard errors. These were derived from the comparisons shown in the previous table. The

Table XV. Increased length of stay (in days per patient) under exposure to various levels of air pollution.

	AIR POLLUTION LEVELS			
Diseases	At or Below Standards	Low SO_2 Med Part.	High SO_2 Low Part.	High SO_2 High Part.
Respiratory	0	1.02 (0.39)	+0.35 (0.55)	+1.15 (0.37)
Suspect Circulatory	0	0.47 (0.93)	3.46 (1.46)	0.61 (0.90)
Controls	0	2.12 (3.29)	2.80 (5.40)	2.28 (3.20)

increased stays exceeded their standard error except for the low particulates level. For suspect circulatory diseases, the high SO_2-low particulates exposure showed the greatest effect on length of stay, an increase of 3.5 days. This suggests a strong effect of high SO_2 at moderate particulates levels. The controls showed no significant increase in length of stay with increases in pollutants; sample size was, of course, smaller for controls.

ESTIMATED COSTS

The additional costs to persons in Allegheny County for 1972 was estimated in two steps: the number of hospitalizations for respiratory diseases and for circulatory diseases at each of the three pollutant levels greater than standards (Table XVI) was multiplied by the extra length of stay (Table XV) if significantly greater than zero, to obtain the total extra days of hospitalization (Table XVII). The total was 10,744 days in 1972. This was then converted to 1972 dollars by multiplying by the audited average cost per day. Such costs were available to the study for 26 of the 28 hospitals. The average daily cost was $68.10 for respiratory diseases and $67.20 for suspect circulatory system diseases. The total estimated cost to residents of Allegheny County in 1972 due to increased length of stay in the hospital was thus found to be $731,697.

Table XVI. Hospitalizations in Allegheny County by pollutant levels.

Diseases	At or Below Standards	Low SO_2 Med Part.	Med & High SO_2 Low Part.	High SO_2 Med & High Part.	Total
	AIR POLLUTION LEVELS				
Respiratory	548 (23)	2216 (42)	359 (19)	6021 (64)	9144 (85)
Suspect Circulatory	951 (80)	4292 (155)	451 (56)	10620 (227)	16314 (292)
Control	184 (27)	1016 (58)	102 (20)	2611 (86)	3913 (109)

( ) standard deviation

Table XVII. Estimated additional costs of hospitalization due to exposure to air pollution.

Diseases	At or Below Standards	Low SO_2 Med Part.	Med & High SO_2 Low Part.	High SO_2 Med & High Part.	Total
	AIR POLLUTION LEVELS				
Respiratory					
Estimated additional days	0	2260 (865)	0	6924 (2228)	9184 (2390)
Estimated additional cost, $	0	153906 (58960)	0	471524 (151700)	625430 (162755)
Suspect Circulatory					
Estimated additional days	0	0	1560 (686)	0	1560 (686)
Estimated additional cost, $	0	0	106267 (46125)	0	106267 (46125)
Total additional days		2260 (865)	1560 (686)	6924 (2228)	10744 (2331)
Total additional costs,$		153906 (58960)	106267 (46125)	471524 (151700)	731697 (169164)

( ) standard deviation

SECTION 8

TOTAL HOSPITALIZATION COSTS OF AIR POLLUTION

This study provides estimates of additional hospitalization costs to subpopulations living in the neighborhoods of Allegheny County, Pennsylvania which show levels of SO_2 and particulates in the ambient air that exceed present air-quality standards. There are two types of costs. One is the cost of increased hospitalization rates for relevant diseases; the other, the additional cost to admitted patients due to a greater length of stay related to their having lived in areas of excessive air pollution. Estimates of both types of costs were developed for the year 1972. They are as follows:

Cost of increased rates of hospitalization	\$9,125,000
Cost of additional length of stay	\$ 731,700
Total Cost	\$9,856,700

SECTION 9

REFERENCES

1. R.G. Ridker, Economic Costs of Air Pollution, Frederic A. Praeger, New York, 1967. pp. 31-56.

2. L.B. Lave and E.P. Seskin, "Air Pollution, Climate and Home Heating," American Journal of Public Health, 62:909 (1972).

3. W.R. Park, The Economic Impact of SO_2 Emissions in Ohio, Midwest Research Institute, Kansas City, Mo.

4. T.E. Waddell, The Economic Damages of Air Pollution, Environmental Protection Agency, Report No. EPA-600/5-74-012, 1974. Chapter 5.

5. J.A. Jaksch and H.H. Stoevener, Outpatient Medical Costs Related to Air Pollution in the Portland, Oregon Area, EPA Office of Research and Development, Report EPA-600/5-74-017, 1974.

6. N.A. Huey, "The Lead Dioxide Estimation of Sulfur Dioxide Pollution," J.A.P.C.A., 18(9): 610 (1968).

7. M. Boulerice and W. Brabant, "New PbO_2 Support for the Measurement of Sulfation," J.A.P.C.A., 19(6): 432 (1969).

8. Allegheny County Bureau of Air Pollution Control, Pittsburgh, Pa.

9. U.S. Bureau of Census, Census of Population and Housing, 1970, Census Tracts, Final Report PHC-(1)-162, Pittsburgh, Pa. SMSA (1972).

10. Hospital Utilization Project, 400 Penn Center Blvd., Pittsburgh, Pa.

11. Eight Revision, International Classification of Diseases, U.S. Dept. HEW, Public Health Service, Publication No. 1693, December 1968.

