EPA-600/5-77-010
July 1977

AIR POLLUTION AND HEALTH IN WASHINGTON, D.C.
Some Acute Health Effects of Air Pollution in the Washington Metropolitan Area

by

Eugene P. Seskin
National Bureau of Economic Research, Inc.
Washington, D.C. 20006

Contract No. 68-01-3144

Project Officer

John Jaksch
Criteria and Assessment Branch
Corvallis Environmental Research Laboratory
Corvallis, Oregon 97330

CORVALLIS ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CORVALLIS, OREGON 97330

DISCLAIMER

This report has been reviewed by the Corvallis Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that its contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

The methods, results, and conclusions found in this study do not necessarily reflect the opinions of the sponsoring agencies or the organizations who provide data. Specifically, with regard to the data supplied by the Group Health Association (GHA), it is recognized that: (1) The socio-demographic characteristics of the GHA membership may not be representative of the socio-demographic characteristics of the entire metropolitan Washington population; (2) utilization of medical services by GHA members may also be different than utilization of medical services by the general Washington population; and (3) only within-plan utilization is accounted for, i.e., some GHA members may, at times, seek outside medical care which is not recorded in the data.

FOREWORD

Effective regulatory and enforcement actions by the Environmental Protection Agency would be virtually impossible without sound scientific data on pollutants and their impact on environmental stability and human health. Responsibility for building this data base has been assigned to EPA's Office of Research and Development and its 15 major field installations, one of which is the Corvallis Environmental Research Laboratory (CERL) in Oregon.

The primary mission of the Corvallis Laboratory is research on the effects of environmental pollutants on terrestrial, freshwater, and marine ecosystems; the behavior, effects and control of pollutants in lake systems; and the development of predictive models on the movement of pollutants in the biosphere.

This report was initiated by the Washington Environmental Research Center, Office of Research and Development, Washington, D.C. and completed at the Corvallis Environmental Research Laboratory.

A.F. Bartsch
Director, CERL

ABSTRACT

This study has attempted to assess some of the acute health effects of air pollution. Specifically, the investigation has tested the hypothesis that air pollution can aggravate the health status of a population and can result in increased utilization of certain types of medical care services.

The study period was 1973-1974 and centered in the Washington, D.C. Metropolitan Area. Statistical models were formulated, explaining health-care utilization of a group practice medical care plan. Primary interest was focused on the effects of mobile-source air pollutants including carbon monoxide, nitrogen dioxide, non-methane hydrocarbons, and photochemical oxidants. Meteorological conditions, as well as other variables thought to influence the consumption of medical services, were included in the models as explanatory variables.

The statistical results indicated that air pollution levels had a very limited effect on the health-care utilization of the group practice.

This report was prepared under contract number 68-01-3144 to U.S. Environmental Protection Agency and the U.S. Department of Transportation. This report covers the period from January 1, 1973, to December 31, 1974; and work was completed as of March 1976.

CONTENTS

ACKNOWLEDGEMENTS

I wish to acknowledge several people at the National Bureau who significantly contributed to this research undertaking. Special appreciation must go to Henry Peskin whose valuable suggestions provided guidance throughout the research effort and whose authorship of Section VII provided a theoretical background for the statistical analyses. I also wish to thank James Embersit for the innumerable hours he spent at the computer terminal as well as his other wide-ranging efforts in assisting the research. Research assistance was also provided by Emily Eisner during the initial phase of the study and additional computer programming skills were provided by Robert Chen. Great patience was displayed by Lorraine Patterson in her typing and retyping of the draft manuscript. John Mankin then did an excellent job in preparing the final manuscript.

Several people associated with the Group Health Association must also be acknowledged for their valuable contributions to the study. In particular, Bruce Steinhardt provided many hours of guidance during our efforts to analyze the Group Health data. Our initial discussions with Goldie Krantz led to the resulting cooperation between GHA and NBER. Peter Birk then continued this cooperation between our two organizations.

Finally, those associated with this project, at both the Environmental Protection Agency and the Department of Transportation, should be thanked for their valuable comments and assistance throughout the endeavor,

SECTION I

INTRODUCTION

BACKGROUND

A number of investigators have examined the health effects of air pollution episodes in cities such as New York[1/] and Boston.[2/] They have looked at the effects of air pollution on indices of health (including mortality rates, pediatric and adult clinic visits, emergency hospital admissions, and so on). Although estimates of excess mortality, clinic visits, and hospital admissions (over expected values of these indices) were computed, the studies did not assess the economic impact of such air pollution episodes. Moreover, the air pollutants considered in these studies were primarily those from stationary sources (e.g., sulfur dioxide and smokeshade).[3/]

The absence of economic imputation in these studies represents a serious deficiency. The ultimate objective of policies designed to deal with air pollution problems is to attain ambient levels of pollution at which the corresponding marginal social costs and benefits are balanced. Consequently, there is a critical need for the translation of physical effects (e.g., increased air pollution-associated illness) into economic terms that can be compared to the societal costs associated with more stringent air quality criteria and abatement activities.

RESEARCH OBJECTIVES

This study will attempt to assess the health effects and related impacts Of air pollution in the Washington Metropolitan Area. A major output of this research will be the quantification of the economic costs of air pollution due to its debilitating effects (if they exist) on the health status of the exposed population. Special attention will be focused on mobile-source air pollution (e.g., carbon monoxide, nitrogen oxides, and photochemical oxidants).

Specifically, the objectives to be accomplished by this research are as follows:

(1) A test of the null hypothesis that there is no significant association between air pollution in Metropolitan Washington and health effects.

(2) If the null hypothesis is rejected, an investigation of the relationship between specific pollutants and specific health effects.

(3) An assessment of the economic impacts of the air pollution-health association both in terms of direct costs (e.g., medical treatment expenditures) and indirect costs (e.g., work-days-lost).

1/ See, for example, Greenburg et. al.[19]

2/ See Heimann [23].

3/ For a Survey of studies that have dealt with the health effects of air pollution, see Lave and Seskin [28].

AN OVERVIEW OF THE RESEARCH

The study area of this research is the Washington, D.C. Metropolitan Area during the period 1973 and 1974. The nation's capital is of particular interest because mobile-source air pollution is a dominant factor in Washington, whereas stationary sources (e.g., power plants) are the chief contributors of air pollution in other major eastern seaboard cities. In view of the controversies surrounding environmental legislation of regulations on mobile-source emissions, the results for the Washington area may be extremely significant for policy purposes.

The data for this study came from several sources. The Group Health Association, a prepaid group practice medical care plan with approximately 100,000 members, provided the health data. The air pollution data used in the research came from the Government of the District of Columbia, Department of Environmental Services. Finally, the meteorological data were provided by the National Weather Service.

Section II presents a summary of our findings. In Section III we shall explore the methods that have been previously used to investigate the association between air pollution and human health, and shall provide some illustrations from the literature. Section IV includes a description of the study area (Metropolitan Washington, D.C.) as well as a description of the primary source of health data (The Group Health Association). In Section V, the medical data and our method of compiling them are described in detail. Section VI discusses the compilation of the air pollution and meteorological data. In Section VII, the statistical methods used in the analysis are examined. Section VIII presents the empirical results. Finally, Section IX presents some policy implications, economic consequences, and future research needs.

SECTION II

SUMMARY OF FINDINGS

We have analyzed health care utilization, air pollution, and weather data in an effort to test the null hypothesis that there is no significant association between air pollution levels in Metropolitan Washington, D.C. and health effects.

According to an analysis of these data for 1973, there did not appear to be a significant relationship between photochemical oxidant readings (as measured by the maximum l-hour average) on any given day and the number of unscheduled visits on that day to three of the four departments at the main clinic (Pennsylvania Avenue) of a local group practice medical plan. These included the urgent visit clinic and the internal medicine and pediatric departments. The only exception was for unscheduled visits to the ophthalmology department. Here a suggestive relationship between oxidant levels and unscheduled visits was noted for further investigation.

We then examined the 1974 data in an effort to replicate the 1973 findings. In general, the results were comparable to those for 1973. Again, a positive and statistically significant relationship was exhibited between the oxidant readings and unscheduled visits to the ophthalmology department. In addition, a suggestive relationship between oxidant levels and utilization of the urgent visit clinic was seen. This relationship was further supported by the results of an analysis involving oxidant pollution data monitored at another station. Finally, for 1974 oxidant data from one of the monitoring stations, a positive and statistically significant association was seen with unscheduled visits to the pediatric department. This relationship, however, did not hold when oxidant data from the other monitoring station were substituted.

Looking at both the 1973 and 1974 results together, the magnitude of the association between unscheduled visits to the ophthalmology department and photochemical oxidant levels indicated that a 10 percent decrease in oxidant levels was related to between a 1.1 and 4.3 percent decrease in unscheduled utilization of the ophthalmology department. The statistically significant 1974 result pertaining to the urgent visit clinic indicated that a 10 percent decrease in oxidant levels was related to a 0.5 percent decrease in urgent visits. The single positive and statistically significant 1974 result pertaining to pediatric visits indicated that a 10 percent decrease in oxidant levels was related to a 0.9 percent decrease in unscheduled pediatric visits. These somewhat mixed findings warranted further investigation.

Thus, we performed statistical analyses in an effort to uncover lag or episodic effects of the air pollution levels on the health care utilization. No such effects were found. In this connection it should be noted that the oxidant readings in these data were sufficiently high to trigger six air pollution alerts in 1973 and one alert in 1974 by the Metropolitan Washington Council of Governments (COG) and were among the highest ever recorded in the Metropolitan Washington Area.

Next, we investigated the effects of three other air pollutants related primarily to mobile sources (non-methane hydrocarbons, nitrogen dioxide, and carbon monoxide) and one air pollutant primarily related to stationary sources (sulfur dioxide).

We did not uncover any consistently signficant relationship between unscheduled utilization in any department and the levels of non-methane hydrocarbons or the levels of nitrogen dioxide during 1973. Unfortunately, 1974 data on these two air pollutants were not satisfactory to permit a replication of these analyses.

Our empirical results involving carbon monoxide did suggest an association between unscheduled utilization of the ophthalmology department and, to a lesser extent, unscheduled utilization of the pediatric department during 1973. However, each result held for only one of the two monitoring stations providing air pollution data. Furthermore, the significant and positive associations between carbon monoxide levels and department utilization were not found using 1974 data.

The last air pollutant we examined was sulfur dioxide. Two monitoring stations provided sufficient sulfur dioxide data in 1973 to permit separate analyses. The findings from these analyses indicated two positive and statistically significant associations: one between sulfur dioxide levels and unscheduled visits to the internal medicine department, and the other between sulfur dioxide levels and unscheduled visits to the ophthalmology department. Neither association was significant when air pollution data from the other monitoring station were substituted. Furthermore, the associations failed to hold when 1974 data were analyzed.

Table 2.1 presents a summary of the positive and significant associations between unscheduled department visits and levels of individual air pollutants. Specifically, it displays the estimated percentage reductions in unscheduled visits associated with 10 percent reductions in the relevant air pollution measure.

Since there have been a number of studies suggesting the importance of interactions between air pollutants and their combined effects on health, we examined the possibility of synergistic effects. In particular, we concentrated on synergistic effects of oxidants in combination with nitrogen dioxide, sulfur dioxide, and carbon monoxide. No evidence of interactive effects was found.

We then examined the effects of two additional weather variables, a measure of precipitation and a measure of temperature change. Predominant interest lay in the effects that including these variables had on the magnitude and significance of the coefficients associated with the air pollution variables. Secondary interest was focused on the influence of the specific weather variables on department utilization, In most cases the inclusion and substitution of particular weather variables did not greatly affect the magnitude and significance of the coefficients of the air pollution variables.

TABLE 2.1. POSITIVE AND SIGNIFICANT ASSOCIATIONS BETWEEN UNSCHEDULED VISITS AND AIR POLLUTION LEVELS a/

Air Pollutant[b/] Monitoring Station (year.)	Unscheduled Visits to Departments			
	Pediatrics	Internal Medicine	Ophthalmology	Urgent Visit Clinic
Photochemical Oxidants				
CAMP 1973			1.1%"	
CAMP 1974	0.9%*		4.3%****	
Clv. Park 1974				0.5%*
Carbon Monoxide				
CAMP 1973			1.5%****	
D.C. Hosp. 1973	0.6%*			
Sulfur Dioxide				
D.C. Hosp. 1973		1.5%*		
ACS 1973			0.4%*	

[a/] Numbers represent percentage reductions in unscheduled visits associated with a 10 percent reduction in the relevant air pollution measure.

[b/] All air pollution measures are based on maximum one-hour averages.

*Significant at the 10 percent level.
**Significant at the 5 percent level.
***Significant at the 2 percent level.
****Significant at the 1 percent level.

The only notable exception occurred when the variable representing temperature change was substituted for the average temperature variable. In this case, the air pollution coefficient displayed mixed effects. This was primarily attributed to the relatively high correlation of average temperature with certain air pollution variables.

In general, the weather variables did not exhibit important relationships with unscheduled department utilization. However, in several cases, temperature change (as measured by the difference between the maximum daily temperature and the minimum daily temperature) was positively and significantly related to the utilization data. This was especially true for the pediatric visits.

The next analysis we undertook was a comparison of the results just discussed with those based on an analysis of Metro Transit Employees (Metro). Because of small sample sizes, we examined total department visits rather than only unscheduled department visits. In general, the results based on the Metro sample did not display consistently significant associations between visits to the clinic departments and air pollution levels. The only exception was the association exhibited between visits by the Metro employees to the ophthalmology department and photochemical oxidant levels during 1974. We concluded that the findings for the Metro sample were not at great variance with the previous results based on unscheduled visitation by the total sample. However, given the limited data and the difficulties associated with analyzing small samples, we cautioned against overinterpretation of this conclusion.

Finally, we examined the findings pertaining to the data from a smaller GHA facility located in Takoma Park. In general, the associations involving the Takoma Park data were weaker than the associations based on the data from the main facility. Several possible explanations for this were presented. Since Takoma Park had no ophthalmology department and since the sample sizes at Takoma Park were considerably smaller than those pertaining to the Pennsylvania Avenue clinic, we do not feel that these results negated our previous findings.

SECTION III

INVESTIGATING THE AIR POLLUTION-HEALTH RELATIONSHIP

INTRODUCTION

For more than half a century, scientists have been accumulating evidence that associates ill health with air pollution. One hypothesized relationship between air pollution and human health involves long-term exposure to low levels of air pollution. It is hypothesized that this chronic long-term exposure exacerbates existing disease or increases the susceptibility to disease. A second hypothesized relationship is more subtle and involves an acute response in which high concentrations of air pollutants have an immediate effect on health.

In a classical framework, testing these hypothesized relationships would be based on the assumption that the functional specifications were given and that the relevant variables were known. Statistical theory would then offer procedures for testing competing hypotheses. However, in examining the associations between air pollution and health, the functional forms of the relations are not known and there are only conjectures concerning the factors that should be included. This is especially true with regard to the health effects of mobile-source pollution where even the qualitative relationship is quite uncertain. Finally, it should be stressed that for policy purposes it is not sufficient to know only qualitatively whether air pollution is associated with ill health; it is essential to quantify the air pollution-health relationship.

A basic difficulty in investigating the air pollution-health relationship is isolating the effects of air pollution from the effects of numerous other factors that influence health status. These include physical, socioeconomic, and personal characteristics such as age, sex, race, income, smoking habits, exercise habits, genetic history, nutritional history, and medical care as well as other environmental factors such as climate. In order to estimate the effect of any one of these factors on health the others must be held constant experimentally or controlled statistically. 1/

An ideal investigation of the association between air pollution and health would control for all of the above factors. Unfortunately, many of these factors are difficult to measure conceptually (e.g., genetic history), while others are poorly measured in existing statistics (e.g., medical care). Since we do not even know all the relevant factors, the practical difficulty is to control for as many factors as possible, either experimentally or statistically, explicitly or implicitly.

An additional problem surrounds the fact that there is a lack of data on air pollution doses and dose rates. Available air pollution data are usually in the form of air pollution level readings at a specific point in a geographi-

1/ Only in the remote case in which a particular factor was uncorrelated with all the others could one uncover the “true” effect of that factor using a univariate approach.

cal area for a given time period. However, local topography, location and height of buildings, weather conditions, and location of emission sources, often lead to considerable differences in the actual ambient air quality across an area. Consequently, the air pollution measures are, at best, approximations to the air pollution doses individuals receive. Thus, the data on the variable of primary interest are crude and any estimated air pollution-health relationship is subject to additional uncertainty.

LABORATORY AND TOXICOLOGICAL EXPERIMENTATION

Laboratory experimentation on humans can sometimes provide useful information. For example, short-term fumigation experiments may be helpful in uncovering the physiological mechanisms by which air pollutants affect humans. However, in many instances it is not practical to perform such experiments. If extremely high levels of air pollution are hypothesized to harm people, it would not be socially acceptable to expose subjects to these levels in order to measure the physical effects. More importantly, since air pollution concentrations of the magnitude required to demonstrate these effects in the laboratory are seldom experienced in urban air, it is questionable whether the results of such experiments are valid in assessing the effects of air pollution exposure on the general population. Finally, if the hypothesized effect is small, it may not be feasible to test for it in the laboratory (e.g., a slight increase in the mortality rate of subjects with life expectancies of 70 years could require hundreds of thousands of subject-years to ascertain).

Since experimentation on humans may not be practical, laboratory experiments with animals may be useful in obtaining important knowledge of pollution effects. However, differences in physiology, life span, and dose rate make it difficult to extrapolate results from animal studies to effects on humans. Furthermore, policymakers are more interested in determining the extent to which a pollutant increases the frequency of a disease in the general population than whether high concentrations of the pollutant induce the disease in white mice under controlled laboratory conditions. Thus, epidemiological studies which examine humans in their natural setting are more relevant than are laboratory experiments. 2/

EPIDEMIOLOGICAL APPROACHES

In reviewing these epidemiological studies, one is usually faced with two types of investigations. The first type represents classical epidemiology and attempts to compare groups that differ only in their exposure to air pollution. The ultimate example would be a study that looked at the incidence of disease among sets of identical twins, one of each set living in an area of low pollution and the other living in an area of high pollution. 3/

The second type of investigation examines the incidence of disease in large, geographically-defined groups. 4/ Such large groups permit controls

---

2/ Studies of highly susceptible populations may also be useful in identifying the potential increment in pollution-related illness and death.

3/ See, for example, Cederlof [9].

4/ See Hammond and Horn I- 211.

for other important factors, but preclude the detailed comparisons that are possible with more classical methods. Both types of investigations aid in exploring the air pollution-health association.

The extensive literature that has evolved from investigations of the air pollution-health relationship covers the gamut of epidemiological research. One of the earliest and most common methods of analysis involved cross tabulations or simple correlations. For example, the prevalance of a disease (or even death) in specified population groups was correlated with some index of air pollution. 5/ The difficulty in using the results of such studies is that a host of other factors were allowed to vary across populations and it is impossible to identify the "pure" pollution effects.

Recognizing the need to control for other important factors affecting health, some investigations cross tabulate along several dimensions (e.g., age, race, income), while others compute partial correlations. 6/ However, even these more sophisticated statistical techniques will not produce reliable estimates of the air pollution-health relationship if the groups being compared are not well matched. For instance, if a study compares urban with rural groups, the multitude of factors that differ between urban and rural environments (in addition to pollution levels) cannot be controlled completely by statistical methods. One is inevitably left with a number of important uncontrolled factors known to vary systematically with urbanization.

An improvement in methodology is represented by community studies. 7/ Utilizing air pollution measurements across areas of a city, such investigations contrast measures of health status within those areas, hypothesizing that many relevant factors are constant or vary randomly within communities. However, such studies have problems associated with small sample sizes and the consequent large sampling variation. 8/ In addition, systematic relationships between such factors as low income and exposure to high air pollution levels often confound the observed associations.

Thus, two major shortcomings with attempts to investigate the association between air pollution and health have been (1) failure to control for the numerous factors that influence health status and (2) sample sizes too small to lend confidence to the results.

MULTIVARIATE ANALYSES 9/

To a large extent multivariate analyses of large populations can overcome many of the difficulties in estimating the air pollution-health relationship.

5/ See Stocks [37).
6/ See, for example, Daly [13].
7/ See, for example, the Nashville studies undertaken by Zeidberg and his co-workers [46-50] or the Buffalo studies done by Winkelstein and his colleagues [40-45] listed in the bibliography.
8/ See the discussion on this topic in Lave and Seskin [28].
9/ Specific multivariate techniques are discussed in Section VII.

Since these techniques can be used to control statistically for a number of confounding factors simultaneously, they can reduce the likelihood that such factors will obscure or bias the dose-effect estimates. In addition, the use of these methods lessens the chances that an estimate will reflect a spurious association.

For example, assume that a specific air pollutant that was not damaging to plants could only be formed in the presence of certain meteorological conditions. Further, assume that these weather conditions were damaging to plants independent of pollution levels. Then if an analysis was undertaken relating only levels of this air pollutant to plant damage across areas, it would probably uncover a significant positive correlation. That is, the analyst might erroneously conclude that this air pollutant caused plant damage. The difficulty arises because the "true" cause of both the air pollution and its hypothesized effect (plant damage), i.e., the meteorological conditions, were not controlled in the analysis. Thus, in general, to avoid or minimize this type of spurious association, confounding factors must be explicitly taken into account. 10/

Two basic types of multivariate analyses can be used to explore the air pollution-health association. The first, cross-section analysis, investigates a measure of health status (e.g., mortality rates) across areas having different air pollution levels, while controlling for other area differences (e.g., socioeconomic characteristics). 11/ The second type, time-series analysis, examines a health measure within a single location experiencing changing air quality over a period of time. 12/ Thus, one advantage of the time-series approach is that many of the factors (excluding air pollution) which lead the mortality rate to be higher in one area than in another area, should be relatively constant over time within an area.

In comparing the two approaches, it should be noted that any estimated relationship between air pollution and health is likely to be different in a time-series study than in a cross-section study. For example, analyzing daily deaths in conjunction with daily air pollution levels should primarily uncover very short-term effects of air pollution (if they exist) as opposed to long-term effects one would expect to observe in a comparison of annual death rates across cities.

RESULTS OF A SIMILAR STUDY

Jaksch and Stoevener [25] attempted to quantify in monetary terms the effect of air pollution on the utilization of outpatient medical services in the Portland, Oregon area. The study focused on the impact of suspended particulate pollution on the consumption of outpatient medical services per disease episode. To isolate this effect, meteorological conditions in the area as well as socioeconomic-demographic characteristics of the patients were controlled. Health data were taken from a five percent ongoing random sample of the membership of the Kaiser Foundation Health Plan, a prepaid group medical plan.

10/ For an excellent discussion of spurious correlation, see Simon [35].
11/ See, for example, Lave and Seskin [29].
12/ See Glasser and Greenburg [16].

