Evaluation of CHESS: Utah Asthma Study 1971-1972

EPRI

EPRI EA-2829
Project 1316-1
Final Report
February 1983

words:
epidemiology
CHESS
Criteria Air Pollutants
Asthma
Utah Study

DO NOT MICROFILM
COVER

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Prepared by
Battelle, Pacific Northwest Laboratories
Richland, Washington

ELECTRIC POWER RESEARCH INSTITUTE

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

EPRI-EA--2829

DE83 007426

Evaluation of CHESS: Utah Asthma Study 1971-1972

EA-2829
Research Project 1316-1

Final Report, February 1983

Prepared by

BATTELLE, PACIFIC NORTHWEST LABORATORIES
P.O. Box 999
Richland, Washington 99352

Principal Investigators

A. R. Olsen
H. D. Tolley
J. C. Simpson
T. Namekata
J. S. Woods

NOTICE

**PORTIONS OF THIS REPORT ARE ILLEGIBLE. It
has been reproduced from the best available
copy to permit the broadest possible avail-
ability.**

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Prepared for

Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, California 94304

EPRI Project Manager
R. E. Wyzga

Environmental and Occupational Health Program
Energy Analysis and Environment Division

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

ORDERING INFORMATION

Requests for copies of this report should be directed to Research Reports Center (RRC), Box 50490, Palo Alto, CA 94303, (415) 965-4081. There is no charge for reports requested by EPRI member utilities and affiliates, contributing nonmembers, U.S. utility associations, U.S. government agencies (federal, state, and local), media, and foreign organizations with which EPRI has an information exchange agreement. On request, RRC will send a catalog of EPRI reports.

201700

ALL INFORMATION CONTAINED
HEREIN IS UNCLASSIFIED
DATE 01-10-2017 BY 60322
AUTHORITY 101-101

~~Copyright © 1985 Electric Power Research Institute, Inc. All rights reserved.~~

NOTICE

This report was prepared by the organization(s) named below as an account of work sponsored by the Electric Power Research Institute, Inc. (EPRI). Neither EPRI, members of EPRI, the organization(s) named below, nor any person acting on behalf of any of them: (a) makes any warranty, express or implied, with respect to the use of any information, apparatus, method, or process disclosed in this report or that such use may not infringe privately owned rights; or (b) assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method, or process disclosed in this report.

Prepared by
Battelle, Pacific Northwest Laboratories
Richland, Washington

ABSTRACT

Four panels of asthmatics (156 total) in the Salt Lake Basin participated in a mailed diary study recording the occurrence of daily attacks for 67 weeks. Daily minimum temperatures and concentration data for total suspended particulates, suspended sulfates, suspended nitrates, sulfur dioxide and nitrogen dioxide were collected from monitoring sites located within two miles from panelist's residences. An evaluation of the quality of air pollution data and daily diary responses revealed collection and measurement problems. These problems accompanied by the lack of data on other factors affecting asthmatics limited drawing conclusions based on the data. Statistical analysis of the available data revealed a collinearity problem among the air pollutants precluding associating an effect to a single pollutant. Overall, no indication of an air pollution effect was found.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

EPRI PERSPECTIVE

PROJECT DESCRIPTION

This final report for RP1316-1, Evaluation of CHESS: Utah Asthma Study 1971-1972, is one of a series of research efforts that analyzes in depth an epidemiologic data set originally collected by the EPA. That agency undertook over 100 such studies in an effort to learn more about the relationship between health effects and air pollution. The data sets and their initial analyses have been subject to considerable controversy because of errors in both the data collected and the initial analyses. For this reason, none of the CHESS data are currently being used as part of the regulation-setting process. Detailed analyses have not been applied, however, to all of the data sets, some of which may present a valuable data resource for future analyses.

The Utah asthma studies were never formally considered in any regulation-setting effort; however, their data were regarded as being probably the best of the asthma studies. For this reason it was felt that they should be exploited to determine (1) whether a successful asthma study can be undertaken and (2) whether there is any epidemiologic "real-world" evidence linking asthma attacks to air pollution. The latter is particularly important given the current regulatory emphasis placed on changes in the physiological symptoms of exercising asthmatics exposed to air pollution.

PROJECT OBJECTIVE

The objective of this project is to examine and analyze the Utah asthma data sets obtained under CHESS in order to gain a better understanding of the health effects of air pollution. The use of state-of-the-art statistical techniques will also serve to advance the methodology for analyzing health effects data and to provide some guidelines for future epidemiologic studies.

PROJECT RESULTS

The results reemphasize many of the problems associated with asthma epidemiology studies. Unfortunately many of these problems pose difficulties for the analysis of

the Utah studies. The panelists studied were not a random sample. This leaves open the question of the possibility of bias from the way participants were selected. Also, no records of medication use, pollen levels, emotional stress, and respiratory infections were available. Since all of these factors can trigger asthma attacks, an analysis that ignores them must be incomplete.

Three statistical approaches were nevertheless applied to the data sets. No one approach is probably superior; together, the three approaches provide some indication of the air pollution-asthma link if the data are reliable. No consistent pattern across communities, scenarios, or methodologies supported a conclusion of a positive pollution effect. Specifically, no association can be found in any of the four study communities between asthma attacks and SO_2 or particulate matter. In two of the four communities, for one of the three methods (multiple regression analyses), there were some positive associations between asthma attacks and suspended sulfates; in all of these instances, this result was accompanied by a significant negative association for suspended nitrates. The other two methods found no significant trends between asthma attacks and suspended nitrate or sulfate. The confusing sign on the suspended nitrate variable suggests that collinearity among the pollutants may be responsible for the aberrant results in the multiple-regression analyses for the two communities. The lack of supportive evidence for other methodologies detracts from the significance of this result.

On the whole the three asthma analyses supported by EPRI give little support to an association between asthma attacks and air pollution. The only possible exception to this statement is some limited evidence of an association with particulate matter in the 1971 to 1972 New York studies. Certainly, no evidence whatsoever was found to link asthma attacks with SO_2 exposure at the levels experienced in these studies. This result may be important in interpreting the significance of some of the physiological effects associated with SO_2 exposure in clinical studies of exercising asthmatics.

Ronald E. Wyzga, Project Manager
Energy Analysis and Environment Division

ACKNOWLEDGMENTS

H. Daniel Roth and Edward H. Pechan of Roth Associates, Inc., were helpful in contributing their experience in studying the methodology and interpretation of CHES asthma studies. Ronald E. Wyzga, EPRI project manager, provided overall direction to our effort and was helpful in obtaining the Utah 1971-72 asthma data. They and Dr. Sid Marks of Battelle-Northwest graciously reviewed the report suggesting improvements in the presentation.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

CONTENTS

<u>Section</u>	<u>Page</u>
1. SUMMARY AND BACKGROUND OF STUDY	1-1
1.1 Background of Study	1-2
1.2 Major Findings	1-4
Markov Chain/Grouping Analysis Findings	1-5
Korn and Whittemore Logistic Regression	1-5
Multiple Regression Analysis Findings	1-6
Temperature-Specific Relative Risk Analysis Findings	1-7
2. ASTHMA AS A HEALTH INDICATOR IN ENVIRONMENTAL EPIDEMIOLOGY	2-1
2.1 Clinical and Biological Characteristics of Asthma	2-2
Physiological and Immunological Features of Asthma	2-2
Factors That Can Trigger Asthma Attacks	2-5
2.2 Review of Selected Asthma Panel Studies	2-8
2.3 New Orleans Asthma	2-13
3. AEROMETRY: LIMITATIONS AND PATTERNS	3-1
3.1 Collection Procedures and Measurement Problems	3-3
Sulfur Dioxide and Nitrogen Dioxide Measurement Problems	3-4
Total Suspended Particulate Measurement Problems	3-5
Total Water Soluble Suspended Sulfates (SS) and Suspended Nitrate (SN) Measurement Problems	3-6
Meteorologic Data	3-7
3.2 Community Aerometric Patterns	3-8
Inter-Community Patterns	3-8
Intra-Community Correlations	3-10
Alternate Monitoring Sites	3-14
3.3 Missing Aerometric Data	3-17
Mean Differences	3-18

<u>Section</u>	<u>Page</u>
4. SUBJECT VARIABILITY: IMPACT ON ASSESSMENT OF ASTHMA PANELS	4-1
4.1 Panel Composition	4-3
4.2 Daily Attack Patterns	4-8
Day of Week	4-8
Day of Study	4-12
Clustering of Attacks	4-16
4.3 Panel Characteristics and Observed Attack Rates	4-17
5. ANALYSES CORRECTING FOR VARIATION AMONG PANELISTS	5-1
Selection and Limitations of Analyses	5-2
5.1 Markov Analysis of Variance Model of Panelists Response Profiles	5-4
The Model	5-4
Application of the Model	5-7
Results of Analysis	5-8
Limitations of Analysis	5-10
5.2 Whittemore and Korn Logistic Analysis	5-12
The Logistic Model	5-12
Combination of Coefficients	5-13
Results of the Analysis	5-14
Examination of Results	5-21
6. PERSON-DAY BASED ANALYSES	6-1
6.1 Correlation and Regression Analyses	6-1
Description of Analyses	6-2
Correlation of Analysis	6-4
Regression Analysis	6-4
Analyses for Subsets of Participating Panelists	6-9
6.2 Temperature-Specific Estimates of Risk: Relative Risk Model	6-11
Limitations of Relative Risk Model	6-11
Relative Risk Analysis	6-16
APPENDIX A	A-1

ILLUSTRATIONS

<u>Figure</u>	<u>Page</u>
4-1 Size of Panel and Number of Respondents in Ogden Panel for Each Day of Study	4-9
4-2 Size of Panel and Number of Respondents in Salt Lake City Panel for Each Day of Study	4-9
4-3 Size of Panel and Number of Respondents in Kearns Panel for Each Day of Study	4-10
4-4 Size of Panel and Number of Respondents in Magna Panel for Each Day of Study	4-10
5-1 Relative Risk of Attack Corresponding to Specified Decrease in Minimum Temperature in Ogden with All Other Variables Held Constant	5-19

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

TABLES

<u>Table</u>	<u>Page</u>
1-1 Age and Sex Composition of Community Panels	1-3
2-1 Factors Which Trigger Asthma Attacks	2-6
3-1 Meteorological Measurement Summary Statistics	3-9
3-2 Comparison of Last 41 Weeks of Community Maximum and Minimum Temperatures	3-9
3-3 Air Pollution Measurements Summary Statistics by Community	3-11
3-4 Simple Correlations of Daily Pollutant Levels Among Communities	3-11
3-5 Aerometry Correlation Coefficients in Ogden	3-12
3-6 Aerometry Correlation Coefficients in Salt Lake City	3-12
3-7 Aerometry Correlation Coefficients in Kearns	3-13
3-8 Aerometry Correlation Coefficients in Magna	3-13
3-9 Comparison of Daily Air Pollutant Measurements at CHESS Site with Other Nearby Sites	3-16
4-1 Number of Daily Asthma Diary Responses for Each Diary Question Responses by Community	4-4
4-2 Number of Panelists by Community Included and Omitted for Specific Reasons	4-6
4-3 Characteristics of Utah Asthma Diary Study Population	4-7
4-4 Mean Response of O/B(T) by Day of Week for Adults and Juveniles	4-11
4-5 Frequency of Discrete, Primary and Secondary Attack Days for Adults and Juveniles by Day of Week and Community	4-13
4-6 Serial Correlation of Day of Study with Daily Indicators by Community	4-15
4-7 Serial Correlation of Attack Rate Indicators with Day of Study by Community and Age	4-15
4-8 Clustering of Panelist Attacks by Community	4-17
4-9 Percentage of Panelists Associating Frequent Asthma Attacks with Selected Conditions	4-19
4-10 Age, Age Asthma Began and Attack Rate Summary for Adult/Juvenile Categories by Community	4-20
5-1 Grouping Levels for Aerometric Variables	5-5
5-2 Analysis of Variance for Asthma Attacks Using Model 5-7 when Y_{ijk} is Formed from Equation 5-2	5-9

<u>Table</u>	<u>Page</u>
5-3 Analysis of Variance for Asthma Attacks Using Model 5-7 When Y_{ijk} is Formed from Equation 5-3	5-9
5-4 Combined Coefficients According to the Fixed Effects Model	5-15
5-5 Combined Coefficients According to the Random Effects Model	5-16
5-6 Estimates of Interpanelist Variability, $\hat{\eta}^2$	5-17
5-7 Increase in Attack Probability Corresponding to Specified Baseline Probabilities and Covariate Changes	5-20
5-8 Increase in Attack Probability Corresponding to Specified Baseline Probabilities and Covariate Changes	5-20
5-9 Observed and Expected Number of Attacks Among 36 Panelists in Ogden by Decile of Attack Risk	5-22
5-10 Observed and Expected Number of Attacks Among 36 Panelists in Ogden by Decile of Minimum Temperature	5-22
5-11 Observed Attacks and Estimated Attack Probabilities Aggregated over the 2 by 7 Contingency Table Formed by the Discrete Covariates for a Panelist in Salt Lake City	5-24
5-12 Average Attack Probabilities and Standard Errors Tabulated by the Day of the Week, Previous and Current Day's Observed Responses for a Panelist in Salt Lake City	5-25
5-13 Distribution of Attack Rates for Each Panel	5-26
5-14 Estimated Coefficients and Percent Contribution to the Combined Estimate for the Discrete Covariates for 10 Panelists in Ogden	5-28
5-15 Estimated Coefficients and Percent Contribution to the Combined Estimate for the Continuous Covariates for 10 Panelists in Ogden	5-29
6-1 Simple Correlations of Asthma Attack Variables with Experimental Design, Demographic and Air Quality Variables by Community	6-5
6-2 Summary of Observed Daily Asthma Attack Rate Regressions with Minimum Temperature and Individual Air Pollutants	6-7
6-3 Index of Multiple Regression Analyses Using Observed Asthma Attack Rate as Dependent Variable	6-8
6-4 Observed Daily Attack Rates and Ratio O/B(T) for Subsets of Participating Panelists	6-10
6-5 Temperature-Pollutant Specific Asthma Attack Rates by Community	6-13
A-1 Study Days with Missing Air Pollution Data by Air Pollutant in Each Study Community	A-1
A-2 Comparison of Selected Indicators Between Days Included and Deleted from Analysis - Ogden	A-2
A-3 Comparison of Selected Indicators Between Days Included and Deleted from Analysis - Salt Lake City	A-3
A-4 Comparison of Selected Indicators Between Days Included and Deleted from Analysis - Kearns	A-4
A-5 Comparison of Selected Indicators Between Days Included and Deleted from Analysis - Magna	A-5

<u>Table</u>	<u>Page</u>
A-6 Frequency of Primary, Secondary and Discrete Attack Days by Age, Quarter and Day of Week in Ogden	A-6
A-7 Frequency of Primary, Secondary and Discrete Attack Days by Age, Quarter and Day of Week in Salt Lake City	A-7
A-8 Frequency of Primary, Secondary and Discrete Attack Days by Age, Quarter and Day of Week in Kearns	A-8
A-9 Frequency of Primary, Secondary and Discrete Attack Days by Age, Quarter and Day of Week in Magna	A-9
A-10 Medical History Profile of the Ogden Panel	A-10
A-11 Medical History Profile of the Salt Lake City Panel	A-11
A-12 Medical History Profile of the Kearns Panel	A-12
A-13 Medical History Profile of the Magna Panel	A-13
A-14 Square Root of Average Attack Rates for Treatment Combinations Occurring in Ogden	A-14
A-15 Square Root of Average Attack Rates for Treatment Combinations Occurring in Salt Lake City	A-16
A-16 Square Root of Average Attack Rates for Treatment Combinations Occurring in Kearns	A-18
A-17 Square Root of Average Attack Rates for Treatment Combinations Occurring in Magna	A-20
A-18 Summary of Multiple Regression Analyses of Observed Daily Asthma Attack Rates for Ogden Panel	A-22
A-19 Summary of Multiple Regression Analyses of Observed Daily Asthma Attack Rates for Salt Lake City Panel	A-23
A-20 Summary of Multiple Regression Analyses of Observed Daily Asthma Attack Rates for Kearns Panel	A-24
A-21 Summary of Multiple Regression Analyses of Observed Daily Asthma Attack Rates for Magna Panel	A-25
A-22 Scenario 3 Multiple Regression of Observed Daily Attack Rates for Selected Subsets of Participating Panelists in Each Community	A-26
A-23 Temperature-Specific Relative Risks Based on Odds Ratio for Individual Pollutants and Communities	A-27
A-24 Average Levels of Selected Pollution, Temperature and Design Variables for Statistically Significant Temperature-Specific Scenarios	A-28
A-25 Simple Correlation Coefficients Between Study Variables Based on Daily Observations Included in Statistically Significant Temperature-Specific Scenarios	A-29

Section 1

SUMMARY AND BACKGROUND OF STUDY

The objectives of the project "Evaluation of Statistical Methods and Databases for Utah 1971-72 Asthma (CHESS) Study" were to review and evaluate relevant air pollution literature, to acquire the original 1971-72 Utah asthma data, to assess the quality of the data and its impact on the study results and to apply selected statistical methodologies to the data. The Utah 1971-72 asthma study refers to data collected by the Environmental Protection Agency (EPA) from March 7, 1971 to June 17, 1972 in four Salt Lake Basin communities. These data were part of EPA's Community Health and Environmental Surveillance System (CHESS) program to identify associations between air pollutants and the aggravation of asthma symptoms among subjects with pre-existing asthma. The Utah study design was conceived as monitoring asthmatic panels in four communities using a daily mailed diary format accompanied by daily aerometric measurements and a preliminary baseline health questionnaire.

A review of air pollution literature directly related to asthma panel studies was completed. Emphasis was given to other EPA CHESS asthma studies, including original analyses and subsequent reanalysis. Asthma panel studies conducted prior to the series of CHESS studies were reviewed to place the Utah 1971-72 study design in historical perspective. A brief review of the clinical and biological characteristics of asthma and factors that can trigger asthma attacks was undertaken to provide background information useful in evaluating the results of the Utah 1971-72 asthma study.

After acquiring the original data, the data quality and its impact on study results was assessed. This was accomplished by identifying the field procedures used to collect the data and the procedures used to incorporate the data into a data base, by reviewing relevant literature concerning these procedures and by statistically investigating characteristics of the data itself.

Four separate statistical methodological approaches were applied to the Utah 1971-72 asthma data. Previous asthma panel studies relied extensively on multiple regression of daily panel attack rates and on temperature specific relative risk analyses. These person-day based analyses were applied to the Utah data and methodological limitations were identified. An approach using a multiple logistic regression for

each panelist's attack data was applied and the methodological approach was evaluated. A new approach to the analysis of asthma panel studies was devised which took into account some of the problems identified with prior analyses and also the quality of the data. The latter approach requires further testing and refinement before its results can be considered definitive. The ensemble of approaches does, however, allow some conclusions to be drawn from the data set.

This report is divided into five main sections. The first reviews the use of asthma as a health indicator in environmental epidemiology, including a review of selected asthma panel studies. The next two sections consider the impact of the data quality: the limitations and characteristics of the aerometric data and of the panelists' data, respectively. The last two sections contain statistical analyses: analyses correcting for variation among panelists and analyses based on person-days.

1.1 BACKGROUND OF STUDY

The Utah 1971-72 asthma study was conducted in four Salt Lake Basin communities. The four communities are located immediately west of the Rocky Mountain Wasatch Range. The study areas were sections of Ogden, Salt Lake City, Kearns and Magna. The principal point source of sulfur dioxide emissions, a copper smelter, was located within 2 miles of Magna. The relative locations of the study areas from Salt Lake City were Ogden 33 miles due north, Magna 12 miles southwest and Kearns 9 miles south southwest. Magna and Kearns are approximately 6 miles apart with Kearns located to the southeast of Magna. Pollution exposure levels for sulfur oxides were expected to be highest in Magna, lowest in Ogden and intermediate for Kearns and Salt Lake City.

Asthmatics living in these communities were identified using a common CHES protocol (1). A School and Family Health Questionnaire administered through a chosen school in December 1970 provided the initial sample of asthmatics. This questionnaire was supplemented by other sources of information. All identified asthmatics living within a 2-mile radius of an air monitoring station were interviewed and if eligible were asked to participate. To be eligible they must have had a history of wheezing and shortness of breath with each asthma attack and had two or more attacks in the previous year. No clinical verification of asthma or other verifications of panelist's responses were made as part of the study protocol. The age and sex composition of the panels as analyzed are described in Table 1-1. In regard to smoking status among adults, 26% were smokers, 9% were former smokers and 65% were nonsmokers who had never smoked. Also, 79% of the panelists lived in households where the head of household graduated from high school.

Table 1-1
AGE AND SEX COMPOSITION OF COMMUNITY PANELS

	<u>Adults (≥ 16)</u>		<u>Juveniles (< 16)</u>		<u>Total</u>
	<u>Female</u>	<u>Male</u>	<u>Female</u>	<u>Male</u>	
Ogden	15	6	5	11	37
Salt Lake City	12	3	6	13	34
Kearns	13	6	8	21	48
Magna	14	7	4	12	37
Total	54	22	23	57	156

The first 26 weeks of the Salt Lake Basin 1971-1972 asthma panel study were analyzed and reported by Finklea et al. (2) as part of the 1974 CHES Monograph. Two significant differences existed between their analysis and the present analysis. First, their study covered only the first 26 weeks while the complete 67 weeks were included in this analysis. Second, their analysis was based on unvalidated data. Portions of the data analyzed by Finklea et al. (2) have subsequently been found to be in error (see following paragraph). Because of these differences, this analysis is not a replication of the preliminary CHES study report but a completely new analysis of a substantially different data set.

The Utah 1971-72 asthma data were also studied by Kennecott Copper Corporation and Arthur D. Little, Inc., at Kennecott's request. In 1974, under the Freedom of Information Act, Kennecott requested the data from EPA that was used by Finklea et al. (2). Kennecott, in conjunction with Arthur D. Little, determined that the data obtained from EPA included 41 weeks of additional data beyond the 26 weeks used by Finklea et al. (2). Arthur D. Little and Kennecott discussed with EPA apparent differences between the data sets. It was determined that EPA had corrected data entries from some of the SO₂ data and that a validation of the daily diary data was needed to recover from a computer programming error. The data acquired for the current analysis included the corrected SO₂ data and the validated daily diary data. An unpublished report prepared by Arthur D. Little contains a description of the process involved in checking the validity of the data. No analysis of either previous data or the current data was completed by Arthur D. Little, except for the purpose of determining the data used by Finklea et al. (2).

1.2 MAJOR FINDINGS

The design and implementation of the Utah 1971-72 asthma study limited the conclusions that could be drawn on the relationship of air pollutants and asthma attacks. The panel study design used in the study did not differ in concept from previous asthma panel studies conducted in the United States. The panelists were enrolled from available asthmatics who were willing to participate. The Utah panels were not intended to be a random sample of identified asthmatics. Consequently, the panel asthma attack rates cannot be interpreted as estimates of average attack rates for all asthmatics in the four Salt Lake Basin communities. This implied that all statistical analyses had to rely on internal comparisons. In particular, study of a relationship between air pollutants and asthma attacks had to be based on the variation observed over time, i.e., study days. The purposeful enrollment of panelists also implied that if increased asthma attacks were associated with increased levels of air pollutants, then the only generalization possible was that for some asthmatics in the Salt Lake Basin an increase in air pollutant concentrations was associated with increased asthma attacks (Section 4).

A literature review clearly revealed a problem associated with many epidemiologic asthma studies. A number of factors have been identified that can trigger asthma attacks. Past panel studies, including the Utah 1971-72 study, have not included the collection of data pertinent to factors known to affect attack occurrence. The Utah 1971-72 study did not include information on daily medication use, pollen levels, respiratory infections, emotional stress, exposure to local pollutant sources and other factors. The only factors considered were total suspended particulates (TSP), suspended sulfates (SS), suspended nitrates (SN), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), relative humidity and daily maximum and minimum temperature. Lack of information on the occurrence of other factors made it impossible to determine the extent to which any association found with air pollutants could have been due to the unmeasured factors (Section 2).

Air pollutant data were collected using collection and analysis procedures accepted at the time. The Jacobs-Hochheiser procedure was used for NO_2 which has subsequently been found to have significant analytical limitations. Field collection procedures, delays between time of collection and analysis and limitations of analytical procedures resulted in daily air pollutant data that was subject to bias and high variability (Section 3.1). This was particularly the case for SO_2 .

Meteorological data were obtained from existing weather stations, not from the same site as the air pollutant collection location. Relative humidity data for all four

communities were from the Salt Lake City International Airport. Daily minimum and maximum temperature data were from the Salt Lake City Airport for the first 26 weeks. Subsequently, temperature data from Ogden and from Magna (also used for Kearns) were used in those communities (Section 3.1).

Air pollutant and panelists' attack response data were missing for many of the study days. Approximately 15% of the 469 study days were unavailable for analysis when the analysis included the four pollutants TSP, SS, SN and SO₂. Of 244 panelists who agreed to participate in the study, 88 never returned a diary, never reported an attack or returned less than one-third of the diaries. New panelists were added to the panels as late as 240 days into the study. The missing data and changing panel composition created a possibility of bias in some of the statistical analyses. To compensate partially for missing panelist data, most analyses were restricted to a subset of 156 panelists (Section 3.3).

Markov Chain/Grouping Analysis Findings (Section 5.1)

For each community, total suspended particulate, suspended nitrate, suspended sulfate, sulfur dioxide and minimum temperature data were grouped into three or four discrete levels. Because of the interest in detecting increased attack occurrence, only each panelist's episode responses were used where the previous day was recorded as no attack occurrence. This recorded information formed the input for the analysis of variance (Section 5.1). A severe collinearity problem was identified among the air pollutants and minimum temperature. The extent of the problem resulted in no observations in more than half of the "treatment" combinations formed from the grouping variables and precluded a standard factorial analysis. Each community did show differences among the "treatment" combinations but an effect could not be assigned to any particular pollutant or minimum temperature.

Korn and Whittemore Logistic Regression (Section 5.2)

Separate multiple logistic models were fit for each panelist. The factors included in the model were the occurrence of an attack on previous day, day of week indicators, minimum temperature, relative humidity, TSP, SN, SS and SO₂. The coefficients from the separate models were combined for all panelists in each community yielding four sets of summary estimates of the effects. In estimating the logistic models for each panelist, the model did not converge for 12 panelists. This was a direct result of sparse data. The major conclusions from the analysis were:

- The presence of an asthma attack on the previous day was the most important factor leading to increased attack probability.

- Higher attack probabilities occurred during the latter part of the week, with Thursday and Friday generally the highest.
- No air pollutant or minimum temperature had a significant effect on attack probability. Minimum temperature in Ogden did suggest a decrease in attack probability as temperatures increased. No consistent trends were noted for the air pollutants.

No method for evaluating the goodness of fit of the individual logistic regressions was found to be entirely satisfactory. The procedures for combining coefficients appeared to allow a small fraction of the panelists to determine the value of the combined coefficient.

Multiple Regression Analysis Findings (Section 6.1)

Twelve specific regression scenarios were analyzed for each community. In all scenarios the dependent variable was daily attack rates, O . To adjust for variable panel composition due to participants dropping out and back into the study, two variables, the total daily base rate $B(T)$ and the quarterly daily base rate $B(Q)$ were defined and included in the selected scenarios. In addition the ratios $O/B(T)$ and $O/B(Q)$ were used as dependent variables for the 12 scenarios but not explicitly reported as their qualitative results agreed with the observed attack rate models. The inclusion of $B(T)$ or $B(Q)$ in the observed attack rate models was an alternate adjustment procedure.

O is defined on each day as the number of attacks reported divided by the number of individuals responding, i.e., panel daily attack rate. $B(T)$ is used to represent the expected attack rate on a given day. It is an average of averages. The outer averaging is over the individuals reporting on a given day. The inner average, computed for each individual is the number of days with attacks reported divided by the number of days on which the individual reported. $B(Q)$ is the same as $B(T)$ except that the individual averages are taken over the quarter of the year for which $B(Q)$ is being computed. $B(Q)$ can compensate partially for the fact that attack rates may vary seasonally.

The most notable feature of all the scenario results was the poor fit, i.e., small R^2 , exhibited. Clearly important contributors to asthma attack occurrence were omitted from the model. The major findings were:

- Day of week indicators were the most important, with higher rates on Thursday, Friday and Saturday.
- Base rate total $B(T)$ showed positive effects in Ogden and Kearns but not in Magna and Salt Lake City. This implied that overall

attack rates for panelists responding on a given day was related to daily attack rates.

- No strong consistent effect for minimum temperature was present. When present, it showed a negative association.
- Air pollutants were not significant predictors in Kearns or Ogden.
- In Salt Lake City, when significant positive associations were indicated for suspended sulfates, they occurred in scenarios with significant negative associations for suspended nitrates. For other scenarios with significant pollution effects, the association was negative.
- Magna, the high exposure community, consistently showed a significant but negative effect for suspended nitrates. In most cases this was accompanied by a significant positive effect for suspended sulfates.

In summary, the collinearity among the pollutants precluded the separation of individual pollutant effects. No consistent pattern across communities or scenarios supported a conclusion of a positive pollution effect.

Temperature-Specific Relative Risk Analysis Findings (Section 6.2)

The relative risk model was evaluated for 60 scenarios resulting from the consideration of three classes of temperature and five pollutants across four communities. Of the 60 scenarios, seven scenarios demonstrated a significant gradient in "risk" associated with increasing or decreasing pollution. Two were rejected as the results were biologically inconsistent--declining relative risk with increased suspended nitrate levels. Four of the remaining scenarios were for minimum temperatures greater than 50°F and occurred for TSP, SS and SO₂ in Magna and TSP in Kearns. The remaining significant scenario occurred in Salt Lake City for SS with minimum temperatures from 30-50°F. In all cases, the increased "risk" occurred because the attack rate at the lowest pollutant level was lower than the remaining categories. A steady increase in attack rates did not occur. The significant scenarios for Magna and Kearns included a time period when a strike forced the shut-down of the major source of sulfur dioxide emissions. During this time all pollutants were at their lowest observed levels. The possibility of a confounding effect cannot be dismissed.

REFERENCES

1. U.S. Environmental Protection Agency. Health Consequences of Sulfur Oxides: A Report from CHES, 1970-1971. Research Triangle Park, NC. May 1974. EPA-650/1-74-004.
2. J. F. Finklea, et al. "Aggravation of Asthma by Air Pollutants: 1971 Salt Lake Basin Studies." In Health Consequences of Sulfur Oxides: A Report from Chess 1970-1971. Research Triangle Park, NC: U.S. Environmental Protection Agency, May 1974. EPA-650/1-74-004.

Section 2

ASTHMA AS A HEALTH INDICATOR IN ENVIRONMENTAL EPIDEMIOLOGY

This section contains background information related to using asthma as a health indicator in environmental epidemiology. The material is not directly related to the Utah 1971-72 asthma panel study conducted under the Environmental Protection Agency's CHES program. The material does provide:

- a brief description of clinical and biological characteristics of asthma
- a list of factors that can trigger asthma attacks
- a historical review of selected asthma panel studies
- an account of a thorough epidemiologic study of New Orleans' asthma.

The contents of the section place the Utah 1971-72 asthma panel study in perspective. The discussion on clinical and biological aspects of asthma illustrates the variety of asthmatics and the difficulty in their characterization for epidemiologic study purposes. Investigating the effect of air pollutants on asthma is complicated by the subjective definition of what constitutes an asthma attack and by the numerous factors other than air pollutants that can trigger an attack. A historical review of asthma panel studies clearly shows the CHES Utah 1971-72 study did not depart significantly from previous study methodology designs. In subsequent sections of this report the Utah study design and its implementation are discussed in detail.

A series of New Orleans asthma studies is reviewed because, of the United States studies, they are most comprehensive in examining the relationship between asthma and environmental factors. Unlike most panel studies, the incidence of asthma was evaluated through emergency room admission records, more objective than asthmatic attack reports by panelists. Another unique feature of the New Orleans asthma studies was that suspected causative agents were examined one by one through administration of skin tests of extracts to asthmatic subjects. In addition, respirable particles (less than 10 microns in diameter) were monitored and compared with asthmatic outbreaks. Most asthma studies have not considered particles of such small size partly because of difficulties with their measurement. Finally, extensive monitoring measured a variety of pollens, molds and spores in the ambient

air. It is our recommendation that epidemiologists apply some of the study approaches used in the New Orleans asthma studies to future air pollution/asthma investigations.

2.1 CLINICAL AND BIOLOGICAL CHARACTERISTICS OF ASTHMA

A major problem in the design and evaluation of epidemiologic studies involving asthmatics or the relationship between asthma and air pollution exposure is how to characterize asthma for the population base used in the asthma studies. This problem occurs because neither the subjects selected for the study nor the investigators have a clear understanding of the etiology of asthma or the biological and environmental factors which exacerbate the asthmatic condition. Thus, most epidemiologic studies of living persons have depended almost completely on what either investigators or study subjects themselves call "asthma." In general, this definition has been based on the symptoms most commonly experienced by asthmatic patients, such as abnormal breathlessness and/or paroxysmal or persistent wheezing over short periods of time. Using this symptom definition as a criterion for selecting study subjects does not directly account for the exceptionally complex and rather poorly understood nature of asthma, as well as the multiplicity of environmental, immunological and genetic factors that determine individual human susceptibility to asthma attack. An approach based on symptomatic criteria generally introduces significant subjectivity among panelists in reporting attack episodes in most asthma studies.

To better understand both the complex nature of asthma as a disease state, and to provide a more realistic scientific basis for selection of study subjects for epidemiologic asthma studies, it is appropriate to review the known physiological and immunological aspects of asthma and the host of intrinsic and extrinsic factors that can trigger the disease in humans.

Physiological and Immunological Features of Asthma

One way to define the nature of asthma is to consider the disease in terms of the physiological and immunological features that characterize persons who are diagnosed as asthmatic. In this respect, two distinct categories of asthma, and hence, asthmatic patients, can be identified: (1) atopic, and (2) idiopathic (non-atopic). Each category is distinguished by specific physiological and immunological characteristics that determine individual susceptibility to asthma attacks by air pollution and other triggering agents. In addition, two other categories of asthma are: (3) exercise-induced, and (4) chronic. The triggering factors of the latter asthma types may precipitate attacks among individuals with or without atopy.

The term atopic asthma is applied to persons with variable difficulty in breathing with wheezing, associated with corresponding variations in resistance to gas flow in the intrapulmonary airways caused by definable antigen-antibody reactions. For many persons in this category, the asthma begins in childhood; they also have paroxysmal rhinitis manifested either as seasonal hay fever caused by pollen hypersensitivity, or perennial allergies attributed to hypersensitivity to other environmental factors. These persons comprise about 10% of the population, who have special liability to become sensitized to a wide range of environmental antigens as a result of minor exposures to substances encountered in everyday life. Since the causal factor in atopic asthma is an antigen which is encountered from the external environment, persons belonging to the atopic group are also characterized as having extrinsic atopic asthma. Patients with this type of asthma have family histories of similar allergies and, hence, this predisposition is considered to be genetically determined. The antibody concerned in atopic asthma belongs to a special class of immunoglobulins, immunoglobulins E (IgE), which are elicited when the susceptible person comes in contact, usually by injection, ingestion or inhalation, to an appropriate antigen. Inhaled antigens include the components of pollens, molds, and dusts which are frequently encountered in the environment at low dose levels (often under 1 $\mu\text{g}/\text{yr}$). Such antigens, or allergens, seem to have an upper size limit of about 50,000 daltons, perhaps determined by the reduced ability of substances of greater molecular weight to permeate the mucosal membranes of the respiratory tract, and thereby stimulate IgE responses. Ingested allergens are not characterized as easily because they often appear to be fragments of various antigens, which the host ingests and which subsequently permeate the intestine in sufficient quantity to stimulate IgE responses. The doses of injected and ingested allergens are usually several orders of magnitude larger than those of inhaled allergens. The actual dosages of allergen which reach IgE-producing cells (located primarily in the upper respiratory tract and intestinal mucosa) are probably very low, and this may be an important common feature which tends to favor IgE responses regardless of the route of entry of the antigen.

Recent evidence has suggested that variable bronchoconstriction may also be associated with types of antigen-antibody reactions other than those mediated by IgE antibodies. Notably, it has been shown that sufficiently heavy exposure of non-atopic individuals to inhalation of certain organic dusts can give rise to sensitization. This type of asthma is referred to as extrinsic non-atopic asthma. This finding is important in indicating that IgE antibody is not the only type of antibody that can react with antigens to cause bronchoconstriction in persons presenting the clinical and functional picture of asthma.

Idiopathic (non-atopic) asthma is applied to persons who have episodic or variable wheezy breathlessness that can be correlated with variations in gas flow resistance in intrapulmonary airways, but without evidence of any known external causal factors or immunological (antigen-antibody) reactions. Most non-atopic asthmatics develop symptoms in adult life, often in middle age or later. Since no evidence of any precipitating factors can be established (except for occasional sensitivity to aspirin), this type of asthma is also referred to as intrinsic asthma. Non-atopic asthma tends to be more persistent and responds less well to symptathomimetic bronchodilator drugs (e.g., ephedrine, sudofed) than does that associated with atopic hypersensitivity, but usually responds strikingly to corticosteroids (e.g., cortisone). In many cases of idiopathic asthma there is a considerable increase in the number of eosinophilic leukocytes both in the blood and in the sputum.