12. Consultation with Dr. Edward Haag, M.D., Human Effects Research Branch, Environmental Protection AGency.

13. U.S. Bureau of Census, General Social and Economic Characteristics, U.S. Summary, PC(1)-C1, Appendix B, pages APP-29-32 (1970).

14. B. MacMahon, T.F. Pugh, and J. Ipsen, Epidemiologic Methods, Little, Brown and Company, Boston, 1960.

15. G.P. Cressman, "An Operational Objective Analysis System," Mon. Wea. Rev. 87, 367-374 (1959).

16. T.W. Sager, "Relating Spatial Distributions of Pollutants to Health Effects", Proceedings 9th International Biometric Conference, Vol. II, Biometric Society,Box 5962, Raleigh, N.C., p. 35-58, 1976.

17. T.D. Sterling, J.J. Phair, S.V. Pollack, D.A. Schunsky, I. DeGroot, "Urban Morbidity and Air Pollution", Archives of Environmental Health, 13, August 1966, p. 158-170.

18. T.D. Sterling, S.V. Pollack, and J.J. Phair, "Urban Hospital Morbidity and Air Pollution," Archives of Environmental Health, 15, September 1967, p. 362-374.

19. T.D. Sterling, S.V. Pollack, and J. Weinham, "Measuring the Effects of Air Pollution on Urban Morbidity," Archives of Environmental Health, 18, April 1969, p. 485-494.

APPENDIX

Table XVIII. Number of cases treated in 1972 by H.U.P. hospitals in Allegheny County.

Disease	ICDA -8 No.	Number of Cases Primary Diagnosis
Respiratory Diseases		
Acute pharyngitis	462	201
Acute laryngitis and tracheitis	464	185
Acute upper resp. infect.	465	558
Acute bronchitis and brochiolitis	466	1382
Influenza, unqualified	470	250
Influenza with pneumonia	471	87
Influenza w/other resp. manifestations	472	88
Influenza w/digestive manifestations	473	17
Influenza w/nervous manifestations	474	3
Viral pneumonia	480	302
Pnemococcal pneumonia	481	344
Other bacterial pneumonia	482	71
Pneumonia due to other specified organism	483	90
Acute interstitial pneumonia	484	14
Bronchopneumonia, unspecified	485	726
Pneumonia, unspecified	486	2201
Bronchitis, unqualified	490	647
Chronic bronchitis	491	430
Emphysema	492	775
Asthma	493	1395
Chronic pharyngitis & nasopharyngitis	502	12
Chronic sinusitis	403	238
Chronic laryngitis	506	55
Hay fever	507	32
Other diseases of upper resp. tract	508	965
Empyema	510	43
Pleurisy	511	302
Spontaneous pneumothorax	512	175
Pulmonary congestion & hypostasis	514	137
Pneumoconiosis due to silica & silicates	515	53
		11778
less children under 1 year		228
total data for the study		11550
Suspect Circulatory System Diseases		
Acute myocardial infarction	410	4126
Other acute & subacute forms of ischemic heart diseases	411	1094

continued

Table XVIII (continued)

Disease	ICDA -8 No.	Number of Cases Primary Diagnosis
Chronic ischemic heart disease	412	11308
Angina pectoris	413	219
Asymptomatic ischemis heart disease	414	6
Symptomatic heart disease	427	2936
Other myocardial insufficiency	428	73
Ill-defined heart disease	429	117
Transient cerebral ischemia	435	392
Acute but ill-defined cerebrovascular disease	436	881
		21152
less children under 1 yr.		19
total data for the study		21133

Control Circulatory System Diseases

Rheumatic fever w/o heart involvement	390	4
Rheumatic fever w/heart involvement	391	71
Diseases of pericardium	393	1
Diseases of mitral valve	394	248
Diseases of aortic valve	395	101
Diseases of mitral & aortic valve	396	98
Diseases of other endocardial structures	397	12
Other heart diseases, specified as rheumatic	398	224
Malignant hypertension	400	17
Essential benign hypertension	401	331
Hypertensive heart disease	402	259
Hypertensive renal disease	403	36
Hypertensive heart & renal disease	404	16
Acute pericarditis, nonrheumatic	420	14
Acute & subacute endocarditis	421	23
Acute myocarditis	422	5
Chronic disease of pericardium, nonrheu.	423	15
Chronic disease of endocardium	424	89
Cordiomyopathy	425	100
Pulmonary heart disease	426	53
Subarachnoid hemorrhage	430	27
Cerebral hemorrhage	431	106
Occlusion of precerebral arteries	432	100
Cerebral thrombosis	433	623
Cerebral embolism	434	49

continued

Table XVIII (continued)

Disease	ICDA -8 No.	Number of Cases Primary Diagnosis
Acute but ill-defined cerebrovascular dis.	436	140
Generalized ischemic cerbrovascular dis.	437	462
Other & ill-defined cerebrovascular dis.	438	91
	439	1
Arteriosclerosis	440	398
Aortic aneurysm (nonsyphilitic)	441	125
Other aneurysm	442	22
Ohter peripherial vascular dis.	443	46
Arterial embolism & thrombosis	444	170
Gangrene	445	93
Polyarteritis nodosa & allied conditions	446	13
Other dis. of arteries & arterioles	447	19
Diseases of capillaries	448	7
Pulmonary embolism & infarction	450	303
Phlebitis & thrombophlebitis	451	193
Other venous embolism & thrombosis	453	11
Varicose veins of lower extremities	454	104
Hemorrhoids	455	104
Varicose veins of other sites	456	6
Nonifective dis. of lymphatic channels	457	1
Other diseases of circulatory system	458	51
Acute nephritis	580	69
		5051
less children under 1 yr.		2
total data for the study		5049

Table XIX

1972 ANNUAL AVERAGE CONCENTRATIONS OF SO2 AND PARTICULATES

AT CENSUS TRACTS IN ALLEGHENY COUNTY, PA.