The method of analysis involved the application of multivariate regression analysis to the data using models with both unlagged and lagged air pollution and weather variables. The statistical results indicated significant effects of air pollution (as measured by suspended particulates) on medical services used to treat respiratory diseases, but not on medical services used to treat circulatory-respiratory diseases.

In addition, each medical procedure, treatment, and clinic visit was assigned a dollar value according to the California Relative Value System. This scaling system was used by Kaiser to quantify the medical services performed,. As an economic cost, the researchers concluded that air pollution had a minimal effect on increasing the quantity of outpatient medical services consumed per contact with the medical system.

SECTION IV

A DESCRIPTION OF THE STUDY AREA AND THE GROUP HEALTH ASSOCIATION

THE STUDY AREA 1/

The area of study can be roughly described as the section of the Washington Standard Metropolitan Statistical Area encompassed by U.S. Interstate 495 (the Beltway). Shown in Figure 4A, this 164,753 square acre area includes the District of Columbia, Arlington County, parts of Fairfax County, and the city of Alexandria, Virginia as well as portions of Montgomery and Prince Georges Counties in Maryland. With a population of 1,707,668, the study area accounts for approximately 62 percent of the entire Washington SMSA population of 2.9 million.

Metropolitan Washington is situated on the western edge of the Atlantic coastal plain, 35 miles west of the Chesapeake Bay. The Blue Ridge Mountains rise to 3,000 feet about 50 miles to the west with an orographic effect of warming and drying westerly winds. The coastal plain to the east of the study area is essentially flat. Although no topographical barriers exist between the study area, the Chesapeake Bay, and the Atlantic Ocean, the Washington Metropolitan Area is too far inland to be affected by summer sea breezes.

The District of Columbia, the largest city in the study area, (population 767,000) is located at the head of navigation of the Potomac River near its confluence with the Anacostia River. The terrain of the city itself ranges from sea level to slightly over 400 feet. Bluffs along the Potomac River and Rock Creek, and to the southeast and east of the Anacos tia River suggest some channeling of the airflow, but, generally, the terrain does not impede the free movement of air about the city.

The Washington area climate has the seasonal and daily variations characteristic of the eastern seaboard, with moderate winters and frequent intervals of high humidity and oppressive heat in the summer. During the summer, high temperatures average in the upper eighties. The average annual precipitation is about 40 inches, with no pronounced wet or dry season. Annual snowfall averages about 20 inches.

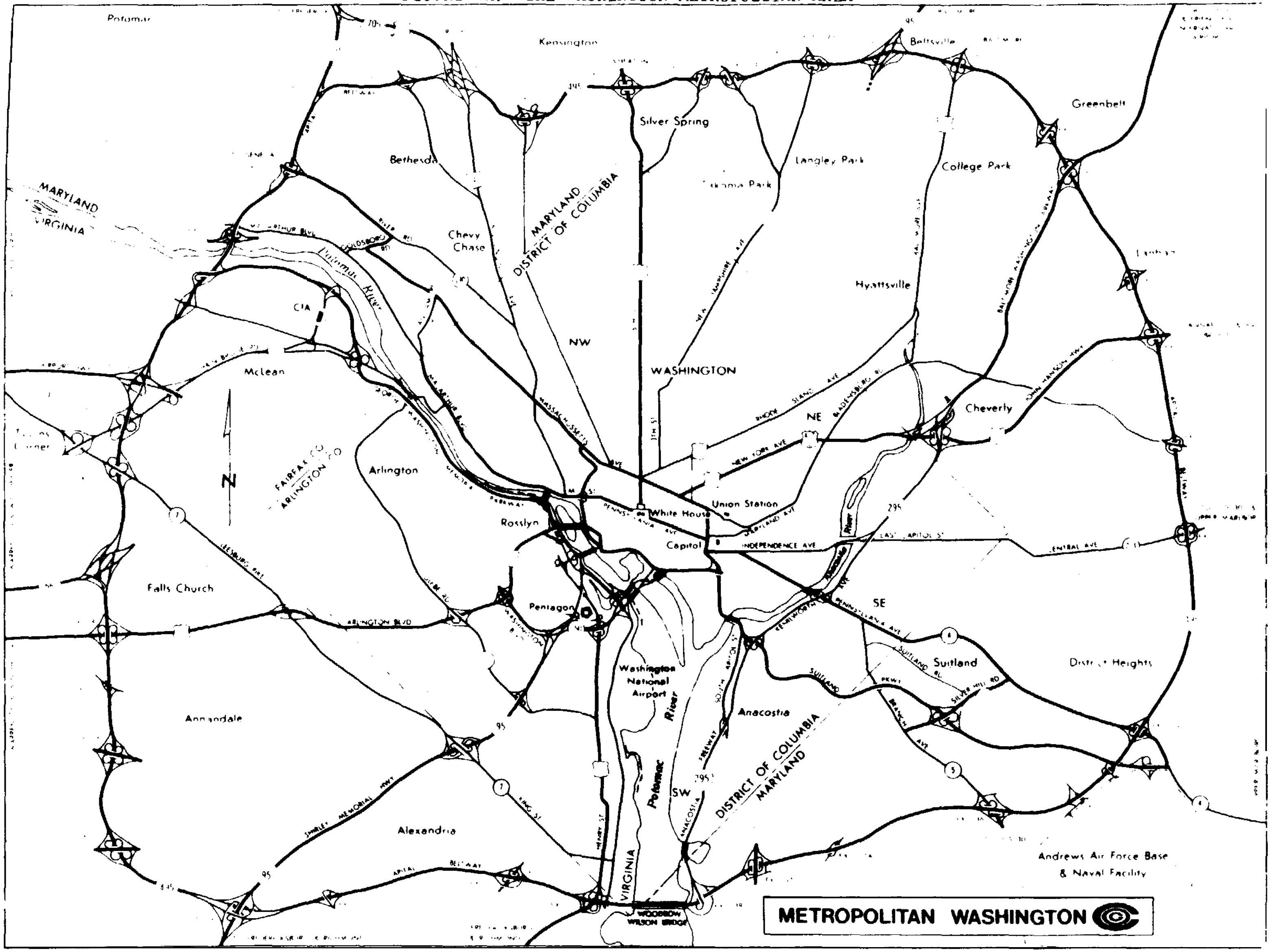
The frequent movement of cold arctic air masses into the Middle Atlantic States from Canada results in a prevailing northwest flow of unstable air in Washington from late November through April. The unstableness and relatively high wind speeds attending these air masses result in good atmospheric dilution conditions. In general, the winter and spring months constitute the period of most frequent unstable weather in Washington (i.e., storminess and high winds) and thus result in good atmospheric dilution and good ventilation in the lower atmosphere.

The summer and fall months are characterized by a reduction of wind speed and the prevalance of southerly winds. These months also have a higher fre-

---

1/ This information was taken from [39].

FIGURE 4A. THE WASHINGTON METROPOLITAN AREA



Source: [10].

quency of cloudiness and light wind conditions during nocturnal hours permitting a higher frequency of radiational surface-based inversions to form. Consequently, the summer and fall seasons constitute the period of lowest ventilation and highest potential for atmospheric stagnation in the Washington area.

THE GROUP HEALTH ASSOCIATION

The Group Health Association (GHA) is the largest and oldest prepaid group practice medical care plan for persons living in the Washington, D.C. Metropolitan Area. 2/ As of December 31, 1973, GHA had approximately 90,000 members. Enrollment by residential location was as follows: District of Columbia - 50%, Maryland - 35%, and Virginia - 15%. Until the end of 1973, GHA operated from four health center locations: The Downtown Center (henceforth referred to as the Pennsylvania Avenue Center), the Labor-Management Health Center (henceforth referred to as the Takoma Park Center), and two smaller centers in Annandale, Virginia and in Northwest Washington. 3/ A fifth center was opened in Rockville, Maryland at the beginning of 1974.

The membership of GHA is comprised of basically three types of enrollees: Federal, metro, and general. The largest group (about 75%) consists of Federal government employees. The next largest group (about 15%) is made up of employees of the Washington metropolitan transit system (Metro). The general membership (about 10%) includes college students, medicaid participants, and other miscellaneous enrollees. Figures 4b and 4c and 4d and 4e indicate the GHA enrollment distribution by sex and major age groups, respectively, for 1973 and 1974. Figure 4f indicates the GHA enrollment by 5-year age groups for 1973. 4/

Members of GHA pay a monthly premium which in turn provides a broad range of medical care. The services that are outpatient in nature are provided in GHA health care centers. Inpatient services are provided in neighboring hospitals. The services provided by GHA include physician visits in the health centers or in the hospital, hospitalization, surgery, laboratory tests and X-rays, emergency service, mental health, and routine physical examinations, among other medical services. In 1973, the utilization of GHA facilities had the following characteristics: 0.97 injections per enrollee, 1.32 X-ray films per enrollee, 9.92 laboratory tests per enrollee, and 3.25 physician visits per enrollee. 5/ In 1974, the figures were: 0.89, 1.38, 9.60, and 3.29, respectively.

A number of factors can affect the utilization of medical services at the facilities, both from the supply side and the demand side. For example, supply, or capacity to deliver, influences utilization rates. Physicians usually join the GHA staff in July. Hence, in some instances backlogs may develop in areas of elective treatment and this, in turn, can bias utilization upward during the

---

2/ As with other group practices, physicians are organized into a medical group or partnership, from which they receive their salaries.

3/ The Northwest Washington center closed August 15, 1975.

4/ These data were not available for 1974.

5/ This does not include visits with referral for physicians or retainer physicians; nor does it include (1) hospital calls, of which there were 35,853 for 1973, estimated on a minimal basis of one call for each hospital day, or (2) home calls of which there were 619 in 1973.

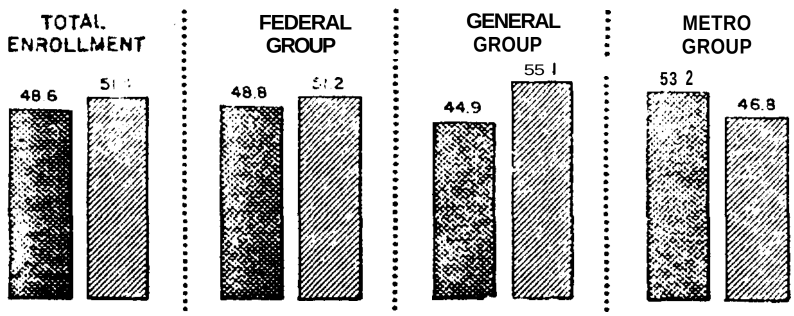


Figure 4b. GHA enrollment by sex (December 31, 1973).

Source: r 143.

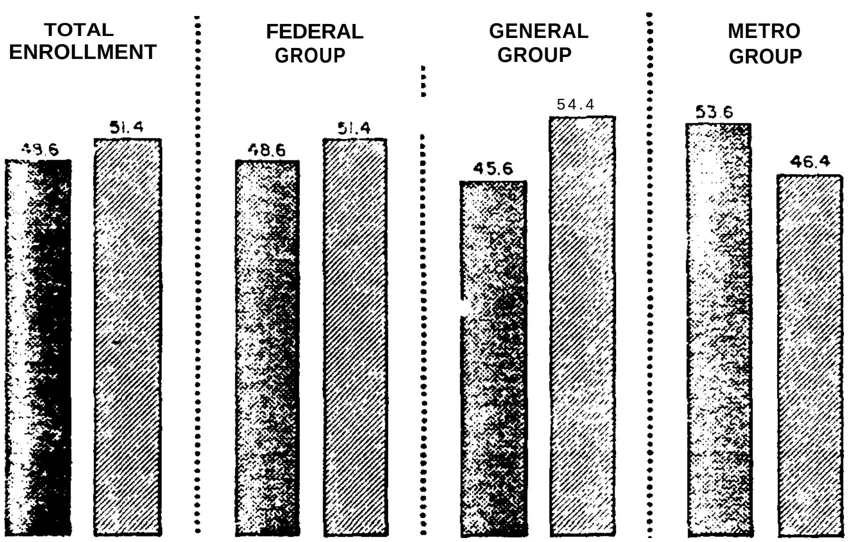


Figure 4c. GHA enrollment by sex (December 31, 1974).

Males

Source [15].

Femoles

Note: Scales used in these figures differ.

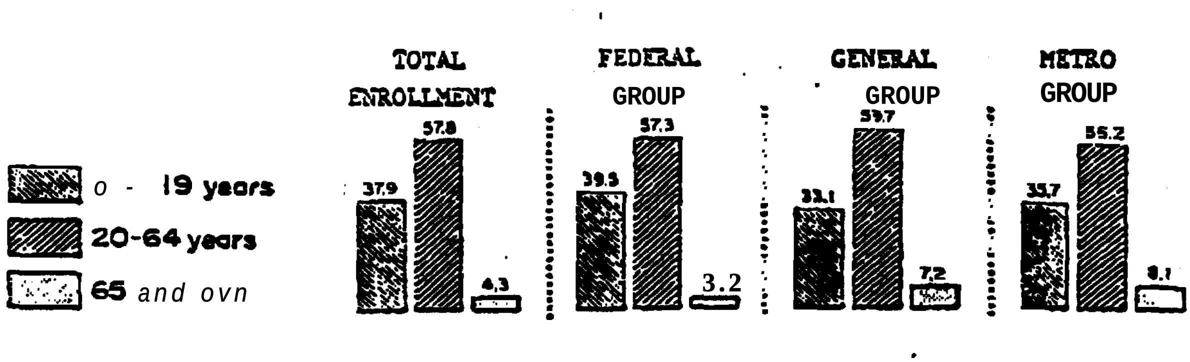


Figure 4d. GHA enrollment by major age groups (December 31, 1973).

Source: [14].

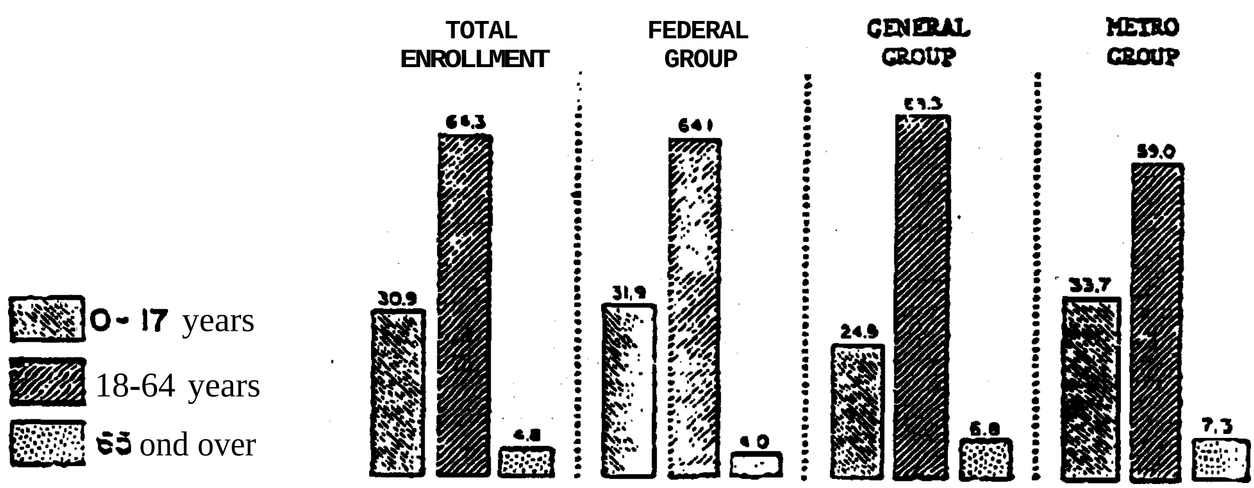


Figure 4e. GHA enroolment by major age groups (December 31, 1976).

Source: [15].

Note: Scales used in there figures differ.

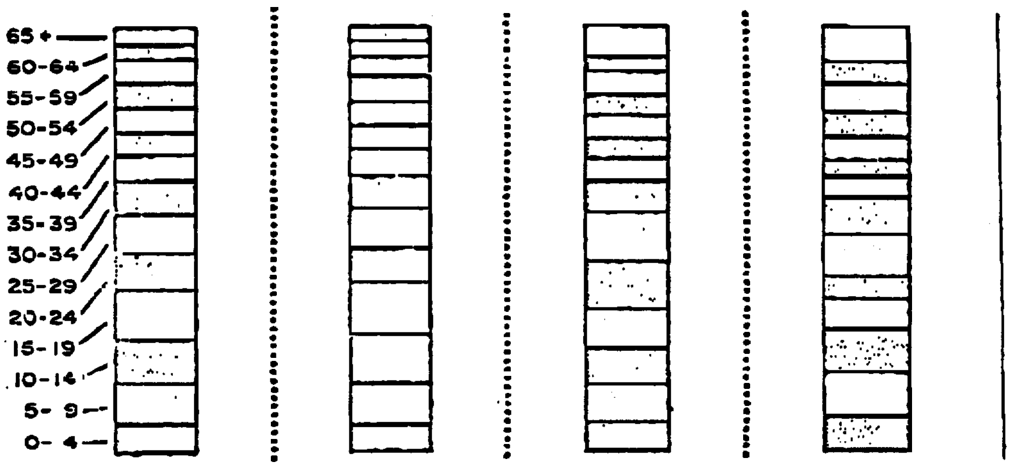


Figure 4f. GHA enrollment by five-year ape groups (December 31, 1973).

Source: [15].

summer months when the staff has increased. 6/ In addition, there is some movement of patients between facilities. For ins tance, if staffing is low in a particular department at a specific center, patients can be shifted from one clinic to another. A more extreme situation took place when the new GHA facility opened in Rockville, Maryland. Patients previously utilizing the center in Takoma Park now had the option of using a new facility that was in some cases more convenient.

On the demand side, it should be noted that the Federal "open season," i.e., the period in which government employees can join GHA, begins in November. Consequently, since the majority of GHA members are civil service workers, this means that utilization can increase substantially during the winter months as new enrollees join the plan. ,Both the supply and demand factors will be taken into account in the subsequent analyses.

Access to the GHA data for this study was indeed fortunate. Anelyaia in the air pollution-health area has been hampered by the lack of basic data. For example, very fev measures of a population'6 health statue are available. In fact, the only information that is available on a comprehensive basis consists of mortality rates. Since many of the health effects of air pollution (particularly mobile-source pollution) are likely to manifest themselves in less severe conditions,the scarcity of other health measures has presented a serious problem to the analys t and, in turn, to the policymaker. The extensive morbidity data from GHA permit significant questions co be answered on the complex issue of the health effects of mobile-source air pollution.

6/ This phenomenon is not likely to be an important factor in our analysis since we will be focusing primarily on "urgent" or unscheduled non-elective cases.

At the same time, two additional caveats should be mentioned regarding the use of these data. The first is that the socio-demographic characteristics, such as the racial composition and income distribution, represented by the GHA membership may not be typical of the socio-demographic characteristics of the entire metropolitan Washington population. The second, and related point, is that the utilization of medical services by GHA members may also be different than the utilization of medical services by the general Washington population.

SECTION V

COMPILING THE MEDICAL DATA

INPATIENT VS. OUTPATIENT DATA

As noted previously, there are basically two types of medical services offered by GHA: outpatient care at health centers and inpatient care in local hospitals. In this study only outpatient data will be examined. The chief reason for this lies in the fact that the subtle health effects of exposure to air pollution (especially mobile-source air pollution) are not likely to manifest themselves in a time-series analysis of inpatient data such as hospital admissions. Exceptions to this might take place if either the sample were restricted to extremely vulnerable individuals (e.g., heart patients) or if the sample were limited to emergency room admissions. Neither of these limitations was feasible for this analysis.

One caveat that should be mentioned with regard to the use of outpatient data is that only within-plan utilization is accounted for. If a patient received medical services outside the GHA system, such services would not be captured in the data. By their very nature, inpatient data are much less subject to this problem. Nevertheless, despite this disadvantage, outpatient data would seem to be far more relevant than inpatient data in examining the health effects of air pollution on a daily basis.

THE SELECTED OUTPATIENT DATA

Virtually all registration information recording visits to nine departments at the GHA Pennsylvania Avenue Health Center and at the Takoma Park Health Center during 1973 and 1974 was collected for analysis. 1/

The departments were:

1. Urgent Visit Clinic (both centers)
2. Internal Medicine (both centers)
3. Pediatrics (both centers)
4. Optometry (both centers)
5. Ophthalmology (Pa. Ave. only)

The reasons for selecting these departments are discussed in the next section.

For each visit, both patient information and service information were available, Briefly, the patient information consisted of six items: the Policy group to which the patient belonged, the type of membership plan, the membership status of the patient, restrictions on policy coverage of the Patient, the patient's sex, and the patient's age.

1/ The study was restricted to these two centers since they account for approximately 84 percent of all visits made to GHA facilities in the Washington area.

In addition to the department and the date in which the service was rendered, the other service information included the doctor number and the type of visit. The type of visit will be of particular importance to this analysis. 2/ The six possible types of visits are: urgent visit, regular or scheduled visit, general physical examination, well baby care, unscheduled appointment, and OB/GYN (obstetrics/gynecology).

For our purposes the last category, OB/GYN, is not relevant since we did not collect utilization data pertaining to obstetrical or gynecological visits. The urgent visit classification applies only to visits at the Urgent Visit Clinics. Regular or scheduled appointments can take place at any of the remaining four departments. General physical examinations are given in both the internal medicine and pediatric departments. Well baby care only applied to the pediatric department and involves routine checkups of infants following their birth until the age of three or four. As with regular or scheduled appointments, unscheduled appointments can take place in all departments except the Urgent Visit Clinic where such visits are termed "urgent visits."

THE SELECTION OF DEPARTMENTS

The departments listed above were chosen for several reasons. Since July 1, 1973, the Urgent Visit Clinic (UVC) at the Pennsylvania Avenue Center operated 24 hours a day seven days a week. Prior to that time, it operated six days a week from 9:00 am to 10:00 pm. The UVC at Takoma Park operates 9:00 am to 4:30 pm Mondays through Fridays and 9:00 am to 11:00 am on Saturday. These two clinics operate on a basis whereby GHA members can walk in off the street and seek immediate treatment for ailments without prior appointments. At the discretion of the UVC staff, members are either treated immediately or referred to more specialized departments. As a general rule visits are officially recorded in the department in which a member receives treatment. Thus, UVC "walk-ins" referred to other departments would be recorded as unscheduled visits in those departments. In 1973 the two Urgent Visit Clinics saw approximately 45,000 and 15,000 patients, respectively (see Tables 5.1 and 5.2). 3/ Since one might hypothesize that the type of health effects from air pollution would cause patients to utilize such facilities, and since other investigators have found that similar clinic visits have been correlated to air pollution episodes, 4/ data from these clinics were thought to be of particular interest.

The internal medicine departments at both centers operate between the hours of 9:00 am and 5:00 pm five days a week. 5/ In 1973 they saw about 45,000 and 10,500 patients, respectively (see Tables 5.1 and 5.2). The three

---

2/ We did not feel that the attending physician was a relevant factor for analyzing the occurrence of unscheduled visits.