Exercise-induced asthma is defined by an observable bronchoconstriction and increase in airway resistance after exercise. This type of asthma appears to be heterogeneous in that, aside from its always being induced by exercise, it is in some cases associated with exposure to external antigens and in some cases not. Provocation of exercise-induced asthma is dependent upon the nature and duration of exercise, and its recognition varies with individual ability to perceive changes in airway obstruction and to draw proper inferences regarding its association with exercise. Such variables, and a lack of standardization of methods for eliciting and measuring responses to exercise in asthmatics, prevents a conclusive determination of the frequency of the phenomenon and its magnitude as a clinical problem. These factors also seriously complicate the assessment of air pollution in the etiology of asthmatic attacks, an especially important consideration because most exercise-induced asthma is expected to be elicited through outdoor activities..

The terms chronic asthma and chronic asthmatic bronchitis are sometimes used to describe the disease entity in which persistent airway obstruction is associated with chronic bronchitis or emphysema. These conditions always show some variability in airway obstruction, and although relatively little variation is seen in emphysema, a somewhat greater degree of paroxysmal restriction very much akin to acute episodes of asthmatic attacks occurs in chronic bronchitis, usually attributable to exacerbation of viral or bacterial infections. One of the most persistent symptoms in chronic bronchitis patients is excessive secretion of bronchial mucus, which is exacerbated by both cigarette smoking and exposure to air pollution. It frequently happens, therefore, that in a person with long standing asthma with persistent cough and expectoration, the question arises whether these symptoms are due to the same causes as asthma, to private and public air pollution (which are recognized as

the most important causes of chronic bronchitis), or to both. These considerations are of major importance in the identification and selection of subjects for participation in epidemiologic studies of asthma and air pollution since major differences pertain to the etiology of asthma as compared with chronic obstructive pulmonary disorders.

Factors That Can Trigger Asthma Attacks

As reviewed in the previous section, a wide variation exists in the expression of asthma among a given population of subjects, as well as in the frequency with which several factors are involved in the production of asthma in a single individual. By definition, persons with extrinsic asthma react to substances in the environment that are innocuous to the general population and even to other asthmatic subjects. Thus, although the fundamental underlying disturbance of the asthmatic cannot be defined with certainty, several factors can be identified that trigger or induce an asthmatic attack in a susceptible individual. These factors are listed in Table 2-1.

Of the many factors, immunological precipitants of asthma are the most common. These can be divided into two major groups: (1) allergenic, to which atopic persons form reaginic antibodies (IgE) upon natural exposures; and (2) other antigens, which can induce the formation of reaginic antibodies in persons regardless of genetic predisposition. Allergens are a specialized class of antigen which participate in allergic (hypersensitivity) reactions, and are used in diagnostic skin testing. As indicated in Table 2.1, common allergens include tree, grass and weed pollens, house dust, animal dander, molds and many foods. Other antigens which participate in immunologically mediated allergic responses include certain drugs and other metabolites and occupational chemicals and their intermediates produced during manufacture.

Numerous non-immunologic factors and conditions can also trigger asthmatic attacks in susceptible individuals. Such attacks do not involve antigen-antibody reactions but rather pharmacological effects such as direct chemical reactions with bronchiolar tissues, bronchial irritation, stimulation of reflex action, and so forth. Also included in this category are effects resulting from physiological anomalies, such as an inherited abnormality of the autonomic nervous control of the bronchial smooth muscle, which renders the individual more susceptible to bronchoconstriction by non-immunologic triggers of asthma.

Among the non-immunological initiators of asthma attack are aspirin and aspirin-like drugs, certain other drugs and chemicals which directly irritate or otherwise stimulate the respiratory tract, endocrine system and hormonal imbalance, exaggerated

Table 2-1

FACTORS WHICH TRIGGER ASTHMA ATTACKS

- A. Immunologic Factors
 - 1. Allergens
 - a. Pollens
 - b. Molds
 - c. Dust
 - d. Dander
 - e. Foods
 - 2. Drugs and Chemicals
- B. Non-immunologic Factors
 - 1. Known
 - a. Aspirin and aspirin-like drugs
 - b. Chemicals which produce irritation or other pharmacologic effects
 - c. Exercise
 - d. Infections
 - e. Reflexes
 - 2. Probable
 - a. Air pollutants
 - b. Sinusitis
 - c. Chemical irritants
 - d. Tobacco and cigarette smoke
 - 3. Possible
 - a. Emotions
 - b. Endocrine imbalance
 - c. Autonomic nervous system abnormality
 - d. Weather

reflexes, exercise and, possible, emotions (e.g., fear of attack). Respiratory infections have also been implicated as triggers of asthma, as have certain diseases of the lung and parasitic infestations. Weather, including temperature, humidity and other meteorologic factors have been implicated as precipitators of asthmatic attacks or in the exacerbation of asthmatic attack incidence in numerous studies; however, no definitive conclusions regarding the contribution of these factors to asthma have been drawn.

It is known that some asthmatics are sensitive to subtle meteorological changes. Greenburg et al (1) examined the daily numbers of emergency clinic visits for asthma at three large hospitals in New York City. Their results indicate that the most

pronounced and statistically significant increase in asthma visits was associated with the onset of the first or second cold periods when heating was required at the beginning of the fall season. Tromp (2) discussed complex physiological mechanisms of asthmatics in relation to meteorological conditions. According to his observation, "periods of steep barometric fall, due to rapidly approaching low pressure areas, have a particularly marked asthma-increasing effect in western Europe if these weather changes are accompanied by a sudden influx of cold polar or continental air masses followed by one or more 'active' cold fronts."

Cigarette smoking is also one of the most important factors in the development of respiratory disease in general, but its role in the induction or aggravation of asthma is not yet clear. Some studies have suggested that cigarette smoke acts as an irritant particularly in atopic individuals, and that passive smoking aggravates asthma in asthmatic children. Whether passive smoking in children is a risk factor in the development of asthma is not known. There are also well documented cases of acute asthma caused by hypersensitivity to tobacco. This condition may affect both smokers and non-smokers, and cause severe asthma in infancy.

Air pollution has been closely studied as a trigger of asthma attack, but evidence to date is inconclusive. Sulfur dioxide (SO_2) is the pollutant most frequently measured in epidemiologic studies, and has been largely accepted as an indicator of the degree of air contamination from industrial smog resulting largely from combustion of solid and liquid fossil fuels. Studies of the effects of SO_2 on airway resistance in both animals and humans produced variable results ranging from a definite increase in resistance due to bronchoconstriction to no change at all. The apparent discrepancy of these effects results from differences in the concentrations of inhaled SO_2 and from marked variability in subject responsiveness. Thus, even among healthy volunteers without a history of asthma, approximately 10%, referred to as "hyper-reactors," will respond with a marked decrease in pulmonary function. This observation serves to demonstrate the remarkable variability in responsiveness among a given population of exposed individuals, both with or without asthma, during pollution episodes. A similar variation in respiratory function and responsiveness has also been observed among humans exposed to photochemical oxidants and other pollutants. Although a rise in morbidity among asthmatic subjects has been observed during episodes of increased air pollution, the contribution of specific pollutants or air pollution in general to the etiology of those changes needs to be evaluated against other factors which are known or suspected to exacerbate asthma conditions and which may change at the same time as changes in air pollution levels.

2.2 REVIEW OF SELECTED ASTHMA PANEL STUDIES

Schoettlin and Landau (3) undertook a study to determine if asthmatic attacks are associated with high-smog periods in Los Angeles, California. Five physicians practicing in or near Pasadena (where episodes of air pollution were frequent and severe) selected 157 patients, 137 of whom participated in the study. All patients resided and worked in the Pasadena area. Fifty-four of the patients were younger than age 15. Most had had asthma for at least five years. Daily records of the time of onset and severity of asthmatic attacks were maintained by the patients between September 3 and December 9, 1956.

In their study, the greatest number of asthmatic attacks occurred between midnight and 6 a.m., whereas the maximum oxidant levels were recorded between 10 a.m. and 4 p.m. Of the 3,435 attacks reported, fewer than 5% were consciously associated with smog by the patients. No severe attacks were consciously associated with smog. One-third of the attacks consciously associated with smog were reported by a single patient. The correlation coefficient between daily attack rates and the concurrent maximum oxidant reading was 0.37. Accounting for other variables in the analysis did not significantly alter these results. Lagged correlations between oxidant concentration and the number of patients having attacks 6, 12, 18 and 24 hours later were generally lower than concurrent correlations. There was no significant difference between the average number of subjects having attacks on days above the median maximum hourly oxidant level of $250 \mu\text{g}/\text{m}^3$ (0.13 ppm) ozone and the average number of patients having attacks on days when levels were below the median. However, the mean number of patients having attacks on days when daily maximum hourly oxidant levels exceeded $490 \mu\text{g}/\text{m}^3$ (0.25 ppm) was significantly higher than on days when the daily maximum hourly oxidant level fell below this level. The authors suggested that this finding might indicate a threshold level for oxidants. Also, attack rates on days in which plant damage occurred were significantly higher than on days without plant damage. Specific oxidant levels associated with plant damage were not reported in this study, however. The effect of oxidant on asthmatic attack rates was most pronounced in persons who had lived in the area for 10 years or more. The data were examined further to see whether a small number of the subjects might be responsible for the observed correlation. The authors identified eight individuals (6% of the total panel) whose attacks corresponded most often to days on which plant damage occurred. Seven of these eight people were females. No other common characteristic could be discerned.

Because the authors did not mention pollution measurement methods or averaging times used in data analysis, the U.S. Environmental Protection Agency consulted with the

authors and California Air Pollution Control District to fill out such missing information. As a result, Schoettlin and Landau are presumed to have used daily maximum hourly oxidant concentrations, as measured by the potassium iodide method (4). Such problems in the Schoettlin and Landau study were pointed out by Kurata et al (5):

They did not provide in their report values for the means, number of people reporting each day and type of statistical test used. They also did not report whether the "0.25 ppm" criteria was based on instantaneous maxima or one-hour averaging times. This is especially important since, through correspondence with the Los Angeles Air Pollution Control District, we know that there were only five days during which 0.25 ppm was exceeded based on the one-hour averaging time, and 11 days based on the instantaneous maxima criterion. Thus at the best, 11 days were compared with 87 days and, at the worst, five days were compared with 93 days. It is also important to know that there were only three days in September and two days in October when ozone exceeded 0.25 ppm, based on the one-hour averaging time; while only seven days in September and four days in October exceeded this level based upon instantaneous maxima. Thus, since there were no "high oxidant" days in November and December, the data for the high versus low oxidant groups were sampled over different times of the year when other seasonal factors may have influenced the results. An even more important point is that the mean for each group should be based upon the proportion of persons reporting attacks (n of attacks/n of people reporting) per day. For example, since the number of persons reporting each day was not given, there may have been fewer persons reporting by November when there were not days on which ozone exceeded the criterion level. Thus this significant result, using the mean number of reported attacks, could actually be due to fewer persons turning in reports during the last month of the three-month study.

Zeidberg et al. (6) carried out a daily follow-up study of 84 persons with bronchial asthma in Nashville, Tennessee, from August 2, 1958, to July 12, 1959. The panel patients were grouped according to their residence in an area of relatively low, moderate, or high sulfation (measured by the lead peroxide candle method). Low pollution was considered to be any value below 0.150 mg; moderate pollution ranged between 0.150 mg and 0.349 mg; and high pollution was represented by values of more than 0.350 mg. For the whole group of patients the asthmatic attack rate showed a direct correlation with the degree of sulfation, while the correlation was not demonstrated for the pediatric asthmatic patients. To further examine if persons with bronchial asthma showed variation in the frequency and severity of their attacks depending on variation in their exposure to air pollution, the investigators compared the asthmatic attack rate for the days with SO_2 above the median (0.02 ppm) with that for the days with SO_2 below the median. The attack rate for the higher SO_2 days was 0.131 per person-day, with an average of 9.4 daily attacks reported, while the attack rate for the lower SO_2 days was 0.127 per person-day with an average of 7.5 daily attacks. The differences were not statistically significant. "However, when attack rates on the thirty days with the highest SO_2 levels were

compared with the rates on the forty-six days with the lowest levels, the difference in the respective rates of 0.130 and 0.110 was significant at the 5 percent level."

These study results above were again criticized by Kurata et al. (5) as follows:

Two important points should be noted. First, the attack rate of 0.130 on days of high sulfation was lower than the average attack rate (0.133) for all days, irrespective of SO₂ levels. Second, a check of the graph (Figure 5, from Zeidberg, 1961) shows that the two peaks (maximum attack rates) for asthma attacks occur in October and May when SO₂ is near its minimum levels. From these observations it is difficult to accept that the difference between mean attack rates of 0.130 and 0.110 could be very meaningful.

In addition, Landau et al. (1) re-evaluated the same data set used in the study from Zeidberg et al. (6) and recognized several serious limitations in their analysis:

An important limitation of the study group should be noted. Eleven of the 84 patients never had an attack during the entire conduct of the study. It is obvious that these panel members contributed no information. Possibly the therapy received by many of the patients may have influenced the frequency and severity of attacks. Preferably, a study of this kind should be done with patients receiving no therapy so as to study the natural history of the disease. This, admittedly, would be a difficult restriction to impose on asthmatics. In fact, the presence of one out of eight who reported no attacks, coupled with the small number of persons who reported an attack virtually every day, served to dilute the data substantially. This situation of complete nonresponse for diagnosed asthmatics requires further investigation.

Another important limitation of the analysis of the data to date should be noted. This stems only in part from the composition of the group itself. Although there is general recognition of the likelihood of different types of asthma in children and adults, the decision was made to analyze the data for the two segments in combination prior to consideration of the groups separately. This decision was based on the thinness of the sample. On further reflection it is likely that working with the segments instead of the whole may tend to increase the chances of finding any significant relationship.

Still another important limitation of the analysis must be mentioned again. Unfortunately, the role of pollen as an allergic agent cannot be assessed from the available data.

The analysis of Landau et al. (7) demonstrated the strongest negative association of the day-of-study variable (day from beginning of study) with asthmatic attacks. This association could be reflected by the inability to keep a panel reporting conscientiously over an extended period of time. It seems premature to draw any conclusions of asthma-air relationships from the studies by Zeidberg et al. (6) and Landau et al. (7).

Kurata et al. (5, 8) developed a computer-assisted data collection system to obtain and evaluate information on air pollution measurements and pollen counts which may

affect conditions of asthmatics. Sixty-nine patients were asked to fill out daily diaries and mail them back weekly from July 1974 to June 1975. All patients were diagnosed asthmatics on the basis of physical examinations, medical histories and response to bronchodilator medication. Most patients were on hypersensitization schedules based on histories and skin test reactivity. Six months after the initiation of the study only 49 patients were still participating. Air pollution data from 13 air monitoring stations in the Los Angeles area were supplied by the Los Angeles Air Pollution District. They used the following formula to measure severity of asthmatic conditions:

$$\begin{aligned}\text{Asthma Index} = & \text{Wheezing (Day)} + \text{Wheezing (Night)} + \text{Coughing (Day)} \\ & + \text{Coughing (Night)} + \text{Shortness of Breath} \\ & + \text{Medication for Coughing or Wheezing}\end{aligned}$$

The range of values for this index was 0-9. Each individual's daily asthma index was matched with the daily pollution level in his/her residential zone. Averages of the asthma index scores were computed according to exposure to four levels of air pollution concentrations. Their graphic analysis appeared to show a positive relationship between sulfur dioxide and ozone levels and average asthma index scores. The investigators denied this relationship because these graphic displays "do not take into account the variance and number of reports which comprise each level of pollutants." It sounds logical, but it would have been better if the investigators had performed statistical tests to see if those differences in average asthmatic index scores among four pollution levels were actually meaningful. According to Figure 10 (Kurata et al., 5) we can observe a distinct linear relationship between average asthma index scores and SO₂ exposure levels. In fact, averages of the daily instantaneous SO₂ maxima during the study period (July 1974-June 1975) were fairly high; those from seven monitoring stations were 0.055 ppm, 0.043 ppm, 0.038 ppm, 0.036 ppm, 0.032 ppm (from two stations) and 0.019 ppm. It may be worthwhile to further re-examine this question in the future if more detailed information can be made available.

Another interesting analysis by Kurata et al. (5) was a test of the difference between severity of asthmatic symptoms (average asthma index scores) for the patients who did not own cats and dogs and those who owned such pets. The results of the data for the first six months and for the whole year showed that patients who owned cats and dogs reported a significantly higher mean asthma index score. In addition, their step-wise multiple regression analysis indicated that a much greater

percentage of the within panelist variation of the asthma symptoms can be accounted for by exposure to animals than to air pollutants.

The Kurata et al. studies remain inconclusive for the following reasons: (1) The number of patients who participated in diary reports throughout the entire study period was not shown in Kurata's reports. Fluctuations of participants from day to day may bias daily asthmatic attack rates. As an example, it is known that asthmatic attacks are more frequent in old people than in young people and that young people are more likely to drop out as the study progresses. The study sample included a broad age group ranging from 7 to 72 years of age. (2) Seasonal analysis is essential to examine the relationship between asthmatic attacks and air pollution. Inclusion of other seasonal factors (e.g., pollen counts, climatological measurements) may be important. (3) The day-of-study variable (day from beginning of study) should be included as an independent variable. According to Figure 6 in their second report (5), there was a decreasing trend in daily averages of asthma index scores as the study progressed. (4) The day-of-the-week should also be included as an independent variable. Both asthmatic attacks reported by patients and air pollution concentrations might fluctuate according to the day of the week.

The United States Environmental Protection Agency conducted a series of epidemiologic studies under the aegis of the Community Health and Environmental Surveillance System (CHESS) program. Some of these studies were designed to provide dose-response information relating short-term pollutant exposures to adverse health effects, in particular asthma. The results of asthma studies in New York for 1970-72 and the Salt Lake Basin for 1971 were reported in the 1974 CHESS Monograph (9). An investigation of the entire CHESS program commonly referred to as the Brown Committee report (10) detailed a number of limitations associated with the data and analysis in the 1974 CHESS monograph. The committee concluded that the data and analysis did not provide a reliable quantitative basis for relating SO₂ or sulfate levels in the air to health effects.

In addition to the Brown Committee's investigation, the Electric Power Research Institute has undertaken an analysis of several CHESS data sets to re-examine CHESS conclusions. The first such analysis, a re-examination of the same data set used in the section entitled Aggravation of Asthma: 1970-71 New York Studies of the CHESS Monograph (9), was performed by Roth, Viren and Colucci (11). The results of their re-evaluation did not support the hypothesis of a positive association between the incidence of asthma attacks and levels of suspended particulates or suspended sulfate.

Whittemore and Korn (12) analyzed the Los Angeles asthma data set which was collected under the EPA-CHESS program for the years 1972-75. Their results showed that the asthmatics who participated in the study, on the average, "have significantly increased attacks on days with high levels of Oz and TSP, and on days with cool temperatures." Furthermore, the presence of attacks on the preceding day, day of week, and day of study were found to be significant predictors of an attack. This implies (according to the investigators) that the "likelihood is poor of detecting small pollutant effects and interactions among pollutants and weather variables by such panel studies without altering the study design." Among limitations pointed out by the investigators, three of them are perhaps most serious: (1) attacks were ascertained based upon the subjective appraisal of the panelist, without any clinical validation; (2) like most epidemiologic studies of air pollution/health effects, there was no information on individual pollutant exposure (air conditioning, type of home cooking and heating, cigarette smoking, etc.); and (3) there was a lack of information on factors other than air pollution and climatological measurements which influence conditions of asthma (respiratory infection, pollen, mold, spore, dog and cat hair, emotional factors, etc.). A discussion of Whittemore and Korn's methodology and its limitations is given in Section 5.

A review of the historical context of the asthma panel studies conducted as part of CHESS shows that the study designs were very similar to those in previous studies. CHESS study designs were not an advancement in methodology. The Brown committee investigative report also clearly documents how difficult it is to implement a study design and how failure to implement the design can decrease the data quality and invalidate the study.

2.3 NEW ORLEANS ASTHMA

In New Orleans a series of asthma studies were completed that differ significantly from the studies previously reviewed. The New Orleans studies were started in response to a previously identified increase in asthmatic attacks. The question studied was one of identification and elimination of possible causes for the increase. In that respect the studies were successful and followed classic epidemiologic investigative procedures.

An increased admittance of asthmatic patients has been observed at the Emergency Unit of Charity Hospital, New Orleans, both in summer (lesser increase) and in fall (greater increase). On October 26, 1955, a total of 350 asthmatic cases and two deaths were reported in 24 hours. A 1958 outbreak of more than 100 cases with two

deaths aroused the attention of the United States Public Health Service, which initiated a series of investigations to find a cause(s) of such asthmatic outbreaks.

Lewis et al. (13) reported that only one of the numerous airborne particles identified and counted in the fall of 1960 and the spring of 1961 had a significant relationship to the fluctuations in the emergency admissions for asthma. They found that the source of this particular type of particle was a large, closed, city dump where spontaneous underground burning occurred. This observation was also confirmed by the fact that telephone calls to the fire department to extinguish fires at city dumps over the past years were related closely to the level of emergency asthma admissions.

To further investigate the properties of the above mentioned particles, Weill et al. (14) collected emission samples on filters from seven smoke plumes at the Agriculture Street dump using high volume sampling devices. From these plume samples 16 solutions were extracted. The extracts differed in source plumes and associated length of collection time from the plume. They were also prepared by separate blendings. Intradermal skin tests of these plume extracts were performed on university students with and without histories of asthma and hay fever and on Charity Hospital patients known to have been involved in previous local outbreaks of asthma. Percentages of persons reacting positively to one or more extracts were 83% in the asthmatic outbreak patients, 58% in the combined asthma and hay fever students and 31% in the normal students. The emissions from the Agriculture Street dump were thereby considered one of the prime etiologic factors in epidemic asthma in New Orleans. Accordingly, the city government cleaned up that dump area, significantly decreasing the volume of material at that site as well as the amount of spontaneous underground burning. However, the incidence of daily asthma admissions to Charity Hospital was higher during October and November of 1963 after cleaning the dump site than during the same period of 1962, before the cleanup. This observation implied that there were additional sources of pollutants related to the asthma outbreaks.

To examine additional pollutant sources, various air sampling stations were situated at strategic locations in the city of New Orleans. Skin tests of extracts made from material collected on filters at those stations from late September through early December of 1962 were given to 122 asthmatics who were treated at Charity Hospital during outbreak days in October and June of 1962. In addition, the same skin tests were performed on family members (control subjects) of those asthmatics with no history of allergic or respiratory disease. Of the asthmatic patients, 60% reacted

positively to one or more of the air sample extracts, while 14% of the control subjects showed one or more positive reactions. No relationship was observed between the extract concentration and the percentage of patients with positive skin reactions. Furthermore, there was little relationship between the skin test responses and the time of collection for a given lot of extracts. Considering that positive reactions were obtained with extracts from all sampling stations, the investigators concluded that there was more than one point source of air pollution causing asthmatic outbreaks in New Orleans (14). In regard to the characteristics of the asthmatics, 99% of these asthmatic outbreak patients were allergic on the basis of history and/or response to standard allergen skin tests. Of the patients over 16 years of age, 31% were cigarette smokers.

Kenline (15) examined the relationship between asthma outbreaks and air pollution concentrations in New Orleans. No significant relationships were observed between the number of asthmatic outpatient visits in Charity Hospital and daily variation in concentrations of suspended particulates (as measured by the high-volume sampler), benzene-soluble particulates, particulate sulfate, sulfur dioxide, nitrogen dioxide, and aldehydes from the six-station network as well as NO, NO₂, SO₂, and oxidant from the continuous air monitoring program (CAMP) station. To further investigate the role of smaller particles in asthma outbreaks, Kenline measured the diameter of particles (in microns): 0.5-1, 1-2, 2-4, 4-8, and 8-16 (by the Royco PC 210) in addition to the total particles smaller than 8 microns (by the high-volume elutriator). The results showed that concentration levels measured by both methods were well correlated with asthma outbreaks. Thus, asthmatic attacks could be related to only particles of 10 and less, which can penetrate into the lower respiratory tract. Although no attempt was made to identify the source of those small particles, Salvaggio et al. (16) considered the possibility that the particles would consist of Ambrosia pollen, large "basidiospore-like" spores, and small spores, all of which contributed to the allergic load imposed upon the local atopic population.

The series of studies carried out for the past decade led to the conclusion that "New Orleans epidemic asthma is not related to a point source chemical pollutant but rather involves sensitization of the local atopic population to a host of diverse particulates, notably 'natural' inhalant allergens, as is commonly noted in such individuals" (17). The most likely major allergens were Ambrosia pollen, small deuteromycete and ascomycete spores, basidiospores, and possible common antigens in plant remnants. Certain climatologic conditions seem necessary for precipitation of epidemics, particularly large outbreaks in the fall. A striking association existed

between sharp decreases in relative humidity, decreased temperature, rising barometric pressure, and large epidemics in the fall. The investigators emphasized that "If our findings are correct, New Orleans epidemic asthma ... may merely reflect the natural history of bronchial asthma as it affects the atopic population of a large metropolitan community, and it serves to remind us of the deleterious effects of natural pollutants on a restricted but large segment of the population."

REFERENCES

1. L. Greenburg, F. Field, J. I. Reed, and C. L. Erhardt. "Asthma and Temperature Change: An Epidemiological Study of Emergency Clinic Visits for Asthma in Three Large New York Hospitals." Arch. Environ. Health 8:642-647, 1964.
2. S. W. Tromp. "Influence of Weather and Climate on Asthma and Bronchitis." Review of Allergy 22:1127-1144, 1968.
3. C. E. Schoettlin and E. Landau. "Air Pollution and Asthmatic Attacks in the Los Angeles Area." Public Health Reports 76:545-548, 1961.
4. U.S. Environmental Protection Agency. Air Quality Criteria for Ozone and Other Photochemical Oxidants. Chapter II. Epidemiologic Appraisal of Photochemical Oxidants. Research Triangle Park, NC, 1978.
5. J. H. Kurata, M. M. Glovsky, R. L. Newcomb, and J. G. Easton. "A Multifactorial Study of Patients with Asthma. Part 2: Air Pollution, Animal Dander and Asthma Symptoms." Ann. Allergy 37:398-419, 1976.
6. L. D. Zeidberg, R. A. Prindle and E. Landau. "The Nashville Air Pollution Study. I. Sulfur Dioxide and Bronchial Asthma. A Preliminary Report." Amer. Rev. Resp. Dis. 84:489-503, 1961.
7. E. Landau, R. A. Prindle and L. D. Zeidberg. "The Nashville Air Pollution Study. Sulfur Dioxide and Bronchial Asthma - A Multivariate Analysis." Intern. J. Environ. Studies 2:41-45, 1971.
8. J. H. Kurata, M. M. Glovsky, R. L. Newcomb, and J. G. Easton. "A Multifactorial Study of Patients with Asthma. Part 1: Data Collection and Rapid Feedback." Ann. Allergy 37:231-245, 1976.
9. U.S. Environmental Protection Agency. Health Consequences of Sulfur Oxides: A Report from CHESS, 1970-1971. Research Triangle Park, NC, 1974. EPA-650/1-74-004.
10. U.S. Congressional Report. The Environmental Protection Agency's Research Program, with Primary Emphasis on CHESS: An Investigative Report. Prepared for the Committee on Science and Technology. U.S. House of Representatives. Washington, DC: Government Printing Office, 77-509, 1976.
11. H. D. Roth, J. R. Viren and A. V. Colucci. Evaluation of CHESS: New York Asthma Data 1970-71. Palo Alto, Calif.: Electric Power Research Institute, May 1977. EPRI-EA-450, Vol. I.
12. A. S. Whittemore and E. L. Korn. "Asthma and Air Pollution in the Los Angeles Area." Am. J. Public Health 70:687-696, 1980.
13. R. Lewis, M. M. Gilkeson and R. O. McCaldin. "Air Pollution and New Orleans Asthma." Public Health Reports 77:947-954, 1962.
14. H. Weill, M. M. Zisking, V. Derbes, R. Lewis, R.J.M. Horton and R. O. McCaldin. "Further Observations on New Orleans Asthma." Arch. Environ. Health 8:184-187.
15. P. A. Kenline. "October 1963 New Orleans Asthma Study." Arch. Environ. Health 12:295-314, 1966.
16. J. Salvaggio and J. Seabury. "New Orleans Asthma. IV. Semiquantitative Air-borne Spore Sampling, 1967 and 1968." J. Allergy Clin. Immunol. 48:82-95, 1971.

17. J. Salvaggio, J. Seabury and E. A. Schoenhardt. "New Orleans Asthma. V. Relationship Between Charity Hospital and Asthma Admission Rates, Semiquantitative Pollen and Fungal Spore Counts, and Total Particulate Aerometric Sampling Data." J. Allergy Clin. Immunol. 48:98-114, 1971.

Section 3

AEROMETRY: LIMITATIONS AND PATTERNS

This section describes the limitations and patterns of the aerometry data collected for the 1971-72 Utah asthma panel study conducted as part of the CHES program. Aerometry data refers to both meteorological data and air pollutant data.

Air pollutant measurements were obtained by installing an air monitoring station in each community at a second story building level approximately 25 feet above the ground. Measurement devices at each station included high-volume samplers for measuring total suspended particulates, including suspended sulfates and nitrates, and sulfur dioxide and nitrogen dioxide bubblers. Continuous 24-hour monitoring was maintained during the study. Equipment and/or analysis problems resulted in approximately 15% of the study days with one or more pollutant species data missing. Sample filters and bubblers were replaced daily and sent to EPA in Research Triangle Park, North Carolina, for laboratory analysis. Sulfur dioxide and nitrogen dioxide gas bubblers were analyzed by techniques standard at the time, the West-Gaeke and Jacobs-Hochheiser methods, respectively. High-volume sample filters were measured gravimetrically and analyzed for sulfate and nitrate fractions. For sulfates a turbidimetric method, with turbidity measured by spectrophotometer, was used. Suspended nitrate was determined by a reduction-diazo coupling method with automatic analysis.

Meteorological data, consisting of minimum and maximum temperature and relative humidity, were obtained from existing meteorologic collection sites. Information from Salt Lake International Airport was used for all four communities during the first 26 weeks. For subsequent weeks minimum and maximum temperature data for Ogden and Magna/Kearns were obtained from other local sites.

The first 26 weeks of the study corresponded to the time period used in a preliminary analysis of the Utah 1971-72 asthma study reported by Finklea et al. (1). Two factors concerning aerometry are important in evaluating their results:

- meteorologic data from a single location is used for all four communities, and

- incorrect SO₂ data, subsequently corrected by EPA, were included (Section 1).

Several limitations exist in interpreting any analysis of the Utah 1971-72 asthma study because of problems connected with the aerometry data. When information allows, these problems are discussed in detail in this section. During, and subsequent to, the collection and analysis of the air monitoring data, a number of problems with their quality were identified. An extensive description of the problems is given in the Brown committee congressional report (2).

Since the conduct of the Utah study, major difficulties with the Jacobs-Hochheiser method for determining NO₂ have been found. These problems are described by Hartwell et al. (3). Subsequent analyses include NO₂ data only to present a more complete picture and must be viewed with caution. Nitrogen dioxide levels during the study were, however, relatively low in all communities. Measurement problems occurred for the other pollutants as well, mainly as a result of faulty field procedures and lack of a good quality control program. Loss of reagent occurred during SO₂ and NO₂ gas bubbler shipment. A temperature effect for SO₂ due to the time delay between sampling and analysis was also found. An interference effect of high levels of SO₂ with sulfates on the filter resulted in an unknown positive bias for sulfate concentrations (Section 3.1).

Missing data were a common problem in all four communities. Total suspended particulates, suspended nitrates and suspended sulfates tended to be missing together. Sulfur dioxide and nitrogen dioxide missing data did not occur in any pattern. Missing data affected the statistical analyses by reducing the number of days actually available for analysis. The pattern of days missing varied among the communities.

The study period extended for 67 weeks and included a full seasonal pattern of air pollution concentrations in the communities. The common seasonal pattern for all pollutants had the lowest levels occurring during the summer months, gradually increasing to peak levels during winter and then gradually decreasing in the spring. Similar seasonal patterns occur for other factors relating to asthma. Hence, it was not possible to ascribe effects identified totally to pollution without other supporting evidence. Confounding among the pollutants made it impossible to ascribe an effect to a single pollutant species.

All panelists' residences were within a two-mile radius of a monitoring site. The panelists "exposure" to a pollutant species was assumed to be the 24-hour average concentration measured at the monitoring site. No direct information was obtained during the study on whether a panelist spent all, part, or none of the day within the two-mile radius of the site. If a panelist had no attack during a day, the daily diary form did not provide him a means of stating where he spent the day. If an attack occurred, then he was asked if he was in his home neighborhood at the time of the attack. Unfortunately, this information was not reliable. Even if information on the presence of each panelist in his home neighborhood was adequate, the spatial variability of the pollutant concentrations within the two-mile radius was substantial. Available data from other monitoring sites within two-miles of a study monitoring site were obtained for comparison purposes. No consistent bias was apparent from a paired comparison of the sites. However, typically the standard deviation of the difference was only slightly less than the standard deviation of the concentrations from either site. Goldstein and Landovitz (4), using New York City air pollution data as an example, discuss the problem of using a single fixed station monitoring site to estimate the exposure of panelists. Using a fixed monitoring site to obtain exposure concentrations also ignores known differences between indoor and outdoor pollutant concentrations.

3.1 COLLECTION PROCEDURES AND MEASUREMENT PROBLEMS

An air pollution monitoring station was located, specifically for the CHESS studies, in each of the study communities. At each station a standard HiVol sampler was used to collect daily 24 hour average samples for total suspended particulates (TSP), water soluble suspended sulfates (SS) and water soluble suspended nitrates (SN). Bubblers for nitrogen dioxide and sulfur dioxide were collocated. During the 1971-72 asthma study, the samplers were located 15 to 20 feet above the ground on the roofs of buildings. Air monitoring personnel of the Utah Division of Health replaced sample filters and bubblers at approximately 10 a.m. daily. The filters and bubblers, along with supporting information, were returned to EPA for laboratory analysis.

The West-Gaeke colorimetric and Jacobs-Hochheiser procedures were used for the determination of ambient SO_2 and NO_2 , respectively. HiVol sample filters were measured gravimetrically for TSP with portions of each filter analyzed for SS and SN. From the beginning of the study until September 1971, a turbidimetric method, with turbidity measured by spectrophotometer, was used. For the remainder of the study the methylthymol blue method was used. Suspended nitrate was determined by a reduction-diazo coupling method with automatic analysis. Further details on the

specific procedures used are given in Appendix A of the CHESS monograph (5) and in the Brown committee investigative report (2).

During, and subsequent to the collection and analysis of the air monitoring information, a number of problems with the quality of the data were identified. An extensive description of the problems is given in the Brown committee report (2). The following, abstracted from that report, is a brief description of the problems.

Sulfur Dioxide and Nitrogen Dioxide Measurement Problems

By mid-1971, Utah field personnel reported that severe spillage of reagent was occurring during SO₂ and NO₂ bubbler tube shipment. The magnitude of the problem was indicated in the investigative report by quoting from an EPA memo: "The present reagent tubes for SO₂ and NO₂ leak during shipment It follows therefore, that the resultant pollution data are unreliable." The same EPA memo stated one-half of all SO₂ data taken between November 1970 and March 1973 were likely to have been biased by an average of 17% low.

A second and even more severe error, dependent on temperature, with the SO₂ measurements during the 1971 Utah asthma study was associated with the time delay between sampling and analysis. A brief study by the CHESS monitoring group scientists resulted in a correction factor of +1.5% per day arithmetically applied to the SO₂ data to compensate for the time delay. Subsequently a more comprehensive study was carried out using SO₂ concentrations over the range 35 to 278 µg/m³. The findings presented were:

- Over a normal range of temperature, the rate of decay of the TMC-SO₂ complex increased five-fold for every 10°C increase in temperature.
- The rate of decay was independent of SO₂ concentration.
- At 20, 30, 40 and 50°C, the following SO₂ losses were observed: 0.9, 5, 25, and 74% loss per day, respectively.

For the Utah study, estimates of summer temperature exposures ranged from 25 to 40°C and estimates of time delays between sampling and analysis ranged from 7 to 14 days. Hence, an unknown but negative bias can be assumed for the SO₂ data, especially in the summer months.

Additional problems with the SO₂ collection procedure were related to air flow rates and bubbler train leakage. CHESS personnel connected with the 1971 Utah asthma study noticed unusually high SO₂ values for the Salt Lake City monitoring site in

comparison to other Utah sites from April 1971 to January 1972 (internal EPA memo). On investigation, a problem of obtaining a sufficient flow rate for analysis was found. This had been noted on the daily sample collection cards but apparently was not corrected until January 1972. The delay in responding to an identified field sampling problem was due in part to the lack of a well defined quality assurance program during this period. A correction (exact procedure unknown) was applied to the Salt Lake City SO₂ data for the April-January period when the problem was known to be present. Approximately 130 values were modified by reducing the original concentration by approximately 50%. This correction was not made to the SO₂ data in the analyses reported by Finklea et al. (1).

The Brown committee report concluded CHES S O₂ data pertinent to the 1971 Utah asthma study had limitations in precision and accuracy. For 1971 SO₂ data, a comparison to data collected by the State of Utah led them to conclude "that due to the difference between the independent methods an error bar of at least 100% must be applied to the data and explicitly correct data cannot be drawn from these observations." Based on an EPA collaborative study using a 95% confidence interval, the Brown committee concluded the minimum differences between High and Low SO₂ exposures which may be considered "real":

- Below 100 µg/m³ SO₂, a difference of at least 50 µg/m³ is necessary to be statistically significant.
- Between 100 and 300 µg/m³ SO₂, a difference of at least 60 µg/m³ is necessary to be significant.
- Below 25 µg/m³, a single determination is not significantly different from zero.