CENSUS TRACT	UTM COORDINATES EASTING	NORTHING	SO2* (PPB)	PARTICULATES (UG/M**3)
101	584.575	4476.695	31.1	87.9
102	586.040	4476.578	32.9	87.3
201	584.962	4477.066	31.1	87.9
202	586.050	4478.109	33.2	86.7
301	586.040	4477.547	33.5	86.4
302	585.560	4476.840	31.2	87.8
303	586.102	4477.258	33.8	86.3
304	586.348	4476.891	36.4	86.0
401	587.310	4476.797	39.1	100.7
402	587.930	4477.035	39.1	101.2
403	588.683	4477.691	39.0	100.2
404	589.110	4477.520	39.2	99.5
405	588.490	4476.781	39.2	101.1
406	588.730	4476.547	39.3	100.9
407	588.735	4476.008	39.7	100.2
408	587.790	4476.402	39.3	101.0
501	586.664	4477.488	35.1	86.2
502	587.150	4477.727	38.3	98.5
503	586.820	4476.918	38.9	98.6
504	587.470	4477.258	39.0	100.8
505	587.980	4477.719	38.9	100.6
506	588.172	4478.445	30.9	86.1
507	588.750	4478.516	31.3	85.9
508	587.595	4478.098	38.1	98.0
509	587.040	4478.063	33.8	86.4
601	587.033	4479.031	30.5	86.9
602	587.253	4478.625	30.9	86.6
603	587.660	4479.727	30.1	87.1
604	588.093	4479.504	30.1	86.3
605	587.960	4478.922	30.3	86.5
701	589.490	4478.059	37.5	85.4
702	590.130	4478.453	34.2	85.3
703	590.380	4478.199	35.3	85.0
704	590.815	4478.883	30.9	85.1
705	590.813	4478.566	32.3	85.0

*ppb x 2.667 = $\mu g/M^3$

Table XIX (continued)

1972 ANNUAL AVERAGE CONCENTRATIONS OF SO2 AND PARTICULATES

AT CENSUS TRACTS IN ALLEGHENY COUNTY, PA.

CENSUS TRACT	UTM COORDINATES EASTING	UTM COORDINATES NORTHING	SO2* (PPB)	PARTICULATES (UG/M**3)
706	591.085	4478.422	32.6	84.8
707	591.420	4479.016	30.4	84.7
708	591.600	4478.605	30.4	84.4
801	589.455	4479.633	30.4	86.2
802	588.865	4479.176	30.3	86.2
803	589.190	4478.547	34.7	85.7
804	589.530	4478.863	32.5	85.7
805	589.260	4479.313	30.4	86.1
806	589.873	4479.215	31.7	85.7
807	590.346	4479.281	31.2	85.6
808	590.760	4479.211	30.8	85.3
901	588.070	4480.648	30.1	87.3
902	588.382	4480.137	30.1	87.0
903	588.735	4479.625	30.1	86.5
1001	588.955	4481.523	28.7	87.4
1002	590.050	4481.938	26.4	87.1
1003	590.460	4482.020	26.2	86.9
1004	590.890	4481.699	26.7	86.4
1005	589.870	4481.270	28.9	86.8
1006	589.950	4480.293	30.5	86.3
1007	589.706	4479.934	31.2	86.3
1101	590.910	4480.805	29.4	85.9
1102	591.410	4480.773	29.5	85.4
1103	591.690	4480.047	30.0	84.9
1104	590.597	4480.094	30.6	85.9
1105	591.480	4479.473	30.2	84.9
1106	591.810	4480.980	28.9	85.0
1107	591.155	4480.137	30.3	85.5
1108	591.026	4479.688	30.5	85.4
1201	593.505	4481.043	31.8	83.9
1202	593.967	4480.000	32.0	83.7
1203	593.080	4480.020	31.9	84.1
1204	592.328	4479.719	31.5	84.3
1205	591.992	4479.563	29.9	84.4
1206	592.290	4479.105	29.9	84.1

*ppb x 2.667 = μg/M3

Table XIX (continued)

1972 ANNUAL AVERAGE CONCENTRATIONS OF SO2 AND PARTICULATES

AT CENSUS TRACTS IN ALLEGHENY COUNTY, PA.