3/ Tables 5.1 and 5.2 present a breakdown of the department visitation data for 1973 by type of visit for the Pennsylvania Avenue Center and the Takoma Park center, respectively. Tables 5.3 and 5.4 present a similar breakdown for the 1974 data.

4/ See Greenburg et al. [18].

5/ In addition, the internal medicine department at the Pennsylvania Avenue Center sees patients between 9:00 am and 12:00 noon on Saturdays and the internal medicine department at Takoma Park sees patients between 9:00 am and 11:00 am on Saturdays.

TABLE 5.1. 1973 GHA DATA (PENNSYLVANIA AVENUE)

Type of Visit	Department: Optometry	Internal Medicine	Pediatrics	Ophthal-mology	Urgent Visit Clinic	Total
Urgent Visit	0	0	0	0	44,795 (100.0%)	44,795 (31.1%)
Regular Visit	14,668 (97.2%)	29,925 (66.6%)	1,873 (5.9%)	5,227 (70.2%)	0	51,693 (35.9%)
General Physical	0	10,352 (23.0%)	6,924 (21.8%)	0	0	17,276 (12.0%)
Well Baby Care	0	0	9,814 (31.0%)	0	0	9,814 (6.8%)
Unscheduled Appointment	427 (3.8%)	4,682 (10.4%)	13,078 (41.3%)	2,221 (29.8%)	0	20,408 (14.2%)
Total	15,095 (10.5%)	44,959 (31.2%)	31,689 (22.0%)	7,448 (5.2%)	44,795 (31.1%)	143,986 (100.0%)

Note: Except for the last row of numbers, the percentage figures in parentheses all sum by column (department) to represent the composition of department visits by type of visit. The last row sums across to represent the composition of total visits by department.

TABLE 5.2. 1973 GHA DATA (TAKOMA PARK)

Type of Vis[illegible]	Department					Total
	Optometry	Internal [illegible]	Pediatrics	Ophthal-[illegible]	Urgent Visit [illegible]	
Urgent Visit	0	0	0	0	15,398 (100%)	15,398 (100%)
Regular Visit	4,503 (99.4%)	7,337 (70.3%)	704 (4.3%)	0	0	12,544 (26.8%)
General Physical	0	2,871 (27.4%)	3,012 (18.3%)	0	0	5,883 (12.6%)
Well Baby Care	0	0	3,412 (20.8%)	0	0	3,412 (7.3%)
Unscheduled Appointment	29 0.6%)	2[illegible]5 2.[illegible]%)	9,297 (56.6%)	0	0	9,561 (20.4%)
Total	4[illegible]32 9.[illegible]%)	10,443 (22.3%)	16,425 (35.1%)	0	15,398 (32.9%)	46,798 (100.0%)

Note: Except for the last row of numbers, the percentage figures in parentheses all sum by column (department) to represent the composition of department visits by type of visit. The last row sums across to represent the composition of total visits by department.

TABLE 5.3. 1974 GHA DATA (PENNSYLVANIA AVENUE)

	Department					
Type of Visit	Optometry	Internal Medicine	Pediatrics	Ophthal-mology	Urgent Visit Clinic	Total
Urgent Visit	0	0	0	0	53,439 (100.0%)	53,439 (35.4%)
Regular Visit	14,436 (92.8X)	33,628 (77.6%)	2,008 (6.4%)	5,544 (73.6%)	0	55,616 (36.8%)
General Physical	0	6,840 (15.8%)	6,816 (21.9%)	0	0	13,656 (9.0%)
Well Baby Care	0	0	6,442 (20.7%)	0	0	6,442 (4.3%)
Unscheduled Appointment	1,106 (7.2%)	2,849 (6.6%)	15,883 (51.0%)	1,993 (26.4%)	0	21,831 (14.5%)
Total	15,542 (10.3%)	43,317 (28.7%)	31,149 (20.6%)	7,537 (5.0%)	53,439 (35.4%)	150,984 (103.0%)

Note: Except for the last row of numbers, the percentage figures in parentheses all sum by column (department) to represent the composition of department visits by type of visit. The last row sums across to represent the composition of total visits by department.

TABLE 5.4. 1974 GHA DATA (TAKOMA PARK)

Type of Visit	Department: Optometry	Internal Medicine	Pediatrics	Ophthal-mology	Urgent Visit Clinic	Total
Urgent Visit	0	0	0	0	13,793 (100.0%)	13,793 (32.5%)
Regular Visit	3,768 (99.0%)	8,096 (73.2%)	1,056 (7.7%)	0	0	12,920 (30.4%)
General Physical	0	2,464 (22.3%)	2,183 (15.8%)	0	0	4,647 (11.0%)
Well Baby Care	0	0	1,823 (13.2%)	0	0	1,823 (4.3%)
Unscheduled Appointment	37 (1.0%)	503 (4.5%)	8,714 (63.3%)	0	0	9,254 (21.8%)
Total	3,805 (9.0%)	11,063 (26.1%)	13,776 (32.4%)	0	13,793 (32.5%)	42,437 (100.0%)

Note: Except for the last row of numbers, the percentage figures in parentheses all sum by column (department) to represent the composition of department visits by type of visit. The last row sums across to represent the composition of total visits by department.

types of visits to the internal medicine departments are: regular scheduled appointments, general physical, and unscheduled appointments. Although a relatively small percentage of the visits to the internal medical departments are unscheduled appointments, there is a procedure whereby patients may call the physicians and if deemed, necessary an appointment can be scheduled within a day or two. Thus, even though the appointment will be recorded as being previously scheduled, it may be air pollution-related. 6/ In addition, since studies have linked respiratory illness and cardiac distress to air pollution, 7/ the internal medicine department which sees patients with these conditions seemed quite relevant for our analysis.

The pediatric departments at both the Pennsylvania Avenue and Takoma Park facilities follow approximately the same schedule as the internal medicine departments. 8/ In 1973 they saw about 31,500 and 16,500 children, respectively* As shown in the tables, there are basically four types of visits that occur in the pediatric departments: regular scheduled, general physicals, well baby care, and unscheduled appointments. Primary attention will be focused on the unscheduled visits; however, in general, the visitation data pertaining to small children are of interest because there is evidence in the literature that the very young as well as the very old are especially susceptible to health effects from air pollution. 9/

The final departments from which we collected data were the optometry and ophthalmology departments. As noted above, Takoma Park has no ophthalmology department. In addition, their optometry department only operates during the hours 9:00 am to 1:00 pm and 2:00 pm to 5:00 pm Monday through Friday and 9:00 am to 1:00 pm on Saturday. At the main Pennsylvania Avenue facility, both departments operate five days a week between 8:40 am and 5:00 pm and on Saturday between 8:30 am and 12:30 pm. (See Tables 5.1 to 5.4 for a breakdown of these departments by type of visit.) These departments see individuals with eye problems and since eye discomfort is one of the primary symptoms that has been related to mobile-source pollution 10/, it was felt that examining the frequency of visits to these departments would be particularly relevant for the study. 11/

PREPARING THE GHA DATA FOR USE

The visitation data were received from GHA on a magnetic tape. The tape contained information representing 190,784 visits for 1973 and 195,903 visits

---

6/ These visits are called "write-ins." Unfortunately, our data do not permit identification of them.

7/ See Cohen et al. [ll].

8/ The only difference is that the pediatric department at Pennsylvania Avenue is open until 1:00 pm on Saturdays.

9/ See for example the study that was undertaken by Pearlman et al. [33]. It investigated the relationship between illness of the lower respiratory tract and nitrogen dioxide exposure in school children and infants.

10/ See for example Hammer et al. [20].

11/ After the fact, it was learned that the optometry departments almost exclusively saw patients with problems relating to vision correction; hence, these data were not utilized in the subsequent analyses.

for 1974. Since interest lay in the day-to-day relationship between GHA utilization and both daily air pollution and daily weather conditions, it was necessary to aggregate these data on a daily basis.

Specifically, for each day of the year at each of the two health centers in each of the nine departments, the following items were calculated and a new tape containing the information was created:

1. The number of patient visits affiliated with each of the five policy groups.

2. The number of patient visits in each of the nine membership plans.

3. The number of patients having each of the five possible membership statuses.

4. The number of department visits of patients with restricted policy coverage.

5. The number of department visits by male patients and the number of department visits by female patients.

6. The number of department visits of patients in each of five age categories: under 1 year, 1 to 14 years, 15 to 44 years, 45 to 64 years, and 65 years and older. 12/

7. The number of clinic visits in each of the five types discussed above. 13/

12/ These age classifications were chosen because they correspond to the age breakdown used by Vital Statistics. In addition, there is reason to believe that air pollution could exhibit differential health effects across these age groups. See Lave and Seskin [28].

13/ This information was not all used in this analysis. The means and standard deviations of the specific health utilization variables used in the analysis appear in Appendices A and B.

SECTION VI

COMPILING THE AIR POLLUTION AND METEOROLOGICAL DATA

THE AIR POLLUTION DATA

The air pollution data used in this research came from the Government of the District of Columbia, Department of Environmental Services. The specific ways in which the raw data were transformed for use in the analysis will be discussed below.

Metropolitan Washington's primary air pollution problem involves photochemical oxidants. This air pollutant, which is often referred to as photochemical smog, is a secondary air pollutant, It is not emitted directly into the atmosphere by any source, but is created in the atmosphere by complex chemical reactions triggered by sunlight acting on precursors--hydrocarbons and nitrogen oxides. Figures 6a and 6b show the maximum one-hour readings in relation to the primary and secondary national standard (0.08 ppm) across several monitoring stations in the region for 1973 and 1974, respectively. As can be seen, each station exhibited readings in excess of the standard. 1/ Note, too, that in most cases the levels reported at these stations did not differ greatly.

In addition to measurements of photochemical oxidants, readings were also available for its two precursors, hydrocarbons and nitrogen oxides. With regard to hydrocarbons, principal interest is focused on the levels of non-methane hydrocarbons. 2/ Levels of non-methane hydrocarbons are determined by measuring separately the total hydrocarbons and methane at a monitoring Station. 3/ In 1973, the primary and secondary standard for non-methane hydrocarbons was exceeded on 165 days of the 225 days for which data were valid. (Bar graphs were not available.)

Probably the most frequently mentioned oxide of nitrogen is nitrogen dioxide (NO_2). Nitrogen dioxide is formed when fuels are burned at high temperatures with air containing nitrogen. Automobiles and power plants are

---

1/ It should be noted that the actual air pollution data used in the analysis were not identical to those data represented in the graphs. The data represented in the graphs were obtained from publications of the Metropolitan Washington Council of Governments and only depict maximum readings taken at a number of stations throughout the region. For our statistical analyses, we required more comprehensive data on a daily basis. As noted earlier, these were obtained from the District of Columbia, Department of Environmental Services.

2/ In fact, the national standards were formulated in terms of non-methane hydrocarbons because they were thought to be more photochemically reactive.

3/ The readings of non-methane hydrocarbons are probably subject to more uncertainty than the other air pollution readings because of difficulties associated with the measurement of methane and the fact that two machines are involved.

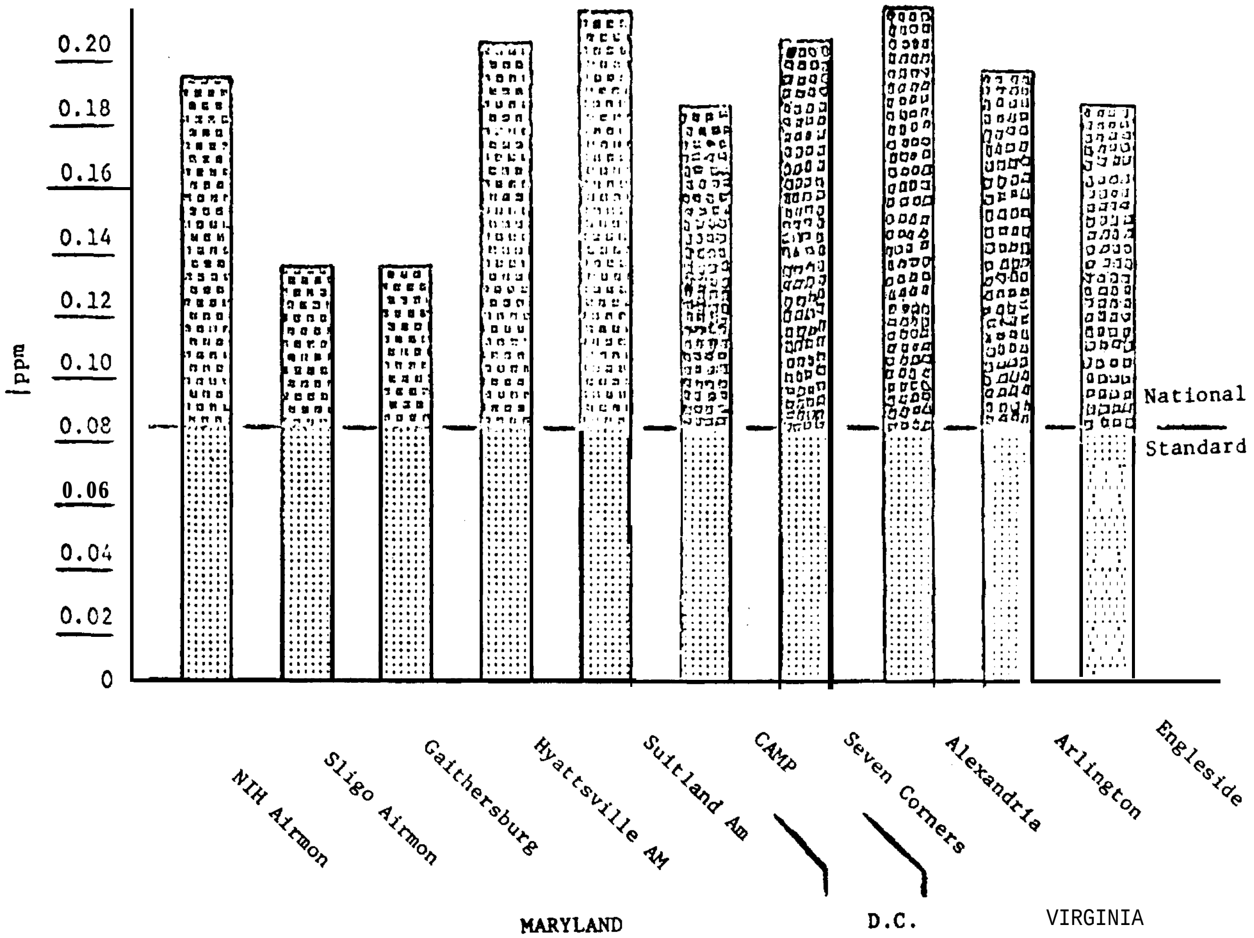


Figure 6a. Concentrations of photochemical oxidants (maximum hour - 1973).

Source: [1].

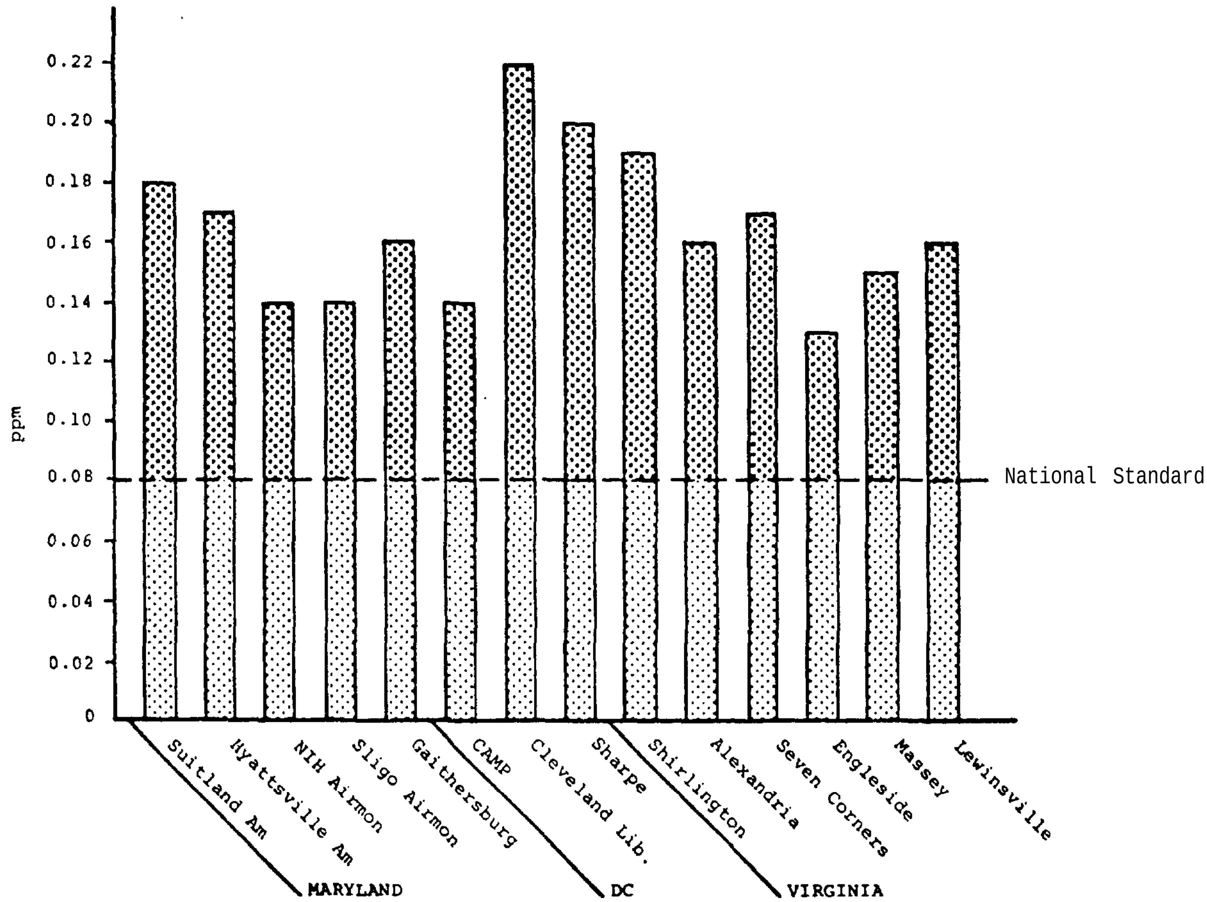


Figure 6b. Concentrations of photochemical oxidants (maximum hour - 1974).

Source: [2].

the principal emission sources for this air pollutant. In 1973, the levels of nitrogen dioxide obtained from the sampling stations in the Metropolitan Washington Area were somewhat below the national primary and secondary standard (0.05 ppm).

Carbon monoxide is another air pollutant emitted by mobile-sources--automobiles, trucks, and planes. This colorless, odorless, tasteless gas, is caused by combustion of fuels with insufficient oxygen. Levels of carbon monoxide across the metropolitan region have also been at or above the primary and secondary national standard (9 ppm maximum 8-hour average). Figures 6c and 6d show the relation of monitored levels to the standard at a number of stations in 1973 and 1974, respectively.

Other air pollutants that would be of secondary interest in a study such as this one include suspended particulate matter and sulfur dioxide. 4/ Particulates are fine pieces of dirt and dust that are so small they tend to float--suspended in air. Man-made particulates are primarily emitted by stationary sources (e.g., power plants, businesses, schools, residences, and industrial operations) when fuels such as oil and coal are burned. 5/ Similarly, sulfur dioxide is a gas formed when a fuel containing sulfur (coal and oil in particular) is burned. Consequently, stationary sources are, again, the primary emitters of this air pollutant.

COLLECTING AND PREPARING THE AIR POLLUTION DATA FOR USE

Specifically, the air pollution data were taken from [5 & 6]. These publications by the District Government report air pollution readings monitored at a number of stations within the District of Columbia (see Table 6.1).

A number of missing observations occurred in the air pollution data series. Consequently, to handle the problem of missing air pollution readings, we adopted the technique of simple linear interpolation. This method replaces the missing data in a series by a linear interpolation of the numeric values before and after the missing point(s). The method can be used to handle consecutive missing observations as well as missing observations that may occur at the beginning or end of a series. 6/ The general formula for linear interpolation is:

$$\text{value}_t = \text{value}_{t-1} + \frac{\text{value}_{t+n} - \text{value}_{t-1}}{n}$$

where value_t is the numeric estimate used to replace the missing data point and n is the number of consecutive observations that are missing (it can, of course, equal one). In the case where the missing observations occur at either

---

4/ Unfortunately, comprehensive data on suspended particulates were not available for analysis.

5/ It should be noted that a large percentage of total suspended particulates can be attributed to natural sources.

6/ It should be noted that in these cases, the estimates are based on less information.

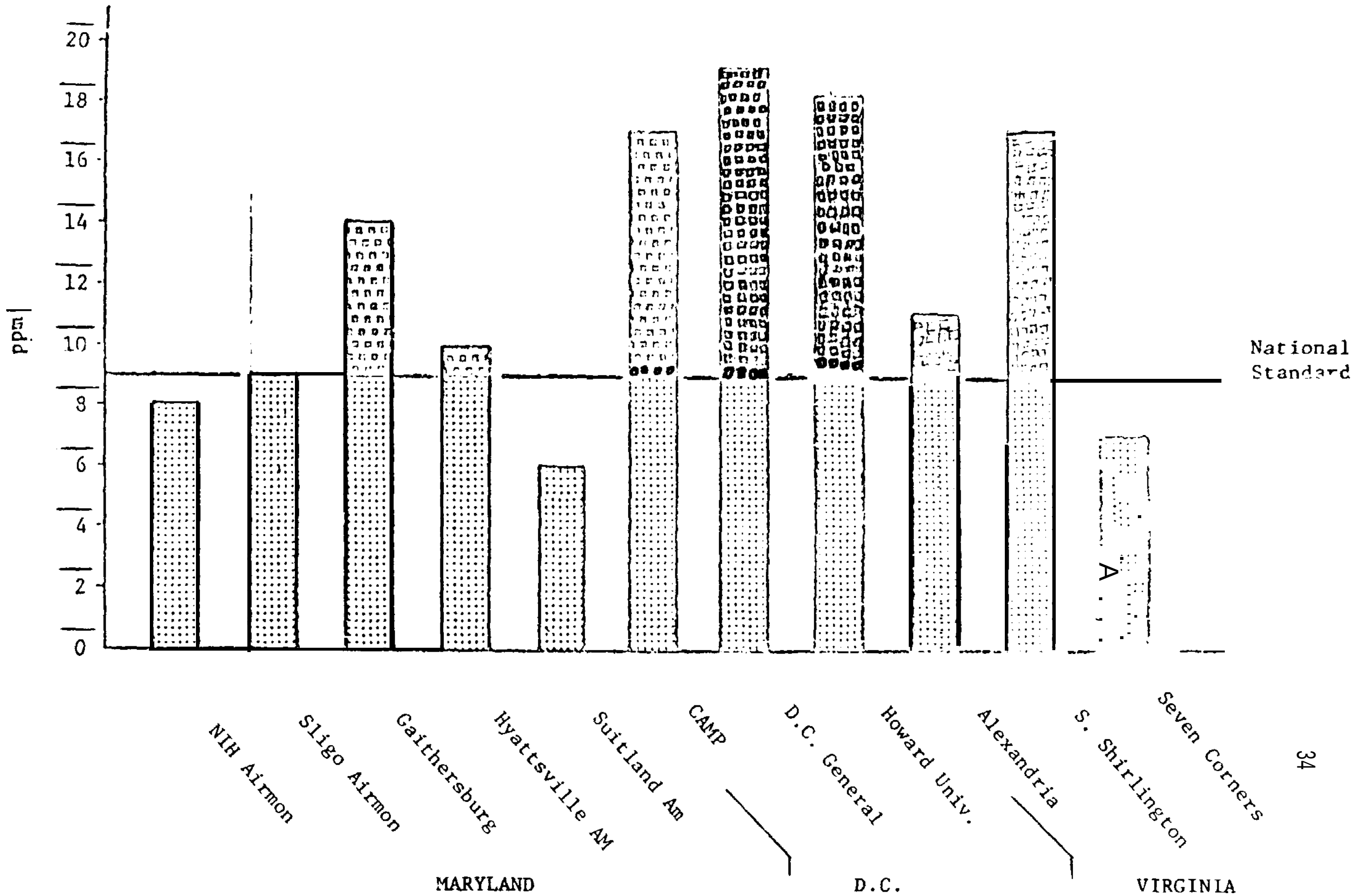


Figure 6c. Concentrations of carbon monoxide (maximum 8 hr. average - 1973).