Nitrogen dioxide collection procedures also used a gas bubbler methodology. The problems of reagent leakage and bubbler train loss discussed for SO₂ also applied to NO₂ collection procedures. A more fundamental problem with the Jacobs-Hochheiser analysis method was discovered subsequently. The problems of the method are described and comparisons of nine methods of measuring NO₂ are given by Hartwell et al. (3). Additional data can be found in Decker et al. (6).

Total Suspended Particulate Measurement Problems

The simplest and most reliable pollutant measurement method used in the Utah study was the determination of total suspended particulate (TSP) concentration. The Reference Method, using a HiVol sampler, measures an arbitrary and poorly defined portion of the total atmospheric particulate burden. Best estimates of the particle size range sampled are from 0.05 to 60 µm diameter. The particle size range

generally acknowledged applicable to normal human respirable size ranges from 0.05 to 2-3 μm diameter. Under laboratory conditions the method is capable of reproducible measurements with less than 5% error at the 95% confidence level. The minimum detectable amount of TSP is approximately $2\ \mu\text{g}/\text{m}^3$ for a 24-hour sampling period.

The CHESS collection and sampling procedures for TSP differed from the laboratory procedure. The CHESS filters were weighed and analyzed at the EPA Research Triangle Park Laboratory. This resulted in the shaking-off of particles from the filter during transit and the evaporation of organic substances. Laboratory reorganizations at RTP resulted in up to 6 months delay between sampling and laboratory analysis. The locations of the HiVol samplers sometimes made it difficult under cold and windy conditions to remove the filter without losing part of the sample. This was particularly noted during the winter months at the Utah sites.

The overall effect of the summed errors with the HiVol TSP measurement was estimated to be a slight negative bias. Data collected from side by side samplers in Salt Lake City indicated the bias could be as small as 10% or as large as 30%.

Total Water Soluble Suspended Sulfates (SS) and Suspended Nitrate (SN) Measurement Problems

The determination of suspended sulfate concentrations was a methodological extension of the HiVol TSP method. Thus, all errors associated with the TSP method also affected the sulfate method. A portion of each HiVol filter was analyzed for water-soluble sulfate using the manual turbidimetric method until September 1971 and the methylthymol blue method until the end of the study period. The turbidimetric method is subject to interferences from other common pollutants. Problems associated with the sampling of sulfates also occurred. In the 1971-73 time period, sulfate blanks (the level of sulfate on the filter pad as manufactured) were found to be high, $1\text{--}2\ \mu\text{g}/\text{m}^3$ SS, and variable. Adsorption of atmospheric SO_2 to sulfate was known. The average positive bias from this factor can be 5-10%. In areas like the Salt Lake Basin with high levels of SO_2 , the positive bias probably becomes more severe.

The Brown committee report conclusions applicable to this study were:

- From 1970 to September 1971 the sulfate data were obtained using the turbidimetric method. It should be used only as a sulfate level indicator. Due to interferences, severe problems will result if an attempt is made to correlate sulfate levels in one part of the country with sulfate levels in another.

- From October 1971 until October 1972, the data were subject to the following considerations:
 - The data were likely biased in the positive direction from 1-2 $\mu\text{g}/\text{m}^2$. This bias may be more severe in areas of high SO_2 concentration.
 - The random error component of the measurement was probably in the order of 25% at an atmospheric concentration of 10 $\mu\text{g}/\text{m}^3$.

For suspended nitrate measurements the same problems associated with TSP collection procedures apply. The CHES monograph gives a detailed description of the analytic methods employed. A change in analysis procedure occurred during the time period of the present study. Until December 1971 the hydrazine sulfate-copper sulfate method of analysis for nitrate was used. It was replaced with the copper-cadmium reduction method "to refine the baseline stability of the instrumentation used"

Meteorologic Data

Meteorological data were obtained from existing weather stations in the Salt Lake Basin. Relative humidity data was obtained from the Salt Lake City International Airport. These data were used for all four communities. For the first 26 weeks of the study, daily minimum and maximum temperatures ($^{\circ}\text{F}$) from the Salt Lake City International Airport were used for all four communities. For the remaining 41 weeks the temperature data differed among Ogden, Salt Lake City, and Magna. Magna and Kearns temperature data were the same throughout the 67 week study period. Since the Salt Lake City temperatures were used in all four communities during the first 26 weeks, separate summaries were given for the first 26 weeks and the last 41 weeks. The first 26 weeks coincided with the time period used by Finklea et al. (1).

The average maximum temperature during the study period was approximately 64°F in all communities, with an approximate average minimum temperature of 40°F (Table 3-1). The maximum temperature ranged from 16°F to 100°F and the minimum temperature ranged from -4°F to 71°F during the study period. The relative humidity varied from 18% to 96% with the high humidity occurring during winter months. Relative humidity and temperature showed a strong negative correlation. The average daily temperature range (difference between daily maximum and minimum) was approximately 25°F for Ogden and Salt Lake City and 22°F for Kearns/Magna. Temperatures at Kearns/Magna tended to be slightly more moderate than at Ogden or Salt Lake City, although the difference was small.

There were two concerns about the meteorological data used in the study. One concern was the substantial differences existing between the first 26 week and last 41 week

periods, mostly due to seasonal patterns in temperatures. The first 26 weeks extended from March 7, 1971 thru September 4, 1971, while the latter period extended until June 17, 1972. Including minimum temperature in an analysis of asthma attack rates could result in substantially different temperature effects when only the first 26 weeks or the entire 67 weeks were used.

Another concern was the propriety of using Salt Lake City meteorological data for all communities during the first 26 weeks. Summaries of the last 41 weeks for Ogden, Salt Lake City and Kearns/Magna indicated small but statistically significant ($p < 0.05$) differences between the communities. For maximum temperature a one degree average difference existed with the ordering from highest to lowest being Salt Lake City, Ogden and Kearns/Magna (Table 3-2). The exact reverse ordering occurred for minimum temperature. The correlation between Ogden and Salt Lake City was 0.99 and 0.97 for maximum and minimum temperature, respectively. Between Kearns/Magna and Salt Lake City the same correlations were 0.88 and 0.92, respectively. Based on these comparisons it appears that using Salt Lake City data for Ogden was reasonable with a 0.5°F upward adjustment to minimum temperature if necessary. For Kearns/Magna the differences were more substantial and the correlations less substantial. In our analyses, no corrections to the first 26 weeks of temperature data were made. The above differences, although real, were not deemed large enough to justify modification of the data.

3.2 COMMUNITY AEROMETRIC PATTERNS

Pollutant data summaries for the 1971-72 study period are given in Table 3-3. The arithmetic average of total suspended particulate (TSP) levels for the study period of 469 days ranged from 51 $\mu\text{g}/\text{m}^3$ in Kearns to 91 $\mu\text{g}/\text{m}^3$ in Salt Lake City. All communities except Kearns exceeded the 24 hour TSP primary standard of 260 $\mu\text{g}/\text{m}^3$. This occurred four times in Ogden, nine times in Salt Lake City and seven times in Magna. Suspended nitrate and nitrogen dioxide levels in the communities were relatively low. A definite gradient for suspended sulfates and sulfur dioxide levels existed among the communities. The highest levels occurred at Magna and decreased with increasing distance from Magna. However, even in Magna the average SO_2 concentration during the study was 69 $\mu\text{g}/\text{m}^3$, below the annual primary standard of 80 $\mu\text{g}/\text{m}^3$. Only in Magna was the 24 hour primary standard of 365 $\mu\text{g}/\text{m}^3$ exceeded (five times during the study).

Inter-Community Patterns

For the air pollutants measured during the study, a common seasonal pattern occurred in all four communities. The lowest levels occurred during the summer, increasing

Table 3-1

METEOROLOGICAL MEASUREMENT SUMMARY STATISTICS: UTAH 1971-72 ASTHMA STUDY

Indicator	Full 67 Weeks				First 26 Weeks		Last 41 Weeks	
	Mean	Standard Deviation	Min.	Max.	Mean	Standard Deviation	Mean	Standard Deviation
Relative Humidity	50.5	15.9	18.4	95.9	43.4	13.2	55.0	15.9
Maximum Temperature								
Ogden	63.6	19.7	16	100			55.6	17.5
Salt Lake City	64.2	19.4	21	100	76.3	16.0	56.5	17.4
Kearns/Magna	63.2	19.5	20	100			54.8	16.8
Minimum Temperature								
Ogden	39.5	15.1	-4	71			34.1	14.1
Salt Lake City	39.2	14.7	3	71	48.0	12.6	33.6	13.1
Kearns/Magna	41.5	14.4	6	71			37.3	14.0
Lag Min. Temp.								
Ogden	39.5	15.1					34.1	14.1
Salt Lake City	39.1	14.7			48.0	12.6	33.5	13.1
Kearns/Magna	41.4	14.4					37.2	13.9
Daily Temp. Range								
Ogden	24.1	7.5					21.5	6.4
Salt Lake City	25.0	8.0			28.3	7.2	23.0	7.8
Kearns/Magna	21.7	8.3					17.5	5.9
Min. Temp. Change								
Ogden	0.1	5.4					0.1	5.7
Salt Lake City	0.1	5.5			0.1	4.8	0.1	5.9
Kearns/Magna	0.1	4.7					0.1	4.7

Table 3-2

COMPARISON OF LAST 41 WEEKS OF COMMUNITY MAXIMUM AND MINIMUM TEMPERATURES: UTAH 1971-72 ASTHMA STUDY

Communities Compared	N	Mean Difference	Standard Deviation	Correlation
Maximum Temperature				
Ogden-Salt Lake City	287	-0.97	2.48	0.99
Kearns/Magna-Salt Lake City	285	-1.70	8.30	0.88
Minimum Temperature				
Ogden-Salt Lake City	287	0.54	3.57	0.97
Kearns/Magna-Salt Lake City	285	3.78	5.45	0.92

through autumn to a peak during winter. This seasonal pattern was more typified by high pollutant levels due to an increase in variability rather than a consistent overall increase in the daily pollutant levels. Successive days during autumn and winter can have widely differing pollutant levels. This is in sharp contrast to the seasonal cyclic pattern for daily minimum temperature where a definite sinusoidal pattern occurs accompanied by constant variability throughout the year.

Using a student's t-test for pairwise comparisons of average pollutant levels in communities, substantial differences were found. For TSP, all communities were significantly different ($p < 0.01$) with the order from highest to lowest being Salt Lake City, Ogden, Magna and Kearns. A similar pattern occurred for suspended nitrates (SN) and nitrogen dioxide (NO_2) with Magna having the lowest levels instead of Kearns. Ogden and Kearns did not differ significantly for SN while Magna and Kearns did not for NO_2 . Suspended sulfate and SO_2 levels also differed significantly among the communities, except for SS between Kearns and Salt Lake City. The highest to lowest ordering of the communities was Magna, Kearns, Salt Lake City and Ogden. This was consistent with the ordering expected when a single source dominates emissions for a pollutant and the communities are located at different distances but in the same general direction from the source.

Another measure for common pollution patterns among the communities was the simple correlation of the daily pollutant levels. The correlations are given in Table 3-4. As expected from the sampling procedure, the higher correlations occurred for TSP, SN and SS with the higher correlations generally occurring for communities closer together. The simple correlations for SO_2 were lower between communities with the highest correlation of 0.63 occurring between Magna and Kearns. Magna and Kearns also had the highest (0.69) correlation for NO_2 . But in contrast to SO_2 , the NO_2 correlations remained relatively high between all communities. The correlations reflected the common seasonal pattern across the communities.

Intra-Community Correlations

In each community a complex association existed among the air pollutants and meteorological measurements. As previously discussed, the air pollutants exhibited seasonal differences, with higher levels occurring during fall and winter. The meteorological measurements also had definite seasonal patterns, more sinusoidal than the air pollutants. Tables 3-5 to 3-8 present the simple correlation coefficients for the aerometric variables for each community. Based on these tables it is apparent that:

Table 3-3

AIR POLLUTION MEASUREMENTS SUMMARY STATISTICS
BY STUDY COMMUNITY: UTAH 1971-72 ASTHMA STUDY

Variable	Number Missing	Number Observations	Median	Mean	Standard Deviation	Minimum	Maximum
Total Suspended Particulates ($\mu\text{g}/\text{m}^3$)							
Ogden	27	442	75.5	86.2	48.4	12.3	316.6
Salt Lake City	10	459	77.1	91.2	54.2	20.1	407.3
Kearns	20	449	44.2	51.3	30.8	6.9	227.9
Magna	25	444	58.4	73.5	52.8	5.8	482.4
Suspended Nitrates ($\mu\text{g}/\text{m}^3$)							
Ogden	27	442	1.7	2.9	4.3	0.0	49.3
Salt Lake City	10	459	2.1	3.5	5.2	0.3	52.2
Kearns	19	450	1.6	2.7	4.6	0.0	47.1
Magna	22	447	1.2	2.2	3.7	0.0	32.6
Suspended Sulfates ($\mu\text{g}/\text{m}^3$)							
Ogden	26	443	4.9	5.9	4.2	0.0	34.1
Salt Lake City	9	460	5.7	7.7	6.9	0.0	69.6
Kearns	21	448	5.8	7.8	6.7	0.0	65.9
Magna	21	448	9.6	12.3	9.2	1.1	63.9
Sulfur Dioxide ($\mu\text{g}/\text{m}^3$)							
Ogden	33	436	6.4	8.6	8.6	0.0	59.1
Salt Lake City	77	392	11.3	15.6	17.6	0.0	175.5
Kearns	33	436	11.7	23.1	34.2	0.0	357.5
Magna	53	416	46.2	69.3	79.4	0.0	531.4
Nitrogen Dioxide ($\mu\text{g}/\text{m}^3$)							
Ogden	40	429	34.0	39.3	24.3	2.8	222.1
Salt Lake City	57	412	35.9	42.5	29.8	0.9	246.5
Kearns	63	406	18.9	22.9	19.6	0.0	201.8
Magna	55	414	16.3	21.7	19.4	0.0	134.3

Table 3-4

SIMPLE CORRELATIONS OF DAILY POLLUTANT LEVELS AMONG
STUDY COMMUNITIES: UTAH 1971-72 ASTHMA STUDY

Communities	Pollutant				
	TSP	SN	SS	SO ₂	NO ₂
Ogden-Salt Lake City	0.78	0.73	0.74	0.26	0.60
Ogden-Kearns	0.58	0.69	0.58	0.20	0.51
Ogden-Magna	0.55	0.65	0.51	0.34	0.48
Salt Lake City-Kearns	0.70	0.88	0.68	0.41	0.48
Salt Lake City-Magna	0.67	0.75	0.58	0.36	0.54
Kearns-Magna	0.74	0.71	0.67	0.63	0.69

Table 3-5
AEROMETRY CORRELATION COEFFICIENTS IN OGDEN: UTAH 1971-72 ASTHMA STUDY

SN	SS	SO ₂	NO ₂	Max. Temp.	Min. Temp.	Relative Humidity	Lag Min. Temp.	Temp. Range	
0.43*	0.49	0.37	0.41	-0.16	-0.22	-0.03	-0.24	0.00	TSP
	0.76	0.44	0.49	-0.20	-0.22	0.24	-0.28	-0.07	SN
		0.46	0.50	-0.28	-0.29	0.29	-0.34	-0.14	SS
			0.43	-0.32	-0.32	0.26	-0.39	-0.17	SO ₂
				-0.29	-0.31	0.24	-0.34	-0.11	NO ₂
					0.94	-0.81	0.89	0.73	Max. Temp.
						-0.69	0.94	0.45	Min. Temp.
							-0.63	-0.72	Relative Humidity
								0.44	Lag Min. Temp.

* All sample sizes are greater than 400.
Coefficients exceeding 0.10 are significant at 5% level.
Coefficients exceeding 0.13 are significant at 1% level.

Table 3-6
AEROMETRY CORRELATION COEFFICIENTS IN SALT LAKE CITY: UTAH 1971-72 ASTHMA STUDY

SN	SS	SO ₂	NO ₂	Max. Temp.	Min. Temp.	Relative Humidity	Lag Min. Temp.	Temp. Range	
0.64*	0.55	0.47	0.55	-0.27	-0.32	0.14	-0.38	-0.07	TSP
	0.81	0.58	0.49	-0.25	-0.27	0.26	-0.36	-0.10	SN
		0.47	0.39	-0.35	-0.35	0.37	-0.42	-0.21	SS
			0.46	-0.22	-0.24	0.23	-0.31	-0.08	SO ₂
				-0.23	-0.26	0.18	-0.32	-0.06	NO ₂
					0.93	-0.82	0.87	0.73	Max. Temp.
						-0.66	0.93	0.42	Min. Temp.
							-0.60	-0.77	Relative Humidity
								0.41	Lag Min. Temp.

* All sample sizes are greater than 400.
Coefficients exceeding 0.10 are significant at 5% level.
Coefficients exceeding 0.13 are significant at 1% level.

Table 3-7

AEROMETRY CORRELATION COEFFICIENTS IN KEARNS: UTAH 1971-72 ASTHMA STUDY

SN	SS	SO ₂	NO ₂	Max. Temp.	Min. Temp.	Relative Humidity	Lag Min. Temp.	Temp. Range	
0.43*	0.42	0.31	0.43	-0.04	-0.06	-0.07	-0.07	-0.01	TSP
	0.68	0.32	0.64	-0.32	-0.31	0.27	-0.35	-0.22	SN
		0.56	0.69	-0.35	-0.30	0.31	-0.34	-0.30	SS
			0.41	-0.28	-0.24	0.21	-0.26	-0.24	SO ₂
				-0.36	-0.31	0.30	-0.33	-0.32	NO ₂
					0.92	-0.76	0.89	0.75	Max. Temp.
						-0.67	0.95	0.43	Min. Temp.
							-0.64	-0.61	Relative Humidity
								0.45	Lag Min. Temp.

* All sample sizes are greater than 400.
Coefficients exceeding 0.10 are significant at 5% level.
Coefficients exceeding 0.13 are significant at 1% level.

Table 3-8

AEROMETRY CORRELATION COEFFICIENTS IN MAGNA: UTAH 1971-72 ASTHMA STUDY

SN	SS	SO ₂	NO ₂	Max. Temp.	Min. Temp.	Relative Humidity	Lag Min. Temp.	Temp. Range	
0.41*	0.55	0.38	0.52	-0.27	-0.28	0.09	-0.27	-0.16	TSP
	0.50	0.31	0.49	-0.31	-0.29	0.21	-0.33	-0.22	SN
		0.65	0.63	-0.40	-0.35	0.31	-0.38	-0.32	SS
			0.47	-0.43	-0.43	0.29	-0.44	-0.28	SO ₂
				-0.44	-0.40	0.32	-0.40	-0.34	NO ₂
					0.92	-0.76	0.89	0.75	Max. Temp.
						-0.67	0.95	0.43	Min. Temp.
							-0.64	-0.61	Relative Humidity
								0.45	Lag Min. Temp.

* All sample sizes are greater than 400.
Coefficients exceeding 0.10 are significant at 5% level.
Coefficients exceeding 0.13 are significant at 1% level.

- TSP, SN, SS, SO₂ and NO₂ were positively correlated in all four communities. The strongest correlations were between SN and SS in Ogden (0.76) and Salt Lake City (0.81). In Magna, the strongest correlations were between SO₂ vs. SS (0.65) and between NO₂ vs. SS (0.63).
- The highest correlations occurred among the meteorological variables where maximum and minimum temperature were positively correlated. Relative humidity exhibited a strong negative correlation with the two temperature variables.
- The correlations between air pollutants and weather variables was generally weaker than either within air pollutants or within meteorological variables. With the exception of relative humidity, the weather variables were negatively correlated with air pollutants.
- SS tended to be more highly correlated with the remaining air pollutants. Across the communities the correlations with SS ranged from 0.39 to 0.81 with most exceeding 0.50.
- The derived variable "lagged minimum temperature" reflected the same correlation structure as minimum temperature, although the correlations were consistently higher. Daily temperature range showed minimum correlation with air pollutants.

The simple correlation structures for the aerometric measurements showed a consistent pattern across the communities. The high positive correlations among the air pollutants made it unlikely that mutually independent statistical estimates of the effect of individual pollutants on asthma could be determined. The generally stronger correlation of suspended sulfates with the other pollutants (possibly due to its being a secondary pollutant) may result in it being the air pollutant most commonly found to be related to asthma attack rates. If so, this would not imply sulfates to be the causative factor, because the confounding problem remains. The strong correlations among the weather variables indicate that a single weather variable such as minimum temperature will most likely be sufficient to adjust for a temperature effect. The negative, but weak, correlations between temperature and air pollutants may make it difficult to separate a low temperature from high pollution effect on asthma. If other factors not measured, such as pollen levels, are correlated with temperature, then any effect on attack rates attributed to temperature may be due to those confounding factors.

Alternate Monitoring Sites

Asthmatics in each community panel were originally selected to live within a two-mile radius of a monitoring station specifically implemented for the CHESS program. No information is available to confirm that all panelists lived, worked or attended school within the designated area. Since the monitoring sites were located near or on a school building, it is assumed that the juveniles spent most of their time

in the area. A major concern, especially for Magna and Kearns, which are located near a major point source for the pollutants, was the spatial variability of individual pollutant daily concentrations. The fixed station monitoring site was intended to represent a panelist's 24-hour integrated exposure. The validity of that assumption is determined in part by the ability of a point measurement to represent the concentration levels throughout the area. This assumption was examined by obtaining pollutant concentrations measured at other sites located within the two-mile radius.

All data collected and entered into the SAROAD air pollution data base maintained by EPA were requested for the counties that included Ogden, Salt Lake City, Magna and Kearns. Although a massive amount of air pollution data was available for the communities, only one or occasionally two sites satisfied the criteria of being within the two-mile radius and having data for the same time period. The specific sites are indicated in Table 3-9 by part of their SAROAD site identification code. Even for these sites, comparable data were available for only a few days. The alternate site collected data on a biweekly schedule in some cases. In all cases, care was taken to match the data from two sites for the same collection period. For sulfur dioxide data not collected on a biweekly schedule, hourly measured concentrations were averaged to obtain daily concentrations. The hours averaged corresponded to the 24-hour CHESS sampling period beginning at 11 a.m. on the previous day. The units were converted from ppm to $\mu\text{g}/\text{m}^3$ by multiplying by the conversion factor 2616 for SO_2 .

The alternate sites were located within one-half mile of the CHESS site. From Table 3-9 it is apparent that no major differences in the average concentration levels measured by the sites during the study period were found. A paired t-test showed a significant ($p < 0.05$) difference in mean levels for seven comparisons. Four of these were for sulfur dioxide when daily values for the alternate site were based on hourly data. In all cases, the alternate site had higher values. The other significant comparison occurred in Ogden and Salt Lake City for TSP and SS.

For assessing the panelists exposure estimation procedure, the standard deviation of the difference and the correlation between concentrations from two adjacent sites were important. The correlations were positive and from 0.6 to 0.8 in most cases. The lowest correlations involved the hourly SO_2 data. In Magna the correlations for TSP and SO_2 were 0.44 and 0.55, respectively. Magna was located close to the dominant point pollution source, resulting in higher spatial variability from pluming. The standard deviation of the differences reflected the same pattern as

Table 3-9

COMPARISON OF DAILY AIR POLLUTANT MEASUREMENTS
AT CHESSE SITE WITH OTHER NEARBY SITES
UTAH 1971-72 ASTHMA STUDY

Community Pollutant Comparison Site	Sample Size	Comparison Site		Chess Site		Correlation	Pairwise		t-value
		Mean	Standard Deviation	Mean	Standard Deviation		Mean Difference	Standard Deviation	
Ogden									
TSP									
1A01	33	98.9	41.2	82.1	30.3	0.76	16.9	26.7	3.63 ^a
1F01	160	111.8	55.3	108.5	53.4	0.79	3.3	35.2	1.20
SN									
1A01	32	2.5	1.7	2.4	1.3	0.78	0.1	1.1	0.50
SS									
1A01	32	4.3	2.5	5.3	1.8	0.64	-1.0	1.9	-3.00 ^a
SO ₂									
1F01	396	18.3	16.3	9.9	8.2	0.39	8.4	15.1	11.12 ^a
Salt Lake City									
TSP									
1A01	32	105.7	38.2	98.8	51.4	0.83	5.9	29.0	1.36
1F01	163	120.2	60.9	117.0	62.4	0.87	3.2	31.8	1.28
4F01	147	91.8	46.6	114.3	55.6	0.54	-22.5	49.8	-5.49 ^a
SN									
1A01	28	2.4	1.3	2.4	3.1	0.80	<0.1	2.2	0.11
SS									
1A01	28	6.4	2.5	7.0	4.1	0.67	-0.6	3.1	-1.01
SO ₂									
1A01	28	9.4	10.1	13.3	13.3	0.62	-3.9	10.6	-1.94
1F01	378	19.7	25.2	16.0	17.3	0.42	3.7	23.9	3.02 ^a
Kearns									
TSP									
1F01	150	64.3	33.4	61.8	34.1	0.80	2.5	21.5	1.44
SO ₂									
1F01	421	32.0	45.2	24.6	34.0	0.72	7.4	31.4	4.87 ^a
Magna									
TSP									
1F02	155	93.4	30.6	90.2	53.1	0.44	3.2	74.7	0.53
SO ₂									
1F02	387	95.4	117.0	68.1	77.5	0.55	27.3	98.8	5.44 ^a

^aSignificant at p < 0.05 level.

the correlation coefficients. It was significant that the standard deviation of the difference was 50% of the magnitude of the individual primary pollutant data series standard deviation. The data series standard deviation reflected the seasonal variation in the pollutants. Based on such comparisons it was concluded that the single CHESS monitoring site provided only a general indication of the pollutant concentration throughout each study area. When a panelist's lifestyle was considered in addition, the propriety of the single fixed site concentration was further questioned. Because of these uncertainties, only grouped pollutant data was meaningful for the analysis.

3.3 MISSING AEROMETRIC DATA

In all four communities a common problem was missing air pollution data. Total suspended particulates, suspended nitrates and suspended sulfates measurements tended to be missing together, as one would expect if the reason for missing data was the collection process. Sulfur dioxide and nitrogen dioxide data tended to be missing independent of each others' and the other pollutants' missing data. Previously mentioned difficulties with the SO₂ and NO₂ bubbler tubes were consistent with the patterns of missing data. It was assumed that missing values were the result of collection (sampling) and analytical malfunctions which occurred during the course of the study.

Patterns in missing data varied among the communities. The study days with missing pollution data are given by pollutant species for each community in Table A-1 in Appendix A. The number of missing data values ranged from 9 (out of a possible 469) for SS in Salt Lake City to 77 for SO₂, also in Salt Lake City. The percent of missing data by pollutant species ranged from 2 to 16% with the higher percentages for SO₂ and NO₂. The actual number of days used in subsequent statistical analyses depended on whether a single pollutant or multiple pollutants were included in the analysis. The maximum number of days deleted would occur when TSP, SN, SS and SO₂ were all included, in which case 60, 86, 58 and 76 days were deleted from Ogden, Salt Lake City, Kearns, and Magna, respectively. Hence, approximately 15% of the study days would be excluded for each community. Since NO₂ was analyzed by the Jacob-Hochheiser method, which has been determined to be unreliable, NO₂ was not used in any statistical analyses except for completeness purposes.

To contrast study days included in analyses with those deleted, four sets of indicators were composed for included versus deleted study days:

- Asthma Attack Indicators
 - Observed attack rate (O)
 - O/B(T)
 - O/B(Q)
- Daily Experimental Design Indicators
 - Day of Study
 - Day of Week
 - Daily Base Rate Total, B(T)
 - Daily Base Rate Quarterly, B(Q)
- Daily Demographic Indicators
 - Average Age of Respondent
 - Ratio of Adult to Juvenile Respondents
 - Ratio of Male To Female Respondents
 - Average Smoking Index of Respondents
 - Average Education Level of Head of Household
- Aerometry Indicators
 - Average Daily TSP, SN, SS, SO₂ and NO₂ levels
 - Maximum and Minimum Daily Temperatures
 - Minimum Temperatures Lagged One Day
 - Change in Minimum Temperature
 - Daily Temperature Change
 - Average Daily Relative Humidity

Definitions for base rate total B(T) and base rate quarterly B(Q) are given in Section 4. Indicators based on panelists data were constructed using a subset of 156 participating panelists as defined in Section 4.

Mean Differences

The mean values for the above indicators by community for those study days included and deleted (one or more missing pollutant values) are given in Appendix A, Tables A-2 through A-5. Based on 92 comparisons of included and deleted days, 14 showed a significant ($p < 0.05$) difference. In only two cases was a pollutant variable significantly different between included and deleted days. This occurred in Ogden and Magna where in both cases NO₂ levels were higher on included days than on deleted days. Age and adult/juvenile ratio differed for Ogden and Salt Lake City, with younger panelists reporting on deleted days. No other demographic variables differed significantly.

Asthma attack rate variables showed no consistent differences for included/deleted days across communities. Only Magna's observed attack rates and ratios O/B(T) and O/B(Q) were significantly different. Lower attack rates occurred for included days. No difference for B(T) and B(Q) was present for Magna, implying the expected base rates were not the cause of the difference.

Salt Lake City experimental design variables were all significantly different with the exception of Day of Week. In Salt Lake City, Day of Study was significantly different with more deleted days occurring early in the study. This was primarily due to a block of TSP missing data early in the study. Both base rate total and quarterly were significantly higher for included days.

In summary, differences did exist between included and deleted days but the differences were not consistent across the communities. Ogden and Salt Lake City showed evidence of panel composition differences. Magna was the only community with differences in the asthma attack variables. Differences between included and deleted days were not a factor in Kearns. The selection of the 156 participating panelists, partly on the basis of their response rate, reduced the number of drop in/drop outs in the study. This helped to minimize differences between included and deleted days for the attack rate, $B(T)$, $B(Q)$ and demographic variables.

REFERENCES

1. J. F. Finklea, et al. "Aggravation of Asthma by Air Pollutants: 1971 Salt Lake Basin Studies." In Health Consequences of Sulfur Oxides: A Report from CHES 1970-1971. Research Triangle Park, NC: U.S. Environmental Protection Agency, May 1974. EPA-650/1-74-004.
2. U.S. Congressional Report. The Environmental Protection Agency's Research Program, with Primary Emphasis on CHES: An Investigative Report. Prepared for the Committee on Science and Technology. U.S. House of Representatives. Washington, DC: Government Printing Office, 77-509, 1976.
3. T. D. Hartwell, et al. Comparability of Nine Methods for Monitoring NO₂ in Ambient Air. Research Triangle Park, NC: U.S. Environmental Protection Agency, EPA-650/4-74-012.
4. I. F. Goldstein and L. Landovitz. "Can One Aerometric Station Represent the Area Surrounding it?" Atmos. Environ. 11:53-57, 1977.
5. U.S. Environmental Protection Agency. Health Consequences of Sulfur Oxides: A Report from CHES, 1970-1971. Research Triangle Park, NC. May 1974. EPA-650/1-74-004.
6. C. E. Decker et al. "Program for Upgrading the NO₂ Instrumentation Employed in the 1972-1973 Chattanooga NO₂ Exposure Study. Final Report Project No. 43N-869." Research Triangle Park, NC: Research Triangle Institute.

Section 4

SUBJECT VARIABILITY: IMPACT ON ASSESSMENT OF ASTHMA PANELS

Health information for each panelist in the Utah CHES study was obtained from a baseline health questionnaire at the beginning of the study and from daily diaries returned for each of 67 study weeks. The baseline questionnaires were completed during the initial asthma panel selection process. Potential panelists were identified through a School and Family Health Questionnaire (as another part of the overall CHES protocol) administered in December 1970. Additional asthmatics were found by searching the records of community agencies and through the help of local participating physicians. It is possible that, except for asthmatics who refused to participate, essentially the complete population of asthmatics in each study area was included in the study.

Each panelist was personally interviewed, asked to participate and taught the daily diary method for recording daily symptoms. Asthmatics were asked to participate if they had a history of wheezing and shortness of breath with each asthma attack and if they had two or more attacks the previous year. The study design called for the selection giving the highest priority for participation to nonsmokers over 16 years of age. Because of difficulty in obtaining enough panelists, this method of selection proved to be impossible. Based on the data files received for analysis, 244 panelists were selected for participation in the study. Not all of these began the study. Some were subsequently added to replace panelists who were dropped from the study because of continued nonresponse.

Each panelist received a diary each week by mail. The diary began on Sunday and ended on Saturday. An asthma attack was said to occur whenever a panelist became aware of shortness of breath combined with wheezing. The diaries were returned by mail. Nonresponse and diaries requiring clarification were scheduled to be investigated by telephone followup. Diaries not returned within 12 days from end of a reporting period and diaries not able to be clarified were not to be included in the data processing. A detailed examination of the data files received for analysis revealed that the study team was not successful in reducing nonresponse by panelists (Section 4.1). Nor were the procedures for clarifying the responses on

each diary adequately carried out. In addition to difficulty in conducting the field operations, an unfortunate computer programming error occurred that essentially scrambled the diary responses after the first 26 weeks. When this error was brought to EPA's attention by A. D. Little, EPA undertook a validation of the diary data. This consisted of checking that the data file diary information agreed with the information actually recorded on the original diaries. No attempt was made to ensure the consistency of recorded information (nor would it be recommended). Any analysis of the data should objectively handle the inconsistencies and report the procedures used (Section 4.1).

Several limiting factors have been identified for this type of study design (1-6). A day of week effect was reported by Zeidberg et al. (1) and a day of study effect was reported by Landau (2) in their analysis of a 1961 study of asthmatics in Nashville, Tennessee. Roth and his coworkers (3, 4) further documented the presence of these effects. Higher attack rates occurred on weekends at the end of a weekly diary period and there was a steady decline of attack frequency through the course of the study. This suggested problems with the use of a self-administered diary to assess asthma.

In this study a definite day of week effect was present in all four communities. Attack frequencies showed a gradual increase from Sunday through Friday with a leveling off or even a slight drop on Saturday. Further day of week effects were indicated when asthma attacks were classified as primary, secondary, or discrete attacks. Discrete and secondary attack frequencies increased across the week, while primary attacks concentrated on Sunday and Friday. Accompanying the day of week effect was a definite clustering of attacks for individual panelists. This dependence of attack occurrence on the previous day's invalidated the assumptions for some of the analytical methodologies. In particular, temperature-specific and multiple regression analysis procedures were affected.

The baseline (medical history) questionnaire provided information which, while cross-sectional, revealed that asthmatics perceived exacerbation of attacks associated with a number of factors of a non-pollutant nature. This included general allergies, cold weather, emotional upset and respiratory infection. Section 4.3 summarizes the medical profiles indicating the importance of these personal factors in the longitudinal assessment of asthma.

4.1 PANEL COMPOSITION

The daily diary data for the Utah 1971-72 asthma study used in this analysis differed from that used by Finklea et al. (7). EPA became aware of data problems associated with the original file and recreated the correct diary data by checking against the original diary forms. In discussions with EPA investigators, it was found that the first 8 weeks of daily diary data for Magna and Kearns were not able to be checked. The preliminary analysis completed by Finklea et al. (7) in the CHESS monograph was based on the first unvalidated data file. Substantial differences existed between the two data sets. The baseline questionnaire data and the first 26 weeks of attack occurrence responses agreed, with a few exceptions, between the two data sets. Considerable disagreement occurred during the first 26 weeks for the remaining responses on the daily diary form. Since the recreated file was validated back to the diary form, it was used for this study.

A check on the internal consistency of recorded responses was made. The EPA data check only ensured that the responses recorded on each diary form actually coincided with the computerized data. The time, place and severity of attack occurrence information was checked for internal consistency of a panelist's response. Considerable internal inconsistencies were found. This was particularly the case in Magna and Kearns for weeks 1 to 8. Table 4-1 tabulates the responses to the diary questions by community.

The number of potential responses to the episode occurrence questions was determined by multiplying the number of panelists in each community by 469 possible days of participation. Since panelists were dropped and added during the study, this is an overestimate. However, even though a panelist may not have participated in the study until week 31, responses may be present for earlier weeks, e.g., week 14. An important consideration in the actual design of the diary form was that panelists had no way to indicate if they were in their home neighborhood on days when they did not have an attack. Not only does this create severe limitations in any analysis, but it caused computer coding problems when an attempt was made to rectify this problem.

For time of day, in home neighborhood and severity of attack, two types of invalid responses exist. The first type, a small fraction of the total, resulted from an invalid coded response given when a response was expected. The second, more predominant type, was the recording of a response when no attack episode occurred for a day. The following is an example of the responses that occurred:

Table 4-1

NUMBER OF DAILY ASTHMA DIARY RESPONSES FOR EACH DIARY QUESTION
RESPONSES BY COMMUNITY: UTAH 1971-72 ASTHMA STUDY

<u>Episode Occurrence</u>	<u>Ogden</u>	<u>Salt Lake City</u>	<u>Kearns</u>	<u>Magna</u>	<u>Total</u>
Possible Responses	24,857	27,202	37,051	25,326	114,436
Actual Responses	16,447	15,734	20,705	17,491	70,377
No attack	13,752	14,161	17,721	14,581	60,215
1 or more attacks	2,695	1,573	2,984	2,910	10,162
1 attack	1,719	1,250	1,490	2,086	6,545
2 or more attacks	976	323	1,494	824	3,617
Invalid response	1	5*	0	1**	7
<u>Time of Day</u>					
Possible Valid responses	2,695	1,573	2,984	2,910	10,162
Nonresponse	92	25	417	391	925
12 m - 6 am	777	473	873	717	2,840
6 am - 12 noon	866	462	884	1,085	3,297
12 n - 6 pm	427	501	501	378	1,606
6 pm - 12 midnight	533	311	307	338	1,489
Invalid Responses	46	19*	159	279**	503
<u>Home Neighborhood</u>					
Possible valid responses	2,695	1,573	2,984	2,910	10,162
Nonresponses	73	22	417	364	876
Not home	457	257	280	378	1,372
Home	2,162	1,291	2,287	2,165	7,905
Invalid responses	49	15*	197	222**	483
<u>Severity of Attack</u>					
Possible valid responses	2,695	1,573	2,984	2,910	10,162
Nonresponse	86	27	551	517	1,191
Not severe	1,993	1,008	1,885	1,946	6,832
Severe	603	537	547	446	2,133
Invalid responses	6	7*	2	4**	19

*Five responses are coded '8' - not in home neighborhood

**One response is coded '8' - not in home neighborhood

- Did you have an asthma episode today? No.
 - Were you in your home neighborhood when the episode began? Yes!
 - At what time did the episode begin? 6-12 a.m.!
- Did you have an asthma episode today? No.
 - Was the episode severe enough to keep you from work or school or from your normal activity? Yes!