CENSUS TRACT	UTM COORDINATES EASTING	NORTHING	SO2* (PPB)	PARTICULATES (UG/M**3)
1207	592.900	4479.070	31.5	83.8
1301	593.620	4479.297	31.9	83.7
1302	593.834	4479.027	31.7	83.9
1303	593.543	4478.590	30.1	84.1
1304	594.292	4478.313	30.3	84.4
1305	594.720	4478.945	31.3	84.1
1306	595.206	4478.438	31.2	84.6
1401	590.254	4477.227	40.2	84.9
1402	591.050	4477.699	36.4	84.8
1403	591.554	4477.168	37.2	85.0
1404	592.042	4478.027	31.9	84.5
1405	592.972	4478.309	29.5	84.4
1406	593.300	4477.594	29.2	84.8
1407	590.400	4476.340	43.2	85.2
1408	591.775	4476.227	22.9	85.4
1409	591.493	4475.320	22.4	85.6
1410	593.560	4476.250	32.8	80.5
1411	593.210	4474.961	31.8	60.3
1501	589.630	4474.266	68.6	89.6
1502	589.445	4473.219	60.0	89.9
1503	590.143	4473.168	61.3	89.7
1504	590.990	4473.297	63.5	89.0
1505	589.877	4473.238	61.3	89.8
1506	589.560	4475.184	77.3	85.2
1507	590.492	4475.031	76.3	85.5
1601	587.232	4475.520	45.5	86.6
1602	587.248	4474.777	49.2	84.9
1603	587.296	4474.195	50.2	84.7
1604	587.940	4474.309	51.1	84.9
1605	586.657	4473.637	47.8	84.6
1701	584.790	4476.000	31.2	87.9
1702	586.355	4475.570	42.2	85.4
1703	586.052	4475.020	42.8	85.2
1801	584.722	4475.293	31.6	87.4
1802	585.665	4474.891	40.5	85.3

*ppb x 2.667 = μg/M^3

Table XIX (continued)

1972 ANNUAL AVERAGE CONCENTRATIONS OF SO2 AND PARTICULATES

AT CENSUS TRACTS IN ALLEGHENY COUNTY, PA.

CENSUS TRACT	UTM COORDINATES EASTING	NORTHING	SO2* (PPB)	PARTICULATES (UG/M**3)
1803	585.250	4474.773	37.4	85.4
1804	584.628	4474.574	32.7	85.5
1805	584.603	4474.148	32.3	85.3
1806	584.800	4473.270	32.2	84.8
1901	582.757	4476.379	29.7	86.7
1902	583.505	4476.273	31.0	87.8
1903	583.600	4475.887	31.0	87.7
1904	583.926	4475.480	31.2	87.5
1905	583.852	4474.641	31.3	85.7
1906	582.921	4473.875	30.4	85.6
1907	582.691	4472.922	31.4	85.3
1908	583.622	4472.527	31.3	84.8
1909	583.020	4471.945	31.7	84.7
1910	583.292	4471.281	31.4	84.3
2001	580.260	4479.313	21.4	86.9
2002	579.250	4478.658	12.3	76.8
2003	579.330	4478.270	14.7	74.9
2004	580.075	4478.813	20.4	86.7
2005	580.470	4478.668	21.2	87.0
2006	580.290	4478.047	24.2	86.8
2007	581.575	4477.426	24.4	87.0
2008	581.286	4476.953	23.8	86.8
2009	581.970	4477.059	26.0	86.9
2010	581.442	4473.145	28.7	85.4
2011	581.727	4476.008	26.1	86.6
2012	582.700	4475.629	29.7	86.4
2101	582.556	4478.797	28.3	87.4
2102	582.650	4479.160	29.7	87.5
2103	582.695	4478.441	28.5	87.3
2104	582.010	4478.939	26.2	87.4
2105	582.797	4477.953	29.0	87.2
2201	583.406	4478.086	30.5	87.2
2202	583.723	4478.598	31.0	87.4
2203	584.260	4478.703	31.9	87.4
2204	584.385	4478.270	32.0	87.4

*ppb x 2.667 = $\mu g/M^3$

1972 ANNUAL AVERAGE CONCENTRATIONS OF SO2 AND PARTICULATES

AT CENSUS TRACTS IN ALLEGHENY COUNTY, PA.

CENSUS TRACT	UTM COORDINATES EASTING	NORTHING	SO2* (PPB)	PARTICULATES (UG/M**3)
2205	584.210	4477.785	31.1	87.9
2301	584.956	4478.754	32.3	87.4
2302	585.000	4478.445	32.5	87.2
2303	585.140	4478.098	31.8	87.5
2401	585.221	4479.391	32.3	87.5
2402	585.833	4479.270	32.5	87.4
2403	586.525	4480.090	32.1	87.5
2501	583.473	4479.391	31.5	87.6
2502	583.225	4478.992	30.8	87.5
2503	583.717	4478.863	31.1	87.4
2504	584.260	4479.375	31.9	87.6
2505	584.415	4478.961	32.0	87.5
2601	582.660	4482.453	34.8	88.9
2602	583.190	4482.652	34.9	89.0
2603	583.050	4480.020	32.4	87.8
2604	583.760	4479.852	32.1	87.7
2605	583.737	4480.465	32.7	87.9
2606	584.380	4480.105	31.9	87.8
2607	583.792	4481.531	33.8	88.4
2608	584.240	4482.152	34.1	88.7
2609	584.400	4480.809	32.6	88.1
2610	585.320	4480.094	32.1	87.7
2611	583.730	4483.250	35.0	88.9
2701	581.135	4481.742	32.5	87.8
2702	581.905	4481.918	33.1	88.3
2703	581.555	4480.980	31.2	88.0
2704	581.670	4479.797	27.3	87.6
2705	582.050	4480.352	30.8	87.9
2706	582.290	4480.848	32.9	88.1
2707	582.245	4479.668	29.3	87.6
2801	578.296	4478.723	8.9	72.2
2802	580.100	4477.566	26.3	86.6
2803	579.970	4476.898	26.6	86.2
2804	579.787	4475.938	26.4	85.5
2805	578.513	4474.172	22.0	82.3

*ppb x 2.667 = μg/M^3

Table XIX (continued)

1972 ANNUAL AVERAGE CONCENTRATIONS OF SO2 AND PARTICULATES

AT CENSUS TRACTS IN ALLEGHENY COUNTY, PA.