Source: [1].

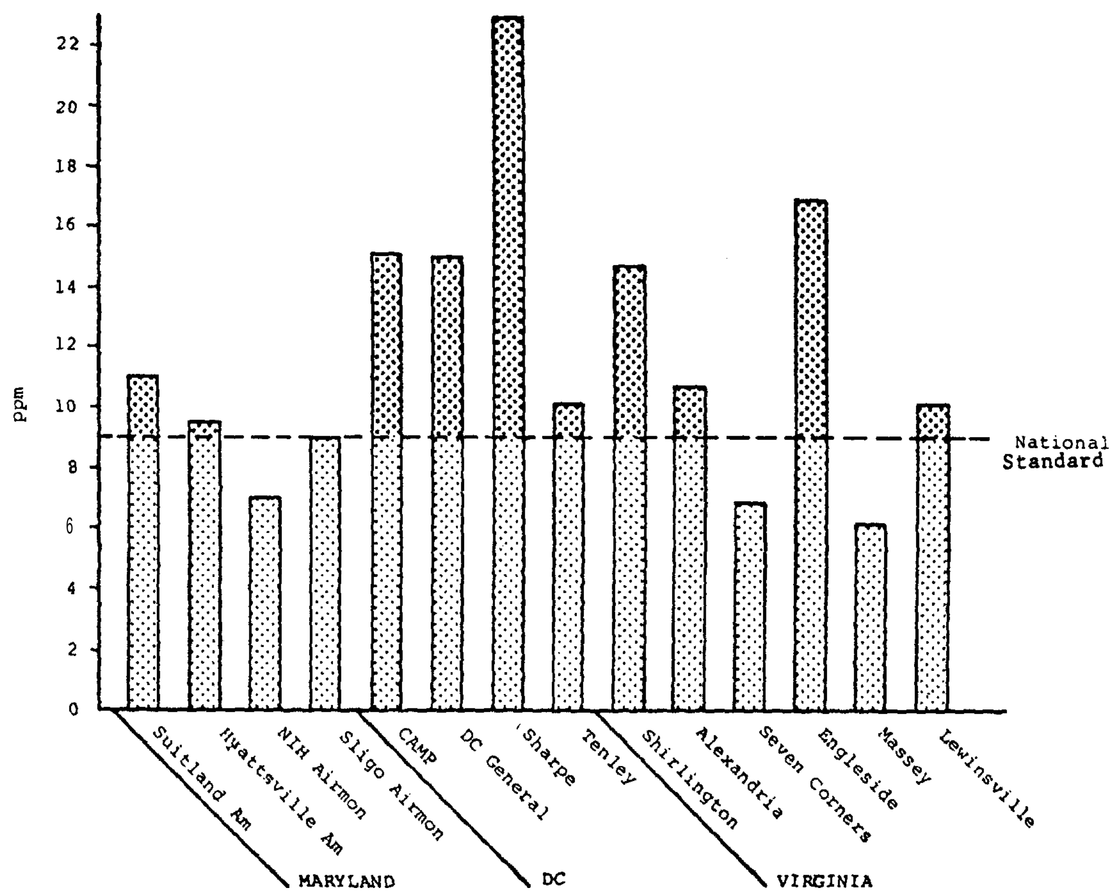


Figure 6d. Concentrations of carbon monoxide (maximum 8 hr. average - 1974).

Source: [2].

TABLE 6.1. AIR POLLUTION PROFILE

Air Pollutant	Primary Standard	Secondary Standard	Monitoring station*	Equipment	Method	Type of Average	Number of Observations	Number of Times Standard Exceeded
Photochemical Oxidants	0.08 ppm[a,b]	0.08 ppm[a,h]	CAMP Cleveland Par	Bendix 8000 " "	Chemiluminescence " " "	max. 1-hr. " "	331 (354)[d] (344)	48[c] (20)[d] (37)
Non-Methane Hydrocarbons	0.24 ppm[a,e]	0.24 ppm[a,e]	CAMP	Beckman	Flame ionization[f]	3-hr. 6:00am - 9:00am	225	165
Nitrogen Dioxide	0.05 ppm[g,b]	0.05 ppm[g,h]	CAMP	Bendix 8001	Chemiluminescence	24-hr.	348	na
Carbon Monoxide	9 ppm[a] 35 ppm[i]	9 ppm[a] 35 ppm[i]	CAMP D.C. General	Intertech A561 Beckman IR315A	Nondispersive Infrared " " "	max. 1-hr. " "	337 310 (311)	2 0 (0)
Sulfur Dioxide	0.14 ppm[a,h] 0.03 ppm[g]	0.50 ppm[a,j] 0.50 ppm[a,j]	CAMP Am. Chem. D.C. General D.C. General Am. Chem. D.C. General CAMP	Technican Beckman 906a Beckman 906 Beckman 906a " " Beckman 906 Technican	Pararosanaline Coulometric " " " " " " " " Pararosanaline	24-hr. 24-hr. " " " " max. 1-hr. " " " "	(323) 310 322 (303) 309 322 (322)	(0) 1 0 (0) 0 0 (0)

*Monitoring Station Locations

CAMP - 427 New Jersey Ave., N.W.

Cleveland Park Library -
Conn. Ave. & Macomb Sts., N.W.

D.C. General Hospital -
9th & Mass. Ave., S.E.

American Chemical Society
1155 16th St., N.W.

Source: [5 & 6]

a - Not to be exceeded more than once a year.
b - Based on maximum one hour average.
c - Data for 197 .
d - Data for 197 .
e - Based on 3-hour average (6:00 am - 9:00 am)
f - Readings were obtained by measuring separately total hydrocarbons and methane.

g - Annual arithmetic mean.
h - Based on 24-hour averages.
i - Based on 8-hour averages.
j - Based on 3-hour averages.

the beginning or the end of the series, they are replaced by the increment computed from the two nearest numeric values. 7/

THE METEOROLOGICAL DATA

Since weather conditions are the other major environmental factors hypothesized to affect illness on a day-to-day basis, they must be controlled for in the analysis. Consequently, we obtained meteorological data from the National Weather Service. These data, in the form of a magnetic tape, contained daily weather information for 1973 and 1974 from the station located at Washington National Airport. National Airport was selected as being the most representative weather station for the Washington Metropolitan Area. 8/ The specific climatological variables that were collected on a daily basis and that will enter this analysis were measures of temperature, wind, and precipitation. 9/

Since the study was using daily health data, and since the air pollution data were also being utilized as daily observations, the daily form of the weather data posed no difficulties of compatibility. Consequently, daily vectors of each climatological variable were created for use in conjunction with the health and air pollution data.

7/ The means and standard deviations of the specific air pollution variables used in the analysis appear in Appendix C.

8/ The alternatives were the weather stations located at either Dulles International Airport or Baltimore-Washington International Airport. Dulles is 24 miles from downtown Washington and Baltimore International is 34 miles from the downtown area.

9/ The means and standard deviations of the specific weather variables appear in Appendix D.

SECTION VII

STATISTICAL METHODS

INTRODUCTION

As discussed in Section III, techniques of multivariate analysis may be the most promising approach to investigating the air pollution-health relationship. Consequently, several multivariate methods were used to analyze the health, air pollution, and weather data. Before presenting the results of applying these procedures, two specific multivariate techniques, discriminant analysis and multivariate regression analysis, will be discussed.

THE CHOICE OF TECHNIQUES

Discriminant analysis and regression analysis should not be viewed as two alternative ways of solving the same problem. On the contrary, these techniques address different questions under different statistical assumptions and make different demands on the talents of the investigator. Neither technique is superior on every count; it is for this reason that both are being employed in this study.

A discriminant analysis permits the investigator to draw the following type of conclusion: "A 20 percent increase in the oxidant level will lead to a 0.005 increase in the probability of a person experiencing a sudden illness on any given day." A regression analysis, on the other hand, permits the investigator to draw the following sort of conclusion: "A 20 percent increase in the oxidant level will lead to a 5 percent increase in the number of persons experiencing a sudden illness on any given day."

If both of these conclusions could be made with 100 percent certainty, the latter, more quantitative conclusion would be preferable to the former, more probabilistic conclusion. Quantitative statements from a regression analysis are more readily translated into information that a policymaker can use to develop specific programs. For this reason, everything else being equal, a regression analysis produces more powerful results. However, it is seldom the case that everything else is equal. Hence, at times, the weaker probability statement generated by the discriminant analysis may provide not only sufficient, but also better guidance for the policymaker.

One reason why everything else is not equal is that the two techniques require different statistical assumptions. The discriminant analysis assumes that the variables explaining the probabilistic outcome are being randomly drawn from two normally distributed multivariate populations having different means but identical variances. 1/ On the other hand, the regression analysis assumes that the outcome is functionally or algebraically determined by certain explanatory variables and a single, usually additive, random term (having zero

1/ For certain discriminant analyses more than two populations may be assumed.

mean). 2/ It is important that the functional relationship between the outcome and the explanatory variables is stable for all values of the explanatory variables and that this function is correctly specified. Equally important is the assumption that the values of the random error term are distributed independently of the values of the explanatory variables. Although it is not necessary to assume that this random error term is drawn from a normal population, this assumption is usually made to enable certain types of hypothesis testing.

If the two important assumptions for regression analysis hold -- the independence of the error term and the specification of a correct and stable functional relationship -- then it is known that “on average” statements relating changes in an explanatory variable (e.g., oxidant levels) to changes in the outcome (e.g., the number of sudden illnesses) will be correct. Moreover, the likelihood that the statements will be correct improves as the amount of data (number of observations) used in the analysis increases. However, if these two assumptions fail to hold, such statements are known to be biased (often in uncertain direction and magnitude) and the situation will not improve even if the amount of data becomes quite large.

Thus, much of the analyst’s research effort in applying the techniques of regression analysis involves an attempt to specify the “correct” functional relationship. This task is especially difficult if a theory relating the outcome to the explanatory variables is lacking. Unfortunately, as pointed out earlier, this lack of theory accurately describes the air pollution-health relationship. This explains the attractiveness of the discriminant approach, since it makes relatively weaker theoretical demands (albeit stronger statistical demands) than the regression approach.

Fortunately, the two techniques can be complementary. For example, if it is found from a discriminant analysis that a particular variable does not affect the probability of an outcome, then this variable is unlikely to make a significant quantitative contribution to explaining an outcome in a regression analysis. Consequently, since the discriminant approach is relatively easy to undertake (see below), it can serve as a useful “screening” device to limit the number of variables that must be considered in specifying a relationship for a regression analysis. 3/

THEORY AND METHOD

The basic theories underlying multivariate regression and discriminant analysis are thoroughly discussed in several well-known texts. 4/ There is no need to repeat the discussion of regression analysis, since it is clearly pre-

---

2/ This remark applies to the type of single-equation analysis used in this study. The assumptions underlying multiple-equation regression analysis are somewhat more involved.

3/ There are several theoretical reasons for wanting to minimize the number of explanatory variables in a regression analysis. These include saving degrees of freedom and reducing the likelihood of multicollinearity.

4/ See, for example, Johnston [26] or Goldberger [17] on regression analysis; and Kendall [27] or Anderson [4] on discriminant analysis.

sented in these texts. However, our use of discriminant analysis is somewhat unconventional. Even though we do not alter the basic theoretical principles or the mathematical formulation, it may be difficult for the reader to see the connection between the conventional textbook presentation and our unconventional application. Thus, we feel the following discussion is warranted.

Classical discriminant analysis is a procedure for optimally classifying data into two or more groups. Each piece of data represents a set of measurements and the classification procedure attempts to group data with similar measurements together. Our use of discriminant analysis starts with the assumption that the data have already been classified. We then use the discriminant analysis to draw certain inferences about that classification.

Formally, we let our datum be represented by X. We assume that X is a random variable that could be drawn from either of two populations, π_1 or π_2, with probabilities q_1 and q_2, respectively. That is,

$$\text{Prob}(X \epsilon \pi_1) = q_1$$

and

$$\text{Prob}(X \epsilon \pi_2) = q_2$$

Let the ith observed value of X be X_1. Suppose we know that X will have the value X. with a known probability provided we also know from which group X was drawn? In particular, suppose we know that

$$\text{Prob}(X = X_i \mid X \epsilon \pi_1) = P_1(X_i)$$

and

$$\text{Prob}(X = X_i \mid X \epsilon \pi_2) = P_2(X_i)$$

We then pose the following problem: Given a value of X = Xi, what is the probability that X, in fact, came from population π_1? That is, what is

$$\text{Prob}(X \epsilon \pi_1 \mid X_i)?$$

From Baye's Theorem

$$\text{Prob}(X \epsilon \pi_1 \mid X_i) = \frac{\text{Prob}(X \epsilon \pi_1)\,\text{Prob}(X_i \mid X \epsilon \pi_1)}{\text{Prob}(X \epsilon \pi_1)\,\text{Prob}(X = X_i \mid X \epsilon \pi_1) + \text{Prob}(X \epsilon \pi_2)\,\text{Prob}(X = X_i \mid X \epsilon \pi_2)}$$

$$= \frac{q_1 P_1(X_i)}{q_1 P_1(X_i) + q_2 P_2(X_i)}$$

This can be rewritten

$$\text{Prob}(X\epsilon\pi_1 | X_i) = \frac{\frac{q_1 P_1(X_i)}{q_2 P_2(X_i)}}{\frac{q_1 P_1(X_i)}{q_2 P_2(X_i)} + 1}$$

In other words, two pieces of information are required to solve our problem. First, we must know (or estimate) the relative chances that X came from population π_1; that is, we must determine q_1/q_2. Since we have assumed that our data have already been classified into two groups of, say, size N_1 and N_2, the ratio N_1/N_2 could be used to estimate q_1/q_2. However, often it may be desirable to neglect the sample count and instead set q_1/q_2 by other, a priori considerations. (For example, q_1/q_2 is often set at unity indicating equal chances.)

The other piece of required information is the relative probability that X will have the value Xi given that X was drawn from population π_1, i.e., $P_1(X_i)/P_2(X_i)$. To estimate this ratio we assume that X is a function of p variables represented by a vector Z. Moreover, if X is from population π_1, we assume that Z has a multivariate normal distribution with a vector mean of μ_1. If X belongs to population π_2, we assume that Z has a multivariate normal distribution with a vector mean of μ_2. Both normal distributions are assumed to have the same variance, Σ.

Under this assumption it can be shown that

$$\frac{P_1(X_i)}{P_2(X_i)} = \exp\{Z_i' \Sigma^{-1}(\mu_1 - \mu_2) - \frac{1}{2}(\mu_1 + \mu_2)' \Sigma^{-1}(\mu_1 - \mu_2)\}$$

where Z_i is the ith value of Z.

Each element of μ_1 and μ_2 can be estimated by the sample means. That is, the kth mean of the first group can be estimated:

$$\mu_{1k} \approx \bar{Z}_{1k} = \frac{1}{N_1} \sum_{i=1}^{N} Z_{1k,i}$$

where Z_1 represents the N_1 x p matrix associated with group 1.

The variance Σ can also be estimated from the data by computing the matrix of sums of squared deviations about the means and cross products. Letting $\bar{Z}$ represent the vector of mean values of the p variables taken over all N observations, we estimate Σ as:

$$\Sigma \approx A = \frac{1}{N-2} \sum_{i=1}^{N} (Z_i - \bar{Z})(Z_i - \bar{Z})' .$$

While the above is a perfectly valid computational procedure for calculating $Prob(X \epsilon \pi_1 | X_i)$, we have employed an alternative procedure that yields certain additional useful information.

With a little manipulation, the expression

$$\frac{\dfrac{q_1 P_1(X_i)}{q_2 P_2(X_i)}}{\dfrac{q_1 P_1(X_i)}{q_2 P_2(X_i)} + 1}$$

can be written as

$$Prob(X \epsilon \pi_1 | X_i) = \frac{e^u}{e^u + 1}$$

where

$$e^u = \frac{P_1(X_i)}{P_2(X_i)} e^{\ell n \frac{q_1}{q_2}}.$$

It can be shown that the parameter u in the above expression can be estimated by

$$u \approx K Z_i \hat{b} - \frac{1}{2}(\bar{Z}_1 + \bar{Z}_2)' K \hat{b} + \ell n \frac{N_1}{N_2}$$

where

$$K = \frac{N_1 + N_2 - 2}{\dfrac{N_1 N_2}{N_1 + N_2} - \dfrac{N_1 N_2}{N_1 + N_2} (\bar{Z}_1 - \bar{Z}_2)' \hat{b}} .$$

As before N_1/N_2 is an estimate of q_1/q_2.

The parameter $\hat{b}$ is a vector of least-squares regression coefficients estimated from the regression equation:

$$Y_i = Z_i b$$

where Y_i is an observation vector of binary variables defined such that

$$Y_i = 1 \text{ if } x_i \epsilon \pi_1$$

and

$$Y_i = 0 \text{ if } X_i \epsilon \pi_2$$

The advantage of this procedure is that the parameter $\hat{b}$ can be used to calculate the marginal contribution of the variables Z to the $Prob(X \epsilon \pi_1 | Xi)$. In particular, the vector of slopes is:

$$\frac{\partial Prob(X \epsilon \pi_1 | X_i)}{\partial Z} = Prob(X \epsilon \pi_1 | X_i)[1 - Prob(X \epsilon \pi_1 | xi)]K\hat{b}$$

and the vector of elasticities is

$$\frac{\partial Prob(X \epsilon \pi_1 | X_i)}{Prob(X \epsilon \pi_1 | X_i)} \cdot \frac{Z}{\partial Z} = [1 - Prob(X \epsilon \pi_1 | X_i)]K\hat{b} \otimes Z$$

where the symbol $\otimes$ indicates that direct matrix product.

It should be noted that both the slopes and elasticities change with changes in Prob $(X \epsilon \pi_1 | Xi)$ and changes in Z. Therefore, as a matter of convention we will present these results only for the mean values of $Prob(X \epsilon \pi_1 | X_i)$ and the mean values of the p variables in Z.

APPLICATION AND HYPOTHESIS TESTING

As previously noted, the application of the above procedure starts with the assumption that the data have already been properly classified into one population group or the other (π_1 or π_2). In practice, this classification activity often relies on subjective judgment or guesswork. Fortunately, however, the validity of the classification can be assessed statistically.

Suppose, for example, our data consist of a set of daily observations on the number of visits (X_i) to a clinic treating sudden illness. Suppose, further, that we hypothesize these visits depend on a set of variables (Z_1) including the average daily temperature, the day of the week, and the average daily air pollution level. We might then wish to group the data into two populations, π_1 and π_2, where π_1 contains the daily observations in which the number of visits exceeds the average value of daily visits and π_2 contains the daily observations less than or equal to this average. Our hypothesis is that Z_i Will "explain" why any given Xi is greater or less than the average. In particular, given the concerns of this report, we hypothesize that the greater the air pollution level the greater the probability that X_i will fall in population π_1.

Yet our classification scheme may be erroneous in the sense that Z may not "explain" the classification. We can test for this by computing the following quadratic form:

$$U = (\bar{Z}_1 - \bar{Z}_2)' A (\bar{Z}_1 - \bar{Z}_2)$$

It can be shown that U has a t^2 distribution with $N_1 + N_2 - 1$ degrees of freedom. The appropriate null hypothesis is that the means of the explanatory variables after being grouped into the two populations are the same, i.e., that $Z_1 = Z_2$. (If the means were equal one would not expect the variables to "explain" why a particular Xi fell in one population as opposed to the other.) Should we fail to reject the null hypothesis, we have the choice of either altering the set of explanatory variables (Z) or of changing the classification rule. The correct choice cannot be based on abstract statistical criteria but rather it must be based on theoretical considerations, common sense, and, in some cases, pure luck!

SECTION VIII

EMPIRICAL RESULTS

INTRODUCTION

In the first phase of our empirical analysis we decided to perform simple time-series plots of subsets of the data. The purpose of employing such graphical techniques was to elicit any temporal patterns that might exist in the data (e.g., day-of-the-week or seasonal effects).

From examinations of resulting graphs, we concluded that there were no clear-cut day-of-the-week effects (except for weekend effects when clinic hours were shorter or nonexistent) nor unambiguous seasonal effects. Consequently, we proceeded with the analysis by applying our first multivariate statistical technique, discriminant analysis. In doing so, we explored further the possibility of temporal effects.

DISCRIMINANT ANALYSES

As we have discussed previously, the correct mathematical form of a model to explain utilization of health care facilities is not known. Furthermore, there are a large number of potential variables that could ostensibly fit such a model. For both of these reasons, we began our multivariate investigation by applying discriminant analysis. We felt that by adopting this approach initially, we would be able to look at a large number of potential relationships without the quantitative restrictions inherent in a multivariate regression analysis. Significant associations that were found could then be refined by further examination.

We began by applying discriminant analyses to the 1973 data from the Pennsylvania Avenue clinic. Specifically, we focused on the daily number of unscheduled visits arriving at each of the departments from which we had collected data. We then classified the data according to whether the number of unscheduled visits was greater than (or equal to) or less than the average number of unscheduled visits coming to that department on that particular day of the week. 1/ Once classified, these data were then discriminated against several possible explanatory variables.