Most of the invalid responses occurred in Magna and Kearns. Over 90% of their errors occurred during weeks not checked by EPA, the first 8 weeks.

Overall asthma attack rates for the four communities were 0.164 for Ogden, 0.100 for Salt Lake City, 0.144 for Kearns and 0.166 for Magna. The number of individual attack episodes per day differed across the communities. One-half of the attack person-days in Kearns were recorded as two or more attacks while only one-fourth of the attack person-days in Salt Lake City were recorded as two or more. More attacks occurred from midnight to noon than in the remaining half of the day. This is consistent with results reported by other investigators. Panelists indicated they were not in their home neighborhood on 15% of the days when they had one or more attacks.

In addition to invalid responses by panelists, a wide discrepancy in the consistency of their reporting on a weekly basis occurred. Some of the 244 panelists never returned a valid diary response during the 67 weeks while others responded every week. A restricted set of panelists was chosen based on objective criteria designed to minimize any panelist drop out/drop in problem and to correct for data inconsistencies. The procedures used to accomplish this were:

- Invalid responses were "corrected."
 - A day with an invalid response for occurrence of an attack was changed to no response.
 - A day with a response of no attack, but with responses to other three questions was changed to no response for all questions.
 - A day specially coded to indicate panelist out of home neighborhood was changed to no response. (Refers only to episode occurrence question.)
- The first eight weeks of the study were dropped because they were not validated and contained numerous invalid responses.
- A panelist was dropped from study if:
 - No attacks were recorded at any time during the study.

--Less than one-third (1/3) of the weekly diaries were not returned from the time panelist entered the study.

Table 4-2 shows the number of panelists remaining in each panel and the number of panelists omitted from the study. A total of 88 panelists were omitted leaving 156 panelists for subsequent analysis. Unless stated otherwise, all analyses were based on these 156 participating panelists.

Panelist composition for the four communities is given in Table 4.3. Approximately half the panelists in each community were younger than 16, i.e., juveniles. The panels differed in the percent who smoked, from 7% in Salt Lake City to 42% in Kearns. The educational characteristics of the heads of household were similar across communities. The most notable panelist characteristic was the difference in male/female ratio for juveniles versus adults. This was not unusual, based on known clinical aspects of bronchial asthma (Section 2).

A serious limitation of the study was the addition of panelists during the course of the study due to a decrease in response from panelists. This changed the panel composition in the course of the study and made it mandatory that panelists be analyzed individually or an appropriate adjustment be made if panelists were combined. A related problem was the panelist who responded one week but not the next,

Table 4-2
NUMBER OF PANELISTS BY COMMUNITY INCLUDED AND
OMITTED FOR SPECIFIC REASONS: UTAH 1971-72 ASTHMA STUDY

Community	Omitted Panelists				Included	Total
	No Diary	Not Enough	No Attacks	Total		
Ogden	3	10	3	16	37	53
Salt Lake City	7	13	4	24	34	58
Kearns	12	13	6	31	48	79
Magna	6	6	5	17	37	54
TOTAL	28	42	18	88	156	244

Table 4-3

CHARACTERISTICS OF UTAH ASTHMA DIARY
STUDY POPULATION: UTAH 1971-72 ASTHMA STUDY

<u>Population Characteristics</u>	<u>Ogden</u>	<u>Salt Lake City</u>	<u>Kearns</u>	<u>Magna</u>	<u>Total</u>
Number of panelists	37	34	48	37	156
Age and Sex Characteristics					
Panelists ≥ 16	21(57)*	15(44)	19(40)	21(57)	76(49)
Females	15	12	13	14	54
Males	6	3	6	7	22
Panelists < 16	16(43)	19(56)	29(60)	16(43)	80(51)
Females	5	6	8	4	23
Males	11	13	21	12	57
Smoking Characteristics					
Adults					
Smokers	4(19)**	1(7)	8(42)	7(33)	20(26)
Female	2	0	4	5	11
Male	2	1	4	2	9
Former Smokers	2(10)	2(13)	1(5)	2(10)	7(9)
Female	1	1	1	1	4
Male	1	1	0	1	3
Nonsmokers	15(71)	12(80)	10(53)	12(57)	49(65)
Female	12	11	8	8	39
Male	3	1	2	4	10
Education Characteristics					
Head of household graduated high school	31(84)	25(74)	39(81)	28(76)	123(79)
Panelist ≥ 16 yrs old	18	10	15	16	59
Panelist < 16 yrs old	13	15	24	12	64
Head of household did not graduate from high school	5(16)	9(26)	9(19)	9(24)	33(21)
Panelist ≥ 16 yrs old	3	5	4	5	17
Panelist < 16 yrs old	3	4	5	4	16

*Percentage based on number of panelists in community.

**Percentage based on adults only.

i.e., the drop in/drop out problem. The seriousness of these two problems is illustrated by Figures 4-1 to 4-4. The sequential addition of new panelists is clearly shown. The daily response pattern exemplifies the drop in/drop out problem and suggests a day of study effect when the addition of new panelists is accounted for.

4.2 DAILY ATTACK PATTERNS

Several limiting factors related to attack patterns have been identified with panel studies of daily asthma attack occurrence (1-6). Zeidberg et al. (1) studying asthmatics in Nashville, found that attack rates for adults increased steadily from Monday through Saturday, followed by a decrease on Sunday. For juveniles, attack rates were highest on Monday, Saturday and Sunday. The weekly reporting period was Monday through Sunday. In the CHES New York studies reanalyzed by Roth et al. (3), higher rates were observed on Thursday, Friday and Saturday. A similar pattern was indicated for the Los Angeles CHES study (4). The CHES studies used a Sunday to Saturday diary reporting period. Analyses of the CHES studies also showed a decline in attack frequency during the study. Landau et al. (2), in an expansion of the analysis for Nashville, noted a similar decline. The analyses of the New York and Los Angeles CHES studies also revealed a definite clustering of attacks. These factors suggested the presence of phenomena either unaccounted for or induced by the panel study design.

The results in this and the remaining sections were based on the 156 participating panelists. This eliminated some of the effect due to panelists dropping in and dropping out of the daily diary reporting. For some analyses additional adjustments for that effect were made. Stebbings and Hayes (5) and Roth et al. (3) devised the indices total daily base rate $B(T)$ and quarterly daily base rate $B(Q)$. $B(T)$ on a given study day was defined to be the average study attack rate among participants in the study on that day. $B(Q)$ was defined similarly except that the attack rate for a panelist was computed using only those days from the quarter in which the given study day occurred. Thus $B(Q)$ included a seasonal adjustment factor. Two new variables included in the analyses were the ratios $O/B(T)$ and $O/B(Q)$ where O was the actual daily attack rate.

Day of Week

Based on the health index $O/B(T)$, a definite day of week effect was found in all communities (Table 4-4). Attack frequency for all panelists increased consistently from Sunday through Saturday. Based on the Friedman rank test, a significant ($p < 0.01$) day of week effect was present. When adult and juvenile panelists were

Figure 4-1. Size of Panel and Number of Respondents in Ogden Panel for Each Day of Study.

Figure 4-2. Size of Panel and Number of Respondents in Salt Lake City Panel for Each Day of Study.

Figure 4-3. Size of Panel and Number of Respondents in Kearns Panel for Each Day of Study.

Figure 4-4. Size of Panel and Number of Respondents for Magna for Each Day of Study.

Table 4-4

MEAN RESPONSE OF O/B(T) BY DAY OF WEEK FOR
ADULTS AND JUVENILES: UTAH 1971-72 ASTHMA STUDY

<u>Day of Week</u>	<u>Ogden</u>	<u>Salt Lake City</u>	<u>Kearns</u>	<u>Magna</u>	<u>Sum of Ranks</u>
All Panelists					
Pooled Std. Dev.	0.361	0.571	0.302	0.308	
Sunday	0.953(4)*	0.826(1)	0.838(1)	0.886(1)	7
Monday	0.934(3)	0.859(2)	0.888(2)	0.984(3)	10
Tuesday	0.913(2)	1.000(3)	1.004(4)	0.967(2)	11
Wednesday	0.881(1)	1.084(6)	0.946(3)	1.005(4)	14
Thursday	1.044(5)	1.058(4)	1.142(7)	1.022(5)	21
Friday	1.125(6)	1.066(5)	1.091(5)	1.106(7)	23
Saturday	1.136(7)	1.098(7)	1.099(6)	1.077(6)	26
Adults					
Pooled Std. Dev.	0.361	0.679	0.377	0.371	
Sunday	0.967(4)	0.913(1)	0.865(1)	0.884(1)	7
Monday	0.920(3)	0.953(3)	0.913(2)	0.983(3)	11
Tuesday	0.901(1)	0.947(2)	0.964(4)	0.942(2)	9
Wednesday	0.918(2)	1.096(7)	0.929(3)	1.012(4)	16
Thursday	1.077(5)	1.014(5)	1.104(5)	1.024(5)	20
Friday	1.118(7)	1.070(6)	1.140(7)	1.094(7)	27
Saturday	1.087(6)	1.006(4)	1.111(6)	1.068(6)	22
Juveniles					
Pooled Std. Dev.	0.835	0.743	0.521	0.534	
Sunday	0.892(2)	0.737(1)	0.792(1)	0.874(1)	5
Monday	0.975(5)	0.770(2)	0.845(2)	0.987(3)	12
Tuesday	0.958(4)	1.059(4)	1.084(6)	1.036(5)	19
Wednesday	0.779(1)	1.102(5)	0.962(3)	0.946(2)	11
Thursday	0.922(3)	1.138(6)	1.208(7)	0.990(4)	20
Friday	1.166(6)	1.052(3)	1.004(4)	1.102(7)	20
Saturday	1.284(7)	1.180(7)	1.069(5)	1.091(6)	25

*Rank of day of week from lowest to highest.

considered separately, a significant day of week effect persisted. Thursday, Friday and Saturday consistently had higher attack rates for both groups. For juveniles higher rates also occurred on Tuesdays. The results for juveniles should not be overinterpreted because the number of juvenile panelists was small.

In order to further understand day of week and attack clustering effects, individual attack days were categorized as discrete, primary or secondary. Discrete attack days were those days with at least one day prior to and after free of an attack. A primary attack day was the first day in a sequence of consecutive attack days. Secondary attack days were the remaining days in such a sequence. Discrete, primary and secondary attack days were categorized by day of week and community for adults and juveniles. Table 4-5 summarizes the results. For adults a significant day of week effect (using Friedman's rank test) was present for discrete ($p < 0.05$), primary ($p < 0.01$) and secondary ($p < 0.05$) attack frequencies. Discrete and secondary frequencies increased across the week, while primary attack days concentrated on Sunday and Friday. Primary attack day tended not to occur on Saturday, the last day of the diary period. A conclusion of a definite causal relationship with the diary reporting period was not possible. Discrete and secondary attack days for juveniles showed a significant ($p < 0.05$) day of week effect with Saturday having higher frequencies. No significant day of week effect for primary attack days was found although Saturday had lower frequencies. Tables A-6 through A-9 in Appendix A present detailed results by study quarters.

A definite day of week effect was indicated by the data and must be considered in any analysis. Sequences of attacks were more likely to begin on Sunday or Friday and least likely on Saturday indicating a bias that may be related to the diary methodology itself and not to asthma. Inclusion of day of week effect, when present, in an analysis will reduce variation observed in attack frequencies and increase the chance of finding a pollution effect. No day of week effect was observed for air pollution levels during the study period. If air pollution levels were correlated with day of week, then inclusion of day of week would reduce bias.

Day of Study

Interpretation of daily associations between air quality and asthma attack indicators was clouded by a day of study effect. Two separate issues arose in this connection:

- panel composition changes over time.
- collinearity of air quality indicators with day of study.

Table 4-5

FREQUENCY OF DISCRETE, PRIMARY AND SECONDARY
ATTACK DAYS FOR ADULTS AND JUVENILES BY DAY OF
WEEK AND COMMUNITY: UTAH 1971-72 ASTHMA STUDY

	<u>Sunday</u>	<u>Monday</u>	<u>Tuesday</u>	<u>Wednesday</u>	<u>Thursday</u>	<u>Friday</u>	<u>Saturday</u>
Adults							
Ogden							
Discrete	32	17	20	14	35	39	48
Primary	45	21	19	25	33	30	12
Secondary	154	183	176	175	184	196	198
Salt Lake City							
Discrete	17	19	22	25	19	23	29
Primary	23	10	12	14	11	17	2
Secondary	37	54	48	52	52	54	58
Kearns							
Discrete	8	20	23	11	26	21	28
Primary	19	12	17	21	37	30	13
Secondary	154	158	160	161	167	189	189
Magna							
Discrete	36	43	34	45	46	49	52
Primary	38	48	22	35	34	45	26
Secondary	136	144	172	165	165	170	178
Sum of Ranks							
Discrete	8	10.5	13	13	18.5	21	28
Primary	23	13	10	18	19	23	6
Secondary	4	13.5	14	13	17	23	27.5
Juveniles							
Ogden							
Discrete	14	18	18	14	16	25	40
Primary	18	10	12	7	22	14	16
Secondary	31	43	36	35	27	41	35
Salt Lake City							
Discrete	11	8	32	26	19	15	38
Primary	16	12	16	20	19	12	9
Secondary	39	49	48	54	66	69	60
Kearns							
Discrete	27	25	42	33	52	33	47
Primary	17	25	21	20	27	14	17
Secondary	66	67	80	81	87	93	84
Magna							
Discrete	13	13	17	17	14	16	17
Primary	16	17	10	14	22	21	9
Secondary	67	76	82	74	75	87	91
Sum of Ranks							
Discrete	7	8	21.5	16	17	16.5	26
Primary	17	15.5	14.5	15	27	13.5	9.5
Secondary	5	16	15	13.5	16	26	20.5

The effect of overreporting was addressed in Section 4.1. Increased attack reporting was indicated at the beginning of the study. Composition of community panels changed during the study due to attrition of panelists, additions to panel and nonresponse (Section 4.1). Further evidence of an effect of panel composition was provided by correlation of selected indicators with day of study (Table 4-6). Except for Ogden, a strong negative correlation of response rate with day of study was present in all communities. Three variables, average age, adult/juvenile ratio and male/female ratio of responding panelists defined for each day, showed substantial correlations with day of study. With all panelists always responding, these variables would be constant during the study period. Clearly, not only was the panel changing but also the changes were correlated with time. The average age of the panel increased over the study period. No consistent pattern across communities' was apparent for ratio of males to females.

Air pollutants were correlated with day of study. In particular, total suspended particulates, suspended sulfates and nitrogen dioxide had positive correlations with time. Refer to Section 3 for more detailed description of seasonal air pollution patterns. Meteorological variables, minimum temperature and daily temperature range were negatively correlated and relative humidity was positively correlated with day of study. When interpreting either air pollutant or meteorological associations with attack rate indicators, these correlations with day of study must be remembered. If other unmeasured factors, e.g., pollens, were also correlated with day of study, then effects due to unmeasured factors may be incorrectly attributed to air pollution.

Day of study was positively correlated with observed daily attack rate, base rate total $B(T)$ and quarterly $B(Q)$. The correlations were consistent across communities and adult/juvenile subsets (Table 4-7). The base rate total $B(T)$ correlation reflected the change in panel composition during the study. Base rate quarterly $B(Q)$ reflected panel composition and seasonal changes in attack rates. When adjustments for drop in/drop out effect were made by defining the ratio of observed attack rates to base rate total, the correlation with day of study was removed. This illustrated the necessity for an adjustment of drop in/drop out effect. An additional seasonal adjustment using the ratio $O/B(Q)$ also removed any significant correlation with day of study. Although not significant, the correlations in this case were slightly negative.

Table 4-6

SERIAL CORRELATION OF DAY OF STUDY WITH DAILY
INDICATORS BY COMMUNITY: UTAH 1971-72 ASTHMA STUDY

<u>Indicator</u>	<u>Ogden</u>	<u>Salt Lake City</u>	<u>Kearns</u>	<u>Magna</u>
Response Rate	-0.04	-0.38	-0.41	-0.41
Age	0.23	0.85	0.43	0.25
Adult/Juvenile	0.07	0.55	0.15	0.10
Male/Female	-0.11	0.36	-0.61	-0.15
TSP	0.32	0.32	0.27	0.28
SN	0.01	-0.01	0.02	0.04
SS	0.15	0.13	0.06	0.08
SO ₂	0.13	0.03	0.06	0.13
NO ₂	0.26	0.24	0.14	0.21
Min. Temperature	-0.31	-0.35	-0.24	-0.24
Relative Humidity	0.14	0.14	0.14	0.14
Temperature Range	-0.35	-0.18	-0.50	-0.50
Min. Temperature Range	0.02	0.02	0.02	0.02

Table 4-7

SERIAL CORRELATION OF ATTACK RATE INDICATORS WITH DAY
OF STUDY BY COMMUNITY AND AGE: UTAH 1971-72 ASTHMA STUDY

<u>Community Age</u>	<u>Observed Attack Rate</u>	<u>B(T)</u>	<u>B(Q)</u>	<u>O/B(T)</u>	<u>O/B(Q)</u>
Ogden					
All	0.10	0.21	0.47	0.05	-0.03
Adult	0.11	0.24	0.43	0.04	-0.03
Juvenile	0.03	-0.09	0.28	0.04	-0.01
Salt Lake City					
All	0.19	0.52	0.65	0.10	-0.06
Adult	0.08	0.41	0.32	-0.04	-0.05
Juvenile	0.19	0.37	0.55	0.16	-0.04
Kearns					
All	0.11	0.41	0.39	0.01	-0.04
Adult	-0.01	0.36	0.06	-0.11	-0.05
Juvenile	0.18	0.28	0.65	0.13	0.00
Magna					
All	0.23	0.29	0.57	0.13	-0.07
Adult	0.24	0.35	0.51	0.14	-0.09
Juvenile	0.04	0.01	0.18	0.07	-0.00

Clustering of Attacks

Previous analyses (3,4) of CHESS asthma studies documented clustering of attacks or sequences of consecutive days with attacks for individual panelists. The occurrence of these sequences supported the contention that attack occurrences were not independent from day to day. For many statistical analyses, especially those based on daily attack rates, a basic assumption of independence is required. This does not appear to be valid.

The daily attacks of individual panelists were categorized as discrete, primary and secondary, as previously defined. For each panelist, the proportion of attacks categorized as discrete, primary and secondary was determined. In addition, the average number of attacks occurring in distinct runs of attacks and the number of weekly runs for each panelist was calculated. A weekly run consisted of at least one attack every day in the Sunday through Saturday diary reporting period. A panelist with 28 consecutive days of attacks beginning on a Sunday would be counted as having 4 weekly runs during that time. Table 4-8 summarizes these attack clustering measures by community. Only 40% of attacks were discrete occurrences. The percent for individual panelists varied widely, from 0 to 100%. On the average, primary attacks accounted for 17% of the attacks for a panelist. Across all communities, the percentage ranged from 0 to 36% with three panelists having 50% as primary attacks. The remaining attacks in a run (secondary) account for approximately 43%.

Average length of attack runs was approximately 5 or 6 days for all communities. The high standard deviation indicated the distribution of run length was highly skewed so that some panelists had much longer average runs. Ten panelists had average run lengths between 20 and 51 days. Weekly attack runs were present for approximately one-third of the panelists in each community. The average number of weekly runs varied from 4 to 13 per panelist across the communities. However, only 16 of 52 panelists who had weekly attack runs had 10 or more weekly runs.

The above summaries and an inspection of the daily attack sequences for individual panelists supported a nonindependence conclusion for daily attack occurrences. They also indicated a wide diversity in attack reporting patterns across panelists. Some tended to report or had many consecutive attacks while others reported or had intermittent attacks. More careful screening of panelists at the beginning of a study would allow either a more homogeneous group of panelists to be selected for study or prior stratification of panelists into subgroups for later analysis. Both procedures would result in reduced variability between panelists. The identification of an air pollutant effect on asthma is usually simplified with reduced variability.

Table 4-8

CLUSTERING OF PANELIST ATTACKS BY
COMMUNITY: UTAH 1971-72 ASTHMA STUDY

	Proportion of attacks that were							Attack Runs					
	Discrete			Primary		Secondary		Average Length			Number of Weekly Runs		
	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	N	Mean	Std. Dev.	N	Mean	Std. Dev.
Ogden	37	0.40	0.33	0.15	0.09	0.45	0.29	32	5.7	6.1	13	9.9	12.2
Salt Lake City	34	0.44	0.37	0.16	0.13	0.41	0.30	27	5.4	6.1	12	4.2	4.2
Kearns	48	0.39	0.33	0.18	0.12	0.43	0.29	42	6.2	9.5	16	10.3	13.6
Magna	37	0.35	0.27	0.19	0.08	0.46	0.26	35	5.5	8.3	11	13.0	19.2

4.3 PANEL CHARACTERISTICS AND OBSERVED ATTACK RATES

In addition to the daily diary information, a substantial amount of medical history baseline data was obtained for each panelist. These ancillary data, although subjective in nature, indicated the complexity of asthma assessment and the need to take these factors into consideration in the design, analysis and interpretation of the data from this and similar studies.

Prior to commencement of the daily diary portion of the study, individuals were asked to assess the frequency of asthma attacks they associated with nonpollutant factors. Each subject recorded whether they had no, some or many attacks occurring with a given condition. The conditions considered were:

- the four seasons (fall, winter, spring, summer)
- fumes or dust on job, food and drug allergies, emotional upsets
- cold weather or respiratory infections
- hay fever.

Tables A-10 through A-13 in Appendix A tabulates the percentage of subjects answering yes to each condition, the overall attack rate for subjects stating yes to that condition and respective quarterly rates.

No consistent pattern across seasons was noted for attack rates for either adults or juveniles. Even within a community, a consistent pattern of attack rates with season was not detectable. This may be due to an inaccurate subjective assessment by the panelist, poor reporting during the diary phase, an inappropriate summary not accounting for panelist drop in/drop out or the nonexistence of a seasonal pattern across panelists. Any or all of the above could be true.

A substantial number of panelists did indicate that they were affected by conditions other than air pollutants or general seasonal patterns. Except for exposure to fumes or dust on job, over 50% of adult and juvenile panelists in each community associated frequent asthma attacks with other conditions (Table 4-9). Attacks associated with respiratory infections and hay fever were most prevalent. A higher percentage of adults in Magna, the community closest to smelter operations, associated frequent attacks with exposure to fumes or dust on the job. The variability among panelists clearly indicated that care had to be taken in any analysis that combined data across panelists and that unless it was possible to account for these conditions the high variability would make it difficult to detect an air pollution effect on asthma.

Present age, age asthma began and asthma attack rates were stratified by adult and juvenile panelists in each community (Table 4-10). In the study population, the adults had higher attack rates than juveniles. Consequently, a diary study with a severe drop in/drop out problem could be misleading if some adjustment was not made. Drop outs will bias the study if the drop out pattern is correlated with asthma attacks and air pollutants. Even without such correlation the increased variability greatly decreases the chances of finding an effect, if one exists. The base rate total B(T) adjustment suggested by Roth et al. (3) and Stebbings and Hayes (5) arose from these considerations.

Table 4-9

PERCENTAGE OF PANELISTS ASSOCIATING FREQUENT ASTHMA ATTACKS
WITH SELECTED CONDITIONS: UTAH 1971-72 ASTHMA STUDY

<u>Condition</u>		<u>Ogden</u>	<u>Salt Lake City</u>	<u>Kearns</u>	<u>Magna</u>
Food and Drug Allergies	Adult ¹	48	60	47	62
	Juvenile	31	53	45	31
Attacks with Respiratory Infection	Adult	67	67	84	71
	Juvenile	88	74	79	56
Attacks with Emotional Upset	Adult	76	47	58	43
	Juvenile	44	37	48	38
Hay Fever	Adult	57	80	68	76
	Juvenile	56	42	69	50
Fumes or Dust on Job	Adult	24	27	21	48
	Juvenile	0	5	7	0
Cold Weather	Adult	48	33	53	38
	Juvenile	63	32	45	50

¹A panelist greater than or equal to 16 years of age was termed an adult.

Table 4-10

AGE, AGE ASTHMA BEGAN AND ATTACK RATE SUMMARY
 STATISTICS FOR ADULT/JUVENILE CATEGORIES
 BY COMMUNITIES: UTAH 1971-72 ASTHMA STUDY

Community Adult/Juvenile			Age	Age Asthma Began	Attack Rate			
					Complete Study	Summer Quarter	Fall Quarter	Winter Quarter
Ogden								
Total	mean	28.4	14.5	0.173	0.159	0.160	0.177	0.188
	std. dev.	18.8	16.9	0.236	0.214	0.232	0.273	0.277
	N	37	37	37	30	37	37	37
Adult	mean	43.1	24.6	0.240	0.219	0.217	0.239	0.261
	std. dev.	10.2	16.2	0.209	0.260	0.288	0.339	0.336
	N	21	21	21	17	21	21	21
Juvenile	mean	9.1	1.3	0.085	0.080	0.084	0.095	0.093
	std. dev.	3.1	2.2	0.093	0.095	0.091	0.112	0.129
	N	16	16	16	13	16	16	16
Salt Lake City								
Total	mean	22.4	10.3	0.111	0.099	0.116	0.099	0.162
	std. dev.	18.3	15.1	0.149	0.116	0.206	0.194	0.238
	N	34	34	34	31	34	34	31
Adult	mean	39.8	19.9	0.138	0.108	0.169	0.141	0.176
	std. dev.	13.7	18.7	0.177	0.122	0.278	0.264	0.259
	N	15	15	15	13	15	15	14
Juvenile	mean	8.6	2.7	0.090	0.093	0.075	0.066	0.150
	std. dev.	3.6	3.0	0.124	0.114	0.118	0.110	0.226
	N	19	19	19	18	19	19	17
Kearns								
Total	mean	23.2	8.7	0.144	0.149	0.138	0.130	0.155
	std. dev.	16.2	9.9	0.219	0.209	0.224	0.249	0.279
	N	48	48	48	43	48	48	46
Adult	mean	42.2	16.7	0.218	0.268	0.194	0.183	0.247
	std. dev.	6.4	11.3	0.266	0.273	0.266	0.303	0.355
	N	19	19	19	16	19	19	18
Juvenile	mean	10.8	3.5	0.096	0.078	0.102	0.095	0.096
	std. dev.	2.8	3.4	0.170	0.117	0.188	0.204	0.203
	N	29	29	29	27	29	29	28
Magna								
Total	mean	25.6	12.1	0.193	0.160	0.202	0.201	0.198
	std. dev.	17.1	12.5	0.266	0.201	0.282	0.298	0.291
	N	37	37	37	37	37	37	37
Adult	mean	39.3	19.1	0.240	0.180	0.262	0.261	0.239
	std. dev.	7.8	12.5	0.273	0.188	0.298	0.299	0.310
	N	21	21	21	21	21	21	21
Juvenile	mean	7.5	2.9	0.132	0.134	0.122	0.121	0.146
	std. dev.	3.3	2.3	0.252	0.221	0.247	0.285	0.265
	N	16	16	16	16	16	16	16

REFERENCES

1. L. D. Zeidberg, R. A. Prindle and E. Landau. "The Nashville Air Pollution Study. I. Sulfur Dioxide and Bronchial Asthma. A Preliminary Report." Amer. Rev. Resp. Dis. 84:489-503. 1961.
2. E. Landau, R. A. Prindle and L. D. Zeidberg. "The Nashville Air Pollution Study. Sulfur Dioxide and Bronchial Asthma - A Multivariate Analysis." Intern. J. Environ. Studies 2:41-45, 1971.
3. H. D. Roth, J. R. Viren and A. V. Colucci. Evaluation of CHESS: New York Asthma Data 1970-71. Palo/Alto, Calif.: Electric Power Research Institute, May 1977. EPRI-EA-450, Vol. I.
4. J. R. Viren, H. D. Roth, A. V. Colucci and P. D. Finkelstein. Asthma in Six Los Angeles Communities: An Outline of Finding Based on CHESS 1972-73. Report for Southern California Edison, Rosemead, Calif., 1978.
5. J. H. Stebbings, Jr. and C. G. Hayes. "Panel Studies of Acute Health Effects of Air Pollution. I. Cardiopulmonary Symptoms in Adults, New York 1971-1972." Environ. Res. 11:89-111, 1976.
6. J. H. Stebbings, Jr. "Panel Studies of Acute Health Effects of Air Pollution. II. A Methodologic Study of Linear Regression Analysis of Asthma Panel Data." Environ. Res. 17:10-32, 1978.
7. J. F. Finklea, et al. "Aggravation of Asthma by Air Pollutants: 1971 Salt Lake Basin Studies." In Health Consequences of Sulfur Oxides: A Report from CHESS 1970-1971. Research Triangle Park, NC: U.S. Environmental Protection Agency, May 1974. EPA-650/1-74-004.

Section 5

ANALYSES CORRECTING FOR VARIATION AMONG PANELISTS

Past analyses of asthma panel studies may be classified into two major types. One type summarizes the person-days of attack responses. In one procedure daily attack proportions are analyzed using the variability across days to study postulated relationships between asthma and air pollution. Another procedure categorizes person-days according to temperature and/or air pollutant values. As noted in detail in Section 6, the person-day approach gives rise to many problems and limitations. These include nonindependence of the daily attack proportions and an inability to adequately adjust for inter-panelist variability, especially when confronted with a significant panelist nonresponse. The second type, most recently proposed by Korn and Whittemore (1), first summarizes each panelist's daily attack responses by using the panelist's day to day variability and then combines across panelists to arrive at an overall panel estimate for a relationship between asthma and air pollution. Here the emphasis is on using each panelist as his own control. This approach allows for certain time dependency relationships in attack occurrence to be explicitly modeled. The approach is also appealing since it considers the high variability in attack propensity among panelists.

In this section two different analyses are given. Both are based on individual panelist's responses considered as time series, i.e., the second type of analysis. The analysis presented in Section 5.1 views the probability of an attack on day t as a Markov chain and explicitly considers the air pollutant measurement problems by categorizing the variables. The remainder of the analysis is based on analysis of variance techniques. The crucial assumption and manner of summarizing the information is connected to the Markov chain concept. In Section 5.2 the method proposed by Korn and Whittemore (1) and subsequently applied to the Los Angeles Basin CHESS asthma panels in Whittemore and Korn (2) is applied to the present study. First, the analysis as proposed, is completed and then a detailed examination of the method is made. The analyses are termed Markov analysis of variance, model of panelist's response profiles and logistic modeling of panelist's response profiles, respectively.

In summary, the Markov Analysis of Variance procedure clearly exposed the collinearity of the air pollutants and minimum temperature. The grouping of variables into categories and the allocation of each day to one of the "treatment" combinations defined by all possible combinations resulted in more than half the combinations not having observations in them. Rather than treating the combinations as a factorial treatment arrangement, the nonempty cells were treated as levels of a single treatment variable. Application of a standard analysis of variance procedure clearly indicated a "treatment" effect. The confounding of the pollutants and minimum temperature precluded assigning the effect to any particular pollutant.

Overall, the analysis led to the conclusion that some "treatment" combinations were associated with increased asthma attack rates. However, confounding of factors precluded the identification of specific accountable factors. In particular, no biologically plausible air pollution effect was found.

The logistic model analysis of the Utah 1971-72 data substantively agreed with the previous results. As expected, the largest single effect in attack rates was the occurrence of an attack on the previous day. This was followed by substantial day of week patterns in attack occurrence. Higher attack rates occurred during the latter part of the week, with Sunday having the lowest rate of attack occurrence. No air pollutant covariate had a significant effect. Only for Ogden was an inverse minimum temperature effect found.

Selection and Limitations of Analyses

A method of analysis for an asthma panel study was selected considering a number of points. The method had to be capable of establishing whether increased air pollutant levels were related to increased asthma attack frequency. The empirically determined dependence of attack occurrence or non-occurrence on successive days had to be explicitly included in the model. It was necessary that the analysis adjusted for large differences in attack rates across individuals. Previous studies had shown that individual panelist variability was significant and needed to be included. Finally, the selection of an analysis method was to consider the quality of data available for analysis. For example, Sections 3 and 4 documented specific limitations of the data collected as part of the study. Sufficient evidence existed to conclude that air pollution data were only capable of qualitatively describing the panelist's individual daily integrated exposure levels. Even more important may have been the lack of information on other factors (see Section 2) that affect asthma attack occurrence. Much of the analysis presented is aimed at making the point that, no matter what model is used, it is difficult to describe the nature of

the effects of the covariates in the model. This is more a limitation caused by the collinearity of the independent covariates than a problem with any of the models used. This fact suggests that the emphasis of the results of any of the analyses should be limited to whether or not there is a pollution effect on asthma attacks rather than on describing the nature of the effect. Neither of the methods described in this section are without limitations. However, both are improvements over other methods of analysis previously applied, in particular, an improvement over regression using daily attack rates and temperature-specific relative risk based on person-days.

The Markov analysis of variance approach detailed in Section 5.1 was appealing because it explicitly modeled dependence, adjusted for individual variability and exposed the limitations of the data. Its simplicity also was appealing. Its basic limitations were that it was difficult to include more than a few variables in the analysis, it was difficult to understand the form of the relationship between the dependent variable and independent variables, and it was difficult to test if the error structure of the model was correct. The logistic time series method of Korn and Whittemore had many of the same advantages as the Markov analysis of variance approach. However, in applying the method to the Utah asthma panel data, certain areas that needed further examination were found. An accepted procedure for assessing how well a logistic model fits an individual panelist's attack occurrence data does not exist. Methods proposed by Whittemore and Korn did not appear to be sensitive to model failure. Collinearity in the aerometric and other cofactor variables was difficult to detect for the logistic model. Further statistical research is needed to resolve these issues.

Even if the logistic regression models for individual panelists were adequate, procedures for combining estimated parameter coefficients had to be evaluated. Although the mechanics of combining coefficients for a panel were easily understood, the interpretation was not. The method used was univariate in that each variable was considered separately. Based on the Utah data, a disturbing aspect of the univariate procedure was that 5 or 6 out of 30 to 40 panelists supplied over 50% of the information for the combined estimate. Even if the estimates combined in this manner were appropriate, a question remained as to the validity of using these combined estimates in the logistic framework to estimate relative risk. The parameter estimates were correlated and this should have been considered if estimates were to be combined. Korn and Whittemore (1) describe a multivariate procedure for combining estimates, which was not applied during these analyses.

5.1 MARKOV ANALYSIS OF VARIANCE MODEL OF PANELISTS RESPONSE PROFILES

All of the methods previously proposed and used for the analysis of asthma panel data have limitations. Some of these were noted by Stebbings (3), Roth et al. (4) and Whittemore and Korn (2) and the references therein. Limitations specific to this study are discussed in other sections of this report. In this section another analysis procedure is defined and used on the Utah asthma data. It too has limitations but had the advantage of being simple and not highly model dependent. Some of the limitations of the original study design and data quality, as described in Sections 2, 3, and 4, cannot be overcome by any statistical procedure. Hence, any conclusions from this analysis must be interpreted with those limitations considered.

The Model

The analysis consisted of known methods that were applied in a new way to the panel study framework. The model is described first, followed by an application to the Utah data.

One of the most important predictors of an asthma attack on a particular day is the occurrence or absence of an attack on the previous day. This fact was shown empirically by Whittemore and Korn (2) in their analyses of asthma panel studies in the Los Angeles Basin. Consequently, the probability of an attack on day t , denoted $p^i(t)$ for the i th panelist, is modeled as a Markov chain such that

$$p^i(t|Z_{t-1}^i) = f^i(\beta X_t^i, D^i, Z_{t-1}^i) \quad (5-1)$$

where $Z_{t-1}^i = \begin{cases} 1 & \text{if } i\text{th panelist has an attack on day } t-1 \\ 0 & \text{if } i\text{th panelist had no attack on day } t-1 \end{cases}$

and where D^i is a vector of demographic variables. Note that the demographic variables for each individual were constant during the study period so that D^i in Eq. 5-1 is redundant but is included for clarity. The parameter β , associated with the concomitants X_t^i , measure how much the values of X_t^i change the probability of attack given the value of Z_{t-1}^i .

Before implementing this model, however, the limitations of the air pollution data had to be considered. In Section 3, serious questions were raised concerning the accuracy and precision of the air pollution data. Measurement and quality control difficulties were noted and were shown to lead to biases or increased variability

in the data. The adequacy of a single monitoring site to represent an individual's daily integrated exposure levels was questioned. We concluded that the pollutant values only grossly indicated a panelist's integrated exposure. Therefore, the concomitant variables were grouped individually into discrete categories. The groupings selected are given in Table 5-1. The selection of the boundaries of the groups was guided by the current air quality standards and groupings selected by other investigators. It was felt that these groupings reflected high and low pollution days without depending too closely on the exact data values.