CENSUS TRACT	UTM COORDINATES EASTING	NORTHING	SO2* (PPB)	PARTICULATES (UG/M**3)
2806	580.713	4475.945	25.5	86.5
2901	585.600	4472.293	39.2	84.1
2902	586.167	4472.336	43.8	84.0
2903	586.333	4470.973	31.8	84.0
3001	585.420	4473.988	39.9	84.9
3101	590.350	4471.520	50.4	86.3
3102	592.313	4469.168	38.5	87.3
3103	591.578	4471.641	48.0	86.7
3201	584.760	4470.590	31.2	83.2
3202	585.432	4470.992	31.8	83.4
3203	584.570	4471.762	31.2	84.1
3204	584.620	4469.727	31.2	82.9
4011	608.690	4499.520	24.8	74.0
4012	607.570	4496.535	24.0	79.2
4013	607.177	4497.375	24.0	79.1
4021	606.390	4495.980	24.0	79.8
4022	606.645	4495.449	24.1	79.8
4031	605.700	4495.117	24.5	80.1
4032	605.480	4495.477	24.5	80.1
4033	604.758	4495.004	24.6	80.3
4040	603.385	4493.563	36.5	80.7
4050	602.295	4493.672	26.3	81.0
4060	604.783	4500.453	25.7	78.2
4070	596.128	4498.242	23.0	83.8
4080	588.497	4499.230	26.2	45.4
4090	580.990	4498.633	22.1	44.7
4100	577.860	4498.703	25.0	45.1
4110	574.660	4499.887	26.0	46.6
4120	576.395	4493.281	26.0	55.7
4131	581.396	4493.852	20.9	50.3
4132	580.181	4492.598	23.9	56.3
4133	581.223	4490.188	25.3	65.4
4134	584.055	4490.125	25.2	62.2
4135	584.221	4491.945	24.9	54.5
4141	587.846	4493.926	26.7	47.3

*ppb x 2.667 = μg/M^3

Table XIX (continued)

1972 ANNUAL AVERAGE CONCENTRATIONS OF SO2 AND PARTICULATES

AT CENSUS TRACTS IN ALLEGHENY COUNTY, PA.

CENSUS TRACT	UTM COORDINATES EASTING	NORTHING	SO2* (PPB)	PARTICULATES (UG/M**3)
4142	588.420	4490.598	29.0	58.9
4150	593.682	4490.609	29.1	81.0
4160	601.985	4489.676	33.0	64.3
4171	602.950	4488.641	30.1	74.6
4172	603.070	4488.133	29.3	82.0
4180	601.410	4488.672	31.8	79.7
4190	598.761	4489.125	24.1	86.8
4200	596.520	4482.855	22.2	81.2
4211	596.266	4483.695	19.2	81.5
4212	591.793	4484.578	21.8	86.5
4220	594.046	4485.855	15.1	83.5
4230	592.943	4482.863	24.4	84.6
4241	591.170	4483.020	26.0	86.9
4242	590.380	4483.195	26.0	87.7
4243	590.050	4482.977	26.0	87.8
4251	589.130	4483.129	26.3	88.3
4252	588.775	4484.031	26.9	89.2
4261	589.960	4483.758	25.9	88.4
4262	589.143	4487.766	29.0	79.6
4263	586.826	4488.617	28.2	70.5
4264	588.170	4485.820	27.2	86.9
4265	586.515	4485.188	32.3	87.1
4266	587.695	4482.852	28.5	88.5
4271	587.020	4481.977	29.7	88.2
4272	586.945	4481.230	30.5	87.9
4281	586.273	4480.602	31.9	87.3
4282	585.390	4481.969	32.9	88.5
4291	583.600	4484.168	35.0	87.7
4292	584.865	4487.160	32.7	79.6
4293	580.485	4487.809	28.6	76.2
4294	582.302	4487.141	33.1	79.0
4295	583.050	4487.387	31.4	78.1
4296	580.635	4484.035	32.7	86.4
4297	581.765	4483.055	34.4	88.3
4301	582.650	4485.063	34.3	85.3

*ppb x 2.667 = μg/M^3

Table XIX (continued)

1972 ANNUAL AVERAGE CONCENTRATIONS OF SO2 AND PARTICULATES

AT CENSUS TRACTS IN ALLEGHENY COUNTY, PA.

CENSUS TRACT	UTM COORDINATES EASTING	NORTHING	SO2* (PPB)	PARTICULATES (UG/M**3)
4302	581.440	4485.684	33.4	83.4
4311	580.430	4482.492	31.1	94.3
4312	579.810	4482.703	31.1	94.6
4313	579.930	4483.270	31.1	94.3
4314	580.140	4483.703	31.3	93.0
4321	579.106	4483.156	31.0	94.4
4322	578.680	4483.543	31.0	93.2
4323	578.982	4483.852	31.2	92.1
4330	578.550	4484.840	30.4	84.6
4340	577.710	4484.336	29.0	85.2
4350	576.356	4484.961	26.7	85.1
4360	576.620	4485.688	26.5	83.9
4370	576.860	4488.059	25.9	78.6
4380	574.390	4491.273	26.1	70.8
4390	569.260	4493.285	36.3	80.6
4400	571.380	4489.863	34.3	85.6
4410	572.770	4486.652	25.2	84.7
4420	573.650	4485.688	25.0	84.4
4430	571.360	4486.430	25.3	82.4
4440	570.140	4487.000	25.9	81.7
4451	569.816	4487.777	32.9	82.7
4452	569.103	4487.266	31.2	80.7
4453	569.090	4488.102	35.1	81.9
4460	568.497	4489.188	36.2	82.4
4470	566.820	4492.703	36.9	81.2
4470	567.130	4492.203	37.0	81.5
4480	566.972	4490.527	36.9	82.0
4490	565.143	4489.340	35.9	80.9
4501	570.440	4485.727	25.4	80.2
4502	570.960	4485.453	25.3	80.5
4503	571.600	4484.730	25.2	80.5
4504	570.552	4485.398	25.4	80.0
4505	570.120	4485.313	26.9	79.3
4511	566.330	4485.402	31.7	75.3
4512	569.160	4481.824	31.6	74.1