In Section III we discussed that a number of factors are hypothesized to affect the health status of a population. However, in analyzing day- to-day variations in an index of health such as health clinic utilization, many of these factors can be assumed to remain essentially constant. For example, the population at risk, its habits, housing, and occupation mix are not likely to exhibit substantial changes on a day-to-day basis if the time period under consideration is not too long. On the other hand, air pollution levels, weather

---

1/ We did this procedure for each day of the week in an effort to control implicitly for a day-of-the-week effects. Saturdays and Sundays were excluded, since as explained in Section V, most departments had shorter hours on Saturdays and were closed on Sundays.

conditions, and specific day-of-the-week factors (e.g. , weekends, holidays, working patterns) would exhibit daily fluctuations. Consequently, in our initial analyses we controlled for these factors explicitly by including variables representing average daily temperature, average daily wind speed, 2/ and daily pollution levels (as measured by the maximum l-hour average photochemical oxidant reading taken at the CAMP station located in downtown Washington). 3/ As discussed in footnote 1, day-of-the-week factors were controlled implicitly by our classification scheme.

The results of one such discriminant analysis are presented in Table 8.1. The classification vector was based on the number of unscheduled visits to the internal medicine department on a given day. Days with a greater than average number of unscheduled visits (for that day of the week) were assigned a one, while days with less than average numbers of unscheduled visits were assigned a zero. This classification vector was then discriminated against the three environmental measures described above.

TABLE 8.1. DISCBIMINANT ANALYSIS ON INTERNAL MEDICINE DEPARTMENT (PENNSYLVANIA AVENUE - 1973)

	Elasticities	10% Δ Mean	Δ Prob.*
Oxidant (ppm)	-.105	.005	-.004
Temp. (°F)	.492	5.974	.019
Wind (mph)	-.021	.a51	-.001

U-Statistic = 0.037 (distributed as t_2)

* The mean probability of being classified as an unscheduled visit was 0.395.

As can be seen by the U-statistic below the table, the three environmental variables did poorly in discriminating between above average and below average unscheduled utilization of the internal medicine department. The signs of the elasticities displayed in the table indicate that air pollution and wind were negatively related to utilization, while temperature was positively related. The magnitude of the elasticities permit "unit-free" comparisons of the relative associations. For example, a 10 percent increase in the oxidant level was associated with a 1.05 percent decrease in the probability, i.e., an increase of 0.005 ppm in the oxidant level was associated with a decrease of 0.004 in the probability of being classified as a day having greater than

---

2/ These climatic variables were selected for initial use on the basis of findings presented in Lave and Seskin [28]. The analysis of other weather variables will be discussed below.

3/ Later, we will explore the results of using photochemical oxidant data from another monitoring station as well as data on other air pollutants.

average unscheduled visits to the internal medicine department. 4/

Similar results were exhibited by discriminant analyses involving two of the three remaining departments (urgent visit clinic and pediatrics). No consistent pattern was uncovered between daily air pollution levels (as measured by photochemical oxidants) and the daily number of unscheduled visits arriving at these departments. However, the data from the ophthalmology department exhibited slightly different characteristics. The results of the discriminant analysis analogous to the one presented above for internal medicine, suggested a possible association between air pollution and unscheduled visits for eye problems. The specifics of the discriminant analysis for the ophthalmology department are shown in Table 8.2.

TABLE 8.2. DISCRIMINANT ANALYSIS ON OPHTHALMOLOGY DEPARTMENT (PENNSYLVANIA AVENUE - 1973)

	Elasticities	10% Δ Mean	Δ Prob.*
Oxidant (ppm)	.379	.005	.016
Temp. (°F)	-.376	5.974	-.016
Wind (mph)	.218	.851	.009

U-Statistic = 0.125 (distributed as t_2)

* The mean probability of being classified as an unscheduled visit was 0.422.

Except for the classification vector, the variables were identical to those described above. Although the U-statistic increased, it was still not statistically significant. The three environmental variables did not discriminate well between above average and below average unscheduled utilization of the ophthalmology department. However, in this case, air pollution (as measured by photochemical oxidants) and wind were positively related to utilization, while temperature was negatively related. As can be seen from the elasticities, air pollution and temperature had effects of roughly the same magnitude, the effect of wind was less pronounced. Although not reported, the t-statistics corresponding to the variables in the 1-0 regression (see previous footnote) indicated that the air pollution variable was statistically significant. This warranted further exploration.

4/ As would be expected from these results, the t-statistics (not reported) for each of the variables derived in the 1-0 regression used in performing the discriminant analysis (see Section VII) were all statistically insignificant. In the context of this analysis, a factor or variable was considered "statistically significant" if its regression coefficient was significantly different from zero at (at least) the 20 percent level. That is, we had at least 80 percent confidence in the individual statements regarding the association.

The next step we took was to rerun the discriminant analyses using only the data for the summer months of 1973. This time period was of special interest because of the relatively high air pollution levels that occurred. (Four air pollution alerts were called by the Metropolitan Washington Council of Governments.) The results of these further analyses were similar to those for the entire year in that no consistent pattern was found between daily photochemical oxidant levels and the daily number of unscheduled visits arriving at these departments.

After examining the summer months, we decided to use the 1974 data in an effort to replicate the 1973 results. Tables 8.3 and 8.4 present discriminant analyses using 1974 data that are analogous to those shown in Tables 8.1 and 8.2, respectively.

With regard to unscheduled visits to the internal medicine department, it can be seen from Table 8.3 that the U-statistic still indicates that the environmental variables did poorly in discriminating between above average and below average utilization. However, the signs of the elasticities now indicate that oxidant levels and temperature were positively related to utilization, while wind was negatively related. The magnitudes of the elasticities show little change for the air pollution variable between the two years, but substantial differences for the two climatic variables. 5/

TABLE 8.3. DISCRIMINANT ANALYSIS ON INTERNAL MEDICINE DEPARTMENT (PENNSYLVANIA AVENUE - 1974)

	Elasticities	10% Δ Mean	Δ Prob.*
Oxidant (ppm)	.150	.004	.007
Temp. (°F)	.061	5.873	.003
Wind (mph)	-.353	.869	-.017

U-Statistic = 0.131 (distributed as t^2)

* The mean probability of being classified as an unscheduled visit was 0.471.

The results of the 1974 analysis of the ophthalmology department (Table 8.4) were comparable to the 1973 results. The U-statistic increased; however, it remained statistically insignificant. The signs of the elasticities were unchanged and their magnitudes were slightly larger in the 1974 replication. 6/

5/ The t-statistics corresponding to the variables in the 1-0 regression (not reported) were all statistically insignificant. (See footnote 4 in this section.)

6/ Again, the t-statistic for the oxidant variable was statistically significant.

TABLE 8.4. DISCRIMINANT ANALYSIS ON OPHTHALMOLOGY DEPARTMENT (PENNSYLVANIA AVENUE - 1974)

	Elasticities	10% Δ Mean	Δ Prob.*
Oxidant (ppm)	.469	.004	.022
Temp. (°F)	-.673	5.873	-.031
Wind (mph)	.334	.869	.016

U-Statistic = 0.284 (distributed as t^2)

* The mean probability of being classified as an unscheduled visit was 0.467.

REGRESSION ANALYSES

Given the findings of the discriminant analyses which in general did not evidence an association between photochemical oxidant pollution and clinic utilization (except possibly a suggestive relationship between oxidant pollution and unscheduled visits to the ophthalmology department), we decided to proceed by analyzing the same data using multiple regression. As discussed earlier, this approach facilitates the investigation of more specific quantitative hypotheses. Initially, we began by running some simple regressions. One such model is shown below and corresponds to regression 1 in Table 8.5:

$$\begin{aligned} UIM = 17.859 &- \underset{(-1.00)}{12.317}\ Ox + \underset{(0.15)}{0.003}\ Av\ T + \underset{(0.24)}{0.024}\ Av\ Wind \\ &- \underset{(-11.59)}{9.709}\ Sat - \underset{(-22.44)}{17.622}\ Sun \qquad (R^2 = 0.638) \end{aligned}$$

UIM represents the number of unscheduled visits to the internal medicine department on a given day, Ox is the maximum l-hour average oxidant reading on a given day, Av T is the average temperature for the day, and Av Wind is the average wind speed for that day. Sat and Sun are dummy variables representing the weekends. 7/ The equation above represents the number of unscheduled visits to the internal medicine department during 1973. 8/ As can be seen, 63.8 per-

---

7/ Dummy variables are specially constructed variables that may be used to represent various factors such as temporal effects, spatial effects, qualitative variables, and broad groupings of quantitative variables. In our analysis we employed two dummy variables for the two days of the weekend. Specifically, if an observation represented data pertaining to a Saturday, the Saturday dummy variable (Sat) was assigned a value of 1 and for all other days it was assigned a value of 0. Similarly, if an observation represented data pertaining to a Sunday, the Sunday dummy variable (Sun) was assigned a value of 1 and for all other days it was assigned a value of 0.

8/ Seven days in April and twenty-three days in May were omitted because no air pollution data were available.

TABLE 8.5. REGRESSION ANALYSIS OF OXIDANT EFFECTS ON UNSCHEDULED DEPARTMENT UTILIZATION (PENNSYLVANIA AVENUE - 1973)

	UIM 1	UOPHTH 2	UPED 3
R^2	0.638 a/	0.460	0.646
Constant	17.859	8.178	51.952
Air Pollution:			
OX	-12.317 b/ (-1.00) c/	13.867 (1.73)	-22.764 (-0.83)
Weather:			
Av T	0.003 (0.15)	-0.013 (-0.90)	-0.051 (-1.02)
Av Wind	0.024 (0.24)	-0.005 (-0.07)	-0.509 (-2.33)
Dummy:			
Sat	-9.709 (-11.59)	-4.444 (-8.10)	-4.387 (-2.34)
Sun	-17.622 (-22.44)	-8.055 (-15.67)	-42.499 (-24.16)

a/ The coefficient of determination; a value of 0.638 indicates that 63.8 percent of the variation in unscheduled visits was "explained" by the independent variables.

b/ The regression coefficient.

c/ The t-statistic; a value of 1.65 indicates significance at the 10 percent level, using a two-tailed test.

cent of the variance in daily unscheduled visits was explained by the right-hand-side variables (R^2 = 0.638). The t-statistics in parentheses below the coefficients indicate that none of the environmental variables was statistically significant; 9/ the signs of the coefficients indicate that oxidant pollution was negatively related to clinic visits, while both average temperature and average wind speed were positively related. It is apparent that the explanatory power of the regression was derived primarily from the influence of the dummy variables for Saturdays and Sundays. As expected, utilization was negatively associated with weekends.

Similar regression results were found for the pediatric department (Table 8.5, regression 3). That is, there was no evidence of a daily effect of photochemical oxidant pollution on daily visitation. The ophthalmology department, however, displayed suggestive results of a possible association. 10/ This can be seen in the equation below which corresponds to regression 2 in Table 8.5:

$$\text{UOPHTH} = 8.178 + \underset{(1.73)}{13.867}\ \text{Ox} - \underset{(-0.90)}{0.013}\ \text{Av T} - \underset{(-0.07)}{0.005}\ \text{Av Wind}$$

$$-\underset{(-8.10)}{4.444}\ \text{Sat} - \underset{(-15.67)}{8.005}\ \text{Sun} \qquad (R^2 = 0.460)$$

UOPHTH represents the number of unscheduled visits to the ophthalmology department on a given day, and the remaining variables are as defined above. As can be seen, 46.0 percent of the variance in the daily unscheduled visits was explained by the right-hand-side variables (R^2 = 0.460). In this case the coefficient and t-statistic of the air pollution variable indicate a positive and statistically significant (at approximately the 10 percent significance level) association with the unscheduled ophthalmology visits. One interpretation of the magnitude of this result is that an increase of 0.01 parts per million (ppm) in the maximum l-hour average oxidant level (raising the mean from 0.048 to 0.058 ppm) was related to an increase of 0.14 (0.01 x 13.867) daily unscheduled visits to the ophthalmology department (raising the mean number of daily unscheduled visits from 6.03 to 6.17). An alternative interpretation of this result is that a 10 percent decrease in the mean of the air pollution variable (decreasing the mean by 0.0048 ppm) would be associated with a 1.1 ((0.0048 x 13.867)/6.03) percent decrease in the number of unscheduled visits to the ophthalmology department. The signs of the coefficients of the other environmental variables indicated a negative relationship with both average temperature and average wind speed; both were statistically insignificant. The weekend dummy variables exhibited similar results to those reported above. 11/

9/ A value of 1.65 indicates significance at the 10 percent level using a two-tailed test; a value of 1.28 indicates significance at the 20 percent level using a two-tailed test.

10/ Regressions were not run for the 1973 urgent visit clinic data because of the schedule change that occurred during the year (see Section V, p. 20).

11/ We experimented with specifications omitting the weekend dummy variables along with all data pertaining to the weekends. As expected, the coefficient of variation (R^2) decreased dramatically; however, the magnitude

Similar results to those just reported were found when regressions were run on only the summer months of 1973 (not shown). That is, a significant association was seen for visits to the ophthalmology department, while no apparent associations were seen for visits to the other departments.

The results of replicating the 1973 regressions using 1974 data are shown in Table 8.6. 12/ Replications for the internal medicine department and the ophthalmology department using air pollution data from the CAMP station are shown in the equations below (they correspond to regressions 2 and 4, respectively) :

$$UIM = 11.195 + \underset{(0.48)}{8.873}\ Ox + \underset{(0.13)}{0.004}\ Av\ T - \underset{(-1.32)}{0.156}\ Av\ Wind$$

$$-\underset{(-5.88)}{6.092}\ Sat - \underset{(-10.32)}{10.135}\ Sun \quad (R^2 = 0.266)$$

$$UOPHTH = 5.996 + \underset{(4.54)}{60.424}\ Ox - \underset{(-1.72)}{0.040}\ Av\ T + \underset{(1.89)}{0.163}\ Av\ Wind$$

$$-\underset{(-6.67)}{5.017}\ Sat - \underset{(-10.54)}{7.528}\ Sun \quad (R^2 = 0.300)$$

One notes that the variance explained of the 1974 unscheduled visits to the internal medicine department dropped substantially (R^2 decreased from 0.638 to 0.266). Again, all three environmental variables were statistically insignificant; only the dummy variables representing the weekends were statistically important.

The results for the ophthalmology department also evidenced a decrease in the coefficient of variation (R^2). However, the t-statistics now indicated that all three environmental variables were statistically significant. The suggestive association between photochemical oxidant levels and unscheduled visits to the ophthalmology department still held. The magnitude of the association exhibited by the 1974 data indicated that an increase of 0.01 ppm in the maximum l-hour average oxidant level (raising the mean from 0.038 to 0.048 ppm) was related to an increase of 0.60 (0.01 x 60.424) daily unscheduled visits to the ophthalmology department (raising the mean number of daily unscheduled visits from 5.38 to 5.98). An alternative interpretation of this result is that a 10 percent decrease in the mean of the air pollution variable (decreasing the mean by 0.0038 ppm) would be associated with a 4.3 ((0.0038 x 60.424)/5.38) percent decrease in the number of unscheduled visits to the ophthalmology department.

11/ (continued) and statistical significance of the other explanatory variables were not significantly affected. Evidently, there are many unaccounted for variables influencing unscheduled utilization of the various departments, but the statistically significant associations we observed were not simply artifacts of a particular specification.

12/ Since homogeneous data for the urgent visit clinic were available, regression results for that department are shown, In addition, photochemical oxidant data were obtained from another monitoring station in Cleveland Park (C.P.) ; hence, two regressions for each department were analyzed.

TABLE 8.6. REGRESSION ANALYSIS OF OXIDANT EFFECTS ON UNSCHEDULED DEPARTMENT UTILIZATION (PENNSYLVANIA AVENUE - 1974)

	UIM		UOPHTH		UPED		WC	
	1	2	3	4	5	6	7	8
R^2	0.210 a/	0.266	0.255	0.300	0.416	0.485	0.302	0.307
Constant	8.732	11.195	5.956	5.996	62.613	69.824	154.942	152.459
Air Pollution:								
ox (CAMP)		8.873		60.424		108.634		138.844
		(0.48)		(4.54)		(1.87)		(1.35)
ox (C.P.)	-28.270 b/		-7.432		-15.353		153.071	
	(-1.82) c/		(-0.61)		(-0.31)		(1.80)	
Weather:								
Av T	0.066	0.004	0.023	-0.040	-0.332	-0.498	0.008	0.114
	(1.98)	(0.13)	(0.88)	(-1.72)	(-3.10)	(-4.86)	(0.04)	(0.63)
Av Wind	-0.137	-0.156	0.067	0.163	1.195	1.044	-0.023	-0.256
	(-1.13)	(-1.32)	(0.71)	(1.89)	(3.10)	(2.78)	(-0.09)	(-0.39)
Dunmy:								
Sat	-6.136	-6.092	-5.188	-5.017	-7.526	-8.242	-31.560	-32.867
	(-5.86)	(-5.88)	(-6.28)	(-6.67)	(-2.25)	(-2.21)	(-5.50)	(-5.67)
sun	-9.829	-10.135	-7.362	-7.528	-50.766	-53.058	-61.257	-64.155
	(-9.97)	(-10.32)	(-9.48)	(-10.54)	(-16.14)	(-17.01)	(-11.34)	(-11.66)

a/ The coefficient of determination; a value of 0.270 indicates that 27.0 percent of the variation in unscheduled visits was "explained" by the independent variables.

b/ The regression coefficient.

c/ The t-statistic; a value of 1.65 indicates significance at the 10 percent level, using a two-tailed test.

The 1974 results, unlike the 1973 findings, also revealed a statistically significant association between unscheduled visits to the pediatric department and levels of photochemical oxidants. The relevant equation is shown below and corresponds to regression 6 in Table 8.6:

$$\begin{aligned} UPED = 69.824 &+ \underset{(1.87)}{108.634}\ Ox - \underset{(-4.86)}{0.498}\ Av\ T + \underset{(2.78)}{1.044}\ Av\ Wind \\ &- \underset{(-2.21)}{8.242}\ Sat - \underset{(-17.01)}{53.058}\ Sun \qquad (R^2 = 0.485) \end{aligned}$$

The variables are as above except for the dependent variable UPED which represents the number of unscheduled visits to the pediatric department on a given day. As can be seen, 48.5 percent of the variance in daily visits to the pediatric department was explained by the right-hand-side variables ($R^2 = 0.485$) The coefficent and t-statistic of the air pollution variable indicate a positive and statistically significant (at the 10 percent significance level) association with the unscheduled visits. One interpretation of the magnitude of this result is that an increase of 0.01 ppm in the maximum l-hour average oxidant level (raising the mean from 0.038 to 0.048 ppm) was related to an increase of 1.08 (0.01 x 108.634) daily visits to the pediatric department (raising the mean number of daily unscheduled visits from 43.70 to 44.78). An alternative interpretation of this result is that a 10 percent decrease in the mean of the air pollution variable (decreasing the mean by 0.0038 ppm) would be associated with a 0.9 ((0.0038 x 108.634)/43.70) percent decrease in the number of unscheduled visits. The coefficients and t-statistics of the other environmental variables indicated statistically significant effects of temperature and wind on pediatric visits; temperature was negatively related and wind was positively related to such visits. The weekend dummy variables again reflected decreased visitation on weekends.

In addition to the photochemical oxidant data monitored at the CAMP station, comprehensive data for this air pollutant were available from another station located at Cleveland Park (see Table 6.1). When those readings were substituted for the CAMP station readings, only the urgent visit clinic exhibited a positive and statistically significant association between air pollution levels and unscheduled utilization. The relevant equation is shown below and corresponds to regression 7 in Table 8.6:

$$\begin{aligned} W\ C = 154.942 &+ \underset{(1.80)}{153.071}\ Ox + \underset{(0.04)}{0.008}\ Av\ T - \underset{(-0.09)}{0.023}\ Av\ Wind \\ &- \underset{(-5.50)}{31.560}\ Sat - \underset{(-11.34)}{61.257}\ Sun \qquad (R^2 = 0.302) \end{aligned}$$

Again, the variables are as above except for the dependent variable WC which represents the number of urgent visits to the urgent visit clinic on a given day. As can be seen, 30.2 percent of the variance in daily visits to the urgent visit clinic was explained by the right-hand-side variables ($R^2 = 0.302$). The coefficient and t-statistic of the air pollution variable indicate a positive and statistically significant (at the 10 percent significance level) association with the urgent visits. One interpretation of the magnitude of this result is that an increase of 0.01 ppm in the maximum l-hour oxidant level (raising the mean from 0.044 to 0.054 ppm) was related to an increase of 1.53 (0.01 x 153.071) daily visits to the urgent visit clinic (raising the mean number of daily urgent visits from 147.50 to approximately 149.03). An alternative interpretation of this result is that a 10 percent decrease in the mean of the air pollution variable (decreasing the mean by 0.0044 ppm) would be associated with a 0.46 ((0.0044 x 153.071)/147.50) percent decrease in the number of urgent visits. The coefficients and t-statistics of the other environmental variables indicated statistically insignificant effects of temperature and wind on urgent visits. The weekend dummy variables again reflected decreased utilization on weekends.

Taken together, the results for 1973 and 1974 relating photochemical oxidant pollution to unscheduled utilization suggest a number of possible associations worthy of further exploration. Both 1973 and 1974 data exhibited a relationship between unscheduled ophthalmology visits and oxidant levels, although 1974 air pollution data from a second monitoring station failed to demonstrate a similar association. In addition, 1974 data indicated mixed associations between unscheduled pediatric visits and oxidant levels ; air pollution data from one monitoring station exhibited a positive and statistically significant relationship with unscheduled visits, while data from a second station displayed a negative and statistically insignificant relationship. Finally, 1974 data suggested an association between urgent clinic visits and oxidant levels. Air pollution readings from one monitoring station were related positively and significantly with such visits and readings from a second station were also related positively although not quite significantly. Given these findings, further analysis was warranted.

LAG AND EPISODIC EFFECTS

In addition to the fact that a time-series multiple regresssion allows one to investigate contemporaneous effects while assuming that many of the factors affecting health status remain essentially constant on a day-to-day basis, it also permits one to investigate other possible effects. In particular we examined lag effects and episodic effects of photochemical oxidants.

Since we might expect that our measure of health status, namely clinic utilization, would be affected by levels of air pollution on immediately preceding days, we included lagged air pollution variables representing the air pollution readings on the three preceding days. 13/ The results (summarized in Table 8.7 and Table 8.8) of including these simple lagged variables indicated that there were no consistent , significant simple lag effects relating department utilization and oxidant levels for both years of data. Specifically the combined net effect of the contemporaneous and lagged pollution variables was positive for only one of the three departments in 1973 (regression 1, Table 8.7) and it failed to hold for that department in 1974 (regression 2, Table 8.8). Furthermore, the combined net effect for the ophthalmology department in 1974 (regression 4, Table 8.8) was not significantly greater than the simple contemporaneous association estimated previously (regression 4, Table 8.6).