The observed proportion of attacks by panelist i when concomitant levels are represented by X_t^i is only an estimate of $p^i(t|Z_{t-1}^i)$. Classically this is represented by adding an error term to Eq. 5-1. In the present case, however, the variances of these error terms will not be constant due to the binomial nature of the observed proportion. Gabriel (5) suggested transforming the observed proportion to obtain a constant variance, using one of the following equations

$$Y^i(T|Z_{t-1}^i) = \sqrt{q^i(T)} \quad (5-2)$$

$$Y^i(T|Z_{t-1}^i) = \frac{q^i(T)\sqrt{n^i(T)}}{\sqrt{q^i(T)(1 - q^i(T))}} \quad (5-3)$$

Table 5-1
GROUPING LEVELS FOR AEROMETRIC VARIABLES

Group	Aerometric Variable				
	TSP ($\mu\text{g}/\text{m}^3$)	SN ($\mu\text{g}/\text{m}^3$)	SS ($\mu\text{g}/\text{m}^3$)	SO ₂ ($\mu\text{g}/\text{m}^3$)	Min. Temp. (°F)
1	≤60	≤5	≤6	≤20	≤30
2	(60,75)	(5,15)	(6,8)	(20,60)	(30,50)
3	(75,150)	>15	(8,10)	(60,80)	>50
4	>150	*	>10	>80	*

* Only three groups were defined.

where $q^i(T)$ represents the proportion of the $n^i(T)$ observed response days of panelist i wherein the panelist reported an attack. In calculating $q^i(T)$ and $n^i(T)$ all days were combined where the levels of the concomitant variables were exactly the same and the previous day's attack response Z_{t-1}^i were the same. For example, all days immediately following a day when a panelist did not have an attack, i.e., $Z_{t-1}^i = 0$, and that had all concomitant variable values in the lowest level were included in the calculation of $q^i(T)$ and $n^i(T)$. Note that T does not represent a specific time period but instead reflects a given "treatment" combination that may have occurred on numerous occasions. Hence for each individual, the number of daily observations were compressed to the number of distinct aerometry days where the aerometry variables were grouped as in Table 5-1 for each value of Z_{t-1}^i .

Since our designated concern was detecting an increase in attack rates, only the cases where $Z_{t-1}^i = 0$, i.e., no attack reported on the day prior to the day of interest, were considered in the remainder of this subsection. Accordingly the notation $Z_{t-1}^i = 0$ is suppressed. Clearly, some responses for each individual were not included in the analysis. Using terminology defined in Section 4, all days with secondary attacks occurring were excluded as well as non-attack days immediately following an attack day. An individual with numerous clusters of attacks had a substantial portion of his attack occurrence responses excluded from the analysis. Although this may not have been an optimal use of the data, it did focus the analysis on the central issue of causes related to the transition from no attack to attack states.

Using either Eq. 5-2 or 5-3, the original model, Eq. 5-1, may be rewritten as

$$Y_i(T) = f_i^*(\beta_i X_i^*(T), D_i) + \epsilon_i(T) \quad (5-4)$$

where $\epsilon_i(T)$ have constant variance with zero expectation over all i and T . Since the model is conditioned on $Z_{t-1}^i = 0$, the $\epsilon_i(T)$ are also independent (assuming in fact that the order of dependence among the panelists is only one day, i.e., first-order Markov chain). The asterisk, $*$, in Eq. 5-4 denotes the transformation of f accordingly as Eq. 5-2 or 5-3 is used.

If the grouping given in Table 5-1 is appropriate, the model can be rewritten as

$$Y_i(T) = \mu + \alpha(T) + \beta(D_i) + \gamma(TD_i) + \epsilon_i(T) \quad (5-5)$$

where α , β and γ represent the effects of T , D_i and the TD_i interaction. This model is correct no matter what the form of f_i^* is! In other words, we either assume the form of f_i in Eq. 5-1 and fit the data assuming that the X_t^i are reliable or we assume the grouping is acceptable and fit model 5-5 without assuming the form of f_i . Assuming the grouping to be "acceptable" or "appropriate" means that knowing the actual value of X_t^i provides no more information about the risk of attack than knowing its group membership. If the concomitant X_t^i variables are measured with high variability as was shown, then knowing the exact measured value gives very little additional information from knowing its general range. We felt that assuming the grouping was preferred to assuming a function form for f .

In applying the model given in 5-5, different levels of T were created by varying each of the four groups of aerometry variables given in Table 5-1. Using the analysis of variance convention of denoting an effect of a treatment by the treatment level itself, the model was written as

$$Y_i(T) = \mu + TSP_j + SN_k + SS_\ell + SO_{2m} + \text{Min. Temp.}_r + D_i \quad (5-6)$$

$$+ \text{Interactions} + \epsilon_i(T) ,$$

where j indexes levels of TSP, k indexes levels of SN, etc.

Application of the Model

The notation used in the model makes the relationship of Eq. 5-6 to factorial experiments straightforward. If we assumed that the $\epsilon_i(T)$ were approximately normally distributed, then standard analysis of variance techniques could be used to estimate and investigate the strengths of the pollutant effects. Gabriel (5) noted that even though the $\epsilon_i(T)$ are not normal, the robustness of the analysis of variance procedure coupled with the large sample approximate normality of $\epsilon_i(T)$ allowed the assumption of normality to be made. By large samples we refer to the length of time each individual was in the study. Due to the sparsity of the data, the sex variable was the only demographic variable included in the model. Recall that because of the non-random selection of the panelists, each location was treated separately. Rewriting Eq. 5-5, using the analysis of variance notation, we have

$$Y_{ijk} = \mu + T_i + S_j + I_{(j)k} + TS_{ij} + TI_{(j)ik} + \epsilon_{ijk} \quad (5-7)$$

where i indexes the level of treatment, j the sex and k the individual nested with

the sex classification. The nesting, represented by the parenthetical j , signifies that the k^{th} individual in sex level 1 is different from the k^{th} individual in sex level 2 for all k . Consequently, the error term for the T_i effect is the treatment by individual interaction $TI_{(j)ik}$. Model 5-6 may be similarly rewritten. In the next section we use model 5-7 to estimate effects of T_i , the contaminant levels.

Results of Analysis

Tables 5-2 and 5-3 present the analysis of variance results using model 5-7. In both tables note that the "error term" for the test of treatment effects is the treatment by individual ($TI_{(j)ik}$) interaction sum of squares divided by its degrees of freedom. Clearly in all cities both tables indicate that the levels of aerometric variables had significant differing effects. Therefore, the variables associated with the different attack rates must be determined.

Tables A-14 through A-17 in Appendix A give the average square root of attack rates (based on Eq. 5-7) corresponding to the particular levels of the aerometric factors. Note that these mean effects have been ordered from smallest to largest for ease in comparison. The standard errors for each table were derived from dividing the sum of squares for $TI_{(j)ik}$ by its degrees of freedom and then dividing by the average number of individuals responding. The square root of this number was the standard error of the mean attack rates. No obvious ordering of the group levels of the aerometric factors is apparent to give much of a clue as to which levels of which factors caused a higher attack rate.

Since the mean attack rates given in the tables have been adjusted for both individual variation and time variation one could use these means as inputs to a 5-way factorial analysis of variance model where the effects of each aerometric factor and its interaction terms could be assumed. When this was tried, considerable confounding among all effects was present resulting from the lack of balance in the levels of the pollutants. Such confounding was determined from the expected mean squares of each effect. These expected mean squares are output of certain analysis of variance routines such as RUMMAGE (6) and to some extent SAS (7). The confounding was serious enough that interpretation of the estimated effects was extremely difficult. This was the same reason model 5-6 was not initially fit to the data.

An indication of the extent of confounding can be obtained by considering the data for Magna. The five factors (four pollutants and minimum temperature) result in a fully crossed 5-way design with $3 \times 4 \times 4 \times 4 \times 3 = 576$ cells or "treatment" combinations.

Table 5-2

ANALYSIS OF VARIANCE FOR ASTHMA ATTACKS USING
MODEL 5-7 WHEN Y_{ijk} IS FORMED FROM EQUATION 5-2

City	Source	df	SS	F-Ratio
Magna	T	103	20.6909	1.83*
	S	1	1.0995	
	I	28	66.4697	
	T x S	103	9.8215	
	T x I	2410	264.1499	
Kearns	T	91	36.9629	4.00*
	S	1	0.0396	
	I	39	58.3291	
	T x S	91	10.5487	
	T x I	2951	299.5055	
Salt Lake City	T	89	28.9227	2.19*
	S	1	0.3721	
	I	30	40.2437	
	T x S	89	15.1046	
	T x I	2257	334.7297	
Ogden	T	67	21.8319	2.96*
	S	1	1.2963	
	I	27	16.8702	
	T x S	67	8.7526	
	T x I	1576	173.7241	

*Significant at the $\alpha = 0.01$ level.

Table 5-3

ANALYSIS OF VARIANCE FOR ASTHMA ATTACKS USING
MODEL 5-7 WHEN Y_{ijk} IS FORMED FROM EQUATION 5-3

City	Source	df	SS	F-Ratio
Magna	T	103	22.8877	1.56*
	S	1	1.5680	
	I	28	82.0438	
	T x S	103	13.7529	
	T x I	2410	343.2831	
Kearns	T	91	22.6419	1.95*
	S	1	0.0734	
	I	39	66.3926	
	T x S	91	12.8164	
	T x I	2951	376.7523	
Salt Lake City	T	89	22.3585	2.12*
	S	1	0.2523	
	I	30	39.4767	
	T x S	89	13.8168	
	T x I	2257	268.0577	
Ogden	T	67	14.6556	1.72*
	S	1	1.3138	
	I	27	18.6475	
	T x S	67	9.3885	
	T x I	1576	200.9121	

*Significant at the $\alpha = 0.01$ level.

For Magna only 103 of these cells actually were filled during the study period. This is a direct result of the high correlation (positive or negative) among the aerometric factors. In regression this problem is referred to as collinearity while in analysis of variance it is termed confounded or unbalanced. The confounding was so extensive that only 6 of the 15 three-way and higher interactions were estimable. The confounding is not a limitation of the analysis procedure but of the data.

Based on the results of the Markov analysis of variance method, it can be concluded that an effect exists between aerometric treatment groups and asthma attack rates. The grouping, although accompanied by some loss of information, clearly exposes the serious confounding among the aerometric variables. Consequently, attributing an effect to individual pollutants is not possible with the current data.

Limitations of Analysis

Many of the advantages of the Markov analysis of variance approach have been pointed out. In this section, some of its limitations are given.

As pointed out, the analysis of variance approach used is appropriate regardless of the functional form of the relationship between the dependent variable and independent variables if the assumptions on the structure of the error terms are correct. Only a limited number of covariates can be included in the model of Eq. 5-7 because of the large number of resulting "treatments." Examples of this limitation are an inability to fit a factorial model, and the exclusion of day of the week, day of study, and age from the model presented.

It is very difficult to obtain any idea of the form of the relationship between the dependent and independent variables from the results of this analysis. The claim is that this is a problem common to all models which are presented in Sections 5 and 6. Because of confounding, the main effects of the Markov analysis of variance model given by Eq. 5-6 was difficult to interpret. It is contended that using some other functional form of the right-hand side of these Markov models (e.g., regressing on the aerometric variables as measured) would provide results that were no more interpretable because the collinearity of the independent variables. Similar problems of interpretation arise for all other regression models of later sections.

Note that the treatment effects accounted, in general, for about 10% of the total variation and thus the model would not be particularly useful in predicting asthma attacks. This is a problem of all analyses of this data discussed in this report.

Although finding the form of the relationship between the dependent and independent variables appears to be impossible, there is a possibility of testing for general pollution effects by breaking down the sums of squares of treatment into portions due to the main effects of minimum temperature and all other effects (pollution) and interactions. This would not, however, have given any information about the specific nature of any pollution associated with asthma attacks, information required as input into the setting of pollution standards and control policy.

There are two apparent problems with the error structure assumed in the models. It was assumed that given no attack on the previous day and the covariates of the model, the incidences of asthma attacks are all independent. This assumption will be violated if there are covariates which are not included in the model, e.g., high pollen counts for a given month may result in high attack rates for that month. It may be there is higher order autocorrelation present, i.e., an attack on Tuesday may make the likelihood of an attack on Thursday greater even if there is no attack on Wednesday. Overall, the assumption of independence seems reasonably plausible. It may be worthwhile to check the possible effects on the analysis if this assumption is violated.

The other possibly more serious violation of the assumed error structure is the assumption that the variation from various treatment effects (the variance of $TI_{(j)ik}$ over k of Eq. 5-7) is the same for all treatments (over i). If, for example, a few of the treatments account for most of the 264 TxI sum of squares in the analysis of variance for Magna in Table 5-2, then the 2410 degrees of freedom used to compute the mean square error could be totally inappropriate. This would imply that the F ratio computed may be very misleading. It would be a good idea to find methods of testing for the homogeneity of the error (TxI) variances for future analyses of this type.

To make the assumption of independence of attacks plausible, all days following an attack were deleted from the analysis. This does cause a possible loss of information as it would be desirable to know the types of conditions which maintain attacks as well as those which bring them on. The complications of the analysis brought on by including days following attacks outweighed the advantages, in our opinion.

Finally, it is noted once again that the conclusions are based on a small number of people and that it is difficult to generalize the results. That is, of course, a problem with any analysis of this data.

5.2 WHITTEMORE AND KORN LOGISTIC ANALYSIS

Korn and Whittemore's method (1) involved two stages. First, a logistic model was fitted for each panelist. Then, the coefficients from the separate models were combined over the individuals in the panel to yield summary estimates of the effects.

The Logistic Model

The diary of a panelist was considered a discrete time stochastic process Z_t , $t = 1, 2, \dots, n$. Z_t equaled zero or one corresponding to the absence or presence of one or more asthma attacks on day t . The probability of one or more asthma attacks on day t , $p(t)$, was assumed to be modeled by the logistic transformation

$$p(t) = \exp(\alpha + \underline{\beta}'\underline{X}_t) / [1 + \exp(\alpha + \underline{\beta}'\underline{X}_t)] .$$

$\underline{X}_t$ was a vector of covariates associated with day t and $\underline{\beta}$ was a vector of unknown coefficients. The parameter α was either α_0 when there was no attack the previous day, or $\alpha_0 + \alpha_1$ when there was one or more attacks the previous day. Thus, α equals $\alpha_0 + \alpha_1 Z_{t-1}$ and Z_t becomes a two-state Markov chain modulated by the covariates in $\underline{X}_t$. Estimates for α_0 , α_1 and $\underline{\beta}$ were obtained by maximizing the likelihood.

$$\exp\left(\alpha_0 \sum_{t=1}^n Z_t + \alpha_1 \sum_{t=1}^n Z_t Z_{t-1} + \underline{\beta}' \sum_{t=1}^n Z_t \underline{X}_t\right) / \prod_{t=1}^n \left[1 + \exp(\alpha_0 + \alpha_1 Z_{t-1} + \underline{\beta}'\underline{X}_t)\right] .$$

For this study, $\underline{X}_t$ consisted of

- Six variables to indicate the day of the week:
 - $x_1 = 1, x_2, \dots, x_6 = 0$ for Monday
 - $x_2 = 1, x_1, x_3, \dots, x_6 = 0$ for Tuesday
 - $\vdots$
 - $x_1, \dots, x_6 = 0$ for Sunday.
- Two meteorological variables
 - x_7 = minimum temperature ($^{\circ}\text{F}$)
 - x_8 = relative humidity (%).
- Four aerometric variables
 - x_9 = total suspended particulates ($\mu\text{g}/\text{m}^3$)
 - x_{10} = suspended nitrates ($\mu\text{g}/\text{m}^3$)
 - x_{11} = suspended sulfates ($\mu\text{g}/\text{m}^3$)
 - x_{12} = sulfur dioxide ($\mu\text{g}/\text{m}^3$).

If data were missing on a given day, that day was deleted from the study. The time period considered was from the beginning of the ninth week (day 57) to the end of

the study (day 469). Day of study was a covariate with possible importance which was not included in the model.

There were 155 panelists from four panels (37 from Ogden, 33 from Salt Lake City, 48 from Kearns and 37 from Magna) who had at least one attack during the time period. Separate estimates for α_0 , α_1 and β were obtained for each of these panelists using a computer program the authors developed called KWLOGIT. This program finds the maximum likelihood estimates by using Marquardt's algorithm in a procedure described by Jennrich and Moore (8).

Combination of Coefficients

Let $\hat{\beta}_j^{(i)}$ be the estimate of the coefficient of the j^{th} covariate for the i^{th} panelist. For simplicity of notation, we will drop j from the rest of the discussion. Conditional on its true value $\beta^{(i)}$, the estimated coefficient $\hat{\beta}^{(i)}$ is asymptotically normally distributed with mean $\beta^{(i)}$ and variance σ_i^2 . Korn and Whittemore assume that the $\beta^{(i)}$ are a random sample from a normal distribution with mean β and variance η^2 . The mean represents an overall population measure of association between covariate and response and the variance represents the inter-panelist variability in level of association. In order to estimate β and η^2 , Korn and Whittemore assume the $\beta^{(i)}$ are normally distributed and regard σ_i^2 as known. Thus, the maximum likelihood estimates of β and η^2 are given by the solution of the maximum likelihood equations:

$$\sum (\hat{\beta}^{(i)} - \hat{\beta}) (\sigma_i^2 + \eta^2)^{-1} = 0$$

$$\sum (\hat{\beta}^{(i)} - \hat{\beta})^2 (\sigma_i^2 + \eta^2)^{-2} - \sum (\sigma_i^2 + \eta^2)^{-1} = 0$$

$$\eta^2 \geq 0.$$

$\hat{\beta}$ is a weighted average of the $\hat{\beta}^{(i)}$, where the weights are inversely proportional to the estimated variances:

$$\hat{\beta} = \sum w_i \hat{\beta}^{(i)} \quad (5-8)$$

where

$$w_i = (\sigma_i^2 + \eta^2)^{-1} [\Sigma(\sigma_j^2 + \eta^2)^{-1}]^{-1}$$

and $\hat{\eta}^2$ is calculated by iterative solution of the maximum likelihood equations. The asymptotic variances of $\hat{\beta}$ and $\hat{\eta}^2$ are

$$\text{Var } \hat{\beta} = [\Sigma(\sigma_i^2 + \hat{\eta}^2)^{-1}]^{-1}$$

and

(5-9)

$$\text{Var } \hat{\eta}^2 = 2[\Sigma(\sigma_i^2 + \hat{\eta}^2)^{-2}]^{-1}$$

Korn and Whittemore define the above as their random effects model. This model is appropriate for testing the hypothesis that the average effect of the covariate on the response of all of the panelists is zero. They also define a fixed effects model. In this model it is assumed that the $\beta^{(i)}$ take on a common value, β , for all the panelists. The maximum likelihood estimate for $\hat{\beta}$ and the $\text{VAR}(\hat{\beta})$ for this model is the same as in Eq. 5-8 and 5-9 except that $\hat{\eta}^2$ is set to zero. This model is appropriate for testing the null hypothesis that the covariate is not associated with the response for any of the panelists.

Using these procedures, combined estimates of α_0 , α_1 and β were calculated for each of the four panels. The estimates were calculated for both the fixed and random effects models.

Results of the Analysis

Separate logistic models were fitted to 143 of the 155 panelists considered (36 from Ogden, 29 from Salt Lake City, 44 from Kearns and 34 from Magna). For the remaining 12 panelists the logistic model did not converge within a reasonable number of iterations or the covariance matrix was ill-conditioned. Eleven of these panelists had only a few asthma attacks over the time period considered (10 or less) and the twelfth panelist had 24 attacks in a row, and no other attacks.

The combined coefficients and their standard errors according to the fixed and random effects models are shown in Tables 5-4 and 5-5, respectively. The inter-panelist variabilities, η^2 , from the random effects model and their standard errors are shown in Table 5-6.

Table 5-4

COMBINED COEFFICIENTS ACCORDING TO THE FIXED EFFECTS MODEL

	Ogden	Panel Salt Lake City	Kearns	Magna
Attack on Previous Day	2.343*** (0.099) ^a	2.275*** (0.119)	2.033*** (0.100)	1.396*** (0.089)
Minimum Temperature x10 ⁻³	-9.782** (4.294)	1.297 (4.995)	0.921 (4.220)	-2.190 (4.274)
Relative Humidity x10 ⁻³	-2.246 (4.087)	5.594 (4.619)	5.482 (3.689)	5.353 (3.499)
Total Suspended Particulates x10 ⁻³	1.206 (1.194)	1.064 (1.125)	2.288 (1.781)	0.012 (1.035)
Suspended Nitrates x10 ⁻²	1.138 (1.705)	2.728 (2.235)	-0.834 (1.464)	-2.048 (1.366)
Suspended Sulfates x10 ⁻²	-0.292 (1.729)	-1.287 (1.524)	1.325 (1.059)	1.337 (0.713)
Sulfur Dioxides x10 ⁻³	8.403 (5.882)	-0.888 (3.961)	2.942 (1.630)	0.707 (0.740)
Monday	0.062 (0.164)	0.129 (0.206)	0.430** (0.174)	0.512*** (0.157)
Tuesday	-0.033 (0.162)	0.498** (0.207)	0.714*** (0.169)	0.403** (0.159)
Wednesday	-0.062 (0.171)	0.580*** (0.204)	0.430** (0.167)	0.584*** (0.164)
Thursday	0.443** (0.174)	0.556** (0.219)	1.060*** (0.172)	0.571*** (0.167)
Friday	0.265 (0.155)	0.499** (0.207)	0.831*** (0.167)	0.731*** (0.155)
Saturday	0.306 (0.157)	0.502** (0.198)	0.827*** (0.170)	0.545*** (0.152)

^aStandard error.

** P < 0.05 (two tailed)

*** P < 0.01 (two-tailed)

Table 5-5

COMBINED COEFFICIENTS ACCORDING TO THE RANDOM EFFECTS MODEL

	Ogden	Panel Salt Lake City	Kearns	Magna
Attack on Previous Day	2.985*** (0.280) ^a	2.737*** (0.340)	3.191 (0.365)	2.350*** (0.321)
Minimum Temperature $\times 10^{-3}$	-9.712 (5.550)	3.779 (7.567)	5.512 (5.294)	-2.357 (5.163)
Relative Humidity $\times 10^{-3}$	-3.267 (4.750)	5.057 (5.646)	6.482 (3.689)	4.352 (3.974)
Total Suspended Particulates $\times 10^{-3}$	0.426 (1.525)	0.949 (1.435)	0.669 (2.411)	0.012 (1.035)
Suspended Nitrates $\times 10^{-2}$	1.138 (1.705)	2.591 (3.336)	-0.834 (1.464)	-2.048 (1.366)
Suspended Sulfates $\times 10^{-2}$	-0.292 (1.729)	-1.551 (2.195)	1.325 (1.059)	1.504 (0.807)
Sulfur Dioxide $\times 10^{-3}$	7.807 (6.863)	-0.973 (4.666)	2.942 (1.630)	0.705 (0.749)
Monday	0.016 (0.217)	0.094 (0.227)	0.430** (0.174)	0.539*** (0.192)
Tuesday	-0.041 (0.183)	0.457 (0.273)	0.701*** (0.177)	0.403** (0.159)
Wednesday	0.011 (0.214)	0.554** (0.256)	0.430** (0.167)	0.573*** (0.179)
Thursday	0.475** (0.236)	0.502** (0.255)	1.060*** (0.172)	0.573*** (0.166)
Friday	0.432 (0.234)	0.466 (0.254)	0.817*** (0.192)	0.744*** (0.166)
Saturday	0.386 (0.263)	0.492 (0.265)	0.813*** (0.177)	0.545*** (0.152)

^aStandard error.

** P < 0.05 (two-tailed)

*** P < 0.01 (two-tailed)

Table 5-6
ESTIMATES OF INTERPANELIST VARIABILITY, $\hat{\eta}^2$

	Ogden	Panel Salt Lake City	Kearns	Magna
Attack on Previous Day	1.633*** (0.577) ^a	1.671** (0.725)	3.774*** (1.105)	2.266*** (0.755)
Minimum Temperature $\times 10^{-3}$	0.279 (0.219)	0.610 (0.380)	0.242 (0.207)	0.147 (0.165)
Relative Humidity $\times 10^{-3}$	0.122 (0.152)	0.174 (0.193)	0 (0)	0.061 (0.096)
Total Suspended Particulates $\times 10^{-3}$	0.019 (0.016)	0.007 (0.011)	0.058 (0.042)	0 (0)
Suspended Nitrates, $\times 10^{-2}$	0 (0)	0.868 (0.640)	0 (0)	0 (0)
Suspended Sulfates $\times 10^{-2}$	0 (0)	0.430 (0.305)	0 (0)	0.023 (0.038)
Sulfur Dioxide $\times 10^{-3}$	0.269 (0.322)	0.090 (0.123)	0 (0)	0.0002 (0.003)
Monday	0.384 (0.309)	0.115 (0.263)	0 (0)	0.189 (0.214)
Tuesday	0.120 (0.203)	0.412 (0.397)	0.044 (0.181)	0 (0)
Wednesday	0.300 (0.293)	0.321 (0.351)	0 (0)	0.071 (0.171)
Thursday	0.449 (0.347)	0.188 (0.316)	0 (0)	0.036 (0.166)
Friday	0.676 (0.383)	0.274 (0.337)	0.143 (0.221)	0.052 (0.155)
Saturday	0.955** (0.482)	0.424 (0.381)	0.041 (0.180)	0 (0)

^aStandard error

** $P < 0.05$ (two-tailed)

*** $P < 0.01$ (two-tailed)

Effect of an Asthma Attack the Previous Day. For both the fixed and random effects models the effects of an asthma attack the previous day was highly significant for all four panels. The presence of one or more asthma attacks on the previous day greatly increased the attack probability on the current day. This coefficient was highly significant in 93 of the 143 individual logistic models. Most of the times when it was not significant, there were a small number of asthma attacks.

Effect of Day of the Week. For both the fixed and random effects models the day of week effects for Monday through Saturday were significant in Kearns and Magna. For these panels there was a significantly lower attack probability on Sunday as compared to other days of the week. In Ogden, only Thursday had a significantly higher attack probability than Sunday for both the fixed and random effects model.

In Salt Lake City, the fixed and random effects models gave different results. For the fixed effects model, Tuesday through Saturday had a significantly higher attack probability than Sunday, while for the random effects model, only Wednesday and Friday had a significantly higher attack probability. These differences in results can be attributed to the fact that the two models are testing two different null hypotheses. For Tuesday, Thursday and Saturday, the fixed effects model tests that there is no significant effect for some panelist(s), while the random effects model tests that on the average for all panelists there is not a significant effect.

Effects of Meteorological and Aerometric Covariates. The only meteorological or aerometric covariate to have a significant effect was the minimum temperature covariate in Ogden for the fixed effects model. The probability of an asthma attack for some panelist(s) in Ogden will significantly decrease as the minimum temperature increases.

Relative Risk. One method of estimating the magnitude of a continuous covariate's effect on the probability of an asthma attack, as suggested by Whittemore and Korn (2), is to calculate the relative risk of attack corresponding to an increase or decrease in the covariate. The relative risk of minimum temperature in Ogden (from the fixed effects model) is shown in Figure 5-1. The relative risk is based on a baseline probability of attack on a Sunday with no attack on the previous day using the minimum temperature of 70°F and the average values for the other five continuous covariates that are reported in Section 3. It can be seen from Figure 5-1 that as minimum temperature decreases from 70°F to 0°F, the attack probability increases by a multiple of approximately 1.8 when all other factors are held constant.

Figure 5-1. Relative risk of attack corresponding to specified decrease in minimum temperature in Ogden with all other variables held constant.

Relative Importance of the Covariates. Whittemore and Korn suggested that a method for showing the relative importance of the covariates in determining the attack probability was to calculate the difference in the probability from a baseline probability due to a specified change (Δ) in the covariate. Table 5-7 shows the relative importance of an attack the previous day versus no attack and the relative importance of the day of the week (Monday through Saturday) versus Sunday. Table 5-8 shows the relative importance of specified changes in the meteorological and aerometric covariates. The specified changes (Δ) used were generally approximately 50% of the range of the covariates.

These differences in attack probabilities shown in Tables 5-7 and 5-8 were calculated using the fixed effects model. The tables show the increase or decrease in attack probability for the specified change. For example, from Table 5-7, a panelist in Ogden with a baseline probability of 0.10 following an attack free day would, on the

Table 5-7

INCREASE IN ATTACK PROBABILITY CORRESPONDING TO
SPECIFIED BASELINE PROBABILITIES AND COVARIATE CHANGES

Panel	Baseline Probability	Attack vs. no attack on previous day	Monday vs. Sunday	Tuesday vs. Sunday	Wednesday vs. Sunday	Thursday vs. Sunday	Friday vs. Sunday	Saturday vs. Sunday
Ogden	0.10	0.436	0.006	-0.003	-0.005	0.048	0.027	0.031
	0.25	0.526	0.012	-0.006	-0.011	0.092	0.053	0.062
	0.50	0.412	0.016	-0.008	-0.016	0.109	0.066	0.076
	0.75	0.219	0.011	-0.006	-0.012	0.074	0.046	0.053
	0.90	0.089	0.005	-0.003	-0.006	0.033	0.021	0.024
Salt Lake City	0.10	0.419	0.012	0.055	0.066	0.062	0.055	0.055
	0.25	0.514	0.025	0.104	0.123	0.118	0.104	0.105
	0.50	0.407	0.032	0.122	0.141	0.136	0.122	0.123
	0.75	0.217	0.023	0.081	0.093	0.090	0.082	0.082
	0.90	0.089	0.011	0.037	0.041	0.040	0.037	0.037
Kearns	0.10	0.359	0.046	0.085	0.046	0.143	0.103	0.103
	0.25	0.468	0.089	0.155	0.089	0.240	0.183	0.182
	0.50	0.384	0.106	0.171	0.106	0.243	0.197	0.196
	0.75	0.208	0.072	0.110	0.072	0.146	0.123	0.123
	0.90	0.086	0.033	0.048	0.033	0.063	0.054	0.054
Magna	0.10	0.210	0.056	0.043	0.066	0.064	0.087	0.061
	0.25	0.324	0.107	0.083	0.124	0.121	0.159	0.115
	0.50	0.302	0.125	0.099	0.142	0.139	0.175	0.133
	0.75	0.174	0.084	0.068	0.093	0.092	0.112	0.088
	0.90	0.073	0.038	0.031	0.042	0.041	0.049	0.039

Table 5-8

INCREASE IN ATTACK PROBABILITY CORRESPONDING TO
SPECIFIED BASELINE PROBABILITIES AND COVARIATE CHANGES

Panel	Baseline Probability	Minimum Temperature $\Delta=-40^{\circ}\text{F}$	Relative Humidity $\Delta=-50\%$	Total Suspended Particulates $\Delta=200\text{ }\mu\text{g}/\text{m}^3$	Suspended Nitrates $\Delta=30\text{ }\mu\text{g}/\text{m}^3$	Suspended Sulfates $\Delta=30\text{ }\mu\text{g}/\text{m}^3$	Sulfur Dioxide $\Delta=100\text{ }\mu\text{g}/\text{m}^3$
Ogden	0.10	0.041	0.011	0.024	0.035	-0.008	0.105
	0.25	0.080	0.022	0.048	0.069	-0.016	0.186
	0.50	0.097	0.028	0.060	0.085	-0.022	0.199
	0.75	0.066	0.020	0.042	0.058	-0.017	0.124
	0.90	0.030	0.010	0.020	0.027	-0.008	0.054
Salt Lake City	0.10	-0.005	-0.023	0.021	0.101	-0.030	-0.008
	0.25	-0.010	-0.049	0.042	0.180	-0.065	-0.016
	0.50	-0.013	-0.069	0.053	0.194	-0.095	-0.022
	0.75	-0.010	-0.056	0.038	0.122	-0.079	-0.017
	0.90	-0.005	-0.028	0.018	0.053	-0.041	-0.008
Kearns	0.10	-0.003	-0.022	0.049	-0.020	0.042	0.030
	0.25	-0.007	-0.048	0.095	-0.044	0.082	0.059
	0.50	-0.009	-0.068	0.112	-0.062	0.098	0.073
	0.75	-0.007	-0.055	0.076	-0.050	0.067	0.051
	0.90	-0.003	-0.028	0.034	-0.025	0.031	0.024
Magna	0.10	0.008	-0.022	0.000	-0.043	0.042	0.007
	0.25	0.017	-0.047	0.000	-0.098	0.082	0.013
	0.50	0.022	-0.067	0.001	-0.149	0.099	0.018
	0.75	0.016	-0.053	0.000	-0.131	0.068	0.013
	0.90	0.008	-0.027	0.000	-0.070	0.031	0.006

average (all the other covariates held constant), have had an attack probability of $0.10 + 0.44 = 0.54$ on the day following an attack.

It can be seen in Tables 5-7 and 5-8 that an attack on the previous day had by far the greatest impact on the probability of having an attack on the current day as compared to all the other covariates. The day of the week as compared to Sunday was also relatively important in many cases as compared to the meteorological and aerometric covariates. The relative importance of the meteorological and aerometric covariates were generally small when compared to the other covariates. It should be remembered that even the covariates in Table 5-8 that showed some relative importance were calculated using coefficients that showed no significant association with the probability of an asthma attack (except for minimum temperature in Ogden).

Examination of Results

Korn and Whittemore's method involves making many assumptions about the validity of the individual logistic models, the combination of the coefficients from these models, and the use of these combined coefficients. In this section the data and the results are examined to determine if these assumptions were appropriate.

The Individual Logistic Models. The statistical theory for examining the validity of the logistic model is not well developed. Since a formal statistical procedure for assessing the goodness of fit of the individual logistic models was not available, we relied on exploratory procedures to determine how well the estimated attack probabilities fit the observed attacks.

One method suggested by Whittemore and Korn was to aggregate the residuals (observed response-estimated attack probability) according to deciles of attack risk (the estimated attack probability) or continuous covariate levels. If the model is assumed correct, that is, the estimated attack probabilities ($\hat{p}$) are completely satisfied, then the residuals for a given panelist on different days are uncorrelated. Thus, the sums of such residuals over several panelists corresponding to different days are uncorrelated and are approximately normally distributed with mean zero and standard error of $[\sum \hat{p}(1 - \hat{p})]^{1/2}$.

Table 5-9 shows the observed and expected number of attacks, among the 36 panelists in Ogden, aggregated according to decile of attack risk. The sums of the standardized residuals $(O-E)/SE$ for each decile are small and indicate no consistent departures from the model according to this criterion. Table 5-10 shows the residuals from Ogden aggregated according to minimum temperature and this table also

Table 5-9

OBSERVED AND EXPECTED NUMBER OF ATTACKS AMONG
36 PANELISTS IN OGDEN BY DECILE OF ATTACK RISK

<u>Decile of Risk</u>	<u>Upper Bound of Decile</u>	<u>Number of Person-Days</u>	<u>Observed (O)</u>	<u>Expected (E)</u>	<u>Standard Error (SE)</u>	<u>O-E SE</u>
1	0.1	7,391	172	170.68	12.72	0.10
2	0.2	909	122	130.03	10.52	-0.76
3	0.3	405	92	98.52	8.62	-0.76
4	0.4	209	87	71.79	6.85	2.22
5	0.5	149	73	67.06	6.06	0.98
6	0.6	199	105	109.71	7.00	-0.67
7	0.7	206	136	133.94	6.83	0.30
8	0.8	227	165	170.31	6.51	-0.82
9	0.9	237	198	202.08	5.44	-0.75
10	1.0	695	674	669.88	4.85	0.85
Total		10,627	1,824	1824.00		

Table 5-10

OBSERVED AND EXPECTED NUMBER OF ATTACKS AMONG
36 PANELISTS IN OGDEN BY DECILE OF MINIMUM TEMPERATURE

<u>Decile of Minimum Temperature</u>	<u>Upper Bound of Decile</u>	<u>Number of Person-Days</u>	<u>Observed (O)</u>	<u>Expected (E)</u>	<u>Standard Error (SE)</u>	<u>O-E SE</u>
1	3.5	135	29	28.86	2.72	0.05
2	11.0	499	99	101.12	5.24	-0.40
3	18.5	634	124	121.64	6.07	0.39
4	26.0	1,231	220	219.62	7.97	0.05
5	33.5	1,381	251	252.02	8.78	-0.12
6	41.0	1,851	306	316.26	10.01	-1.03
7	48.5	1,855	331	321.43	11.02	0.87
8	56.0	1,372	243	223.72	9.24	2.09
9	63.5	1,234	172	109.46	8.85	-2.09
10	71.0	435	49	48.89	4.91	0.02
Total		10,627	1,824	1824.00		

shows no consistent departures from the model. The results shown in Tables 5-9 and 5-10 were similar to the results seen for all the other panels and for all the continuous covariates. The same procedure was also performed on each individual panelist. No panelist showed any consistent departure from the model according to this criterion, whether or not any of the covariates were significant. As long as the logistic model converged, the residuals aggregated according to deciles for the continuous covariate or by attack risk visually appeared satisfactory according to this criterion.