*ppb x 2.667 = $\mu g/M^3$

Table XIX (continued)

1972 ANNUAL AVERAGE CONCENTRATIONS OF SO2 AND PARTICULATES

AT CENSUS TRACTS IN ALLEGHENY COUNTY, PA.

CENSUS TRACT	UTM COORDINATES EASTING	NORTHING	SO2* (PPB)	PARTICULATES (UG/M**3)
4520	561.466	4479.633	28.2	68.0
4530	564.950	4473.270	27.2	61.9
4540	565.580	4468.984	32.9	59.1
4550	569.090	4472.129	33.7	62.0
4560	572.409	4467.277	25.2	61.7
4571	575.213	4467.977	24.1	64.4
4572	575.967	4467.402	23.7	65.0
4580	575.111	4471.090	27.3	68.7
4591	572.897	4481.547	25.5	78.3
4592	573.739	4477.105	13.6	74.4
4600	576.098	4480.801	19.8	82.8
4610	574.276	4484.586	25.0	83.7
4621	578.492	4481.516	29.4	92.4
4622	578.190	4480.813	22.4	85.4
4623	578.030	4480.512	21.3	85.2
4624	578.600	4480.145	21.1	85.6
4625	578.885	4480.488	22.4	85.9
4631	579.407	4480.410	23.0	86.4
4632	580.010	4480.531	25.0	86.8
4633	579.810	4479.680	21.5	86.6
4634	579.360	4479.750	21.1	86.2
4635	579.000	4479.898	21.0	86.0
4636	578.427	4479.813	20.1	85.4
4641	579.440	4477.395	25.5	78.8
4642	578.690	4477.348	16.7	72.2
4651	578.800	4476.719	23.9	75.1
4652	579.390	4476.598	26.6	85.2
4653	579.560	4475.969	26.5	85.2
4654	578.830	4476.105	26.3	84.1
4655	578.410	4475.453	19.2	82.9
4660	577.860	4476.105	17.9	82.4
4670	577.250	4474.758	19.2	80.0
4681	577.336	4473.824	22.8	79.3
4682	576.790	4472.898	27.4	76.5
4683	577.170	4472.759	27.3	77.6

*ppb x 2.667 = $\mu g/M^3$

Table XIX (continued)

1972 ANNUAL AVERAGE CONCENTRATIONS OF SO2 AND PARTICULATES

AT CENSUS TRACTS IN ALLEGHENY COUNTY, PA.

CENSUS TRACT	UTM COORDINATES EASTING	NORTHING	SO2* (PPB)	PARTICULATES (UG/M**3)
4684	577.670	4472.813	27.3	79.0
4685	577.700	4473.484	24.4	79.9
4686	578.475	4472.918	27.3	81.2
4690	580.321	4474.105	24.2	85.3
4701	578.687	4471.953	27.3	80.7
4702	577.143	4472.172	27.3	76.5
4703	578.036	4470.145	27.0	75.8
4704	577.648	4468.734	26.9	71.0
4710	577.115	4471.438	27.1	75.2
4721	581.682	4472.324	29.8	85.1
4722	581.406	4471.723	28.4	84.6
4723	582.050	4471.551	30.4	84.8
4724	581.625	4471.043	28.4	84.4
4731	580.635	4471.367	27.7	83.9
4732	580.756	4470.375	27.7	83.3
4733	582.104	4470.090	29.4	84.1
4734	581.287	4468.809	28.2	83.0
4735	580.318	4468.516	27.7	80.6
4736	579.505	4469.895	27.4	80.0
4741	579.240	4466.504	25.3	73.3
4742	577.383	4464.906	20.8	63.3
4751	581.910	4466.344	32.3	81.7
4752	580.243	4464.020	32.1	72.3
4753	581.970	4463.594	32.2	75.3
4754	583.240	4464.266	32.1	79.4
4761	583.050	4468.844	31.7	83.3
4762	583.622	4468.418	31.6	82.8
4771	584.540	4467.648	31.7	82.6
4772	585.582	4468.605	31.3	83.5
4773	586.695	4467.668	32.7	84.7
4781	586.550	4469.676	31.0	84.4
4782	587.138	4469.574	31.1	84.9
4790	583.632	4470.254	31.3	83.6
4801	585.781	4466.023	32.0	83.4
4802	587.843	4467.430	35.0	85.6

*ppb x 2.667 = μg/M^3

Table XIX (continued)

1972 ANNUAL AVERAGE CONCENTRATIONS OF SO2 AND PARTICULATES

AT CENSUS TRACTS IN ALLEGHENY COUNTY, PA.