13/ Several studies have used lags of up to three days. See, for example Greenburg et al. [19].

TABLE 8.7. LAG EFFECTS OF OXIDANTS ON UN-SCHEDULED DEPARTMENT UTILIZATION (PENNSYLVANIA AVENUE - 1973)

	UIM	UOPHTH	UPED
	1	2	3
R^2	0.636 a/	0.524	0.702
Constant	16.823	9.412	55.257
Air Pollution:			
Ox_t	26.034 b/	1.968	10.246
	(1.78) c/	(0.21)	(0.34)
Ox_{t-1}	-7.190	12.717	37.819
	(-0.46)	(1.24)	(1.16)
Ox_{t-2}	-5.108	-10.803	-69.348
	(-0.34)	(-1.08)	(-2.19)
Ox_{t-3}	18.309	-6.345	-6.880
	(1.39)	(-0.73)	(-0.25)
Weather:			
Av T	-0.034	-0.014	-0.113
	(-1.49)	(-0.92)	(-2.38)
Av Wind	0.058	0.016	-0.335
	(0.54)	(0.22)	(-1.48)
Dunmy:			
Sat	-9.340	-5.347	-4.417
	-(10.94)	(-9.54)	(-2.48)
Sun	-16.833	-8.517	-42.139
	(-20.88)	(-16.10)	(-25.46)

a/ The coefficient of determination; a value of 0.636 indicates that 63.6 percent of the variation in unscheduled visits was "explained" by the independent variables.

b/ The regression coefficient.

c/ The t-statistic; a value of 1.65 indicates significance at the 10 percent level, using a two-tailed test.

TABLE 8.8. LAG EFFECTS OF *OXIDANTS ON UN*-SCHEDULED DEPARTMENT UTILIZATION (PENNSYLVANIA AVENUE - 1974)*

	UIM		UOPHTH		UPED		WC	
	1	2	3	4	5	6	7	8
R^2	0.216 a/	0.278	0.292	0.318	0.515	0.526	0.318	**0.339**
Constant	8.474	12.268	4.136	7.472	60.687	75.134	159.077	165.601
Air Pollution:								
Ox_t	-18.765 b/	10.178	8.314	51.902	31.908	114.358	**88.693**	110.178
	(-1.02) c/	(0.51)	(0.58)	(3.07)	(0.56)	(1.87)	(0.91)	(1.03)
Ox_{t-1}	-13.116	-0.145	-19.418	14.866	-8.579	82.336	102.977	77.995
	(-0.68)	(-0.01)	(-1.29)	(0.99)	(-0.14)	(1.30)	(1.01)	(0.70)
Ox_{t-2}	-12.769	-6.439	-26.272	0.149	-95.987	-111.195	-226.244	-94.740
	(-0.67)	(-0.31)	(-1.77)	(0.01)	(-1.64)	(-1.77)	(-2.23)	(-0.86)
Ox_{t-3}	0 007	-7.580	-14.526	27.646	-92.119	-32.386	122.890	15.747
	(0.01)	(-0.39)	(-1.09)	(1.99)	(-1.75)	(-0.55)	(1.35)	(0.15)
Weather:								
Av T	0.079	0.006	0.081	-0.082	-0.184	-0.508	0.021	0.001
	(1.84)	(0.16)	(2.39)	(-2.90)	(-1.37)	(-4.26)	(0.09)	(0.01)
Av Wind	-0.108	-0.205	0.114	0.139	1.188	0.893	-0.184	-0.590
	(-0.86)	(-1.70)	(1.16)	(1.59)	(3.06)	(2.43)	(-0.27)	(-0.92)
Dummy:								
Sat	-6.059	-6.310	-5.386	-4.863	-7.065	-8.718	-30.759	-35.811
	(-5.66)	(-5.85)	(-6.42)	(-6.23)	(-2.14)	(-2.66)	(-5.38)	(-6.24)
Sun	-10.031	-10.423	-7.722	-7.548	-51.510	-54.769	-61.566	-65.407
	(-9.90)	(-10.28)	(-9.74)	(-10.28)	(-16.46)	(-17.75)	(-11.38)	(-12.12)

* The odd-numbered regressions are based oxidant data collected at Cleveland Park and the even-numbered regressions are based on oxidant data collected at the CAMP station.

a/ The coefficient of determination; a value of 0.276 indicates that 27.6 percent of the variation in unscheduled visits was "explained" by the independent variables.

b/ The regression coefficient.

c/ The t-statistic; a value of 1.65 indicates significance at the 10 percent Level, using a two-tailed test.

In addition to testing for simple lags, we employed the Almon distributed lag technique in order to examine the data for more complicated lag effects. This procedure imposes structure on the coefficients of the lagged air pollution variables by constraining them to fit a polynomial curve of a specified degree. The method often results in the reduction of large standard errors in the distributed lag coefficients that may arise from multicollinearity in the lagged values of the independent variables. It also allows for considerable flexibility. We began by fitting second- and third-degree polynomials, using lags of five days. The results (not reported) did not uncover any consistent, significant lag effects.

Time-series multiple regression also allows one to investigate whether a consecutive period of several days of high air pollution are more "detrimental" to health than isolated days of high air pollution. That is, it permits one to examine the implications of air pollution episodes. This issue is of particular interest since several studies have uncovered such episodic effects. 14/ One way to explore the possibility of episodic effects is to define a new air pollution variable as the product of the air pollution readings on several consecutive days and substituting this variable in place of a simple contemporaneous air pollution measure. Specifically, we defined a new air pollution variable as the product of the photochemical oxidant levels for the current day and the two preceding days. 15/ The results (Table 8.9 and Table 8.10) of using this variable in place of the simple contemporaneous air pollution measure indicated that the data did not evidence episodic effects of this nature. (In fact, when the coefficients for the episodic variables were statistically significant, they were negative.) We then examined "episodes" of different lengths and found similar results. In other words, we did not find that department utilization significantly increased during periods in which air pollution levels were elevated for a successive number of days.

THE EFFECTS OF OTHER AIR POLLUTANTS

In addition to looking at the association between photochemical oxidant levels and clinic utilization, we were able to investigate the effects of three other air pollutants primarily related to mobile sources (non-methane hydrocarbons, nitrogen dioxide, and carbon monoxide) and one air pollutant primarily related to stationary sources (sulfur dioxide). This section will present the regression results pertinent to these air pollutants.

Non-methane Hydrocarbons

We reported in Section VI that the levels of non-methane hydrocarbons exceeded the national standards on most days for which data were available (See Table 6.1). Nevertheless, the results of substituting readings on non-methane hydrocarbons for photochemical oxidants in statistical analyses similar to those reported above did not uncover any consistently significant relationship between unscheduled utilization in any department and the level of non-methane hydrocarbons (as measured by the 3-hour average taken at the CAMP station) during 1973 (Table 8.11). Unfortunately, adequate 1974 non-methane hydrocarbon data were not available to permit a replication of these findings.

14/ For a detailed review of several air pollution episodes, see Ashe [7] and McCarroll [30].

15/ In notational terms, $Ox_t = \prod_{k=0}^{2} Ox_{t-k}$,

TABLE 8.9. EPISODIC EFFECTS OF OXIDANTS ON UNSCHEDULED DEPARTMENT UTILIZATION (PENNSYLVANIA AVENUE - 1973)

	UIM	UOPHTH	UPED
	1	2	3
R^2	0.639 a/	0.448	0.634
Constant	18.120	7.930	52.054
Air Pollution:			
$\prod_{k=0}^{2} Ox_{t-k}$	-0.535 b/ (-0.72) c/	0.152 (0.32)	-1.214 (-0.72)
Weather:			
Av T	-0.005 (-0.22)	-0.001 (-0.07)	-0.067 (-1.47)
Av Wind	0.022 (0.22)	-0.015 (-0.24)	-0.527 (-2.35)
Dummy:			
Sat	-10.189 (-11.74)	-4.352 (-7.87)	-3.618 (-1.86)
Sun	-17.855 (-21.39)	-7.787 (-14.65)	-42.176 (-22.56)

a/ The coefficient of determination; a value of 0.639 indicates that 63.9 percent of the variation in unscheduled visits was "explained" by the independent variables.

b/ The regfession coefficient.

c/ The t-statistic; a value of 1.65 indicates significance at the 10 percent level, using a two-tailed test.

TABLE 8.10. EPISODIC EFFECTS OF OXIDANTS ON UNSCHEDULED DEPARTMENT UTILIZATION (PENNSYLVANIA AVENUE - 197'

	UIM		UOPHTH		UPED		WC	
	1	2	3	4	5	6	7	8
R^2	0.282 a/	0.271	0.275	0.257	0.512	0.500	0.308	0.326
Constant	9.481	11.646	5.436	4.794	64.184	71.825	156.890	161.652
Air Pollution:								
$\sum_{k=0}^{2} Ox_{t-k}$ (CP)	-2.344 b/ (-2.47) c/		-1.997 (-2.65)		-8.067 (-2.73)		1.189 (0.23)	
$\prod_{k=0}^{2} Ox_{t-k}$ (CAMP)		-0.418 (-0.16)		1.354 (0.70)		4.459 (0.56)		10.907 (0.79)
Weather:								
Av T	0.042 (1.50)	0.010 (0.34)	0.034 (1.52)	0.018 (0.83)	-0.321 (-3.67)	-0.445 (-4.87)	0.135 (0.89)	0.096 (0.61)
Av Wind	-0.131 (-1.05)	-0.186 (-1.55)	0.074 (0.77)	0.147 (1.63)	1.107 (2.93)	0.938 (2.50)	-0.289 (-0.44)	-0.539 (-0.84)
Dummy:								
Sat	-6.208 (-5.87)	-6.144 (-5.77)	-5.531 (-6.58)	-4.838 (-6.03)	-8.231 (-2.50)	-8.084 (-2.43)	-31.258 (-5.47)	-35.131 (-6.13)
Sun	-10.219 (-10.33)	-10.230 (-10.32)	-7.595 (-9.66)	-7.159 (-9.60)	-51.337 (-16.65)	-52.911 (-17.10)	-60.700 (-11.36)	-63.847 (-11.98)

a/ The coefficient of determination; a value of 0.282 indicates that 28.2 percent of the variation in unscheduled visits was "explained" by the independent variables.

b/ The regression coefficient.

c/ The t-statistic; a value of 1.65 indicates significance at the 10 percent level, using a two tailed test.

TABLE 8.11. REGRESSION ANALYSIS OF NON-METHANE HYDROCARBON EFFECTS ON UNCHEDULED DEPARTMENT UTILIZATION (PENNSYLVANIA AVENUE - 1973)

	UIM	UOPHTH	UPED
	1	2	3
R^2	0.616 a/	0.542	0.715
Constant	15.475	10.673	53.761
Air Pollution:			
Nm H	0.181 b/ (0.27) c/	-0.021 (-0.05)	0.826 (0.59)
Weather:			
Av T	-0.005 (-0.24)	-0.022 (-1.66)	-0.123 (-2.91)
Av Wind	0.064 (0.49)	-0.070 (-0.81)	-0.208 (-0.76)
Dummy:			
Sat	-8.307 (-8.81)	-5.207 (-8.36)	-6.350 (-3.20)
Sun	-15.738 (-17.29)	-8.777 (-14.61)	-43.082 (-22.53)

a/ The coefficient of determination; a value of 0.616 indicates that 61.6 percent of the variation in unscheduled visits was "explained" by the independent variables.

b/ The regression coefficient.

c/ The t-statistic; a value of 1.65 indicates significance at the 10 percent level, using a two-tailed test.

Nitrogen Dioxide

Unlike the situation with non-methane hydrocarbons, we reported in Section VI that the levels of nitrogen dioxide in the Washington Metropolitan Area were below the national primary and secondary standard. When we substituted a nitrogen dioxide variable for the photochemical oxidant variable (in specifications similar to those reported previously) we did not find evidence of consistently significant associations between unscheduled utilization in any department and the level of nitrogen dioxide (as measured by the 24-hour average taken at the CAMP station) during 1973 (Table 8.12). Again, we did not have sufficient 1974 nitrogen dioxide data to test these findings by replication.

Carbon Monoxide

The final mobile-source air pollutant that we examined was carbon monoxide. The discussion in Section VI indicated that levels of this air pollutant were at or above the national standards at times during 1973 and 1974. Our empirical results from substituting a carbon monoxide variable for the photochemical oxidant variable suggested an association between unscheduled utilization of the ophthalmology department and levels of carbon monoxide (as measured by the maximum l-hour average taken at the CAMP station) during 1973. The relevant equation is shown below and corresponds to regression 3 in Table 8.13:

$$\text{UOPHTH} = 6.301 + \underset{(2.82)}{0.119}\ \text{CO} + \underset{(0.74)}{0.009}\ \text{Av T} + \underset{(0.52)}{0.035}\ \text{Av Wind}$$

$$\underset{(-7.86)}{-4.405}\ \text{Sat} - \underset{(-14.36)}{7.653}\ \text{Sun} \qquad (R^2 = 0.470)$$

The variables are similar to those in the specification above, although CO (the maximum l-hour average carbon monoxide reading on a given day) is substituted for the photochemical oxidant variable, Ox. Rather than discussing this equation in detail, we will interpret the results relative to those obtained for photochemical oxidants. One interpretation of the equation is that an increase of 1.0 ppm in the maximum l-hour average carbon monoxide level (raising the mean from 6.94 to 7.94 ppm) was related to an increase of 0.12 daily unscheduled visits to the ophthalmology department (raising the mean number of unscheduled visits from 6.07 to 6.19). An alternative interpretation of this result is that a 10 percent decrease in the mean of the air pollution variable would be associated with a 1.5 percent decrease in the number of unscheduled visits to the department.

In addition to the carbon monoxide data monitored at the CAMP station, comprehensive data for this air pollutant were available from another station located at D.C. General Hospital (see Table 6.1). When those readings were substituted for the CAMP station readings, the results indicated that the association for the ophthalmology department failed to hold. However, a positive and statistically significant association was seen between unscheduled pediatric visits and carbon monoxide readings from the D. C.

TABLE 8.12. REGRESSION ANALYSIS OF NITROGEN DIOXIDE EFFECTS ON UNSCHEDULED DEPARTMENT UTILIZATION (PENNSYLVANIA AVENUE - 1973)

	UIM	UOPHTH	UVC
	1	2	3
R^2	0.615 a/	0.456	0.645
Constant	18.715	7.979	51.865
Air Pollution:			
NO_2	-17.414 b/ (-0.78) c/	3.275 (0.23)	-38.977 (-0.80)
Weather:			
Av T	-0.010 (-0.53)	0.002 (0.20)	-0.474 (-1.18)
Av Wind	-0.007 (-0.07)	-0.022 (-0.32)	-0.465 (-2.01)
Dummy:			
Sat	-9.729 (-11.48)	-4.497 (-8.21)	-4.634 (-2.52)
Sun	-17.365 (-21.57)	-8.068 (-15.49)	-42.599 (-24.41)

a/ The coefficient of determination; a value of 0.615 indicates that 61.5 percent of the variation in unscheduled visits was "explained" by the independent variables.

b/ The regression coefficient.

c/ The t-statistic; a value of 1.65 indicates significance at the 10 percent level, using a two-tailed test.

TABLE 8.13. REGRESSION ANALYSIS OF CARBON MONOXIDE EFFECTS ON UNSCHEDULED DEPARTMENT UTILIZATION (PENNSYLVANIA AVENUE - 1973)

	UIM		UOPHTH		UPED	
	1	2	3	4	5	6
R^2	0.599 a/	0.634	0.470	0.446	0.650	0.631
Constant	18.377	16.339	6.301	7.939	48.570	44.760
Air Pollution:						
CO (CAMP)	-0.077 b/		0.119		0.136	
	(-1.15) c/		(2.82)		(0.96)	
CO (D.C.)		0.102		-0.037		0.306
		(1.50)		(-0.83)		(1.97)
Weather:						
Av T	-0.010	-0.011	0.009	0.007	-0.057	-0.032
	(-0.52)	(-0.60)	(0.74)	(0.56)	(-1.32)	(-0.75)
Av Wind	-0.010	0.132	0.035	-0.026	-0.312	-0.168
	(-0.09)	(1.27)	(0.52)	(-0.38)	(-1.36)	(-0.71)
Dummy:						
Sat	-9.645	-9.597	-4.405	-4.241	-3.394	-4.400
	(-10.76)	(-11.12)	(-7.86)	(-7.51)	(-1.78)	(-2.22)
Sun	-17.329	-17.375	-7.653	-7.880	-42.192	-42.125
	(-20.32)	(-21.26)	(-14.36)	(-14.74)	(-23.34)	(-22.41)

a/ The coefficient of determination; a value of 0.599 indicates that 59.9 percent of the variation in unscheduled visits was "explained" by the independent variables.

b/ The regression coefficient.

c/ The t-statistic; a value of 1.65 indicate8 signficance at the 10 percent level, using a two-tailed teet.

General Hospital station. 16/ The equation corresponding to regression 6 in Table 8.13 for the pediatric department is presented below:

$$UPED = 44.760 + \underset{(1.97)}{0.306\ CO} - \underset{(-0.75)}{0.032\ Av\ T} - \underset{(-0.71)}{0.168\ Av\ Wind}$$

$$\underset{(-2.22)}{-4.400\ Sat} - \underset{(-22.41)}{42.125\ Sun} \qquad (R^2 = 0.631)$$

The variables are as before except for the fact that the air pollution variable was based on readings monitored at D.C. General Hospital. One interpretation of this equation is that an increase of 1.0 ppm in the maximum l-hour average carbon monoxide level (raising the mean from 6.86 ppm to 7.86 ppm) was related to an increase of 0.31 daily unscheduled visits to the pediatric department (raising the mean number of unscheduled visits from 36.03 to 36.34). This can also be stated in percentage terms: a 10 percent decrease in the mean of the air pollution variable would be associated with a 0.58 percent decrease in the number of unscheduled visits to the department.

Carbon monoxide data were also available for 1974 from the monitoring station located at D.C. General Hospital. The results of statistical analyses using these data in conjunction with 1974 visitation and climatic data failed to uncover any statistically significant associations between carbon monoxide levels and unscheduled department visits (Table 8.14).

Following these results, we examined both the 1973 and 1974 carbon monoxide data in conjunction with the health data in an attempt to uncover lag or episodic effects of air pollution (not reported). As was the case for photochemical oxidants, no consistent lag or episodic effects were exhibited.

Sulfur Dioxide

The last air pollutant for which we had data was sulfur dioxide. As noted in Section VI, this air pollutant is primarily attributed to stationary sources. Notwithstanding, since the air pollution-health literature is dominated by studies involving stationary-source pollutants such as sulfur dioxide, 17/ we felt it would be useful to examine our data for possible associations. We recognized at the outset that the sulfur dioxide levels experienced in the Washington Metropolitan Area are substantially below those in most other metropolitan areas. Hence, we were somewhat surprised that our findings indicated possible associations between levels of sulfur dioxide and unscheduled visits to the internal medicine and ophthalmology departments.

Specifically, two monitoring stations (D.C. General Hospital and American Chemical Society) provided sufficient sulfur dioxide data to permit statistical analyses (see Table 6.1). In addition, each station reported both the 24-hour

---

16/ Note that the results using the CAMP station carbon monoxide data indicated a positive, statistically insignificant association with unscheduled pediatric visits (see regression 5, Table 8.13).

17/ See, for example, Hodgson [24] and Glasser and Greenburg [16].

TABLE 8.14. REGRESSION ANALYSIS OF CARBON MONOXIDE EFFECTS ON UNSCHEDULED DEPARTMENT UTILIZATION (PENNSYLVANIA AVENUE - 1974)

	UIM	UOPHTH	UPED	UVC
	1	2	3	4
R^2	0.256 a/	0.235	0.476	0.306
Constant	10.914	4.991	66.326	145.649
Air Pollution:				
CO (D.C.)	-0.065 b/ (-0.70) c/	0.0002 (0.01)	-0.025 (-0.09)	0.037 (0.07)
Weather:				
Av T	0.024 (0.96)	0.019 (0.99)	-0.364 (-4.74)	0.268 (1.90)
Av Wind	-0.174 (-1.35)	0.126 (1.27)	0.892 (2.25)	-0.048 (-0.07)
Dummy:				
Sat	-6.037 (-5.56)	-4.852 (-5.82)	-7.599 (-2.27)	-31.233 (-5.17)
Sun	-10.050 (-9.79)	-7.023 (-8.92)	-51.597 (-16.35)	-64.436 (-11.36)

a/ The coefficient of determination; a value of 0.256 indicates that 25.6 percent of the variation in unscheduled visits was "explained" by the independent variables.

b/ The regression coefficient.

c/ The t-statistic; a value of 1.65 indicates significance at the 10 percent level, using a two-tailed test.

average reading and the maximum l-hour reading. Our empirical results indicated that the latter measure was more important in terms of significant associations with the health data. 18/ Hence, Table 8.15 presents the results of separate regressions using 1973 sulfur dioxide levels (as measured by maximum l-hour readings) from each station for each department.

As can be seen from the table, none of the associations between unscheduled department visits and sulfur dioxide levels was significant for readings taken from both stations. However, positive and statistically significant associations were exhibited for unscheduled visits to the internal medicine department (regression 1) and for unscheduled visits to the ophthalmology department (regression 4). The relevant equations are reproduced below:

$$\underset{}{UIM} = 14.222 + \underset{(1.78)}{19.502\ SO_2} + \underset{(0.56)}{0.012\ Av\ T} + \underset{(1.35)}{0.147\ Av\ Wind}$$

$$\underset{(-10.50)}{-9.353\ Sat} - \underset{(-19.19)}{16.811\ Sun} \qquad (R^2 = 0.583)$$

$$UOPHTH = 6.166 + \underset{(1.65)}{10.680\ SO_2} + \underset{(1.12)}{0.017\ Av\ T} + \underset{(0.17)}{0.012\ Av\ Wind}$$

$$\underset{(-8.08)}{-4.508\ Sat} - \underset{(-14.45)}{7.875\ Sun} \qquad (R^2 = 0.452)$$

The variables are similar to those in the previous specifications, although SO_2 (the maximum l-hour average sulfur dioxide reading on a given day) is the air pollution variable. One interpretation of the first equation is that an increase of 0.01 ppm in the maximum l-hour average sulfur dioxide level (raising the mean from 0.041 to 0.051 ppm) was related to an increase of 0.20 daily unscheduled visits to the internal medicine department (raising the mean number of unscheduled visits from 13.02 to 13.22). An alternative interpretation of this result is that a 10 percent decrease in the mean of the air pollution variable would be associated with a 1.5 percent decrease in the number of unscheduled visits to the department.

With respect to the ophthalmology department, one interpretation of the second equation is that an increase of 0.01 ppm in the sulfur dioxide level was related to an increase of 0.11 daily unscheduled visits to the ophthalmology department (raising the mean number of unscheduled visits from 6.06 to 6.17). In percentage terms this result signifies that a 10 percent decrease in the mean of the air pollution variable would be associated with a 0.4 percent decrease in the number of unscheduled visits to the department.