The logistic model used for each panelist consisted of 13 covariates and a constant. Seven of these 13 covariates, the six days of the week and the "Markov" parameter that indicated the presence or absence of an attack the previous day, were discrete. These discrete covariates in essence divided the data into a two by seven contingency table. The maximum likelihood estimates of the coefficients for the model are "conditional" on the fact that the sum of the expected attack probabilities across the rows and columns of this contingency table must be equal to the observed number of attacks. Thus, since the marginal totals are predetermined by the discrete covariates, the continuous covariates essentially modulate the attack probabilities within the cells to best fit the observed responses. Table 5-11 shows observed attacks and expected attack probabilities aggregated over the 14 cells of the contingency table determined by the discrete variables, for one of the panelists in Salt Lake City. Again, the standardized residuals were small and indicated no consistent departures from the model.

The most significant covariate for almost every panelist was the "Markov" parameter. As seen in Table 5-11, the presence or absence of an attack on the previous day dramatically changed the average estimated attack probability for the current day (0.171 after an attack free day versus 0.814 after an attack). The question is, how well did the logistic model estimate the attack probability on a transition day? A transition day occurred when there was no attack on a day after an attack or when there was an attack following an attack free day. Table 5-12 shows, for the same panelist in Salt Lake City shown in Table 5-11, the average attack probabilities and standard errors tabulated by the day of the week, previous and current day's observed response. It can be seen in Table 5-12 that although there was some evidence of increase in the attack probability on the no attack to attack transition days and a decrease in the attack probability on the attack to no attack transition days, these differences certainly were not significant when the standard errors were considered. The panelist that was used for this illustration was chosen because the logistic model indicated significant effects due to 3 of the 4 aerometric covariates

Table 5-11

OBSERVED ATTACKS AND ESTIMATED ATTACK PROBABILITIES
 AGGREGATED OVER THE 2 BY 7 CONTINGENCY TABLE FORMED BY THE
 DISCRETE COVARIATES FOR A PANELIST IN SALT LAKE CITY

		Day of the Week							Total
		Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	
No Attack Previous Day	Number of Days	27	25	22	24	17	22	27	164
	Observed (O)	4	2	3	6	3	3	7	28
	Expected (E)	4.801	3.612	3.553	7.321	2.524	1.958	4.231	28.000
	Standard Error (SE)	1.953	1.686	1.672	2.227	1.432	1.314	1.834	
	$\frac{O-E}{SE}$	-0.410	-0.956	-0.331	-0.596	0.333	0.793	1.510	
Attack Previous Day	Number of Days	22	23	23	20	29	29	21	167
	Observed (O)	19	20	19	20	23	20	15	136
	Expected (E)	18.199	18.388	18.447	18.679	23.476	21.042	17.769	136.000
	Standard Error (SE)	1.759	1.891	1.874	1.101	2.083	2.329	1.636	
	$\frac{O-E}{SE}$	0.456	0.853	0.275	1.200	-0.229	-0.447	-1.693	
Total	Number of Days	49	48	45	44	46	51	48	331
	Observed (O)	23	22	22	26	26	23	22	164
	Expected (E)	23.000	22.000	22.000	26.000	26.000	23.000	22.000	164.000

and was one of the "best" models for predicting the transition day attack probabilities. Considering that Table 5-12 showed one of the "best" models, it is obvious that the meteorological and aerometric covariates did not contribute much information toward determining when an asthma attack occurred, even when they did have a significant effect. This is not a limitation of the methodology but results from significant unexplained variation due to factors for which there is no data.

The individual logistic models used in the analysis of the data set could not be considered invalid from visual observation of aggregated residuals. The day of week and "Markov" parameter categorized the data in such a manner that the estimated attack probabilities when aggregated according to various schemes looked satisfactory. The meteorological and aerometric covariates, even when they were significant had little effect in modulating the estimated attack probabilities to account for the transition days. This suggests that one or more important covariates that were associated with the onset or cessation of an asthma attack had not been identified in this model.

Table 5-12

AVERAGE ATTACK PROBABILITIES AND STANDARD ERRORS TABULATED
BY THE DAY OF THE WEEK, PREVIOUS AND CURRENT DAY'S
OBSERVED RESPONSES FOR A PANELIST IN SALT LAKE CITY

Previous Day Current Day	<u>No Attack</u>		<u>Attack</u>	
	<u>No Attack</u>	<u>Attack</u>	<u>No Attack</u>	<u>Attack</u>
Monday	23 ^a 0.179 ^b (0.078) ^c	4 0.174 (0.189)	3 0.813 (0.224)	19 0.829 (0.086)
Tuesday	23 0.133 (0.078)	2 0.271 (0.273)	3 0.714 (0.257)	20 0.812 (0.086)
Wednesday	19 0.141 (0.069)	3 0.289 (0.251)	4 0.799 (0.199)	19 0.803 (0.089)
Thursday	18 0.311 (0.108)	6 0.286 (0.183)	0	20 0.934 (0.055)
Friday	14 0.151 (0.093)	3 0.138 (0.199)	6 0.736 (0.179)	23 0.829 (0.078)
Saturday	19 0.090 (0.079)	3 0.083 (0.159)	9 0.668 (0.156)	20 0.751 (0.093)
Sunday	20 0.147 (0.077)	7 0.184 (0.144)	6 0.836 (0.150)	15 0.850 (0.124)
Average for Monday through Sunday	136 0.163 (0.031)	28 0.206 (0.074)	31 0.749 (0.076)	136 0.829 (0.031)

^aNumber Observed

^bMean Attack Probability

^cStandard Error

Combination of Coefficients. Korn and Whittemore assumed that the estimates of the coefficient for a given covariate produced by the individual logistic models belonged to a family of normal populations with a common mean β and the variances of σ_i^2 for the fixed effects model and $\sigma_i^2 + \eta^2$ for the random effects model. The combined estimate of the coefficients was simply a weighted average of the individual estimates where the weights were inversely proportional to the variances. This section illustrates the effect a panelist's attack rate and attack pattern has on their estimated coefficients and the subsequent effect on the combination of coefficients across the panelists.

Table 5-13 shows the distribution of attack rates for each panel. Nearly 40% of the panelists had attack rates of less than 0.05 (less than 15 attacks for 300 days). Generally this was not a sufficient number of attacks to have had an attack occur in each of the 14 cells of the contingency table in Table 5-11. For those panelists with no observed attack in one or more of the marginal totals in this contingency table, the variances of the estimated coefficients were far greater than variances for the rest of the panelists. These large variances virtually eliminated these panelists from the combined estimates. When the attack rates were greater than

Table 5-13
DISTRIBUTION OF ATTACK RATES FOR EACH PANEL

<u>Attack Rate</u>	<u>Ogden</u>	<u>Salt Lake City</u>	<u>Kearns</u>	<u>Magna</u>
.00- .05	14	14	18	15
.05- .10	6	4	9	4
.10- .15	4	5	7	3
.15- .20	1		1	1
.20- .25	4	1	1	
.25- .30	2		2	3
.30- .35	1	1		1
.35- .40		2	1	1
.40- .45			1	1
.45- .50		1		1
.50- .55				1
.55- .60			1	
.60- .65				
.65- .70	1	1		
.70- .75	1			
.75- .80			1	
.80- .85				
.85- .90	1		1	1
.90- .95	1		1	1
.95-1.00				1

0.95, the same problem arose since there are no attack-free days in the contingency table. In actuality, only 5 or 6 panelists supplied over 50% of the information for the combined estimates for each panel. This may be an inappropriate reflection of the individual attack patterns.

Table 5-14 shows the estimated coefficients and percent contribution ($\sigma_i^{-2} / \sum \sigma_j^{-2}$ x 100%) to the combined estimate for the discrete covariates for 10 panelists in Ogden. All the panelists appeared to respond the same to the presence of an attack on the previous day. The estimate of the coefficient appeared to increase as their variances increased. The effect of the day of week did seem to vary from panelist to panelist. Panelists 3, 11 and 22 showed no differences in attack rates according to the day of week, while panelists 8, 28 and 30 had increased attack rates almost every day as compared to Sunday. Panelists 4 and 13 each had one day that was significantly different from Sunday. Both the fixed and random effects model showed no significant effect due to the day of week except for Thursday. Essentially the differences due to the day of the week either negated each other, by being opposite effects, or the differences occurred to panelists who did not have a major contribution to the combined estimate.

Table 5-15 shows the estimated coefficients and percent contribution to the combined estimate for the continuous covariates for the same 10 panelists in Ogden shown in Table 5-14. Minimum temperature was the only covariate that showed some evidence of a trend; 6 of the 10 panelists had negative coefficients, two of which were significant. Minimum temperature was the only continuous covariate to be significant in the fixed effects model, although it was not significant in the random effects model.

As seen in Tables 5-14 and 5-15 the effects of combining the coefficients was to wash out most of the significant differences. Whether or not the significant differences for the individual panelists were true, and thus the panelists were responding differently to the covariates, was impossible to judge from this visual examination. The differences in the underlying causes of asthma may have caused the individual asthmatic to respond differently to the same set of covariates. The Korn-Whittemore method is based on the logistic regressions of individual panelists followed by the combination of the coefficients across the panel to obtain an overall assessment. This section attempts to point out that an understanding of the logistic regression analysis must include an examination of individual panelist's coefficients and their contribution to the combined panel coefficient estimates.

Table 5-14

ESTIMATED COEFFICIENTS AND PERCENT CONTRIBUTION
TO THE COMBINED ESTIMATE FOR THE DISCRETE
COVARIATES FOR 10 PANELISTS IN OGDEN

Panelist	Attack on Previous Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
11	0.68** (12.4) ^a	0.54 (11.5)	-0.16 (12.8)	-0.55 (13.5)	0.82 (10.2)	0.21 (11.0)	-0.00 (11.6)
3	1.69*** (12.6)	-0.00 (11.5)	-0.23 (11.5)	-0.39 (11.1)	-0.35 (11.6)	-0.73 (9.9)	-0.24 (10.7)
4	1.46*** (10.8)	0.01 (11.5)	0.37 (11.6)	-1.44** (7.5)	-0.00 (10.6)	-0.45 (9.0)	0.20 (10.5)
30	2.20*** (7.9)	1.60*** (7.4)	1.19 (7.1)	0.89 (8.3)	1.56** (7.0)	0.30 (7.5)	0.74 (7.1)
26	1.78*** (5.4)	-1.09 (5.8)	-1.51** (4.7)	-0.41 (7.6)	-0.76 (7.2)	-0.98 (6.3)	-0.80 (7.0)
13	3.53*** (5.1)	0.68 (5.3)	-0.53 (2.6)	0.28 (4.8)	1.79*** (6.5)	-0.14 (5.2)	1.01 (5.4)
8	1.26*** (6.9)	1.24 (3.2)	0.39 (2.6)	1.96** (3.7)	2.56*** (4.1)	2.31*** (3.4)	2.33*** (3.6)
35	2.54*** (3.5)	-2.56*** (3.6)	-2.25** (3.2)	-1.71 (3.3)	-1.03 (4.3)	-1.01 (4.0)	-0.37 (4.3)
22	5.36*** (3.1)	-0.01 (3.7)	0.87 (4.0)	-0.62 (3.8)	0.49 (3.7)	-0.13 (3.2)	-0.13 (3.4)
28	3.20*** (2.8)	1.48 (2.8)	0.95 (2.4)	1.76 (2.9)	1.45 (2.6)	2.52*** (3.0)	4.11*** (3.2)

^aPercent Contribution = $(\sigma_i^{-2} / \sum \sigma_j^{-2}) \times 100\%$

** P < 0.05 (two-tailed)

*** P < 0.01 (two-tailed)

Table 5-15

ESTIMATED COEFFICIENTS AND PERCENT CONTRIBUTION
TO THE COMBINED ESTIMATE FOR THE CONTINUOUS
COVARIATES FOR 10 PANELISTS IN OGDEN

Panelist	Minimum Temperature $\times 10^{-3}$	Relative Humidity $\times 10^{-3}$	Total Suspended Particulates $\times 10^{-3}$	Suspended Nitrates $\times 10^{-2}$	Suspended Sulfates $\times 10^{-2}$	Sulfur Dioxide $\times 10^{-3}$
11	-16.3 (10.0) ^a	14.8 (10.0)	6.4 (8.6)	-0.4 (10.9)	0.5 (10.1)	-0.4 (9.2)
3	0.4 (10.5)	6.7 (9.9)	6.5 (11.2)	-8.8 (6.0)	-4.6 (8.9)	27.7 (11.6)
4	1.2 (9.1)	-16.4 (9.3)	-6.2 (7.6)	4.3 (15.3)	2.1 (10.7)	-59.5** (4.8)
30	-61.1*** (4.7)	-14.8 (6.4)	14.4** (3.9)	-8.7 (8.7)	6.3 (4.8)	13.3 (5.3)
26	-16.6 (5.3)	-13.7 (5.0)	9.7** (7.1)	1.5 (3.6)	-20.1 (2.6)	38.3 (6.6)
13	-30.2 (5.0)	4.5 (5.3)	2.6 (7.2)	11.9 (5.1)	-10.2 (4.7)	-26.4 (5.3)
8	18.0 (6.6)	32.0** (6.3)	1.1 (7.9)	16.0 (3.4)	1.8 (7.9)	-19.5 (5.0)
35	-46.0** (3.6)	10.4 (3.5)	-9.4 (3.5)	-3.5 (5.6)	1.8 (4.5)	23.1 (5.5)
22	1.9 (3.4)	36.7 (3.5)	3.8 (3.2)	7.3 (1.9)	-37.1*** (1.6)	60.6** (4.8)
28	-12.4 (3.5)	-36.5 (3.2)	-5.4 (4.3)	7.5 (6.7)	-1.2 (3.4)	25.4 (4.2)

^aPercent Contribution = $(\sigma_i^{-2} / \sum \sigma_j^{-2}) \times 100\%$

** P < 0.05 (two-tailed)

*** P < 0.01 (two-tailed)

It must be noted that under the random effects model, the coefficient for a covariate is not assumed to be the same for all panelists. It is assumed that the coefficients across panelists are from a normal population with common mean and variance σ^2 . By looking at individual panelist coefficients, the validity of this assumption may be investigated.

Use of the Combined Coefficients. Assuming the Korn-Whittemore method is appropriate, what do the combined coefficients represent? For the purpose of illustrating relative risk and relative importance, the combined coefficients were placed back into the logistic model framework. We do not know whether or not this is statistically valid. If this is valid, it is reasonable to expect the logistic model, using the combined coefficients, to predict attack probabilities for some "average" panelist. The question is, how far can these predicted attack probabilities, for this "average" panelist, be extended. On Sundays "average" panelists for each panel had attack probabilities following an attack-free day of between 0.10 and 0.14. When the relative importance of the covariates was calculated (see Tables 5-7 and 5-8), baseline probabilities were as high as 0.90. Yet "average" panelists only had baseline probabilities of around 0.10. In fact, for most of the "average" panelists, when the continuous covariates were at their maximum level, the baseline attack probabilities were only around 0.50. Thus, for the values shown in Tables 5-7 and 5-8 for baseline probabilities equal to or greater than 0.25, the model is being used to predict outside the observed range of the data. Calculation of such baseline probabilities are useful in visualizing the possible magnitude of an effect but their interpretation should be limited to the baseline probabilities observed in the study.

Because of the problems noted above, it is probably best to emphasize the testing of the existence of pollutant effects and perhaps trying to get a general notion of the direction of the effects rather than trying to estimate the precise nature of those effects. To this end, this model is useful.

REFERENCES

1. E. L. Korn and A. S. Whittemore. "Methods for Analyzing Panel Studies of Acute Health Effects of Air Pollution." Biometrics 35:795-802, 1979.
2. A. S. Whittemore and E. L. Korn. "Asthma and Air Pollution in the Los Angeles Area." Am. J. Public Health 70:687-696, 1980.
3. J. H. Stebbings, Jr. "Panel Studies of Acute Health Effects of Air Pollution. II. A Methodologic Study of Linear Regression Analysis of Asthma Panel Data." Environ. Res. 17:10-32, 1978.
4. H. D. Roth, J. R. Viren, A. V. Colucci, E. H. Pechan and A. E. Ripps. Evaluation of CHESS: New York Asthma Data 1971-1972. Vol. I. Findings and Supporting Tables. Palo Alto, Calif: Electric Power Research Institute, 1980. Technical report in press.
5. K. R. Gabriel. "Analysis of Variance of Proportions with Unequal Frequencies." J. Am. Stat. Assoc. 58:1133-1157, 1963.
6. G. Rex Bryce. Data Analysis in Rummage - A User's Guide. Department of Statistics, Brigham Young University, 1980.
7. A. J. Barr, et al. A User's Guide to SAS-76. SAS Institute, Inc., Raleigh, NC, 1976.
8. R. I. Jennrich and R. H. Moore. "Maximum Likelihood Estimation by Means of Nonlinear Least Squares." Proc. of Statistical Computing Section, American Statistical Association, Washington, DC, p. 57-65, 1975.

Section 6

PERSON-DAY BASED ANALYSES

Previous analyses of asthma panel studies relied heavily on the person-day concept. Multiple regression analyses of daily panel attack rates, relative risk approaches and hockey stick analyses were typical examples. This section describes a multiple regression analysis of daily attack rates and a temperature-specific relative risk analysis applied to the Utah 1971-72 asthma panel data. Included with each analysis is a discussion of the strengths and weaknesses of the approach.

Finklea et al. (1) used threshold and linear dose-response functions to determine if there was a safe exposure below which pollutant-induced aggravation in asthma would occur. Hockey stick functions were used in their methodology. The present study did not include hockey stick analyses. Problems identified with the quality of the air pollutant data (Section 3) invalidated assumptions necessary for the hockey stick approach. The Brown committee report (2) and Roth et al. (3,4) have discussed other limitations.

6.1 CORRELATION AND REGRESSION ANALYSES

Previous sections described many problems of the study including major difficulties in obtaining accurate air pollution measurements, panelists dropping in/out of the study and failure to measure important factors such as medication use and pollen levels. Any analysis must recognize these problems and adjust for them as well as possible. When conclusions are drawn a qualitative assessment of their probable impact must be made. The subsequent multiple regression analysis attempts to adjust for these factors when possible. We have assumed that data problems will not substantially change any association between pollutants and increased asthma frequency.

The basis for the correlation and regression analysis was the summarization across panelists in a community for each study day to obtain a daily community asthma attack rate. A community's panelists were assumed to have the same exposure to environmental factors. The simple fixed station monitor was assumed to adequately represent the ambient air pollution exposure level for all panelists. The validity of this assumption depended on the pollution data quality, the representativeness of a point

measurement for a circle of one to two mile radius and the amount of time the panelist remained in his home neighborhood. No direct attempt was made to relate the ambient pollutant exposure levels to individual panelist's daily pollutant dose levels.

Wide variation in panelist's average attack rates were demonstrated indicating the panelists were not a homogeneous group. Summarizing across all panelists in a community ignored nonhomogeneity. The drop in/out propensity of the panelists exacerbated the problem and required some type of adjustment. Even with complete responses for all panelists during the study, the nonhomogeneity resulted in increased variability in daily attack rates. This increased the difficulty of finding a significant pollution effect, if one existed.

The correlation and regression analyses assumed that events occurring on different study days were statistically independent of each other. Evidence was presented in earlier sections that showed this was not the case. Attacks followed strong consecutive patterns, with an initial attack followed by successive attacks on subsequent days. This attack clustering was not considered in the regression approach. The air pollution and meteorologic data exhibited strong temporal patterns, hence effects ascribed to air pollutants may be due to excluded factors.

Other researchers have noted the problems associated with using regression in analyzing daily panel studies of health symptoms. Roth et al. (3,4) discussed some of the problems in relation to the CHESS asthma studies conducted in New York City during 1970-71 and 1971-72. Stebbings (5), using data from three asthma panels in Chattanooga, Tennessee, collected in 1972-73, concluded that linear regression models that incorporate only minimum temperature and one air pollutant were potentially misleading. He stated that such models were highly sensitive to reporting trends in the data and do not correct adequately for meteorological variables. Other comments directed at asthma panel studies as reported in the CHESS monograph are contained in the Brown committee report (2)

Description of Analyses

Correlation and regression analyses were based on several sets of variables and several subsets of panelists. Three daily asthma occurrence indices were used:

- Observed daily attack rates.
- Observed daily attack rates divided by total daily base rates (O/B(T)).

- Observed daily attack rates divided by quarterly daily base rates ($O/B(Q)$).

Independent variables, or explanatory factors, considered were:

- Daily Design and Demographic Indicators
 - day of study
 - day of week
 - base rates, both total ($B(T)$) and quarterly ($B(Q)$)
 - age
 - adult/juvenile
 - male/female
 - smoking
 - education
- Daily Aerometry Indicators
 - total suspended particulates (TSP)
 - suspended nitrates (SN)
 - suspended sulfates (SS)
 - sulfur dioxide (SO_2)
 - nitrogen dioxide (NO_2)
 - maximum temperature ($^{\circ}F$)
 - minimum temperature ($^{\circ}F$)
 - relative humidity (%)
 - minimum temperature lagged one day
 - temperature range
 - minimum temperature change.

The day of study indicator was defined by the integers 1 to 469 and would alternately be considered as synonymous with time. Two formats were used for day of week. For the correlation analysis, Sunday through Saturday corresponded to one (1) through seven (7) in a day of week variable. For the regression analysis seven dummy variables were used, one corresponding to each day of the week. A study day occurring on a particular day of the week was assigned a one (1) for the corresponding dummy variable with the remaining six dummy variables assigned the value zero (0). The regressions actually only included the dummy variables for Monday through Saturday, which are sufficient to allow differing basic attack rates for all seven days of the week.

This analysis considered a larger complement of factors than used by Finklea et al. (1), who limited the analysis to minimum temperature and four air pollutants. The additional factors were included to explain more of the day-to-day variation in attack rates and to adjust partially for effects of panelist drop in/drop out. Missing air pollutant measurements were handled pairwise for the correlation analyses. That is, individual correlations were based on all days where both relevant measurements were available. For each multiple regression model, missing data were deleted listwise; i.e., if any measurement was missing for a day, all variables for the day were excluded. However, the days excluded may differ for different regression models.

Not all of the 244 panelists were included in the main analyses. A subset of 156 panelists was defined (Section 4) that met selected response criteria. This selection was aimed at minimizing the drop in/drop out problem. To facilitate external comparisons, some analyses were completed using all 244 panelists. Note however, that 28 of the 244 panelists never returned a diary during the study. Two time periods were considered: weeks 1 through 26 and weeks 1 through 67. The analysis of the first 26 weeks corresponded to the Finklea et al. (1) analysis, but with data corrections included.

Correlation Analysis

Table 6-1 displays for each community the correlations of each independent variable with the three asthma indices. Assuming independence among days, approximate 5% and 1% significance levels for correlations were 0.11 and 0.15, respectively. These levels were included as an aid in judging the importance of the correlations and should not be interpreted as strict significance levels.

Observed daily attack rates exhibited high positive correlations with the design indicators day of study, day of week, base rate total $B(T)$ and base rate quarterly $B(Q)$. The base rates reflected the changing panel composition due to drop in/drop outs. Day of week reflected differing attack propensity throughout the week with generally higher rates at the end of the week. A temporal pattern was indicated by the day of study. This may have been due to seasonal effects, the addition of new panelists during the study period or may have reflected temporal patterns of environmental factors. The negative correlations with temperature supported a conclusion of seasonal patterns in attack rates. Air pollutant correlations were smaller than for study design or temperature indicators. Magna correlations for SS , SO_2 and NO_2 were an exception, with positive correlations.

Results for the ratio asthma indices $O/B(T)$ and $O/B(Q)$ did not differ greatly from observed attack rate results. Differences that occurred were expected from the adjustments. The relative importance of indicators associated with panel drop in/drop out was decreased, but the adjustment was not totally successful. In comparison with other studies that have used a base rate total $B(T)$ adjustment, the current study showed it to be of lesser importance. This was due in part to the restriction to the subset of 156 panelists.

Regression Analysis

An initial regression analysis, intended only for comparison purposes, replicated the simple regression model, which included only minimum temperature and one air

Table 6-1

SIMPLE CORRELATIONS OF ASTHMA ATTACK VARIABLES WITH EXPERIMENTAL DESIGN,
DEMOGRAPHIC AND AIR QUALITY VARIABLES BY COMMUNITY. UTAH 1971-72 ASTHMA STUDY

Condition	Observed Attack Rate				O/B(T)				O/B(Q)			
	Ogden	Salt Lake City	Kearns	Magna	Ogden	Salt Lake City	Kearns	Magna	Ogden	Salt Lake City	Kearns	Magna
Day of Study	0.10	<u>0.19*</u>	0.11	<u>0.23</u>	0.05	0.10	0.01	0.13	-0.03	-0.06	-0.04	-0.07
Day of Week	<u>0.20</u>	<u>0.18</u>	<u>0.29</u>	<u>0.21</u>	<u>0.21</u>	<u>0.18</u>	<u>0.30</u>	<u>0.20</u>	<u>0.21</u>	<u>0.19</u>	<u>0.32</u>	<u>0.20</u>
Base Rate Total B(T)	<u>0.20</u>	<u>0.16</u>	<u>0.29</u>	<u>0.18</u>	-0.06	-0.02	0.04	-0.12	-0.05	-0.09	0.02	-0.27
Base Rate Quarterly B(Q)	<u>0.33</u>	<u>0.37</u>	<u>0.40</u>	<u>0.37</u>	0.12	<u>0.25</u>	<u>0.22</u>	0.11	0.04	-0.05	0.01	-0.14
Age	0.09	<u>0.15</u>	<u>0.23</u>	0.08	0.01	0.03	0.13	-0.06	-0.01	-0.10	0.10	<u>-0.17</u>
Adult/Juvenile	0.06	<u>0.19</u>	<u>0.21</u>	0.08	0.01	0.06	<u>0.15</u>	-0.07	0.01	-0.05	0.13	<u>-0.16</u>
Male/Female	-0.01	-0.04	<u>-0.17</u>	-0.02	0.05	-0.04	-0.06	-0.04	0.05	-0.14	-0.05	-0.09
Total Suspended Particulates	0.08	0.02	0.03	0.10	0.04	-0.03	0.01	0.04	0.01	-0.04	-0.01	-0.04
Suspended Nitrates	0.06	-0.09	-0.11	-0.03	0.02	-0.10	-0.11	-0.07	0.02	-0.03	-0.06	-0.10
Suspended Sulfates	0.02	0.03	-0.09	<u>0.18</u>	-0.01	0.02	-0.11	0.14	-0.02	0.03	-0.05	0.07
Sulfur Dioxide	0.13	-0.03	0.01	<u>0.18</u>	0.07	-0.04	0.00	<u>0.17</u>	0.04	0.03	0.04	0.12
Nitrogen Dioxide	0.09	0.07	-0.06	<u>0.20</u>	0.04	0.03	-0.08	0.12	0.01	0.01	-0.02	0.02
Maximum Temperature	<u>-0.21</u>	<u>-0.15</u>	0.04	<u>-0.25</u>	<u>-0.15</u>	-0.11	0.12	<u>-0.18</u>	-0.11	<u>-0.17</u>	0.03	-0.05
Minimum Temperature	<u>-0.22</u>	<u>-0.15</u>	0.07	<u>-0.19</u>	<u>-0.16</u>	-0.11	0.14	-0.12	-0.12	<u>-0.15</u>	0.05	-0.02
Temperature Range	-0.11	-0.10	-0.02	<u>-0.29</u>	-0.07	-0.07	0.05	-0.23	-0.05	-0.14	-0.02	-0.07
Minimum Temp. Change	-0.01	-0.03	0.05	0.04	-0.01	-0.02	0.06	0.03	-0.02	-0.03	0.04	0.04

*Correlations underlined are nominally significant at 5% level.

pollutant, used by Finklea et al. (1). For each community, different combinations of panelists and time periods included are summarized in Table 6-2. The most notable aspect was the extremely small amount of daily asthma attack variability explained by the models. No indication of the goodness-of-fit was given by Finklea et al (1).

The results for all panelists during weeks 1-26 did not agree with those of Finklea et al. (1) for the same panelists and time period. A positive effect was indicated for TSP in Kearns and for SS in Magna. Although the NO₂ data was of questionable validity, a negative effect was indicated for Kearns. No other effects were significant when minimum temperature was included in the model. Note the significance of a coefficient was evaluated based on the regression coefficient's t-value when both minimum temperature and the pollutant were in the model.

When the subset of 156 participating panelists for weeks 9-67 was regressed on minimum temperature and one air pollutant, a few differences arose. Suspended nitrates (SN) were significant for Kearns and Magna but the association was negative. Suspended sulfates remained significantly positive for Magna but were accompanied by positive associations for SO₂ and NO₂ clouding the identification of a specific pollutant. The high correlation demonstrated among the pollutants in Magna was consistent with this conclusion.

More complex regression models were performed for each community. Table 6-3 lists 12 specific models analyzed using observed attack rates as the dependent variable. Similar models using the ratio indices O/B(T) and O/B(Q) were also completed but are not explicitly included in the report as their qualitative results agreed with the observed attack rate models. The inclusion of B(T) or B(Q) in the observed attack rate model was an alternative adjustment procedure.

Tables A-18 to A-21 in Appendix A summarize the 12 regression models applied to each community. In each case the attack rates were based on the participating subset of panelists and included weeks 9 through 67. The small R² exhibited by the models indicated inherent variability among panelists or model improvements where possible. In all communities day of week was important in modeling daily attack rates. The positive coefficients in the latter part of the week indicated higher attack rates.

Base rate total B(T) showed significant positive effects in Ogden and Kearns but not in Magna and Salt Lake City. Base rate quarterly B(Q) was a significant independent variable for all communities. Since the quarters were 15 weeks in length and

Table 6-2

SUMMARY OF OBSERVED DAILY ASTHMA ATTACK RATE REGRESSIONS WITH MINIMUM
TEMPERATURE AND INDIVIDUAL AIR POLLUTANTS. UTAH 1971-72 ASTHMA STUDY

Community	Minimum Temperature Plus											
	Minimum Temperature		TSP		SN		SS		SO ₂		NO ₂	
	R ²	Coefficient Significance	R ²	Coefficient Significance	R ²	Coefficient Significance	R ²	Coefficient Significance	R ²	Coefficient Significance	R ²	Coefficient Significance
Ogden												
Participating Panelists												
Weeks 9-67	5	<0.001-	6	NS	6	NS	6	NS	5	NS	5	NS
Weeks 9-26	9	<0.001-	9	NS	11	NS	10	NS	8	NS	9	NS
All Panelists												
Weeks 1-67	4	<0.001-	4	NS	4	NS	5	<0.10-	3	NS	4	NS
Weeks 1-26	13	<0.001-	13	NS	14	NS	13	NS	11	NS	14	NS
Salt Lake City												
Participating Panelists												
Weeks 9-67	2	<0.01-	2	NS	4	NS	2	NS	3	NS	2	NS
Weeks 9-26	21	<0.001-	18	NS	18	NS	18	NS	24	NS	22	NS
All Panelists												
Weeks 1-67	2	<0.01-	2	NS	4	<0.001-	2	NS	3	<0.10-	2	NS
Weeks 1-26	19	<0.001-	17	NS	16	NS	16	NS	19	NS	18	NS
Kearns												
Participating Panelists												
Weeks 9-67	0.5	NS	1	NS	1	<0.10-	1	NS	0.1	NS	0.4	NS
Weeks 9-26	15	<0.001-	17	<0.10+	15	NS	15	NS	15	NS	18	<0.10-
All Panelists												
Weeks 1-67	0.4	NS	0.4	NS	2	<0.01-	2	<0.01-	0.4	NS	4	<0.001-
Weeks 1-26	19	<0.001-	22	<0.05+	20	NS	20	NS	19	NS	21	<0.05-
Magna												
Participating Panelists												
Weeks 9-67	4	<0.001-	4	NS	5	<0.05-	5	<0.05+	5	<0.10+	5	<0.05+
Weeks 9-26	4	<0.05-	5	NS	4	NS	11	<0.01+	6	<0.10+	17	<0.001+
All Panelists												
Weeks 1-67	6	<0.001-	7	NS	9	<0.01-	8	<0.05+	6	NS	6	NS
Weeks 1-26	22	<0.001-	22	NS	22	NS	26	<0.01+	21	NS	24	NS

Table 6-3

INDEX OF MULTIPLE REGRESSION ANALYSES USING
OBSERVED ASTHMA ATTACK RATE AS DEPENDENT VARIABLE

Independent Variables	Scenario											
	1	2	3	4	5	6	7	8	9	10	11	12
Day of Study	X	X	X	X	X	X	X	X	X	X		
Day of Week Var 2-7	X	X	X	X	X	X	X	X	X	X	X	X
Base Daily Attack Rate (Total)	X		X	X	X	X	X	X	X		X	
Base Daily Attack Rate (Quarterly)		X								X		X
Age	X	X										
Adults/Juveniles	X	X										
Males/Females	X	X										
Smoking	X	X										
Education	X	X										
TSP	X	X	X	X					X	X	X	X
SN	X	X	X		X				X	X	X	X
SS	X	X	X			X			X	X	X	X
SO ₂	X	X	X				X		X	X	X	X
NO ₂	X	X	X					X	X	X	X	X
Maximum Temperature	X	X										
Minimum Temperature	X	X	X	X	X	X	X	X	X	X	X	X
Relative Humidity	X	X							X	X	X	X
Minimum Temperature Lag	X	X										

generally coincided with seasons, any seasonal pattern in attack rates was partially reflected in B(Q). This would have remained so without the drop in/drop out effect.

No strong consistent effect for minimum temperature was present. Ogden, and to a lesser extent Salt Lake City and Magna, showed a significant negative association when minimum temperature was the only meteorologic variable. Because of the length of the study period, minimum temperature may more appropriately have been interpreted as a seasonal adjustment. Minimum temperature effects for Kearns were significant for some models but not in the accepted direction.

Air pollutants were not indicated as important in either Kearns or Ogden, intermediate and low pollution communities. Significant associations were found in Salt Lake City; however, they were either negative or occurred in models with other pollutants with significant negative coefficients. Magna, the high exposure community, consistently had a significant but negative effect for suspended nitrates (SN) across the regression models. For scenarios in Magna with only one of the air pollutants included, suspended sulfates (SS), sulfur dioxide (SO₂) and nitrogen dioxide (NO₂) were significant and positive.

Analyses for Subsets of Participating Panelists

The previous analyses used only the daily diary episode occurrence response information. Daily attack rates were obtained by including all panelists and only the episode occurrence response. Rather than including all participating panelists, subsets of panelists were used to obtain a daily attack rate for the subset. The baseline questionnaire contained information usable for defining subsets of panelists. The objective of such a procedure was to obtain an attack rate for a more homogeneous group of panelists. A limitation of the subsetting was the small number of panelists involved in defining a daily attack rate. Because of the small number of panelists, the analyses in this section should be viewed with caution and used only to suggest possible associations and future analyses.

In Section 4 it was determined that approximately 15% of the time when an asthma attack was recorded the panelist was not in his home neighborhood at the time of the attack. No clear definition was given to what constituted a panelist's home neighborhood. Nor was a panelist explicitly asked if he/she was in the home neighborhood on days when an attack did not occur. All previous analyses assumed the panelist was not. An alternative attack rate was defined using the same procedure as before except if a person indicated an attack occurred during a day and he was not in his home neighborhood, then that day was treated as no response for the person. This procedure biases the daily attack rates down. Attack rates defined in the above manner are referred to as "All: home neighborhood."

The subsets of panelists investigated were all panelists, all: home neighborhood, all adults, all females, all juveniles, juvenile males, no fumes on job, no hay fever and original panelists. The last subset consisted of those participating panelists who were in the panel at the beginning of the study. The remaining subsets included age/sex groupings and groups who indicated they were not affected by the confounding factors: exposure to fumes on job and hay fever. Table 6-4 tabulates the average number of respondents, observed daily attack rates and the adjusted ratio O/B(T) for each subset and community. Clearly, some subsets had too few panelists responding to place any confidence in the results. In particular, only 10-14 panelists in each community indicated no history of hay fever. If allergen levels were correlated with pollutant concentrations and/or seasonal patterns, then any analysis that did not account for this must be questioned. Non-homogeneity within a panel was demonstrated by the substantial differences in average attack rates among the subsets. Adults had higher attack rates than juveniles, for example.