CENSUS TRACT	UTM COORDINATES EASTING	NORTHING	SO2* (PPB)	PARTICULATES (UG/M**3)
4803	587.315	4471.813	47.3	84.6
4804	588.287	4470.516	33.0	85.6
4811	586.016	4474.238	43.9	85.0
4812	586.096	4473.695	44.8	84.7
4813	585.710	4473.379	42.3	84.7
4821	591.230	4472.047	49.2	86.5
4822	592.030	4472.887	44.8	86.5
4823	592.400	4471.590	42.9	87.1
4831	592.370	4473.387	39.2	74.2
4832	592.470	4473.008	42.3	86.6
4833	592.700	4473.188	40.9	86.6
4834	592.935	4472.849	39.6	86.8
4835	592.410	4472.652	42.8	86.7
4841	593.990	4472.852	32.7	87.2
4842	593.160	4473.223	36.5	71.8
4843	593.130	4472.500	38.3	87.0
4844	593.373	4471.512	34.9	87.5
4845	592.973	4470.477	36.2	87.7
4850	594.306	4472.359	29.3	87.6
4861	596.800	4470.695	22.6	93.7
4862	597.430	4469.672	38.5	94.3
4863	597.360	4469.180	38.3	97.9
4864	597.990	4469.379	38.7	91.7
4865	597.950	4468.676	37.6	99.3
4866	597.360	4468.563	36.4	107.1
4870	594.064	4467.047	40.3	89.3
4881	594.438	4471.363	27.7	88.1
4882	595.121	4471.563	23.2	88.[illegible]
4883	593.950	4469.387	31.7	88.6
4884	596.390	4468.730	33.5	95.7
4885	590.017	4467.848	40.5	73.7
4886	592.138	4466.145	40.0	77.9
4890	588.177	4465.145	36.3	85.8
4900	584.837	4462.109	32.2	81.0
4911	590.173	4460.719	30.5	87.8

*ppb x 2.667 = $\mu g/M^3$

1972 ANNUAL AVERAGE CONCENTRATIONS OF SO2 AND PARTICULATES

AT CENSUS TRACTS IN ALLEGHENY COUNTY, PA.

CENSUS TRACT	UTM COORDINATES EASTING	NORTHING	SO2* (PPB)	PARTICULATES (UG/M**3)
4912	592.222	4462.063	36.8	89.5
4921	593.830	4462.602	31.6	83.1
4922	594.330	4462.043	38.7	93.4
4923	595.457	4461.055	43.9	96.5
4924	594.795	4460.820	40.9	96.4
4925	593.875	4460.320	37.0	90.5
4926	594.410	4459.945	37.0	90.8
4927	595.015	4460.336	40.1	94.4
4930	596.060	4458.438	35.8	91.6
4940	596.796	4457.770	36.6	92.0
4950	596.483	4454.285	35.6	88.8
4961	598.506	4457.906	36.4	93.3
4962	601.189	4461.949	25.1	95.5
4970	598.240	4461.563	40.9	93.4
4980	597.175	4464.352	56.1	88.5
4991	594.393	4463.711	27.8	77.7
4992	594.213	4464.367	28.5	78.3
4993	594.502	4464.930	36.9	85.7
5001	596.018	4465.340	55.2	88.5
5002	595.540	4466.152	41.5	90.5
5010	599.125	4463.355	24.7	94.2
5020	601.640	4461.250	25.7	95.9
5030	601.217	4466.469	32.0	95.1
5041	599.912	4470.941	33.9	91.8
5042	601.167	4468.641	37.0	94.1
5043	603.243	4471.777	31.3	95.7
5050	604.250	4470.605	35.4	97.8
5060	602.930	4471.930	29.8	95.1
5070	601.150	4470.926	37.0	93.0
5081	600.863	4472.367	35.2	91.9
5082	601.055	4471.723	36.4	92.5
5091	600.248	4473.645	30.1	90.5
5092	600.100	4472.902	32.5	90.8
5093	599.400	4473.477	30.4	89.9
5101	598.810	4472.535	30.6	90.1

*ppb x 2.667 = μg/M^3

Table XIX (continued)

1972 ANNUAL AVERAGE CONCENTRATIONS OF SO2 AND PARTICULATES

AT CENSUS TRACTS IN ALLEGHENY COUNTY, PA.

CENSUS TRACT	UTM COORDINATES EASTING	NORTHING	SO2* (PPB)	PARTICULATES (UG/M**3)
5102	598.285	4472.223	30.2	89.9
5110	598.490	4473.688	28.7	89.2
5121	598.010	4473.199	28.8	89.2
5122	598.260	4472.703	29.7	89.7
5123	597.010	4472.445	23.4	89.0
5124	596.550	4472.938	28.6	88.5
5125	596.790	4473.250	28.5	88.4
5126	596.433	4473.711	28.1	88.0
5127	596.070	4473.738	27.9	87.8
5131	595.950	4473.438	27.9	87.9
5132	595.760	4473.227	27.9	87.9
5133	596.400	4472.637	23.5	88.6
5134	596.385	4472.203	22.6	88.8
5135	595.790	4472.828	28.1	88.1
5141	595.423	4473.727	27.6	87.5
5142	595.130	4473.945	27.7	87.2
5143	594.630	4474.195	29.0	86.8
5151	594.876	4474.637	28.3	86.7
5152	594.917	4475.352	28.7	86.4
5153	594.125	4474.766	34.7	61.9
5154	593.773	4475.160	34.9	61.1
5155	593.730	4475.945	34.4	65.4
5161	594.137	4476.129	29.9	85.3
5162	594.872	4476.023	29.4	86.0
5170	595.990	4474.883	28.3	87.0
5180	597.440	4474.988	27.5	87.7
5190	597.610	4477.348	34.0	86.0
5200	599.682	4475.285	26.7	89.0
5211	603.872	4478.027	25.2	83.6
5212	601.902	4474.895	25.7	91.4
5213	603.919	4474.598	25.6	93.8
5214	606.666	4474.730	26.4	96.0
5215	606.917	4477.602	26.2	83.1
5221	603.870	4473.477	26.1	95.1
5222	603.630	4472.949	26.4	95.4

*ppb x 2.667 = μg/M[3]

Table XIX (continued)

1972 ANNUAL AVERAGE CONCENTRATIONS OF SO2 AND PARTICULATES

AT CENSUS TRACTS IN ALLEGHENY COUNTY, PA.