Maximum l-hour readings for sulfur dioxide were available for only one station in 1974 (see Table 6.1). Analyses of these data in conjunction with the 1974 utilization data failed to replicate the positive associations

---

18/ This is a somewhat interesting result since the national primary standard for sulfur dioxide is based on a 24-hour average rather than a maximum l-hour average.

TABLE 8.15. REGRESSION ANALYSIS OF SULFUR DIOXIDE EFFECTS ON UNSCHEDULED DEPARMENT UTILIZATION (PENNSYLVANIA AVENUE - 1973)

	UIM		UOPHTH		UPED	
	1	2	3	4	5	6
R^2	0.583 a/	0.585	0.466	0.452	0.626	0.643
Constant	14.222	15.153	8.230	6.166	48.399	46.208
Air Pollution:						
SO_2 (D.C.)	19.502 b/ (1.78) c/		0.781 (0.12)		18.986 (0.81)	
SO_2 (ACS)		7.593 (0.72)		10.680 (1.65)		23.058 (1.07)
Weather:						
Av T	0.012 (0.56)	0.007 (0.29)	0.004 (0.30)	0.017 (1.12)	-0.049 (-1.07)	-0.024 (-0.47)
Av Wind	0.147 (1.35)	0.116 (1.03)	-0.032 (-0.48)	0.012 (0.17)	-0.331 (-1.42)	-0.317 (-1.38)
Dummy:						
Sat	-9.353 (-10.50)	-9.682 (-10.62)	-4.763 (-8.71)	-4.508 (-8.08)	-4.150 (-2.18)	-5.152 (-2.76)
Sun	-16.811 (-19.19)	-16.937 (-19.03)	-8.216 (-15.29)	-7.875 (-14.45)	-42.383 (-22.68)	-42.157 (-23.14)

a/ The coefficient of determination; a value of 0.583 indicates that 58.3 percent of the variation in unscheduled visits was “explained” by the independent variables.

b/ The regression coefficient.

c/ The t-statistic; a value of 1.65 indicates significance at the 10 percent level, using a two-tailed test.

exhibited in Table 8.15 for the 1973 data (Table 8.16). We also examined both the 1973 and 1974 data for evidence of lag or episodic effects involving sulfur dioxide data, but none were discovered (not reported).

SYNERGISTIC EFFECTS

There have been a number of studies suggesting the importance of interactions between air pollutants and their combined effects on health. Particular reference has been made to possible synergistic effects of ozone in combination with nitrogen oxides 19/, and oxidants in combination with sulfur dioxide. 20/ Consequently, in an effort to investigate our data for possible synergistic effects, we regressed the variables representing unscheduled utilization of the various departments on variables representing the possible interactions between photochemical oxidants and nitrogen dioxide, and between photochemical oxidants and sulfur dioxide. In addition, we examined the interaction between photochemical oxidants and carbon monoxide. 21/

The empirical analyses involving interaction terms for photochemical oxidants and nitrogen dioxide failed to uncover any evidence of synergism (Table 8.17). When the interaction term was substituted in the previous specifications, its coefficient failed to attain statistical significance. The results for the interaction between photochemical oxidants and sulfur dioxide were generally similar (Table 8.18). However, in this case, the interaction term was statistically significant in explaining the variation in 1974 unscheduled visits to the ophthalmology department (regression 4).22/ Nevertheless, upon comparing the estimated effect represented by the interaction term with the estimated effects corresponding to each of these air pollution variables in previous regressions, there was no indication of a synergistic relationship. That is, the magnitude of the association between the interaction variable (Ox x S02) and unscheduled ophthalmologic visits was less than the sum of the associations between unscheduled ophthalmologic visits and both photochemical oxidant levels and sulfur dioxide levels (regression 4, Table 8.6 and regression 2, Table 8.16, respectively). Finally, the results for the interaction between photochemical oxidants and carbon monoxide are presented in Table 8.19. Again, despite positive and statistically significant coefficients for the air pollution interaction term in regressions 4 and 7, the magnitude of the estimated effects did not indicate any evidence of synergism.

19/ See Thorp [38].

20/ See Amdur [3].

21/ In notational terms the interactions were equal to the product of the photochemical oxidant reading and the nitrogen dioxide reading, Ox x NO_2; the product of the photochemical oxidant reading and the sulfur dioxide reading, Ox x S02; and the product of the photochemical oxidant reading and the carbon monoxide reading, Ox x CO.

22/ This might be expected since the previous results indicated significant associations between unscheduled visits to the ophthalmology department and both photochemical oxidant levels and sulfur dioxide levels (measured at the American Chemical Society).

TABLE 8.16. REGRESSION ANALYSIS OF SULFUR DIOXIDE EFFECTS ON UNSCHEDULED DEPARTMENT UTILIZATION (PENNSYLVANIA AVENUE - 1974)

	UIM	UOPHTH	UPED	W C
	1	2	3	4
R^2	0.276 a/	0.234	0.472	0.292
Constant	15.038	3.844	75.379	149.633
Air Pollution:				
SO_2 (CAMP)	-29.222 b/ (-2.17) c/	1.511 (0.14)	-54.658 (-1.25)	-19.604 (-0.27)
Weather:				
Av T	-0.024 (-0.87)	0.033 (1.56)	-0.467 (-5.33)	0.246 (1.66)
Av Wind	-0.217 (-1.62)	0.015 (1.43)	0.960 (2.21)	-0.159 (-0.22)
Dummy:				
Sat	-6.284 (-5.72)	-5.009 (-5.88)	-9.397 (-2.66)	-34.847 (-5.83)
Sun	-10.329 (-9.88)	-6.974 (-8.54)	-51.772 (-15.32)	-60.162 (-10.50)

a/ The coefficient of determination; a value of 0.276 indicates that 27.6 percent of the variation in unscheduled visits was "explained" by the independent variables.

b/ The regression coefficient,

c/ The t-statistic; a value of 1.65 indicates significance at the 10 percent level, using a two-tailed test.

TABLE 8.17. SYNERGISTIC EFFECTS OF OXIDANTS AND NITROGEN DIOXIDE ON UNSCHEDULED DEPARTMENT UTILIZATION (PENNSYLVANIA AVENUE - 1973)

	UIM 1	UOPHTH 2	UPED 3
R^2	0.629 a/	0.445	0.632
Constant	18.314	8.198	49.565
Air Pollution:			
Ox x NO_2	-204.237 b/ (-1.12) c/	168.168 (1.40)	-447.909 (-1.10)
Weather:			
Av T	-0.003 (-0.14)	-0.007 (-0.52)	-0.018 (-0.38)
Av Wind	0.008 (0.07)	-0.016 (-0.24)	-0.491 (-2.13)
Dummy:			
Sat	-9.823 (-11.36)	-4.319 (-7.58)	-5.019 (-2.60)
Sun	17.748 (-21.49)	-7.992 (-14.70)	-42.535 (-23.03)

a/ The coefficient of determination; a value of 0.629 indicates that 62.9 percent of the variation in unscheduled visits was “explained” by the independent variables.

b/ The regression coefficient.

c/ The t-statistic; a value of 1.65 indicates significance at the 10 percent level, using a two-tailed test.

TABLE 8.18. SYNERGISTIC EFFECTS OF OXIDANTS AND SULFUR DIOXIDE ON UNSCHEDULED DEPARTMENT UTILIZATION (PENNSYLVANIA AVENUE - 1973 and 1974)*

	UIM		UOPHTH		UPED		WC
	1	2	3	4	5	6	7
R^2	0.636 a/	0.276	0.450	0.257	0.641	0.470	0.293
Constant	18.034	12.746	7.775	2.706	52.409	71.133	149.154
Air Pollution:							
Ox x SO_2 (ACS)	-146.976 b/ (-1.21) c/		105.900 (1.33)		-69.059 (-0.25)		
ox x SO_2 (CAMP)		-480.82 (-1.76)		397.534 (1.99)		390.013 (0.44)	819.820 (0.55)
Weather:							
Av T	-0.001 (-0.06)	0.004 (0.16)	0.000 (0.01)	0.029 (1.54)	-0.077 (-1.81)	-0.456 (-5.23)	0.229 (1.60)
Av Wind	0.018 (0.18)	-0.185 (-1.41)	-0.008 (-0.13)	0.233 (2.43)	-0.488 (-2.13)	1.129 (2.64)	-0.111 (-0.15)
Dummy:							
Sat	-9.777 (-10.82)	-6.233 (-5.67)	-4.444 (-7.49)	-4.780 (-5.95)	-3.499 (-1.73)	-9.073 (-2.54)	-35.214 (-5.85)
Sun	-17.8 (-21.39)	-10.303 (-9.67)	-7.892 (-14.44)	-6.897 (-8.85)	-42.570 (-22.77)	-52.361 (-15.10)	-60.703 (-10.39)

*Regressions 1, 3, and 5 are based on 1973 data and regressions 2, 4, 6 and 7 are based on 1974 data.

a/ The coefficient of determination; a value of 0.636 indicates that 63.6 percent of the variation in unscheduled visits was "explained" by the independent variables.

b/ The regression coefficient.

c/ The t-statistic; a value of 1.65 indicates significance at the 10 percent level, using a two-tailed test.

TABLE 8.19. SYNERGISTIC EFFECTS OF OXIDANTS AND CARBON MONOXIDE ON UNSCHEDULED DEPARTMENT UTILIZATION (PENNSYLVANIA AVENUE - 1973 and 1974)*

	UIM		UOPHTH		UPED		WC
	1	2	3	4	5	6	7
R^2	0.634 a/	0.192	0.447	0.197	0.632	0.659	0.292
Constant	17.865	3.182	7.665	1.291	51.140	6.003	104.409
Air Pollution:							
ox x co	-0.838 b/	1.161	0.285	2.995	-0.124	-1.359	20.359
	(-1.52) c/	(0.69)	(0.80)	(2.46)	(-0.10)	(-0.34)	(2.23)
Weather:							
Av T	-0.004	-3.223	0.003	-3.272	-0.065	2.132	-17.789
	(-0.18)	(-2.83)	(0.22)	(-3.99)	(-1.53)	(0.78)	(-2.89)
Av Wind	0.056	0.252	0.001	0.004	-0.440	0.399	0.818
	(0.52)	(3.35)	(0.01)	(0.07)	(-1.86)	(2.21)	(2.01)
Dummy:							
Sat	-10.231	-0.019	-4.426	0.062	-5.498	0.912	0.697
	(-11.09)	(-0.63)	(-7.39)	(2.92)	(-2.71)	(13.08)	(4.42)
Sun	-17.926	0.132	-7.865	0.057	-42.346	0.391	0.567
	(-20.23)	(6.25)	(-13.67)	(3.76)	(-21.73)	(7.73)	(4.96)

*Regressions 1, 3 and 5 are based on 1973 data and regressions 2, 4, 6, and 7 are based on 1974 data.

a/ The coefficient of determination; a value of 0.634 indicates that 63.4 percent of the variation in unscheduled visits was "explained" by the independent variables.

b/ The regression coefficient.

c/ The t-statistic; a value of 1.65 indicates significance at the 10 percent level, using a two-tailed test.

THE EFFECTS OF OTHER METEOROLOGICAL VARIABLES

Thus far we have reported results using only two meteorological variables, average daily temperature and average daily wind speed. Here, we investigate the effects of two additional climatic variables, daily precipitation and daily temperature change. These two variables were selected on the basis of findings from other studies. For example, precipitation has been included in a study of emergency hospital admissions to account for the fact that rain (or snow) might render transportation by foot or automobile more hazardous and consequently cause accidents. 23/ We feel this factor has only limited applicability to our analysis; however, for completeness, we felt it appropriate to examine the effects of including a precipitation variable. Similarly, mention has been made in some studies that various illnesses such as asthma can be aggravated by sudden temperature changes; 24/ hence, we defined a temperature change variable as the difference between the maximum daily temperature and minimum daily temperature and explored the effects of including this variable in our statistical analyses.

In general, the inclusion and substitution of the various climatic variables did not greatly affect the magnitude and significance of the coefficients of the air pollution variables. The only noteworthy exception indicated that substitution of the temperature change variable for the average temperature variable had a moderate effect on the importance of certain air pollution variables. This was not unexpected, since the air pollution variables were, in general, more highly correlated with average temperature than with temperature change (see Appendix E).

As with the previous results, the additional weather variables seldom exhibited statistically significant associations with the unscheduled visitation data from the various departments. However, some generalizations can be stated. Without question, the climatic variable that most often was statistically significant was the temperature change variable. At those times when the variable was significant in explaining unscheduled visits, the signs of its coefficient indicated that the greater the difference between the minimum and maximum daily temperature the more unscheduled visits occurred. This result was particularly true for visits to the pediatric department and to a lesser extent for visits to the internal medicine department. 25/

THE EFFECTS ON METRO TRANSIT EMPLOYEES

As discussed in Section IV, approximately 15 percent of the membership of the Group Health Association is comprised of Washington metropolitan transit system employees. We felt that an examination of this subset of GHA

23/ See Silverman [34].

24/ See [8].

25/ To put this result into perspective we note that a 10 percent increase in the temperature difference variable (raising the mean from about 18 to about 20 degrees) would be related to an increase of between 0.3 and 0.4 Percent in the mean number of unscheduled pediatric visits. This can be contrasted with the elasticities corresponding to the significant associations with the air pollution variables in Table 2.1.

members would be of particular interest. This was based on the presumption that many of the Metro employees would be likely to be exposed to significantly higher doses (or more prolonged exposure) to mobile-source air pollution in their occupations as bus drivers or repair workers than other members of GHA. Consequently, we replicated most of the analyses already discussed for this group. In doing so, however, we found it necessary to aggregate unscheduled utilization and scheduled utilization. 26/

In general, the results based on the Metro sample did not display significant associations between monitored levels of the various air pollutants and visits to the clinic departments. 27/ In fact, the only consistently significant associations were exhibited between visits by Metro employees to the ophthalmology department and photochemical oxidant levels during 1974.

The following two equations present these results:

$$\underset{}{\text{METRO-OPHTH}} = 1.331 + \underset{(2.00)}{9.526}\ \text{Ox} + \underset{(0.79)}{0.006}\ \text{Av T} + \underset{(1.34)}{0.038}\ \text{Av Wind}$$

$$\underset{(-7.14)}{-1.771}\ \text{Sat} - \underset{(-10.39)}{2.454}\ \text{Sun} \qquad (R^2 = 0.299)$$

$$\text{METRO-OPHTH} = 1.595 + \underset{(1.59)}{6.012}\ \text{Ox} + \underset{(0.59)}{0.005}\ \text{Av T} + \underset{(1.06)}{0.031}\ \text{Av Wind}$$

$$\underset{(-6.97)}{-1.778}\ \text{Sat} - \underset{(-10.13)}{2.428}\ \text{Sun} \qquad (R^2 = 0.293)$$

The top equation is based on 1974 photochemical oxidant data monitored at the CAMP station, while the bottom equation is based on 1974 photochemical oxidant data monitored at the Cleveland Park Public Library (see Table 6.1). In other respects, these equations are similar to previous specifications except that the dependent variable is now total department visits by the Metro sample rather than unscheduled department visits by the total sample.

One interpretation of these results is that a 10 percent decrease in the mean of the relevant air pollution variables would be associated with between a 2.0 and a 1.5 percent decrease in the number of visits by Metro employees to the ophthalmology department. Our conclusion from this analysis is that, in general, the findings for the Metro sample were not at significant variance from the findings for the total sample. Given the limited data and the aforementioned difficulties associated with statistical analyses of small samples, we caution against overinterpretation of these results.

26/ This was necessary since the sample size was greatly reduced resulting in relatively large sampling variation. Large sampling variation greatly impedes attempts to uncover significant statistical associations in such data. See Lave and Seskin [28].

27/ We concentrated primarily on visits to the internal medicine and ophthalmology departments, since pediatric visits were not thought to be relevant for this subsample.

THE FINDINGS FOR ANOTHER HEALTH CLINIC

As discussed in Section V, in addition to the data for the main GHA facility in downtown Washington, we had data from a smaller suburban clinic located in Takoma Park (see Tables 5.2 and 5.4). In this section we will report on the empirical analyses pertaining to these data. Emphasis will be placed on the differences between the Takoma Park results and the findings for the Pennsylvania Avenue clinic previously discussed.

Our "strongest" results involve the association between unscheduled visits to the ophthalmology department and levels of photochemical oxidants. Unfortunately, as mentioned in Section V, the Takoma Park clinic does not run an ophthalmology department; hence, we could not examine this association at that facility. With regard to our other findings, the general statement can be made that the associations between unscheduled utilization at Takoma Park and levels of air pollution were weaker than the associations seen in using the data from the main Pennsylvania Avenue facility.

At least two possible explanations for this fact come to mind. The first involves difficulties that may be associated with analyzing the relatively small samples represented by department utilization at Takoma Park (see Appendix B). As discussed in the preceding section, small samples and the accompanying large sampling variation raise statistical problems in analyses of this nature.

Another possible explanation for the "poor" results from using the Takoma Park data concerns the fact that both air pollution exposures and the relevant population group may exhibit different characteristics than the data represented by the analysis involving the Pennsylvania Avenue Clinic. This hypothesis is more difficult to assess.

SECTION IX

DISCUSSION

POLICY IMPLICATIONS

The lack of information on the effects of mobile-source air pollutants, especially with regard to health, has made it difficult to evaluate the potential benefits (including health benefits) from abatement of air pollution attributed to mobile sources. 1/ Given that the annual cost of controlling mobile-source emissions from automobiles has been estimated to be as high as $11 billion by 1985, this is a serious shortcoming. 2/

The only association we found to be consistent and statistically significant for data from both 1973 and 1974 was between daily unscheduled visits to the ophthalmology department at GHA and levels of photochemical oxidant pollution. Even here, 1974 air pollution data from a second monitoring station did not confirm the relationship. In addition, a relationship between urgent clinic visits and photochemical oxidant levels during 1974 (both stations) was noted with interest. Isolated positive and significant associations were also found between photochemical oxidant Levels and unscheduled pediatric visits, carbon monoxide levels and both unscheduled ophthalmologic and unscheduled pediatric visits, and sulfur dioxide Levels and both unscheduled internal medicine and unscheduled ophthalmologic visits. What can we say about these results?

The association between mobile-source air pollutants and eye irritation has been well documented. 3/ What is of particular interest here is the fact that the levels of photochemical oxidant pollution in our data were considerably below most "threshold" levels noted in the literature. 4/ Unfortunately, the specific complaint associated with the urgent clinic visits cannot be determined from our data. Hence, we have no way of examining the association between specific ailments and photochemical oxidant levels in light of the literature. Nevertheless, we should note the association, although statistically significant, was of smaller magnitude than the association with eye problems (see Table 2.1). That is, even if the association proved to be causal in nature, it is questionable as to how serious the policy implications (or economic consequences) would be. Finally, despite the fact that positive and significant associations were noted between levels of other air pollutants (carbon monoxide and sulfur dioxide) and unscheduled department visits (see above), these results were mixed. Hence, we believe that it would be overinterpreting the data to draw policy conclusions from the isolated findings pertaining to these air pollutants.

While investigators may later find a strong association between ill health and automobile emissions (as represented by ambient Levels of carbon monoxide, nitrogen oxides, hydrocarbons, and photochemical oxidants), current evidence is somewhat to the contrary. This is in contrast to the relatively large number of studies that document significant associations between ill health and ambient levels of such stationary-source air pollutants as suspended particulates and sulfates. In general, the results from this study pertaining to the Washington Metropolitan Area support this difference.

1/ See National Academy of Sciences [31].

2/ Ibid., p. 12.

3/ See Hammer *et al*. [20].

4/ *Ibid.*, p. 257.

ECONOMIC CONSEQUENCES

Despite our very limited findings, we will make a crude calculation of the economic consequences pertaining to the relationship between oxidant levels and ophthalmologic visits. First we will determine the percent reduction in oxidant levels that would be necessary in order that the national standard of 0.08 ppm (maximum l-hour average) not be exceeded. From our data, we estimate the necessary reductions to be 55.6 percent for 1973 oxidant levels and 42.9 percent for 1974 oxidant levels. Thus, if oxidant levels were reduced by about 50 percent in the Washington D.C. Metropolitan Area, the air quality in the region would probably be in compliance with the national ambient air quality standard for photochemical oxidants. Using the estimated reductions, we can then apply them to the elasticities computed pertaining to the oxidant-ophthalmology association (see Table 2.1). The results indicate that the above reductions in oxidant levels would correspond to a 6.1 percent reduction in unscheduled ophthalmologic visits during 1973 and an 18.4 percent reduction during 1974. This, in turn, represents approximately 136 unscheduled visits to GHA in 1973 and 367 unscheduled visits to GHA in 1974.

The second step involves attaching a monetary value to these visits. To estimate the direct medical costs, we will assign the value of $20.00 per visit. We have no specific cost data but that value is representative of the average medical costs associated with visits for simple eye problems in Maryland [22]. This translates into direct medical costs of approximately $2700 in 1973 and $7300 in 1974.

However, the direct medical costs calculated above represent only one component of the benefits that would be obtained from abating oxidant air pollution if a causal relationship exists between oxidant levels and unscheduled ophthalmologic visits. Additional indirect costs would be associated with lost worker productivity and restricted activity. Unfortunately, it is difficult to estimate these indirect costs as they might relate to ophthalmologic problems. Nevertheless, Cooper and Rice (12′ recently estimated the economic cost of illness in the United States. They found that for diseases of the nervous system and sense organs indirect costs (including losses due to illness of homemakers who cannot perform their housekeeping duties) were approximately 80 percent as great as direct medical costs. Hence, using this proportion, we can obtain crude estimates of the indirect costs associated with reduced ophthalmologic problems. Specifically, the indirect costs were calculated to be $2160 for 1913 and $5840 for 1974.

Finally, there are additional costs associated with pain and suffering. However, no one has successfully quantified this dimension of illness. Rather than assign completely arbitrary numbers to this category, we prefer to conclude that the sum of the direct and indirect costs estimated above represent an underestimate of the “true” costs associated with reduced ophthalmologic visits. Thus, $4860 in 1973 and $13,140 in 1974 represent underestimates of the “true” benefits of reducing ophthalmologic visits that would be obtained from the assumed reductions in photochemical oxidant levels (if the relationship between oxidant levels and ophthalmologic visits were a causal one).