Table 6-4

OBSERVED DAILY ATTACK RATES AND RATIO O/B(T) FOR SUBSETS
OF PARTICIPATING PANELISTS. UTAH 1971-72 ASTHMA STUDY

Community Panel Subset	Number of Respondents		Observed Attack Rate		O/B(T)	
	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
Ogden						
All Panelists	31.1	3.9	0.166	0.061	0.998	0.371
All: Home Neighborhood	30.0	4.0	0.134	0.062	0.855	0.386
All Adults	17.6	2.1	0.225	0.083	0.998	0.369
Adult Females	13.2	1.4	0.169	0.096	0.988	0.551
All Juveniles	13.5	2.1	0.088	0.075	0.997	0.844
Juvenile Males	9.5	1.3	0.077	0.089	1.004	1.140
No Fumes on Job	27.1	3.4	0.155	0.082	1.001	0.411
No Hay Fever	13.7	1.9	0.215	0.100	0.977	0.435
Original Panelists	27.5	2.0	0.161	0.063	1.000	0.388
Salt Lake City						
All Panelists	27.6	3.1	0.108	0.057	0.999	0.524
All: Home Neighborhood	27.1	3.1	0.090	0.055	0.870	0.522
All Adults	12.5	1.6	0.114	0.075	1.000	0.677
Adult Females	10.0	1.3	0.118	0.085	1.006	0.757
All Juveniles	15.2	2.0	0.104	0.080	1.005	0.756
Juvenile Males	11.4	1.3	0.127	0.097	1.002	0.756
No Fumes on Job	23.1	2.9	0.114	0.062	0.994	0.529
No Hay Fever	10.7	1.6	0.065	0.072	0.989	1.100
Original Panelists	24.5	3.3	0.106	0.067	1.012	0.652
Kearns						
All Panelists	39.4	3.5	0.149	0.049	1.001	0.318
All: Home Neighborhood	38.8	3.7	0.136	0.052	0.921	0.345
All Adults	15.2	1.9	0.235	0.089	1.004	0.388
Adult Females	10.4	1.7	0.282	0.109	1.003	0.393
All Juveniles	24.2	2.1	0.095	0.050	0.995	0.534
Juvenile Males	16.7	1.9	0.050	0.053	1.022	1.120
No Fumes on Job	34.3	3.3	0.156	0.053	0.998	0.324
No Hay Fever	13.7	1.1	0.181	0.096	0.979	0.508
Original Panelists	34.7	3.0	0.155	0.052	1.001	0.327
Magna						
All Panelists	31.5	2.6	0.189	0.059	1.007	0.313
All: Home Neighborhood	30.0	4.0	0.134	0.062	0.855	0.386
All Adults	17.3	1.8	0.235	0.089	1.001	0.375
Adult Females	12.0	1.2	0.253	0.108	0.995	0.410
All Juveniles	14.2	1.3	0.131	0.068	1.004	0.536
Juvenile Males	10.4	1.1	0.082	0.079	1.014	1.000
No Fumes on Job	23.7	1.9	0.154	0.057	1.003	0.373
No Hay Fever	10.6	1.7	0.061	0.075	0.986	1.230
Original Panelists	27.9	2.4	0.162	0.059	1.006	0.361

The multiple regression defined by scenario 3 was completed for the subsets of panelists defined. From Table A-22 in Appendix A the relatively poor explanatory power for each regression is shown by the low multiple R^2 values. Compared to the corresponding regression including all panelists, no substantive difference was indicated for the subsets investigated. As many significant negative coefficients for air pollutants were found as positive. For a given subset no consistent pattern across communities was apparent. Either no pollution effect on asthma was present at the exposure levels occurring during the study, or the substantial variability in attack occurrence both across the individual panelists and over time for a single panelist precluded detecting an effect that did exist or the method of analysis was inadequate.

6.2 TEMPERATURE-SPECIFIC ESTIMATES OF RISK: RELATIVE RISK MODEL

Temperature-specific relative risk models for selected pollutant levels were used to control for a temperature effect. Finklea et al. (1) relied on a "relative risk" model to find pollutant effects within three specific temperature ranges. For each temperature category, relative risk was defined as the ratio of the asthma attack rate for a higher pollutant level and the base asthma attack rate of the lowest pollutant category. Roth et al. (3) used the same stratification procedure but chose to define relative risk as the odds-ratio associated with a 2 x 2 table. The odds-ratio approach was chosen for the current analyses as it is readily useful in hypothesis testing and in the establishment of association.

Limitations of Relative Risk Approach

The relative risk model had several methodological problems or limitations in its application to the Utah asthma panel study. Such problems were not unique to the present study and must be considered before using the relative risk model for similar studies. These limitations included:

- Nonrandom selection of panelists.
- Lack of independence of asthma attacks for subjects.
- Assumption that factors not considered in analysis were independent of factors included.
- Univariate consideration of air pollutants that were known to be intercorrelated.
- Multiple subsets of data statistically tested, leading to a multiple comparison problem.

Stratifying study days according to minimum temperature levels was intended to control for a possible temperature effect while studying the relative risks of

individual air pollutants. The analysis methodology involved a number of assumptions which required examination. In addition, the analytical strategy led to a multiple comparison problem and possible misinterpretation of results. Sections 2-4 described problems basic to the definition and quality of the data entering the analyses. Such limitations must be kept in mind when interpreting the present results.

The panel subjects were not chosen at random, and comparability of panels among areas cannot be assumed. This is evident from the wide variation in overall panel attack rates in Table 6-5. Considerable variation among individuals in their pulmonary responses to season, weather and air pollution was documented in Section 2. It is also plausible to hypothesize that not all panelists were susceptible to the same pollutants. The determination of responsible pollutants must take into account the proportion of susceptibles in the population. In the absence of random panelist selection or a means of prior definition of susceptibles, no firm conclusions on the association of asthma with air pollutants is possible using the present methodology. It is necessary for an individual to serve as his own control to elicit the required information. Even then, quantitative dose-response estimates for the general population are not possible.

Lack of independence of an individual's asthma attacks was documented in Section 4. A clustering of attacks was common for the panelists as well as extensive runs of attacks. The present methodology utilized a chi-square test for association in a $2 \times r$ contingency table (where the pollution levels were categorized into r cells). For each pollutant category each person-day observation was assumed to be a random observation from the corresponding population. In particular, independence of person-day observations was assumed. Clustering of attacks for individuals and the serial correlation of daily pollutant values strongly suggested the independence assumption was not satisfied.

By design, the temperature-specific analyses considered one air pollutant factor at a time. All other factors, including other pollutants, were not adjusted for in the analysis. Minimum temperature, hypothesized to be a confounding factor, was considered by explicit stratification. Ignoring for the moment the confounding existing among the air pollutants, all other factors known or suspected to be related to asthma attacks were assumed to be independent of the pollutant considered. For example, for those person-days included in a temperature-specific scenario it was assumed no relationship existed between pollen counts and air pollutant concentrations. This Utah asthma study did not have any direct information that could be used to test this assumption. Numerous other examples could be given.

Table 6-5

TEMPERATURE-POLLUTANT SPECIFIC ASTHMA ATTACK
RATES BY COMMUNITY: UTAH 1971-72 ASTHMA STUDY

Pollutant	Minimum Temperature	Pollutant Concentration $\mu\text{g}/\text{m}^3$	Ogden				Salt Lake City				Kearns				Magna			
			Person Days	Rate P_i	s.e. (P_i)	χ^2 ^a	Person Days	Rate P_i	s.e. (P_i)	χ^2 ^a	Person Days	Rate P_i	s.e. (P_i)	χ^2 ^a	Person Days	Rate P_i	s.e. (P_i)	χ^2 ^a
TSP	$\leq 30^\circ\text{F}$	≤ 60	959	0.188	0.013		503	0.109	0.014		2,552	0.143	0.007		1,109	0.198	0.012	
		60-75	584	0.176	0.016		416	0.103	0.015		217	0.129	0.023		457	0.212	0.019	
		75-260	2,004	0.182	0.009	0.79 ^b	1,776	0.104	0.007	1.79	1,113	0.129	0.010	1.46	1,487	0.191	0.010	1.41
		>260	36	0.139	0.058		186	0.075	0.019		-	-	-		99	0.222	0.042	
		All	3,583	0.182	0.006		2,881	0.103	0.006		3,882	0.139	0.006		3,152	0.198	0.007	
	30-50°F	≤ 60	1,712	0.160	0.009		1,532	0.126	0.008		5,535	0.153	0.005		2,927	0.197	0.007	
		60-75	407	0.170	0.019		1,142	0.108	0.009		504	0.141	0.016		655	0.197	0.016	
		75-260	2,817	0.176	0.007	2.21	2,812	0.131	0.006	4.05	931	0.162	0.012	1.13	1,908	0.198	0.009	0.75
		>260	108	0.148	0.034		84	0.119	0.035		-	-	-		60	0.183	0.050	
		All	5,044	0.169	0.005		5,570	0.125	0.004		6,970	0.153	0.004		5,550	0.197	0.005	
	>50°F	≤ 60	850	0.141	0.012		775	0.077	0.010		3,521	0.144	0.006		2,402	0.150	0.007	
		60-75	1,066	0.135	0.010		931	0.092	0.009		707	0.180	0.014		754	0.199	0.015	
		75-260	1,413	0.161	0.010	3.73	969	0.077	0.009	1.79	515	0.177	0.017	8.17*	646	0.176	0.015	10.71*
		>260	-	-	-		-	-	-		-	-	-	3.30 ^c	-	-	-	1.46
		All	3,329	0.148	0.006		2,675	0.083	0.005		4,743	0.153	0.005		3,802	0.164	0.006	
	All	≤ 60	3,521	0.163	0.006		2,810	0.110	0.006		11,608	0.148	0.003		6,438	0.180	0.005	
		60-75	2,057	0.154	0.008		2,489	0.101	0.006		1,428	0.158	0.010		1,866	0.202	0.009	
		75-260	6,034	0.174	0.005	5.94	5,557	0.113	0.004	3.60	2,559	0.151	0.007	1.08	4,041	0.192	0.006	5.77
		>260	144	0.146	0.029		270	0.089	0.017		-	-	-		159	0.208	0.032	
		All	11,956	0.167	0.003		11,126	0.109	0.003		15,595	0.149	0.003		12,504	0.187	0.003	
SS	$\leq 30^\circ\text{F}$	≤ 6	1,410	0.183	0.010		651	0.108	0.012		1,093	0.136	0.010		298	0.201	0.023	
		6-8	761	0.183	0.014		558	0.115	0.014		791	0.150	0.013		400	0.208	0.020	
		8-10	513	0.170	0.017	0.50	384	0.115	0.016	3.35	541	0.135	0.015	1.15	270	0.215	0.025	1.07
		>10	970	0.180	0.012		1,319	0.092	0.008		1,497	0.136	0.009		2,217	0.193	0.008	
		All	3,654	0.180	0.006		2,912	0.103	0.006		3,922	0.139	0.006		3,185	0.197	0.007	
	30-50°F	≤ 6	3,783	0.169	0.006		2,735	0.112	0.006		3,492	0.155	0.006		1,169	0.180	0.011	
		6-8	780	0.167	0.013		1,371	0.131	0.009		1,264	0.150	0.010		688	0.215	0.016	
		8-10	239	0.186	0.025	0.68	560	0.146	0.015	9.39*	1,040	0.159	0.011	0.75	827	0.191	0.014	4.38
		>10	242	0.165	0.024		904	0.140	0.012	7.84	1,177	0.147	0.010		2,879	0.203	0.007	
		All	5,044	0.169	0.005		5,570	0.125	0.004		6,973	0.153	0.004		5,583	0.198	0.005	
	>50°F	≤ 6	2,586	0.146	0.007		1,901	0.080	0.006		3,202	0.161	0.006		1,760	0.130	0.008	
		6-8	521	0.134	0.015		516	0.089	0.013		913	0.139	0.011		548	0.177	0.016	
		8-10	72	0.181	0.045	1.65	104	0.096	0.029	0.73	259	0.143	0.022	4.43	393	0.204	0.020	30.18*
		>10	121	0.165	0.034		154	0.084	0.022		331	0.130	0.018		1,161	0.198	0.012	26.65*
		All	3,300	0.147	0.006		2,675	0.083	0.005		4,705	0.153	0.005		3,862	0.164	0.006	
	All	≤ 6	7,779	0.165	0.004		5,287	0.100	0.004		7,787	0.155	0.004		3,247	0.155	0.006	
		6-8	2,062	0.164	0.008		2,445	0.119	0.007		2,968	0.147	0.006		1,636	0.200	0.010	31.06*
		8-10	824	0.176	0.013	1.73	1,048	0.130	0.010	11.74*	1,840	0.149	0.008	4.23	1,490	0.199	0.010	21.73*
		>10	1,333	0.176	0.010		2,377	0.110	0.006	3.66	3,005	0.139	0.006		6,257	0.198	0.005	
		All	11,998	0.167	0.003		11,157	0.109	0.003		15,600	0.150	0.003		12,630	0.187	0.003	

Table 6-5 (Cont.)

TEMPERATURE-POLLUTANT SPECIFIC ASTHMA ATTACK
 RATES BY COMMUNITY: UTAH 1971-72 ASTHMA STUDY

Pollutant	Minimum Temperature	Pollutant Concentration $\mu\text{g}/\text{m}^3$	Ogden				Salt Lake City				Kearns				Magna			
			Person Days	Rate P_i	s.e. (P_i)	χ^2	Person Days	Rate P_i	s.e. (P_i)	χ^2	Person Days	Rate P_i	s.e. (P_i)	χ^2	Person Days	Rate P_i	s.e. (P_i)	χ^2
SO_2	$\leq 30^\circ\text{F}$	≤ 60	3,646	0.180	0.006		2,489	0.105	0.006		2,974	0.139	0.006		1,077	0.199	0.012	
		60-80	-	-	-		87	0.115	0.034		430	0.121	0.016		272	0.180	0.023	
		80-365	-	-	-		121	0.083	0.025	0.73	469	0.151	0.017	1.77	1,442	0.199	0.011	
		>365	-	-	-		-	-	-		-	-	-		96	0.188	0.040	
		All	3,646	0.180	0.006		2,697	0.105	0.006		3,873	0.138	0.006		2,887	0.197	0.007	
	30-50°F	≤ 60	5,202	0.173	0.005		4,442	0.127	0.005		6,225	0.152	0.005		2,486	0.199	0.008	
		60-80	-	-	-		31	0.065	0.044		355	0.172	0.020		600	0.185	0.016	
		80-365	-	-	-		29	0.207	0.075	2.76	361	0.147	0.019	1.10	1,997	0.199	0.009	0.63
		>365	-	-	-		-	-	-		-	-	-		61	0.197	0.051	
		All	5,202	0.173	0.005		4,502	0.127	0.005		6,941	0.153	0.004		5,144	0.197	0.006	
	>50°F	≤ 60	3,033	0.150	0.006		2,168	0.080	0.006		4,136	0.147	0.006		3,092	0.158	0.007	
		60-80	-	-	-		-	-	-		78	0.103	0.034		229	0.218	0.027	
		80-365	-	-	-		-	-	-		37	0.189	0.064	1.75	159	0.214	0.033	8.65*
		>365	-	-	-		-	-	-		-	-	-		-	-	-	4.15*
		All	3,033	0.150	0.006		2,168	0.080	0.006		4,251	0.146	0.005		3,480	0.164	0.006	
	All	≤ 60	11,881	0.169	0.003		9,099	0.110	0.003		13,335	0.148	0.003		6,655	0.180	0.005	
		60-80	-	-	-		118	0.102	0.028		863	0.140	0.012		1,101	0.191	0.012	
		80-365	-	-	-		150	0.107	0.025	0.10	867	0.151	0.012	0.45	3,598	0.200	0.007	6.17
		>365	-	-	-		-	-	-		-	-	-		157	0.191	0.031	
		All	11,881	0.169	0.003		9,367	0.110	0.003		15,065	0.147	0.003		11,511	0.187	0.004	
SN	$\leq 30^\circ\text{F}$	≤ 2	1,690	0.182	0.009		973	0.114	0.010		1,556	0.138	0.009		1,391	0.205	0.011	
		2-4	623	0.173	0.015		585	0.116	0.013		710	0.149	0.013		743	0.197	0.015	
		4-6	347	0.170	0.020	1.01	337	0.089	0.016	4.83	387	0.145	0.019	1.33	300	0.190	0.023	0.88
		6-8	169	0.201	0.031		240	0.096	0.019		208	0.125	0.023		-	-	-	
		>8	825	0.182	0.013		743	0.089	0.010		1,111	0.134	0.010		718	0.189	0.015	
	30-50°F	All	3,654	0.180	0.006		2,878	0.104	0.006		3,922	0.139	0.006		3,152	0.198	0.007	
		≤ 2	3,509	0.168	0.006		2,945	0.123	0.006		5,523	0.154	0.005		4,682	0.196	0.006	
		2-4	1,008	0.173	0.012		1,916	0.133	0.008		371	0.148	0.011		582	0.211	0.017	
		4-6	363	0.157	0.019	1.84	339	0.109	0.017	2.83	263	0.144	0.012	1.19	126	0.206	0.036	1.49
		6-8	31	0.261	0.066		166	0.108	0.024		91	0.187	0.041		64	0.156	0.045	
	50°F	>8	99	0.212	0.041		204	0.108	0.022		125	0.160	0.013		129	0.194	0.035	
		All	5,010	0.169	0.005		5,570	0.125	0.004		6,973	0.153	0.004		5,583	0.198	0.005	
		≤ 2	1,437	0.160	0.010		636	0.096	0.012		2,559	0.168	0.007		2,976	0.171	0.007	
		2-4	1,696	0.142	0.008		1,485	0.075	0.007		2,108	0.136	0.007		858	0.145	0.012	
		4-6	167	0.090	0.022	6.62*	527	0.091	0.013	5.43	76	0.132	0.029	9.12*	28	0.107	0.058	4.00
	All	6-8	-	-	-	5.58	27	0.200	0.000		-	-	-	8.76	-	-	-	
		>8	-	-	-		-	-	-		-	-	-		-	-	-	
		All	3,300	0.147	0.006		2,675	0.083	0.005		4,743	0.153	0.005		3,862	0.164	0.006	
	All	≤ 2	6,636	0.170	0.005		4,554	0.117	0.005		9,638	0.155	0.004		9,049	0.189	0.004	
		2-4	3,327	0.157	0.006		3,986	0.109	0.005		3,789	0.142	0.005		2,183	0.180	0.008	
		4-6	877	0.149	0.012	7.88	1,203	0.096	0.008	9.03	676	0.143	0.013	5.87	454	0.189	0.018	1.45
		6-8	200	0.195	0.028		433	0.095	0.014	8.19	299	0.144	0.023		64	0.156	0.045	
		>8	924	0.185	0.013		947	0.093	0.009		1,236	0.137	0.013		847	0.190	0.013	
		All	11,964	0.166	0.003		11,123	0.109	0.003		15,636	0.150	0.003		12,597	0.188	0.003	

Table 6-5 (Cont.)

TEMPERATURE-POLLUTANT SPECIFIC ASTHMA ATTACK
RATES BY COMMUNITY: UTAH 1971-72 ASTHMA STUDY

Pollutant	Minimum Temperature	Pollutant Concentration $\mu\text{g}/\text{m}^3$	Ogden				Salt Lake City				Kearns				Magna			
			Person Days	Rate P_i	s.e. (P_i)	χ^2^a	Person Days	Rate P_i	s.e. (P_i)	χ^2^a	Person Days	Rate P_i	s.e. (P_i)	χ^2^a	Person Days	Rate P_i	s.e. (P_i)	χ^2^a
NO_2	$\leq 30^\circ\text{F}$	≤ 50	1,789	0.177	0.009	0.63	1,651	0.104	0.008	0.08	2,904	0.138	0.006	0.62	2,093	0.196	0.009	0.75
		50-100	1,516	0.177	0.010		721	0.105	0.011		598	0.134	0.014		558	0.190	0.017	
		>100	275	0.196	0.024		453	0.108	0.015		165	0.158	0.028		168	0.220	0.032	
		All	3,580	0.179	0.006		2,825	0.105	0.006		3,667	0.138	0.006		2,819	0.196	0.007	
	30-50°F	≤ 50	3,874	0.174	0.006	2.09	3,239	0.122	0.006	3.62	6,253	0.152	0.005	0.08	5,029	0.197	0.006	0.07
		50-100	1,143	0.169	0.011		1,289	0.143	0.010		169	0.160	0.028		96	0.208	0.041	
		>100	100	0.120	0.032		119	0.134	0.031		-	-	-		-	-	-	
		All	5,117	0.172	0.005		4,647	0.128	0.005		6,422	0.152	0.004		5,125	0.198	0.006	
	>50°F	≤ 50	2,518	0.145	0.007	1.97	2,098	0.083	0.006	0.22	3,866	0.145	0.006		3,425	0.161	0.006	2.04
		50-100	414	0.140	0.017		317	0.076	0.015		-	-	-		56	0.232	0.056	
		>100	30	0.233	0.077		-	-	-		-	-	-		-	-	-	
		All	2,962	0.145	0.006		2,415	0.082	0.006		3,866	0.145	0.006		3,481	0.162	0.006	
	All	≤ 50	8,181	0.165	0.004	0.71	6,988	0.106	0.004	4.63	13,023	0.147	0.003	0.47	10,547	0.185	0.004	1.75
		50-100	3,073	0.169	0.007		2,327	0.122	0.007		767	0.140	0.013		710	0.196	0.015	
		>100	405	0.180	0.019		572	0.114	0.013		165	0.158	0.028		168	0.220	0.032	
		All	11,659	0.167	0.003		9,887	0.110	0.003		13,955	0.147	0.003		11,425	0.187	0.004	

^aChi-square test for relationship of attack rate with pollutant level. Number of degrees of freedom associated with each value is number of pollutant categories with data minus one.

^bCritical χ^2 values with 1, 2, 3 and 4 degrees of freedom respectively: $p < 0.05$ (3.84, 5.99, 7.82, 9.49); $p < 0.01$ (6.64, 9.21, 11.35, 13.28). Those significant at $p < 0.05$ indicated by *.

^cWhen total chi-square is significant, the method of Armitage (3, 4) is used to test for linear trend. The value reported is chi-square test for linear trend with 1 degree of freedom.

Presence of other factors related to occurrence of asthma attacks impacted the analysis even if the independence assumption was satisfied. Not controlling for other factors increased the variability within a temperature-specific scenario. This decreased the chance of finding a pollutant effect if one existed and could have resulted in inconclusive results.

Relative Risk Analysis

For each community, study days were categorized into three discrete minimum temperature categories ($\leq 30^{\circ}\text{F}$, $30-50^{\circ}\text{F}$, $>50^{\circ}\text{F}$). These temperature-specific categories were further stratified by pollutant levels for each pollutant separately. Each person-day observation was then tabulated according to occurrence of asthma attack. The stratification scheme and accompanying strata attack rate are presented in Table 6-5. Specification by three temperature categories and five pollutants resulted in 15 temperature-pollutant scenarios for each of four communities.

Based on a chi-square test for equality of attack rate across pollutant levels, 7 temperature-pollutant scenarios out of 60 showed potentially viable patterns of asthma-pollutant association. The criterion for selection was that the overall variation in rates within a scenario be statistically significant ($p < 0.05$). Two of the seven scenarios were Ogden (SN: minimum temperature $>50^{\circ}\text{F}$) and Kearns (SN: minimum temperature $>50^{\circ}\text{F}$); the associations were negative. When a secondary test for linear trend was applied, both indicated a statistically significant ($p < 0.05$) decline in relative risk with increasing suspended nitrate levels. The five scenarios remaining were distributed among the four communities as follows:

- Magna
 - TSP (total suspended particulates): minimum temperature $>50^{\circ}\text{F}$
 - SS (suspended sulfates): minimum temperature $>50^{\circ}\text{F}$
 - SO₂ (sulfur dioxide): minimum temperature $>50^{\circ}\text{F}$
- Kearns
 - TSP: minimum temperature $>50^{\circ}\text{F}$
- Salt Lake City
 - SS: minimum temperature $30-50^{\circ}\text{F}$

The relative risks were formulated using the odds-ratio as a measure of association and relative risk. For each pollutant and community, temperature-specific relative risks are presented in Table A-23 in Appendix A. The odds-ratios, when interpreted

in conjunction with their standard errors, showed no consistent pattern across communities. Of the five significant scenarios identified, the largest odds-ratios were for suspended sulfates in Magna when minimum temperature exceeded 50°F. The odds-ratios were 1.44, 1.72, and 1.65 for sulfate categories 6 to 8, 8 to 10 and greater than 10 $\mu\text{g}/\text{m}^3$, respectively. Because of confounding, the effect could not be attributed to sulfates. No increasing dose effect with sulfates was apparent except from the lowest levels.

The multiple comparison problem was also an important consideration. If the 60 comparisons made were statistically independent, by chance alone three comparisons would be expected to be judged significant when no association was present. The comparisons made were not independent and depending on correlation structure more than three could be expected.

The five temperature-specific community scenarios would have been indicative of an association between asthma attack rates and specific pollutant species if they had not been confounded. The temperature stratification resulted in a nonrandom allocation of study days to each strata. In this particular study the strata essentially corresponded to a seasonal stratification of winter, spring/fall and summer. All significant scenarios, except for Salt Lake City, occurred when the minimum temperature was greater than 50°F, roughly corresponding to June through August. The two scenarios with significant negative associations also occurred in the greater than 50°F temperature stratum. The possibility of a confounding factor, such as pollen levels, cannot be easily dismissed. It is noteworthy that the highest pollutant levels did not occur on the days included in the significant scenarios.

The confounding of other factors and other air pollutants is illustrated in Tables A-24 and A-25 in Appendix A. Table A-24 gives the average levels of selected pollution, temperature and design variables by pollutant categories for the five statistically significant temperature-specific scenarios. Temperature-specific analyses for Magna when minimum temperatures were greater than 50°F suggested a positive association between attack rates and the pollutants TSP, SS and SO_2 . This association was weakened by a similar association with the design factor male/female ratio. The other scenarios showed similar confounding associations. Additional evidence of confounding was given by temperature-specific simple correlations of air pollution factors and design, temperature or demographic factors.

The analysis procedure considered each air pollutant individually, ignoring the strong correlations among the five pollutants. This correlation was demonstrated in Section 3. For the three communities with significant scenarios, Table A-25

reports simple correlations among the pollutants for temperature-specific strata. When minimum temperatures were greater than 50°F, the correlations for Magna of suspended sulfates and sulfur dioxide with suspended particulates were 0.44 and 0.49, respectively. Between suspended sulfates and sulfur dioxide, it was 0.63. This made it impossible to ascribe any association between asthma attack rates and air pollution to a single pollutant.

The significant temperature-specific scenarios in Magna and Kearns included the 30 day period in July 1971 when a strike caused the shut-down of operations involving the major source of sulfur dioxide emissions. During this time period all pollutants were at or near their lowest levels during the study. The daily asthmatic attack rates also were reduced in Magna and Kearns. The significant scenarios reflected this association but did not show a continuing increase in attack rates as pollutant levels increased. In fact, the attack rates in all scenarios tended to be the same except for the single low pollutant, high minimum temperature category, which was lower. The temporary major impact on the strike on the life styles of the panelists in two small communities cannot be assessed from the available data. However, the possible confounding influence of such factors must be considered. Any conclusion reached by temperature-specific analyses of a positive association between asthma attacks and air pollutants would be based almost exclusively on this time period.

Based on the relative risk analysis alone, a positive association between asthma attack rates and air pollution when minimum temperature is greater than 50°F was indicated. However, no specific pollutant could be uniquely identified and the conclusion was severely limited due to confounding factors not considered in the analysis.

REFERENCES

1. J. F. Finklea, et al. "Aggravation of Asthma by Air Pollutants: 1971 Salt Lake Basin Studies." In Health Consequences of Sulfur Oxides: A Report from CHESS 1970-71. Research Triangle Park, NC: U.S. Environmental Protection Agency, May 1974. EPA-650/1-74-004.
2. U.S. Congressional Report. The Environmental Protection Agency's Research Program, with Primary Emphasis on CHESS: An Investigative Report. Prepared for the Committee on Science and Technology. U.S. House of Representatives. Washington, DC: Government Printing Office, 77-509, 1976.
3. H. D. Roth, J. R. Viren and A. V. Colucci. Evaluation of CHESS: New York Asthma Data 1970-71. Palo Alto, Calif.: Electric Power Research Institute, May 1977. EPRI-EA-450, Vol. I.
4. H. D. Roth, J. R. Viren, A. V. Colucci, E. H. Pechan and A. E. Ripps. Evaluation of CHESS: New York Asthma Data 1971-1972. Vol. I. Findings and Supporting Tables. Palo Alto, Calif.: Electric Power Research Institute, 1980. Technical report in press.
5. J. H. Stebbings, Jr. "Panel Studies of Acute Health Effects of Air Pollution. II. A Methodologic Study of Linear Regression Analysis of Asthma Panel Data." Environ. Res. 17:10-32, 1978.
6. J. L. Fleiss. Statistical Methods for Rates and Proportions. New York: John Wiley and Sons, 1973.
7. P. Armitage. Statistical Methods in Medical Research. New York: John Wiley and Sons, 1971.

Table A-1

STUDY DAYS WITH MISSING AIR POLLUTION DATA BY AIR
POLLUTANT IN EACH STUDY COMMUNITY: UTAH 1971-72 ASTHMA STUDY

Air Pollutant	Occen	Salt Lake City	Kearns	Magna
Total Suspended Particulates (TSP)	(27)* 196-201 222-239 243 257 429	(10) 135 136 141 162 226 288 329 330 331 384	(20) 22-25 27 139 140 142 143 198 208 236 298 299 344 354 355 364 403 413	(25) 16-24 44 45 178 184-187 236 326 361 379 386 420 421 430 461
Suspended Nitrates (SN)	(27) 196-201 222-239 397 455 459	(10) 135 136 141 162 226 239 329 330 331 384	(19) 22-25 27 139 140 142 143 198 208 210 217 298 299 344 354 355 364	(22) 16-24 44 45 184-187 238 326 379 386 420 421 461
Suspended Sulfates (SS)	(26) 196-201 222-239 455 459	(9) 135 136 141 162 226 329 330 331 384	(21) 22-25 27 32 138-140 142 143 198 208 210 217 298 299 344 354 355 364	(21) 16-24 44 45 184-187 326 379 386 420 421 461
Sulfur Dioxide (SO ₂)	(33) 17 27 71 82 115 117 131 132 138 151-154 177 193 222 233 234 242 248 326 347 354 376 382 390 403 404 417 422 425 438 450	(77) 17 19 21 22 68 89 105 123 124 126 130 131 133 137 138 142-146 157 160 167 171 173 180 185 186 191 193 194 199 202-208 213 221 223 229 236 237 243 251 259-270 272 291 293 329 333 376 377 381 384 386 400 408 412 438 441-443 452	(33) 19 40 47 67 89 95 117 122 124 131 132 140 171 173 185 187 199 206 217 222 257 260 290 337 384 422 437 446-448 450 454 467	(53) 12 23 33 36 40 47 49 57 67 82 89 93 95 102 117 124 131 132 171 172 187 199 201 222 257 258 271 304 306 308 313 319 344 349 350 356 362 370 371 384 397 411 412 427 433 437 439 446 448 449 452 459 461
Nitrogen Dioxide (NO ₂)	(40) 29 34 57 77 101 109 118 131 137 138 154 158 187 194 215 233 234 232 296 298 332 348 374 386 390 392 398 399 403 434 407 411 415 424 429 438 443 451 453 458	(57) 49 55 74 85 112 117 126 139 157 160 162 167 176 177 185 186 191 192 203-205 207 208 219 220 228 259-270 272 277 293 342 371 376 377 399 404 416 417 432 433 441-443 450 451 453	(63) 5 33 40 47 54 67 75 77 89 95 101 105 106 122 124 128 130 140 164 170 171 186 187 196 199 206 223 238 257 258 292 301 302 334 336 337 342 355 359 370 383 384 392 403 406 407 409 429 434 436 440 441 444 446-448 454 455 457-459 462 467	(55) 26 28 33 38 40 47 67 89 91 95 100 124 154 167 171 172 185-187 199 244 254 258 260 287 308 309 312 319 341 344 349 356 371 381 383 384 389 403 404 409 411 414 418 425 427-429 436 443 450 453 459-461
One or more of TSP, SN, SS or SO ₂ Missing**	(60) (2) 17 27 (11) 71 82 115 117 131 132 138 151-154 (30) 177 193 196-201 222-239 242 243 248 257 (3) 326 347 354 (14) 376 382 390 397 403 404 417 422 425 429 432 450 455 459	(86) (4) 17 19 21 22 (19) 68 89 105 123 124 126 130 131 133 135-138 141-146 (31) 157 160 162 167 171 173 180 185 186 191 193 194 199 202-208 213 221 223 226 229 236 237 239 243 251 259 (19) 260-270 272 288 291 293 329-331 333 (13) 376 377 381 384 386 400 408 412 438 441-443 452	(58) (9) 19 22-25 27 32 40 47 (13) 67 89 95 117 122 124 131 132 138-140 142 143 (16) 171 173 185 187 197-199 204-206 208 210 217 222 236 257 (9) 260 290 298 299 337 344 354 355 364 (11) 384 403 413 422 437 446-448 450 454 467	(76) (17) 12 16-24 33 36 40 44 45 47 49 (11) 57 67 82 89 93 95 102 117 124 131 132 (14) 171 172 178 184-187 199 201 222 236 238 257 258 (13) 271 304 306 308 313 319 326 344 349 350 356 361 362 (21) 370 371 379 384 386 397 411 412 420 421 427 430 433 437 439 446 448 449 452 459 461

* Number of days missing.

** Number of days and study days missing are listed for weeks 1-8, 9-23, 24-38, 39-53, 54-67.

Table A-2

COMPARISON OF SELECTED INDICATORS BETWEEN
DAYS INCLUDED AND DELETED FROM ANALYSIS
OGDEN: UTAH 1971-72 ASTHMA STUDY

Indicators	Included Days			Deleted Days			Mean Difference	t-value
	Mean	Standard Deviation	Sample Size	Mean	Standard Deviation	Sample Size		
<u>Asthma Attacks</u>								
Observed attacks	0.168	0.061	355	0.156	0.065	58	0.012	1.31
O/B(T)	1.010	0.367	355	0.926	0.386	58	0.084	1.52
O/B(Q)	1.006	0.352	355	0.949	0.380	58	0.057	1.06
<u>Experimental Design</u>								
Day of Study	263.8	122	355	258.1	105	58	5.7	0.37
Day of Week	3.97	2.05	355	4.17	1.71	58	-0.20	-0.81
B(T)	0.166	0.015	355	0.168	0.010	58	-0.002	-1.38
B(Q)	0.167	0.018	355	0.163	0.012	58	0.004	1.90
<u>Demographics</u>								
Age	28.1	1.1	355	27.8	0.8	58	0.3	2.00*
Adult/Juvenile	1.33	0.17	355	1.29	0.09	58	0.04	3.04**
Male/Female	0.82	0.10	355	0.80	0.08	58	0.02	1.85
Smoking	1.41	0.08	355	1.39	0.07	58	0.02	1.66
Education	3.60	0.07	355	3.59	0.07	58	0.01	1.11
<u>Air Quality</u>								
TSP	87.21	48.1	355	99.47	68.0	31	-12.26	-0.98
SN	3.19	4.63	355	2.53	2.70	31	0.66	1.22
SS	6.25	4.34	355	6.23	4.07	32	0.02	0.03
SO ₂	9.10	8.69	355	7.87	5.04	27	1.23	1.14
NO ₂	42.24	25.6	327	35.83	16.7	48	6.41	2.29*
Maximum Temperature	64.25	21.1	355	64.35	17.9	58	-0.10	-0.04
Minimum Temperature	40.09	16.1	355	41.62	13.7	58	-1.53	-0.77
Lag Min. Temp.	40.0	16.1	355	41.9	13.4	58	-1.9	-0.77
Daily Temp. Range	24.2	7.6	355	22.7	6.9	58	1.5	1.45
Min. Temp. Range	0.1	5.4	355	-0.3	4.8	58	0.4	0.53
Relative Humidity	50.3	16.5	355	50.6	15.6	58	-0.3	-0.12

* Significant at $p < 0.05$ level.

** Significant at $p < 0.01$ level.

Table A-3

COMPARISON OF SELECTED INDICATORS BETWEEN
DAYS INCLUDED AND DELETED FROM ANALYSIS
SALT LAKE CITY: UTAH 1971-72 ASTHMA STUDY

Indicators	Included Days			Deleted Days			Mean Difference	t-value
	Mean	Standard Deviation	Sample Size	Mean	Standard Deviation	Sample Size		
<u>Asthma Attacks</u>								
Observed attacks	0.111	0.056	331	0.097	0.060	82	0.014	1.92
O/B(T)	1.019	0.519	331	0.918	0.537	82	0.101	1.54
O/B(Q)	1.010	0.499	331	0.945	0.509	82	0.065	1.03
<u>Experimental Design</u>								
Day of Study	269.3	124	331	237.7	96	82	31.6	2.51*
Day of Week	4.00	2.0	331	4.01	1.9	82	-0.01	-0.06
B(T)	0.110	0.013	331	0.105	0.009	82	0.005	3.83**
B(Q)	0.111	0.023	331	0.101	0.023	82	0.010	3.50**
<u>Demographics</u>								
Age	23.06	1.81	331	22.15	1.82	82	0.91	4.03**
Adult/Juvenile	0.84	0.10	331	0.80	0.11	82	0.04	3.26**
Male/Female	1.04	0.20	331	1.03	0.12	82	0.01	0.87
Smoking	1.26	0.06	331	1.27	0.05	82	-0.01	-1.16
Education	3.35	0.10	331	3.35	0.09	82	<0.01	-0.29
<u>Air Quality</u>								
TSP	94.6	59.0	331	85.0	37.4	72	9.6	1.77
SN	3.9	5.7	331	3.6	4.3	72	0.3	0.45
SS	8.1	7.2	331	8.2	7.2	73	-0.1	-0.13
SO ₂	16.0	18.2	331	17.8	21.4	9	-1.8	-0.25
NO ₂	43.8	30.3	308	42.1	33.0	50	1.7	0.33
Maximum Temperature	64.4	19.9	331	67.1	22.0	82	-2.7	-1.03
Minimum Temperature	39.5	15.1	331	41.8	16.1	82	-2.3	-1.19
Lag Min. Temp.	39.3	15.0	331	42.3	16.4	82	-3.0	-1.50
Daily Temp. Range	24.9	7.8	331	25.3	8.8	82	-0.4	-0.36
Min. Temp. Change	0.2	5.6	331	-0.5	5.2	82	0.7	0.99
Relative Humidity	50.7	15.8	331	48.9	18.3	82	1.8	0.85

* Significant at $p < 0.05$ level.