CENSUS TRACT	UTM COORDINATES EASTING	NORTHING	SO2* (PPB)	PARTICULATES (UG/M**3)
5231	595.159	4480.141	32.1	82.8
5232	596.977	4479.500	32.2	82.8
5233	598.917	4480.512	33.3	80.3
5234	598.757	4478.906	33.7	83.2
5235	601.515	4480.379	26.9	79.7
5236	600.510	4478.676	26.2	82.7
5237	601.191	4483.828	29.2	81.0
5238	598.575	4482.316	32.8	79.8
5241	598.065	4484.047	18.7	80.8
5242	598.305	4484.563	19.3	80.9
5251	598.850	4485.477	25.4	81.4
5252	598.025	4485.473	18.1	81.3
5253	598.586	4486.418	23.9	81.9
5261	606.390	4486.004	40.2	80.4
5262	605.326	4481.184	31.5	80.8
5263	609.380	4480.770	32.8	79.9
5501	595.480	4466.629	40.8	90.3
5502	595.380	4466.977	39.9	90.2
5503	596.545	4467.094	38.3	90.9
5504	596.315	4466.547	40.0	90.9
5505	596.615	4466.512	39.8	91.2
5506	596.620	4466.633	39.5	91.1
5507	597.502	4466.926	35.2	127.2
5508	598.640	4466.855	35.1	127.7
5509	598.770	4467.809	35.0	127.0
5510	599.320	4467.531	35.1	124.7
5511	599.155	4466.020	35.7	105.0
5512	598.930	4466.859	35.1	127.0
5513	598.225	4466.145	35.4	125.5
5514	597.790	4466.145	35.5	124.7
5515	597.340	4465.984	37.1	112.6
5516	598.143	4465.172	39.0	92.7
5517	598.930	4465.473	37.2	93.3
5518	599.260	4464.445	25.2	93.9
5601	596.437	4477.934	32.8	85.2

*ppb x 2.667 = μg/M^3

Table XIX (continued)

1972 ANNUAL AVERAGE CONCENTRATIONS OF SO2 AND PARTICULATES

AT CENSUS TRACTS IN ALLEGHENY COUNTY, PA.

CENSUS TRACT	UTM COORDINATES EASTING	NORTHING	SO2* (PPB)	PARTICULATES (UG/M**3)
5602	595.396	4477.793	30.8	85.0
5603	594.695	4477.730	30.1	84.9
5604	594.092	4477.383	29.5	85.0
5605	594.026	4476.750	29.2	85.4
5606	594.740	4477.098	29.8	85.3
5607	594.950	4477.379	30.1	85.2
5608	595.520	4477.348	30.6	85.3
5609	595.740	4476.828	30.5	85.8
5610	595.080	4476.793	29.9	85.6

*ppb x 2.667 = $\mu g/M^3$

TECHNICAL REPORT DATA

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4. TITLE AND SUBTITLE HEALTH COSTS OF AIR POLLUTION DAMAGES A Study of Hospitalization Costs		5. REPORT DATE February 1977 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Ben H. Carpenter, D.A. LeSourd, James R. Chromy, and Walter D. Bach		8. PERFORMING ORGANIZATION REPORT NO. RTI 41U-768
9. PERFORMING ORGANIZATION NAME AND ADDRESS Research Triangle Institute P.O. Box 12194 Research Triangle Park, N.C. 27711		10. PROGRAM ELEMENT NO. 1AA601 11. CONTRACT/GRANT NO. 68-01-0427
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15. SUPPLEMENTARY NOTES		

16. ABSTRACT

An investigation of the hospitalization costs of exposure to air pollution in Allegheny County, Pennsylvania was conducted to determine whether persons exposed to air pollution incurred higher incidences of hospitalization or additional costs for treatment. A hospitalization data-base comprising 37,818 total admissions for respiratory, suspect circulatory diseases, and control diseases was tested in a cross-section type analysis for relationships between rates of hospitalization, length of stay, and levels of air quality in the neighborhoods of patients' residence. Air quality was identified using data from 49 monitoring stations. Corrections were made in the analysis for race, age, sex.

Respiratory and suspect circulatory system disease showed statistically significant increased hospitalization rates and lengths of stay for those exposed to higher levels of SO_2 and particulates compared to those from neighborhoods meeting air quality standards. At average costs per day for hospitalization in this area in 1972, the total increased costs per day for hospitalization for the 1.6 million persons in the County was estimated at \$9.8 million dollars (\$9.1 million for increased hospitalization rates and \$0.7 million for increased length of stay).

17. KEY WORDS AND DOCUMENT ANALYSIS

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Economic analysis Benefit Cost Analysis Air Pollution Health	Economic Effects, Health	05 C 06 S

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