To extrapolate these benefit estimates to the entire Metropolitan Washington Area is presumably stretching the data beyond its limits. We know, for example, that the population embodied in the Group Health membership is not representative of the Metropolitan Washington Area population. 5/ Furthermore, it is difficult to determine the direction of bias this introduces. Nevertheless, with these caveats in mind, for illustrative purposes we will assume that the Group Health members are characteristic of the metropolitan population. This would imply that the benefits relating to decreased ophthalmologic problems from the assumed reductions in photochemical oxidant levels could be as great as twenty (the ratio of the Metropolitan Washington Area population to the GHA membership) times the monetary estimates derived above. That is, the 1973 benefit estimate could be as high as $97,200 and the 1974 benefit estimate could be as high as $262,800. 6/

The benefit estimates should not be taken out of context. To put these numbers in perspective one must remember that there are costs associated with reducing photochemical oxidant levels. The primary method of abating photochemical oxidants in the Washington Metropolitan Area is by policies designed to control emissions from automobiles. A conservative estimate of the annual costs of emission-control devices on automobiles is $100 per auto [32]. The automobile population for our study area is approximately 700,000. This translates into costs of about $70 million per year. Clearly, the Metropolitan Washington population is incurring substantial costs for the control of mobile-source emissions. Although benefits in addition to reduced ophthalmologic problems may accrue from such control policies, our limited findings cannot be used to justify these large expenditures.

Thus, our findings along with other existing evidence, suggest that mobile-source air pollution exhibits to a limited degree acute health effects. Evidence supporting chronic health effects from mobile-source air pollutants is virtually non-existent. It is possible that, in certain areas of the country, the relationship between the levels of mobile-source air pollutants and acute effects such as eye irritation warrant stringent regional emission control policies. However , the adoption of stringent national emission control policies is questionable. Additional information on the health effects of automobile emissions may, of course, alter these conclusions. Furthermore, if other effects (e.g., aesthetic effects) associated with mobile-source air pollution are found to be of substantial magnitude and importance, policymakers may justify the control of mobile-source emissions on that basis alone.

FUTURE RESEARCH

The nature of the data available for statistical analyses has suggested a number of future research needs. perhaps the most serious deficiency in investigating the air pollution-health relationship is that of good air quality data. As noted in Section III, air quality measurements taken at

---

5/ See Section IV, especially p. 18.

6/ Note, these benefit estimates do not include possible improvements in other health areas or benefits that might be associated with improved visibility, aesthetic effects, and so on.

a single sampling station must often be assumed to be representative of a large geographical area. Furthermore, often inadequate equipment takes infrequent readings of relatively few air pollutants. 7/ If we are to provide better answers as to how much specific air pollutants should be abated, better air quality data are required.

While one category of future needs involves obtaining better measurements of the quality of air at a number of sites, another involves measuring the quality of the air actually breathed by individuals. Thus, a personal, portable device that would enable one to measure the dose of each air pollutant the individual actually experienced would be invaluable in examining the air pollution-health association.

Thus far we have confined the discussion to the air pollution exposure data. However, the particular measure of health status is itself an important concern. As noted in Section III, morbidity data such as those used in this study should be more sensitive indicators of air pollution effects than mortality data. However, comprehensive morbidity data are seldom available. A possible approach to this problem might involve constructing a panel, the members of which are monitored closely for changes in their health status. Variations in the morbidity rate over time for each individual (as a function of changes in air pollution exposure) would provide an almost ideal measure of the air pollution-health association. 8/ While such data are likely to be expensive to gather, they seem to be a prerequisite for sorting out the health effects of various air pollutants.

Needless to say, a great deal of work remains to be done in establishing the relationship between air pollution and human health. For epidemiological investigations of the sort reported in this study, one key to further knowledge is better data.

7/ Many references have been made throughout this study to the inadequacy of many of the air pollution data series. In addition, for a given air Pollutant, there was some evidence that conflicting results may have been related to differences in the specific type of monitoring equipment in place.

8/ See Speizer [36].

SECTION X

REFERENCES

1. "Air Quality in the National Capital Interstate Air Quality Region - 1972," Technical Report No. 2, Addendum, Metropolitan Washington Council of Governments, September 1973.

2. "Air Quality in the National Capital Interstate Air Quality Region - 1974," Technical Report No. 9, Metropolitan Washington Council of Governments, August 1975.

3. Amdur, M. "Toxicological Guidelines for Research on Sulfur Oxides and Particulates," Proceedings of the Fourth Symposium on Statistics and the Environment, forthcoming.

4. Anderson, T.W. An Introduction to Multivariate Statistical Analysis (New York: John Wiley 6 Sons, 1958).

5. Annual Report on the Quality of the Air in Washington, D.C. 1973, Government of the District of Columbia, Department of Environmental Services, Environmental Health Administration, Bureau of Air & Water Quality, Air & Water Monitoring Division.

6. Annual Report on the Quality of the Air in Washington. D.C. 1974, Government of the District of Columbia, Department of Environmental Services, Environmental Health Administration, Bureau of Air & Water Quality, Air & Water Monitoring Division.

7. Ashe, W.F. "Exposure to High Concentrations of Air Pollution (1) - Health Effects of Acute Episodes," Proceedings of the National Conference on Air Pollution, Washington, D.C., Nov. 18-20, 1958, PHS Publ. No. 654, 188 (1959)

8. Berke, J., and V. Wilson. Watch Gut for the Weather (New York: Viking, 1951); and Climate and Man, 1941 Yearbook of Agriculture, U.S. Department of Agriculture Publication (1941).

9. Cederlöf, R. "Urban Factor and Prevalence of Respiratory Symptoms and Angina Pectoris," Archives of Environmental Health 13, 743 (1966).

10. The Chesapeake & Potomac Telephone Company, Yellow Pages, 1976.

11. Cohen, C.A. et al. "Carbon Monoxide and Survival from Myocardial Infarction," Archives of Environmental Health 19, 510 (1969).

12. Cooper, B.S., and D.P. Rice. "The Economic Cost of Illness Revisited." Washington, D.C., U.S. Government Printing Office, Social Security Bulletin, Social Security Administration, DHEW Publication No. (SSA) 76-11703, February 1976.

13. Daly, C. "Air Pollution and Causes of Death," British Journal of Preventive and Social Medicine 13, 14 (1959).

14. GHA News, Annual Report Issue, May 2, 1974, Vol. XXXVII, No. 3, Group Health Association, Inc.

15. GHA News, Annual Report Issue, April-May, 1975, Vol. XXXVII, No. 2, Group Health Association, Inc.

16. Glasser, M., and L. Greenburg. "Air Pollution, Mortality, and Weather," Archives of Environmental Health 22, 334 (1971).

17. Goldberger, A. Econometric Theory (New York: John Wiley & Sons, 1964).

18. Greenburg, L. et al. "Air Pollution and Morbidity in New York City," Journal of the American Medical Association 182, 161 (1962).

19. Greenburg, L. et al. "Report of an Air Pollution Incident in New York City, November 1953," Conference Reports, Public Health Reports 77, 7 (1962).

20. Hammer, D.I. et al. "Los Angeles Student Nurse Study," Archives of Environmental Health 28, 255 (1974).

21. Hammond, E.C., and D. Horn. "Smoking and Death Rates--Report on Forty-four Months of Follow-up of 187,783 Men. II. Death Rates by Cause," Journal of the American Medical Association 166, 1294 (1958).

22. Hatem, T.J. "Medical Costs in the State of Maryland." A Report of the Insurance Commissioner.

23. Heimann, H. "Episodic Air Pollution in Metropolitan Boston -- A Trial Epidemiological Study," Archives of Environmental Health 20, 230 (1970).

24. Hodgson, T.A. "Short-term Effects of Air Pollution on Mortality in New York City," Environmental Science and Technology 4, 589 (1970).

25. Jaksch, J.A., and H.H. Stoevener. "Outpatient Medical Costs Related to Air Pollution in the Portland, Oregon Area." Washington, D.C., U.S. Government Printing Office, Environmental Protection Agency Publication No, 600/5-74-017, 1974.

26. Johnston, J. Econometric Methods 2nd Edition (New York: McGraw Hill, 1972).

27. Kendall, M.G. A Course in Multivariate Analysis (New York: Hafner, 1968).

28. Lave, L.B., and E.P. Seskin. Air Pollution and Human Health, forthcoming for Resources for the Future, Inc., Johns Hopkins University Press.

29. Lave, L.B., and E.P. Seskin. "An Analysis of the Association Between U.S. Mortality and Air Pollution," Journal of the American Statistical Association 68, 284 (1973).

30. McCarroll, J. "Measurements of Morbidity and Mortality Related to Air Pollution," Journal of the Air Pollution Control Association 17, 203 (1967).

31. National Academy of Sciences, Air Quality and Automobile Emission Control, Volume 4. The Costs and Benefits of Automobile Emission Control, A report by the Coordinating Committee on Air Quality Studies, National Academy of Sciences, National Academy of Engineering, Serial No. 93-24, Washington, D.C.: U.S. Government Printing Office, 1974.

32. National Academy of Sciences, Report by the Committee on Motor Vehicle Emissions. Washington, D.C.: National Academy of Sciences, February 12, 1973.

33. Pearlman, M.E. et al. "Nitrogen Dioxide and Lower Respiratory Illness," Pediatrics 47, 391 (1971).

34. Silverman, L.P. "The Determinants of Daily Emergency Admissions to Hospitals," Public Research Institute, Center for Naval Analyses, 1973.

35. Simon, H. "Spurious Correlation: A Causal Interpretation," Journal of the American Statistical Association 49, 467 (1954).

36. Speizer, F. "An Epidemiological Approach to Health Effects of Air Pollutants," Proceedings of the Fourth Symposium on Statistics and the Environment, forthcoming.

37. Stocks, P. British Medical Journal, 1, 74 (1959).

38. Thorp, C.E. "Influence of Nitrogen Oxides on the Toxicity of Ozone," Journal of the American Chemical Society (News Edition) 19, 686 (1941).

39. U.S.D.C. National Oceanic and Atmospheric Administration Environmental Service, Local Climatological Data Annual Summary of Comparative Data, Washington, D.C., National Airport.

40. Winkelstein, W., Jr., and M.L. Gay. "Suspended Particulate Air Pollution," Archives of Environmental Health 22, 174 (1971).

41. Winkelstein, W., Jr., and S. Kantor. "Prostatic Cancer: Relationship to Suspended Particulate Air Pollution," American Journal of Public Health 59, 1134 (1969).

42. Winkelstein, W., Jr., and S. Kantor. "Respiratory Symptoms and Air Pollution in an Urban Population of Northeastern United States," Archives of Environmental Health 18, 760 (1969).

43. Winkelstein, W., Jr., and S. Kantor. "Stomach Cancer: Positive Association with Suspended Particulate Air Pollution," Archives of Environmental Health 18, 544 (1969).

44. Winkelstein, W., Jr. et al. "The Relationship of Air Pollution and Economic Status to Total Mortality and Selected Respiratory System Mortality in Men, I: Suspended Particulates," Archives of Environmental Health 14, 162 (1967).

45. Winkelstein, W., Jr. et al. "The Relationship of Air Pollution and Economic Status to Total Mortality and Selected Respiratory System Mortality in Men,II: Suspended Particulates." Archives of Environmental Health 16, 401 (1968).

46. Zeidberg, L.D., R.J.M. Horton, and E. Landau. "The Nashville Air Pollution Study, V: Mortality From Diseases of the Respiratory System in Relation to Air Pollution," Archives of Environmental Health 15, 214 (1967).

47. Zeidberg, L.D., R.J.M. Horton, and E. Landau. "The Nashville Air Pollution Study, VI: Cardiovascular Disease Mortality in Relation to Air Pollution," Archives of Environmental Health 15, 225 (1967).

48. Zeidberg, L.D., and R.A. Prindle, "The Nashville Air Pollution Study, II: Pulmonary Anthracosis as an Index of Air Pollution," American Journal of Public Health 53, 185 (1963).

49. Zeidberg, L.D., R.A. Prindle, and E. Landau. "The Nashville Air Pollution Study, I: Sulfur Dioxide and Bronchial Asthma," American Review of Respiratory Disease 84, 489 (1961).

50. Zeidberg, L.D., R.A. Prindle, and E. Landau. "The Nashville Air Pollution Study, III: Morbidity in Relation to Air Pollution," American Journal of Public Health 54, 85 (1964).

Appendix A

DAILY DEPARTMENT UTILIZATION VARIABLES USED IN THE ANALYSIS
(Pennsylvania Avenue)

Department	Minimum	Maximum	Mean	Standard Deviation
Internal Medicine				
Unscheduled	0[a] (0)[b]	34[a] (46)[b]	13[a] (8)[b]	8.5[a] (7.7)[b]
Metro	0 (0)	25 (26)	8 (8)	5.2 (5.8)
Ophthalmology				
Unscheduled	0 (0)	20 (37)	6 (5)	4.6 (6.0)
Metro	0 (0)	10 (9)	2 (2)	1.7 (1.9)
Pediatrics				
Unscheduled	0 (0)	79 (151)	36 (44)	19.4 (20.2)
Metro	N A	N A	N A	N A
Urgent Visit Clinic				
Urgent Visit	13 (2)	260 (324)	123 (146)	42.1 (44.4)
Metro	0 (0)	24 (42)	9 (13)	4.4 (5.5)

[a]Figures for 1973.

[b]Figures for 1974.

Appendix B

DAILY DEPARTMENT UTILIZATION VARIABLES USED IN THE ANALYSIS
(Takoma Park)

Department	Minimum	Maximum	Mean	Standard Deviation
In ernal Medicine				
Unscheduled	0[a] (0)[b]	8[a] (7)[b]	1[a] (1)[b]	.35[a] (5.2)[b]
Pediatrics				
Unscheduled	0 (0)	64 (89)	25 (24)	14.6 (17.7)
Urgent Visit Clinic				
Urgent Visit	0 (0)	95 (144)	42 (38)	22.5 (24.3)

[a]Figures for 1973.

[b]Figures for 1974.

Appendix C

DAILY AIR POLLUTION VARIABLES USED IN THE ANALYSIS*

Air Pollution Measure	Minimum	Maximum	Mean	Standard Deviation
Photochemical Oxidants				
CAMP (Max. l-hr. av.)	.001[a](.001)[b]	.180[a](.140)[b]	.048[a](.038)[b]	.032[a](.026)[b]
Clv. Park (Max. 1-hr. av.)	(.001)	(.220)	(.044)	(.033)
Non-methane Hydrocarbons				
CAMP (3-hr. av.)	. 000	4.10	.564	.542
Nitrogen Dioxide				
CAMP (24-hr. av.)	.005	.101	.045	.015
Carbon Monoxide				
CAMP (Max. 1-hr. av.)	1.00	43.0	6.94	5.07
D.C. Hosp. (Max. l-hr. av.)	1.00 (1.0)	30.0 (28.0)	6.86 (6.76)	4.64 (4.34)
Sulfur Dioxide				
CAMP (24-hr. av.)	(.002)	(.082)	(.017)	(.014)
ACS (24-hr. av.)	.002	.134	.035	.022
D.C. Hosp. (24-hr.av.)	.002 (.002)	.070 (.062)	.020 (.014)	.012 (.009)
CAMP (Max. 1-hr. av.)	(.002)	(.076)	(.037)	(.031)
ACS (Max. l-hr. av.)	.008	.222	.059	.038
D.C. Hosp. (Max. l-hr. av.)	.006	.320	.041	.032

*All figures in parts per million (ppm)

[a]Figures for 1973.

[b]Figures for 1974.

Appendix D

DAILY WEATHER VARIABLES USED IN THE ANALYSIS

Climatic Measure	Minimum	Maximum	Mean	Standard Deviation
Average Temperature (°F.)	19[a] (26)[b]	86[a] (85)[b]	59.4[a] (58.8)[b]	16.70[a] (15.1)[b]
Temperature Difference (°F.) (Max. - Min.)	3 (3)	38 (38)	18.1 (18.8)	6.58 (6.41)
Average Wind Speed (m.p.h.)	1.6 (2.7)	22.9 (20.4)	8.4 (8.6)	3.08 (3.09)
Total Precipation (in.)	0 (0)	2.88 (1.90)	.096 (.099)	.256 (.272)

[a]Figures for 1973.

[b]Figures for 1974.

Appendix E

CORRELATION MATRIX OF 1973 EXPLANATORY VARIABLES AND OF 1973-1974 EXPLANATORY VARIABLES

		← 1973 →												
		ACS SO_2 24-Hr	D.C. Hosp. SO_2 24-Hr Ave	ACS SO_2 Max 1-Hr	D.C. Hosp SO_2 Max 1-Hr	CAMP CO Max 1-Hr	D.C. Hosp CO Max 1-Hr	CAMP NO_2 24-Hr Ave	CAMP NmH 3-Hr Ave	CAMP Ox Max 1-Hr	Ave Temp	Diff	Ave Wind	Precip
1973	D.C. Hosp-SO_2-24-Hr	.48												
	ACS-SO_2-Max 1-Hr	.89	.52											
	D. C. Hosp-SO_2-Max 1-Hr	.43	.80	.48										
	CAMP-CO-Max 1-Hr	.25	.23	.31	.35									
	D.C. Hosp-CO-Max 1-Hr	.10	.17	.15	.24	.51								
	CAMP-NO_2-24-Hr	-.13	-.01	-.06	.05	.36	.22							
	CAMP-NmH-3-Hr	.08	11	.10	.23	.56	.53	.39						
	CAMP-Ox-Max 1-Hr	-.28	-.24	-.28	-.11	.28	.08	.29	.45					
	Ave Temp	-.57	-.44	-.57	-.36	-.10	-.09	.28	.09	.66				
	Temp Diff	-.06	.02	.04	.16	.24	.25	.28	.24	.22	.12			
	Ave Wind	-.003	-.08	-.06	-.15	-.29	-.25	-.42	-.34	-.30	-.27	-.15		
	Precip	-.02	-.06	-.05	-.08	-.02	-.03	-.05	.04	-.05	.01	-.24	.04	
	SAT	-.06	.21	-.06	-.04	-.13	-.08	-.15	-.05	-.01	-.01	-.03	.01	-.06
	SUN	-.03	-.08	-.03	-.06	-.18	-.06	-.11	-.12	.02	-.02	-.003	-.08	-.02
1974	CAMP-SO_2-24-Hr	.25	.16	.24	.09	-.03	.09	-.15	-.15	-.39	-.34	-.07	.11	.08
	D.C. Hosp-SO_2-24-Hr	.12	.05	.14	.06	.12	.10	-.03	-.01	-.22	-.34	-.07	.112	.02
	CAMP-SO_2-Max 1-Hr	.18	.12	.17	.07	-.02	-09	-.09	-.12	-.35	-.28	-.09	.08	.12
	D.C. Hosp-CO-Max 1-Hr	-.05	-.03	-.05	.02	.003	.04	.12	.06	-.05	-.02	.01	-.03	.02
	CAMP-Ox-Max 1-Hr	-.49	-.35	-.49	-.30	-.18	-.15	.20	.03	.48	.67	.06	-.12	-.09
	Clv Pk-Ox-Max 1-Hr	-.36	-.28	-.41	-.25	-.14	-.13	.21	.02	.53	.65	.03	-.16	.07
	Ave Temp	-.55	-.43	-.57	.36	-.16	-.13	.22	.01	.59	.80	.04	-.19	-.007
	Temp Diff	-.10	-.06	-.08	04	-.06	.07	18	-.01	.03	.11	.06	-.06	-.04
	Ave Wind	.10	.02	.15	.05	-.01	.02	-.08	-.06	-.15	-.14	.05	.06	.002
	Precip	.007	-.06	-.02	-.04	-.04	-.12	-.08	.03	.12	.06	-.03	-.02	.003

Appendix F

CORRELATION MATRIX OF 1974 EXPLANATORY VARIABLES

	CAMP SO_2 24-Hr	D.C. Hosp SO_2 24-Hr	CAMP SO_2 Max 1-Hr	D.C. Hosp CO Max 1-Hr	CAMP OX Max 1-Hr	Clv. Pk. OX Max 1-Hr	Ave Temp	Temp Diff	Ave Wind	Precip
D.C. Hosp-SO_2-24-Hr	.14									
CAMP-SO_2-Max 1-Hr	.74	.09								
D.C. Hasp-CO-Max 1-Hr	-11	-15	.22							
CAMP-Ox-Max 1-Hr	-.25	-.13	-.22	-.001						
Clv Pk-Ox-Max 1-Hr	-.31	-.19	-.21	.04	.67					
Ave Temp	-.39	-.26	-.30	.05	.71	.71				
Temp Diff	.11	.19	.13	.35	.31	.21	.19			
Ave Wind	-.16	-.12	-.23	-.35	-.16	-.21	-.22	-.14		
Precip	-.05	-.15	-.07	-.07	-.08	-.08	.05	-.19	.17	
SAT	.02	-.03	.03	-.07	.007	-.04	-.02	-.10	-.05	-.01
SUN	.06	-.12	.003	-.09	.11	.05	-.01	.03	.01	.06

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

REPORT NO. EPA-600/5-77-010	2.	3. RECIPIENT'S ACCESSION NO.
TITLE AND SUBTITLE Air Pollution and Health in Washington, D.C. Some Acute Health Effects of Air Pollution in the Washington Metropolitan Area		5. REPORT DATE July 1977 6. PERFORMING ORGANIZATION CODE
AUTHOR(S) Eugene P. Seskin		8. PERFORMING ORGANIZATION REPORT NO
PERFORMING ORGANIZATION NAME AND ADDRESS National Bureau of Economic Research, Inc. 1750 New York Ave, NW Washington, D.C. 20006		10. PROGRAM ELEMENT ND. PF 1HA094 11. CONTRACT/GRANT NO. EPA Contract #68-01-3144
2. SPONSORING AGENCY NAME AN0 ADDRESS Environmental Research Laboratory-Corvallis Office of Research and Development U.S.Environmental Protection Agency Corvallis, Oregon 97330		13. TYPE OF REPORT AND PERIOD COVERED extra-mural,final,1973-74 14. SPONSORING AGENCY CODE EPA/600-02

5. SUPPLEMENTARY NOTES

6. ABSTRACT

This study has attempted to assess some of the acute health effects of air pollution. Specifically, the investigation has tested the hypothesis that air pollution can aggravate the health status of a population and can result in increased utilization of certain types of medical care services.

The study period was 1973-1974 and centered in the Washington, D.C. Metropolitan Area. Statistical models were formulated, explaining health-care utilization of a group practice medical care plan. Primary interest was focused on the effects of mobile-source air pollutants including carbon monoxide, nitrogen dioxide, non-methane hydrocarbons, and photochemical oxidants. Meteorological conditions as well as other variables thought to influence the consumption of medical services were include in the models as explanatory variables.

The statistical results indicated that air pollution levels had a very limited effect on the health-care utilization of the group practice.

7. KEY WORDS AND DOCUMENT ANALYSIS

DESCRIPTORS	b.IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Economic Analysis Benefit/Cost Analysis, Air Pollution Economic Effects, Air Pollution Economic Effects, Health	Air Pollution Economics Economic Impact Air Pollution Effects (Health)	06/F,S

8. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 94
	20 SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-l (Rev. 4-77)

☆ U S GOVERNMENT PRINTING OFFICE 1977-798-504/197