** Significant at $p < 0.01$ level.

Table A-4

COMPARISON OF SELECTED INDICATORS BETWEEN
DAYS INCLUDED AND DELETED FROM ANALYSIS
KEARNS: UTAH 1971-72 ASTHMA STUDY

Indicators	Included Days			Deleted Days			Mean Difference	t-value
	Mean	Standard Deviation	Sample Size	Mean	Standard Deviation	Sample Size		
<u>Asthma Attacks</u>								
Observed Attacks	0.148	0.049	367	0.155	0.54	46	-0.007	-0.88
O/B(T)	0.995	0.317	367	1.053	0.328	46	-0.058	-1.14
O/B(Q)	0.997	0.309	367	1.029	0.286	46	-0.032	-0.72
<u>Experimental Design</u>								
Day of Study	263.5	119	367	259.1	123	46	4.4	0.23
Day of Week	3.95	2.03	367	4.39	1.72	46	-0.44	-1.60
B(T)	0.149	0.011	367	0.148	0.016	46	0.001	0.52
B(Q)	0.149	0.017	367	0.150	0.021	46	-0.001	-0.42
<u>Demographics</u>								
Age	22.95	0.94	367	22.80	0.83	46	0.15	1.10
Adult/Juvenile	0.63	0.07	367	0.62	0.06	46	0.01	1.20
Male/Female	1.20	0.15	367	1.25	0.20	46	-0.05	-1.46
Smoking	1.66	0.08	367	1.66	0.07	46	<0.01	-0.04
Education	3.76	0.11	367	3.74	0.11	46	0.02	0.87
<u>Air Quality</u>								
TSP	51.5	31	367	52.9	23	31	-1.4	-0.31
SN	2.9	4.8	367	3.1	5.0	32	-0.2	-0.12
SS	8.0	6.6	367	8.8	10.3	31	-0.08	-0.42
SO ₂	24.6	35.7	367	17.0	21.4	16	7.6	1.34
NO ₂	24.5	20.5	329	23.8	17.8	26	0.7	0.18
Maximum Temperature	63.1	20.3	365	69.0	21.3	46	-5.9	-1.76
Minimum Temperature	42.1	14.9	365	46.4	14.1	46	-4.3	-1.95
Lagged Min. Temp.	41.9	14.9	366	47.0	14.0	45	-5.1	-2.25*
Daily Temp. Range	21.0	8.2	364	22.6	9.1	46	-1.6	-1.09
Min. Temp. Change	0.1	4.5	364	-0.5	5.0	45	0.6	0.80
Relative Humidity	50.8	16.2	367	46.8	17.1	46	4.0	1.52

* Significant at $p < 0.05$ level.

Table A-5

COMPARISON OF SELECTED INDICATORS BETWEEN
DAYS INCLUDED AND DELETED FROM ANALYSIS
MAGNA: UTAH 1971-72 ASTHMA STUDY

Indicators	Included Days			Deleted Days			Difference	t-value
	Mean	Standard Deviation	Sample Size	Mean	Standard Deviation	Sample Size		
<u>Asthma Attacks</u>								
Observed Attacks	0.186	0.059	354	0.205	0.057	59	-0.19	-2.36*
O/B(T)	0.992	0.314	354	1.094	0.296	59	-0.102	-2.43*
O/B(Q)	0.996	0.321	354	1.088	0.296	59	-0.092	-2.20*
<u>Experimental Design</u>								
Day of Study	258.6	118	354	289.2	126	59	-30.6	-1.74
Day of Week	3.92	2.04	354	4.47	1.73	59	-0.55	-2.22*
B(T)	0.188	0.017	354	0.187	0.016	59	0.001	0.27
B(Q)	0.188	0.028	354	0.189	0.025	59	-0.001	-0.32
<u>Demographics</u>								
Age	25.14	0.95	354	24.97	1.04	59	0.17	1.13
Adult/Juvenile	1.23	0.13	354	1.20	0.15	59	0.03	1.27
Male/Female	1.00	0.11	354	1.00	0.10	59	<0.01	-0.12
Smoking	1.61	0.11	354	1.62	0.12	59	-0.01	-0.40
Education	3.14	0.06	354	3.14	0.06	59	<0.01	-1.13
<u>Air Quality</u>								
TSP	72.8	52.6	354	76.2	41.4	45	-3.4	-0.51
SN	2.4	3.9	354	2.1	3.3	48	0.3	0.59
SS	12.8	9.5	354	11.0	7.3	49	1.8	1.53
SO ₂	70.4	81.6	354	51.2	57.8	13	19.2	1.16
NO ₂	23.0	20.2	327	17.2	12.2	37	5.8	2.52*
Maximum Temperature	63.4	20.7	352	66.2	19.6	59	-2.8	-1.01
Minimum Temperature	42.3	15.0	352	44.1	14.3	59	-1.8	-0.91
Lag Min. Temp.	42.2	15.1	352	44.1	12.9	59	-1.9	-1.03
Daily Temp. Range	21.1	8.3	351	22.1	8.5	59	-1.0	-0.83
Min. Temp. Change	0.1	4.3	350	-0.0	5.8	59	0.1	0.12
Relative Humidity	50.9	16.6	354	47.4	14.2	59	3.5	1.67

* Significant at $p < 0.05$ level.

Table A-6

FREQUENCY OF PRIMARY*, SECONDARY** AND DISCRETE*** ATTACK DAYS
BY AGE, QUARTER AND DAY OF WEEK IN OGDEN: UTAH 1971-72 ASTHMA STUDY

Adults							
	<u>Sunday</u>	<u>Monday</u>	<u>Tuesday</u>	<u>Wednesday</u>	<u>Thursday</u>	<u>Friday</u>	<u>Saturday</u>
Total							
Primary	45	21	19	25	33	30	12
Secondary	154	183	176	175	184	196	198
Discrete	32	17	20	14	35	39	48
1st Quarter							
Primary	9	4	8	7	9	4	1
Secondary	21	28	26	30	32	35	31
Discrete	13	5	9	7	14	14	16
2nd Quarter							
Primary	10	6	5	10	8	14	3
Secondary	31	36	32	34	41	43	49
Discrete	8	6	8	2	8	10	13
3rd Quarter							
Primary	15	5	2	4	10	8	6
Secondary	53	63	59	54	53	59	59
Discrete	4	4	0	3	6	8	10
4th Quarter							
Primary	11	6	4	4	6	4	2
Secondary	49	56	59	57	58	59	59
Discrete	7	2	3	2	7	7	9
Juveniles							
	<u>Sunday</u>	<u>Monday</u>	<u>Tuesday</u>	<u>Wednesday</u>	<u>Thursday</u>	<u>Friday</u>	<u>Saturday</u>
Total							
Primary	18	10	12	7	22	14	16
Secondary	31	43	36	35	27	41	35
Discrete	14	18	18	14	16	25	40
1st Quarter							
Primary	1	1	4	1	4	5	2
Secondary	5	3	4	4	4	7	7
Discrete	6	6	7	1	9	2	11
2nd Quarter							
Primary	5	2	2	1	6	5	4
Secondary	6	10	9	8	4	9	9
Discrete	2	5	5	4	4	7	12
3rd Quarter							
Primary	5	5	5	3	5	1	3
Secondary	8	13	14	16	13	14	8
Discrete	5	6	3	6	1	8	12
4th Quarter							
Primary	7	2	1	2	7	3	7
Secondary	12	17	9	7	6	11	11
Discrete	1	1	3	3	2	8	5

*The first day of a run of attack days.

**Those days in a run following the primary attack day.

***Solitary attack days.

Table A-7

FREQUENCY OF PRIMARY*, SECONDARY** AND DISCRETE*** ATTACK DAYS BY
AGE, QUARTER AND DAY OF WEEK IN SALT LAKE CITY: UTAH 1971-72 ASTHMA STUDY

Adults

	<u>Sunday</u>	<u>Monday</u>	<u>Tuesday</u>	<u>Wednesday</u>	<u>Thursday</u>	<u>Friday</u>	<u>Saturday</u>
Total							
Primary	23	10	12	14	11	17	2
Secondary	37	54	48	52	52	54	58
Discrete	17	19	22	25	19	23	29
1st Quarter							
Primary	5	2	4	1	6	4	1
Secondary	3	5	5	8	5	10	6
Discrete	4	7	13	9	6	9	12
2nd Quarter							
Primary	6	2	2	6	1	1	0
Secondary	7	13	9	11	15	12	12
Discrete	3	4	4	6	6	2	8
3rd Quarter							
Primary	4	5	1	5	3	6	1
Secondary	19	22	21	18	20	20	25
Discrete	4	4	2	4	2	4	7
4th Quarter							
Primary	8	1	5	2	1	6	0
Secondary	8	14	13	15	12	12	15
Discrete	6	4	3	6	5	8	2

Juveniles

	<u>Sunday</u>	<u>Monday</u>	<u>Tuesday</u>	<u>Wednesday</u>	<u>Thursday</u>	<u>Friday</u>	<u>Saturday</u>
Total							
Primary	16	12	16	20	19	12	9
Secondary	39	49	48	54	66	69	60
Discrete	11	8	32	26	19	15	38
1st Quarter							
Primary	6	1	4	6	6	0	1
Secondary	7	12	8	12	18	19	11
Discrete	6	4	7	5	5	3	9
2nd Quarter							
Primary	5	2	3	6	4	5	4
Secondary	8	9	8	8	13	14	13
Discrete	3	1	7	7	6	3	12
3rd Quarter							
Primary	2	6	3	5	7	2	0
Secondary	2	4	9	8	9	14	9
Discrete	1	2	12	7	5	5	9
4th Quarter							
Primary	3	3	6	3	2	5	4
Secondary	22	24	23	26	26	22	27
Discrete	1	1	6	7	3	4	8

* The first day of a run of attack days.

** Those days in a run following the primary attack day.

*** Solitary attack days.

Table A-8

FREQUENCY OF PRIMARY*, SECONDARY** AND DISCRETE*** ATTACK DAYS
BY AGE, QUARTER AND DAY OF WEEK IN KEARNS: UTAH 1971-72 ASTHMA STUDY

Adults							
	<u>Sunday</u>	<u>Monday</u>	<u>Tuesday</u>	<u>Wednesday</u>	<u>Thursday</u>	<u>Friday</u>	<u>Saturday</u>
Total							
Primary	19	12	17	21	37	30	13
Secondary	154	158	160	161	167	189	189
Discrete	8	20	23	11	26	21	28
1st Quarter							
Primary	11	5	5	8	9	4	4
Secondary	35	41	43	40	44	50	46
Discrete	3	5	7	2	9	6	0
2nd Quarter							
Primary	3	3	6	3	11	8	1
Secondary	28	29	30	33	31	40	40
Discrete	3	8	1	3	9	5	7
3rd Quarter							
Primary	2	4	3	5	10	9	3
Secondary	39	36	39	38	40	45	46
Discrete	0	4	9	4	5	8	7
4th Quarter							
Primary	3	0	3	5	7	9	5
Secondary	52	52	48	50	52	54	57
Discrete	2	3	6	2	3	2	6
Juveniles							
	<u>Sunday</u>	<u>Monday</u>	<u>Tuesday</u>	<u>Wednesday</u>	<u>Thursday</u>	<u>Friday</u>	<u>Saturday</u>
Total							
Primary	17	25	21	20	27	14	17
Secondary	66	67	80	81	87	93	84
Discrete	27	25	42	33	52	33	47
1st Quarter							
Primary	7	7	7	2	8	5	5
Secondary	7	10	13	14	9	14	11
Discrete	9	6	9	8	11	12	14
2nd Quarter							
Primary	4	8	3	7	6	3	4
Secondary	15	16	20	18	23	21	21
Discrete	6	7	11	11	14	6	10
3rd Quarter							
Primary	4	7	5	7	11	1	5
Secondary	21	21	25	24	28	32	25
Discrete	7	5	8	6	13	9	11
4th Quarter							
Primary	2	3	6	4	2	5	3
Secondary	23	20	22	25	27	26	27
Discrete	5	7	14	8	14	6	12

*The first day of a run of attack days.

**Those days in a run following the primary attack day.

***Solitary attack days.

Table A-9

FREQUENCY OF PRIMARY*, SECONDARY** AND DISCRETE*** ATTACK DAYS
BY AGE, QUARTER AND DAY OF WEEK IN MAGNA: UTAH 1971-72 ASTHMA STUDY

Adults							
	<u>Sunday</u>	<u>Monday</u>	<u>Tuesday</u>	<u>Wednesday</u>	<u>Thursday</u>	<u>Friday</u>	<u>Saturday</u>
Total							
Primary	38	48	22	35	34	45	26
Secondary	136	144	172	165	165	170	178
Discrete	36	43	34	45	46	49	52
1st Quarter							
Primary	11	13	6	5	9	8	5
Secondary	8	15	25	24	16	21	22
Discrete	12	8	6	3	11	14	16
2nd Quarter							
Primary	13	14	6	9	12	9	7
Secondary	41	46	52	46	51	54	51
Discrete	8	13	13	17	16	13	14
3rd Quarter							
Primary	7	15	7	8	8	12	8
Secondary	50	47	56	57	53	53	56
Discrete	6	16	11	17	8	16	11
4th Quarter							
Primary	7	6	3	13	5	16	6
Secondary	37	36	39	38	45	42	49
Discrete	10	6	4	8	11	6	11
Juveniles							
	<u>Sunday</u>	<u>Monday</u>	<u>Tuesday</u>	<u>Wednesday</u>	<u>Thursday</u>	<u>Friday</u>	<u>Saturday</u>
Total							
Primary	16	17	10	14	22	21	9
Secondary	67	76	82	74	75	87	91
Discrete	13	13	17	17	14	16	17
1st Quarter							
Primary	8	3	2	5	4	8	3
Secondary	11	19	18	16	18	18	20
Discrete	4	4	10	6	5	5	2
2nd Quarter							
Primary	4	6	0	1	6	3	0
Secondary	14	18	20	14	15	20	20
Discrete	6	4	4	5	6	5	7
3rd Quarter							
Primary	2	3	6	4	5	5	2
Secondary	19	18	20	23	21	22	24
Discrete	3	2	0	3	1	2	3
4th Quarter							
Primary	2	5	2	4	7	5	4
Secondary	23	21	24	21	21	27	27
Discrete	0	3	3	3	2	4	5

*The first day of a run of attack days.

**Those days in a run following the primary attack day.

***Solitary attack days.

Table A-10

MEDICAL HISTORY PROFILE OF THE OGDEN PANEL: UTAH 1971-72 ASTHMA STUDY

Condition	Percent Answering Yes	Overall Attack Rate	Quartile Attack Rate				Number Answering Yes	
			Summer	Fall	Winter	Spring	Adult	Juvenile
All panelists (all conditions)	100 (37)*	0.173 12,849**	0.159 2646	0.160 3186	0.177 3596	0.188 3421	21	16
Attacks with fever	13 (5)	0.252 1683	0.161 338	0.239 432	0.217 483	0.249 430	2	3
Attacks with Phlegm	59 (22)	0.200 7768	0.208 1622	0.192 1932	0.194 2182	0.205 2032	12	10
Attacks Restrict Activity	49 (18)	0.175 5797	0.143 1066	0.165 1435	0.169 1770	0.189 1526	8	10
Attacks in Summer	78 (29)	0.194 9931	0.176 2021	0.178 2452	0.194 2786	0.212 2672	18	11
Attacks in Fall	84 (31)	0.179 11,083	0.159 2379	0.174 2789	0.189 3029	0.188 2886	17	14
Attacks in Winter	86 (32)	0.168 11,140	0.157 2267	0.163 2779	0.178 3121	0.169 2973	19	13
Attacks in Spring	89 (33)	0.185 11,410	0.169 2365	0.168 2825	0.186 3177	0.205 3043	20	13
Many Attacks in Summer	35 (13)	0.234 3916	0.289 644	0.189 904	0.209 1246	0.272 1122	8	5
Many Attacks in Fall	35 (13)	0.200 4555	0.170 918	0.195 1095	0.239 1279	0.222 1263	6	7
Many Attacks in Winter	46 (17)	0.119 5669	0.167 991	0.118 1364	0.122 1672	0.100 1642	8	9
Many Attacks in Spring	43 (16)	0.215 5109	0.271 876	0.174 1173	0.185 1574	0.238 1486	11	5
No Seasonal Predominance	32 (12)	0.167 4318	0.195 903	0.162 1064	0.163 1190	0.176 1161	8	4
Fumes and Dust on Job	14 (5)	0.239 1637	0.274 317	0.115 411	0.193 455	0.403 454	5	0
Food and Drug Allergies	41 (15)	0.192 5501	0.142 1243	0.202 1423	0.205 1484	0.180 1351	10	5
Attacks Occur in "Cold" Weather	54 (20)	0.146 6031	0.113 1332	0.152 1671	0.154 1993	0.135 1835	10	10
Attacks with Respiratory Infections	76 (28)	0.184 9672	0.175 1930	0.189 2369	0.196 2763	0.170 2610	14	14
Attacks with Emotional Upset	62 (23)	0.191 8093	0.193 1645	0.190 2026	0.191 2240	0.178 2182	16	7
Hay Fever	57 (21)	0.125 7210	0.165 1494	0.117 1788	0.099 2016	0.144 1912	12	9

*Number of panelists.

**Person-days in base for attack rate.

Table A-11

MEDICAL HISTORY PROFILE OF THE SALT LAKE CITY PANEL: UTAH 1972-72 ASTHMA STUDY

Condition	Percent Answering Yes	Overall Attack Rate	Quartile Attack Rate				Number Answering Yes	
			Summer	Fall	Winter	Spring	Adult	Juvenile
All Panelists (All Conditions)	100 (34)	0.111 11,417	0.099 2661	0.116 3027	0.099 3129	0.162 2600	15	19
Attacks with Fever	24 (8)	0.097 2723	0.089 609	0.082 721	0.051 749	0.190 644	2	6
Attacks with Phlegm	65 (22)	0.108 7456	0.094 1703	0.119 1984	0.077 2051	0.167 1718	11	11
Attacks Restrict Activity	76 (26)	0.138 8823	0.124 1974	0.144 2288	0.124 2461	0.195 2100	9	17
Attacks in Summer	79 (27)	0.126 9182	0.110 2211	0.137 2404	0.121 2492	0.171 2075	13	14
Attacks in Fall	85 (29)	0.121 9525	0.105 2253	0.130 2523	0.111 2639	0.175 2110	13	16
Attacks in Winter	79 (27)	0.128 8894	0.114 2108	0.144 2358	0.122 2440	0.173 1988	11	16
Attacks in Spring	91 (31)	0.120 10,397	0.104 2488	0.124 2782	0.105 2828	0.179 2299	14	17
Many Attacks in Summer	38 (13)	0.125 4393	0.114 1016	0.169 1142	0.130 1220	0.111 1015	7	6
Many Attacks in Fall	41 (14)	0.099 4744	0.120 1086	0.086 1252	0.084 1307	0.118 1099	6	8
Many Attacks in Winter	50 (17)	0.140 5503	0.126 1362	0.130 1481	0.137 1498	0.215 1162	7	10
Many Attacks in Spring	50 (17)	0.085 6061	0.107 1410	0.071 1630	0.063 1611	0.105 1410	9	8
No Seasonal Predominante	35 (12)	0.105 3982	0.078 932	0.161 1065	0.105 1110	0.101 875	8	4
Fumes and Dust on Job	15 (5)	0.079 1865	0.121 438	0.074 496	0.040 490	0.093 441	4	1
Food and Drug Allergies	56 (19)	0.109 6309	0.132 1481	0.094 1702	0.091 1681	0.139 1445	9	10
Attacks Occur in "Cold" Weather	32 (11)	0.143 3457	0.121 772	0.138 886	0.172 987	0.170 812	5	6
Attacks with Respiratory Infection	71 (24)	0.146 7982	0.132 1868	0.159 2113	0.136 2209	0.208 1792	10	14
Attacks with Emotional Upset	41 (14)	0.140 4856	0.096 1037	0.179 1215	0.112 1379	0.180 1225	7	7
Hay Fever	59 (20)	0.143 6992	0.142 1650	0.148 1846	0.124 1862	0.212 1634	12	8

Table A-12

MEDICAL HISTORY PROFILE OF THE KEARNS PANEL: UTAH 1971-72 ASTHMA STUDY

Condition	Percent Answering Yes	Overall Attack Rate	Quartile Attack Rate				Number Answering Yes	
			Summer	Fall	Winter	Spring	Adult	Juvenile
All Panelists (All conditions)	100 (48)	0.144 16,268	0.149 3777	0.138 3992	0.130 4431	0.155 4068	19	29
Attacks with Fever	35 (17)	0.106 5552	0.143 1316	0.102 1401	0.096 1469	0.088 1366	6	11
Attacks with Phlegm	67 (32)	0.102 10,541	0.134 2451	0.087 2632	0.069 2864	0.120 2594	14	18
Attacks Restrict Activity	67 (32)	0.142 10,598	0.137 2382	0.146 2597	0.127 2914	0.161 2705	11	21
Attacks in Summer	85 (41)	0.148 14,010	0.161 3255	0.137 3450	0.127 3806	0.157 3499	16	25
Attacks in Fall	85 (41)	0.158 13,740	0.152 3215	0.156 3386	0.142 3731	0.177 3408	17	24
Attacks in Winter	81 (39)	0.153 12,971	0.154 2919	0.148 3163	0.136 3523	0.170 3316	15	24
Attacks in Spring	88 (42)	0.158 14,032	0.165 3196	0.151 3470	0.144 3865	0.173 3501	18	24
Many Attacks in Summer	38 (18)	0.156 6323	0.188 1647	0.151 1614	0.126 1601	0.145 1461	7	11
Many Attacks in Fall	48 (23)	0.141 8104	0.135 1811	0.143 1992	0.132 2228	0.145 2073	10	13
Many Attacks in Winter	40 (19)	0.162 6303	0.148 1474	0.174 1547	0.163 1752	0.154 1530	9	10
Many Attacks in Spring	42 (20)	0.163 6998	0.194 1679	0.135 1782	0.121 1881	0.205 1656	8	12
No Seasonal Predominance	19 (9)	0.182 2812	0.166 583	0.223 666	0.177 833	0.161 730	4	5
Fumes and Dust on Job	13 (6)	0.098 2083	0.153 553	0.079 523	0.045 538	0.123 469	4	2
Food and Drug Allergies	46 (22)	0.149 7394	0.132 1705	0.129 1804	0.134 2020	0.189 1865	9	13
Attacks Occur in "Cold" Weather	48 (23)	0.112 7467	0.090 1561	0.112 1787	0.114 2116	0.112 2003	10	13
Attacks with Respiratory Infection	81 (39)	0.126 13,092	0.121 2924	0.128 3177	0.106 3614	0.143 3377	16	23
Attacks with Emotional Upset	52 (25)	0.166 8540	0.133 1979	0.172 2081	0.173 2340	0.177 2140	11	14
Hay Fever	69 (33)	0.124 10,628	0.150 2502	0.124 2575	0.102 2920	0.120 2631	13	20

Table A-13

MEDICAL HISTORY PROFILE OF THE MAGNA PANEL: UTAH 1971-72 ASTHMA STUDY

Condition	Percent Answering Yes	Overall Attack Rate	Quartile Attack Rate				Number Answering Yes	
			Summer	Fall	Winter	Spring	Adult	Juvenile
All Panelists (All conditions)	100 (37)	0.193 13,007	0.160 3049	0.202 3402	0.201 3441	0.198 3115	21	16
Attacks with Fever	24 (9)	0.311 3219	0.250 721	0.306 831	0.346 841	0.331 826	3	6
Attacks with Phlegm	86 (32)	0.218 11,153	0.177 2573	0.228 2906	0.227 3007	0.225 2667	19	13
Attacks Restrict Activity	57 (21)	0.165 7315	0.151 1761	0.155 1857	0.179 1940	0.167 1757	9	12
Attacks in Summer	76 (20)	0.194 9881	0.158 2330	0.198 2543	0.198 2607	0.209 2401	15	13
Attacks in Fall	76 (28)	0.197 9777	0.154 2294	0.209 2554	0.206 2598	0.203 2331	17	11
Attacks in Winter	68 (25)	0.255 8849	0.208 2086	0.259 2341	0.269 2352	0.271 2070	13	12
Attacks in Spring	81 (30)	0.188 10,493	0.149 2457	0.193 2743	0.195 2780	0.200 2513	17	13
Many Attacks in Summer	43 (16)	0.252 5827	0.190 1351	0.254 1470	0.278 1536	0.266 1470	8	8
Many Attacks in Fall	54 (20)	0.164 7199	0.124 1718	0.184 1869	0.179 1912	0.166 1700	12	8
Many Attacks in Winter	43 (16)	0.256 5817	0.209 1428	0.272 1538	0.269 1538	0.273 1313	7	9
Many Attacks in Spring	62 (23)	0.195 8180	0.153 1893	0.216 2137	0.188 2127	0.210 2023	12	11
No Seasonal Predominance	32 (12)	0.202 4368	0.157 1112	0.224 1111	0.205 1105	0.218 1040	6	6
Fumes and Dust on Job	27 (10)	0.286 3206	0.197 760	0.340 898	0.301 862	0.295 686	10	0
Food and Drug Allergies	49 (18)	0.218 6394	0.184 1483	0.218 1649	0.241 1687	0.215 1575	13	5
Attacks Occur in "Cold" Weather	43 (16)	0.320 5503	0.265 1262	0.343 1514	0.322 1476	0.334 1251	8	8
Attacks with Respiratory Infection	65 (24)	0.264 8371	0.212 1953	0.276 2204	0.281 2240	0.276 1974	15	9
Attacks with Emotional Upset	41 (15)	0.289 5197	0.245 1265	0.291 1371	0.301 1364	0.297 1197	9	6
Hay Fever	65 (24)	0.260 8638	0.201 1943	0.265 2233	0.279 2319	0.277 2143	16	8

Table A-14

SQUARE ROOT OF AVERAGE ATTACK RATES FOR
TREATMENT COMBINATIONS OCCURRING IN OGDEN

<u>Square Root of Attack Rates</u>	<u>Number of Person-Days</u>	<u>Number of Males</u>	<u>Number of Females</u>	<u>SN</u>	<u>SS</u>	<u>S02</u>	<u>TSP</u>	<u>Min. Temp.</u>
0.0000	22	9	13	1	1	2	3	3
0.0000	51	12	16	1	2	2	3	2
0.0000	23	10	13	3	4	2	3	1
0.0000	24	10	14	2	3	2	1	1
0.0000	23	10	13	2	3	1	2	1
0.0000	70	9	13	1	2	1	2	3
0.0000	24	10	14	1	4	1	3	3
0.0000	43	10	14	2	2	1	3	1
0.0000	26	11	15	2	3	1	4	2
0.0000	25	11	14	1	2	1	4	1
0.0000	21	7	14	2	3	1	1	2
0.0000	26	12	14	3	4	2	4	2
0.0000	21	8	13	2	1	1	3	3
0.0000	25	10	15	2	2	1	4	2
0.0000	49	12	16	1	4	1	1	2
0.0505	49	12	16	1	3	1	4	1
0.0524	49	11	16	1	1	2	3	1
0.0524	40	12	15	1	1	2	1	2
0.0544	71	10	16	1	2	1	4	2
0.0566	44	10	15	1	4	1	2	3
0.0741	42	12	15	2	3	2	4	1
0.0741	47	12	15	1	3	2	3	1
0.0800	25	10	15	1	2	2	1	1
0.0833	24	10	14	2	1	1	2	1
0.0833	24	11	13	1	4	1	1	1
0.0870	23	10	13	2	2	1	4	1
0.0870	23	10	13	2	1	1	3	2
0.0870	45	9	14	1	3	1	3	2
0.0881	201	12	16	1	1	1	2	1
0.0909	41	10	12	2	2	1	3	2
0.0909	22	9	13	1	4	1	4	2
0.0952	21	7	14	2	3	2	4	2
0.0952	21	10	11	2	3	1	3	2
0.0952	21	8	13	3	4	1	4	1
0.0952	21	7	14	2	4	1	3	2
0.1000	20	8	12	3	4	2	1	1
0.1000	20	7	13	1	4	1	1	3
0.1213	69	10	16	1	1	2	3	2
0.1347	39	8	13	1	1	2	2	2
0.1429	28	12	16	2	4	1	4	2
0.1515	47	12	16	1	3	1	4	2
0.1538	26	11	15	1	3	1	2	1
0.1538	26	11	15	1	4	2	4	2
0.1600	25	11	14	2	3	1	4	1
0.1724	95	12	16	2	4	2	3	1
0.1730	48	8	13	1	3	1	3	3
0.1735	166	12	16	1	1	1	4	2
0.1757	84	10	16	1	2	1	1	3
0.1780	91	12	16	2	4	2	4	1

Table A-14 (Cont.)

SQUARE ROOT OF AVERAGE ATTACK RATES FOR
TREATMENT COMBINATIONS OCCURRING IN OGDEN

<u>Square Root of Attack Rates</u>	<u>Number of Person-Days</u>	<u>Number of Males</u>	<u>Number of Females</u>	<u>SN</u>	<u>SS</u>	<u>SO₂</u>	<u>TSP</u>	<u>Min. Temp.</u>
0.1827	233	12	16	1	1	1	2	2
0.1877	160	12	16	1	2	1	3	2
0.1893	277	12	16	1	1	1	3	1
0.1905	21	10	11	2	3	1	3	1
0.2008	223	10	16	1	2	1	3	3
0.2060	533	11	16	1	1	1	2	3
0.2085	124	12	16	2	4	1	3	1
0.2095	48	11	16	1	2	1	2	1
0.2223	372	10	16	1	1	1	1	3
0.2228	144	12	16	3	4	2	4	1
0.2230	52	12	16	1	3	1	3	1
0.2364	93	12	16	1	2	1	3	1
0.2395	239	12	16	1	1	1	1	1
0.2627	236	12	16	1	2	1	1	1
0.2799	953	12	16	1	1	1	3	2
0.2862	264	12	16	1	2	1	1	2
0.2954	823	12	16	1	1	1	1	2
0.3091	602	11	16	1	1	1	3	3
0.3333	24	9	15	2	4	1	4	1

Table A-15

SQUARE ROOT OF AVERAGE ATTACK RATES FOR
TREATMENT COMBINATIONS OCCURRING IN SALT LAKE CITY

<u>Square Root of Attack Rates</u>	<u>Number of Person-Days</u>	<u>Number of Males</u>	<u>Number of Females</u>	<u>SN</u>	<u>SS</u>	<u>SO₂</u>	<u>TSP</u>	<u>Min. Temp.</u>
0.0000	20	11	9	1	1	2	2	1
0.0000	28	13	15	1	4	2	3	1
0.0000	23	10	13	2	1	1	3	3
0.0000	23	11	12	1	3	2	3	2
0.0000	24	11	13	2	2	1	2	3
0.0000	23	12	11	1	4	2	2	3
0.0000	23	11	12	2	3	1	2	3
0.0000	49	14	16	2	4	1	4	1
0.0000	26	12	14	3	4	2	4	2
0.0000	47	13	16	1	1	2	1	2
0.0000	25	12	13	1	3	2	3	1
0.0000	23	11	12	2	2	1	3	1
0.0000	47	12	14	1	3	1	1	1
0.0000	29	13	16	2	4	4	4	1
0.0000	72	14	16	1	2	1	1	1
0.0000	17	8	9	1	2	2	2	2
0.0000	20	7	13	2	4	2	4	2
0.0000	23	9	14	2	2	2	4	2
0.0000	31	14	17	2	4	1	1	1
0.0000	22	9	13	1	4	2	4	2
0.0000	21	12	9	1	1	2	1	1
0.0000	21	9	12	1	3	2	1	2
0.0000	24	12	12	1	4	2	3	3
0.0000	22	9	13	2	2	1	4	2
0.0000	40	13	16	1	3	1	1	3
0.0000	27	12	15	3	4	3	4	2
0.0000	44	13	16	3	4	1	4	1
0.0323	93	14	17	1	3	1	4	2
0.0323	99	14	17	1	1	1	2	1
0.0361	87	14	18	2	4	2	3	1
0.0488	51	13	16	2	4	1	3	1
0.0605	93	13	14	1	1	1	4	2
0.0671	142	14	17	1	1	1	1	1
0.0690	51	12	17	2	3	1	4	1
0.0741	27	13	14	1	4	2	2	2
0.0741	27	13	14	1	4	2	1	2
0.0769	26	13	13	1	3	1	3	3
0.0770	68	14	16	1	2	2	3	2
0.0796	62	12	17	1	4	1	2	2
0.0800	25	12	13	3	4	3	4	1
0.0800	25	12	13	2	2	1	3	2
0.0800	25	12	13	2	2	1	3	2
0.0833	24	11	13	1	3	1	3	1
0.0840	138	14	17	1	4	1	3	2
0.0856	64	13	17	1	4	1	1	2
0.0909	22	11	11	1	1	2	3	2
0.0917	69	13	15	1	2	1	4	1
0.0920	132	14	18	2	4	2	4	1
0.0952	21	10	11	1	1	2	2	3
0.0975	50	14	15	1	3	1	2	2

Table A-15 (Cont.)

SQUARE ROOT OF AVERAGE ATTACK RATES FOR
TREATMENT COMBINATIONS OCCURRING IN SALT LAKE CITY

<u>Square Root of Attack Rates</u>	<u>Number of Person-Days</u>	<u>Number of Males</u>	<u>Number of Females</u>	<u>SN</u>	<u>SS</u>	<u>SO₂</u>	<u>TSP</u>	<u>Min. Temp.</u>
0.1000	20	9	11	2	2	1	3	3
0.1010	50	13	15	1	2	1	2	1
0.1067	112	14	18	1	3	1	1	2
0.1104	146	14	17	1	2	1	3	1
0.1141	93	14	15	1	4	2	3	2
0.1177	65	14	15	1	2	1	1	3
0.1223	60	10	11	1	4	1	3	3
0.1333	75	14	16	3	4	4	4	1
0.1429	28	13	15	1	4	1	4	2
0.1460	123	14	17	1	1	1	3	1
0.1481	43	13	14	1	4	1	3	1
0.1538	76	12	17	1	3	1	2	1
0.1571	49	13	14	2	4	3	4	1
0.1600	25	11	14	2	1	1	2	3
0.1608	194	14	18	3	4	2	4	1
0.1667	24	10	14	3	4	4	4	2
0.1667	24	10	14	2	3	1	3	2
0.1674	80	14	18	2	3	1	3	1
0.1700	404	14	18	1	1	1	3	3
0.1724	55	13	15	1	1	1	4	1
0.1739	36	11	12	1	1	2	1	3
0.1777	95	13	16	1	2	1	2	3
0.1778	116	14	17	1	1	2	3	2
0.1788	46	13	14	1	2	2	1	2
0.1818	22	9	13	1	2	2	3	3
0.1818	22	11	11	2	3	1	3	3
0.1842	263	14	17	1	2	1	3	2
0.1857	45	12	14	2	4	2	3	2
0.2143	28	14	14	2	2	1	2	1
0.2169	96	13	18	1	2	1	3	3
0.2222	27	12	15	2	4	1	2	1
0.2392	362	14	17	1	1	1	1	3
0.2400	25	11	14	1	2	1	2	2
0.2406	235	14	18	1	2	1	1	2
0.2509	470	14	18	1	1	1	2	2
0.2714	44	9	14	1	2	2	2	3
0.2949	498	14	18	1	1	1	3	2
0.3042	182	13	18	1	3	1	3	2
0.3233	107	13	14	1	2	1	4	2
0.3247	562	14	18	1	1	1	1	2
0.3918	382	14	18	1	1	1	2	3

Table A-16

SQUARE ROOT OF AVERAGE ATTACK RATES FOR
TREATMENT COMBINATIONS OCCURRING IN KEARNS

<u>Square Root of Attack Rates</u>	<u>Number of Person-Days</u>	<u>Number of Males</u>	<u>Number of Females</u>	<u>SN</u>	<u>SS</u>	<u>SO₂</u>	<u>TSP</u>	<u>Min. Temp.</u>
0.0000	32	22	10	2	4	3	3	2
0.0000	23	15	8	1	4	2	2	3
0.0000	32	19	13	1	1	3	3	2
0.0000	60	25	12	1	1	1	2	2
0.0000	119	26	14	1	4	4	1	2
0.0000	68	25	14	1	1	2	4	2
0.0000	32	20	12	1	3	3	1	1
0.0000	31	20	11	1	4	3	2	1
0.0000	32	22	10	1	3	2	2	1
0.0000	28	18	10	3	4	1	1	2
0.0000	56	21	12	2	1	2	1	1
0.0000	26	17	9	1	2	1	2	2
0.0000	32	20	12	1	4	1	3	2
0.0000	34	21	13	1	3	4	1	2
0.0000	32	20	12	2	4	1	3	1
0.0000	30	22	8	1	4	1	3	1
0.0000	69	24	14	3	4	2	3	1
0.0289	105	26	14	3	4	4	3	1
0.0330	87	24	11	1	4	3	1	3
0.0393	56	24	12	1	4	4	2	2
0.0471	47	18	12	1	1	2	2	3
0.0526	38	24	14	3	4	3	3	1
0.0527	74	22	9	1	4	1	1	3
0.0556	36	22	14	2	4	2	2	1
0.0556	36	24	12	2	4	4	3	2
0.0571	35	23	12	3	4	3	3	2
0.0588	34	21	13	1	4	3	1	2
0.0588	34	23	11	1	4	1	1	1
0.0606	33	19	14	1	3	2	3	2
0.0625	32	20	12	2	4	3	1	1
0.0625	32	21	11	2	3	3	1	1
0.0645	31	20	11	1	4	2	3	1
0.0667	30	19	11	3	4	1	4	1
0.0667	30	18	12	1	2	2	2	2
0.0690	29	17	12	1	3	2	2	2
0.0714	28	16	12	1	3	1	3	2
0.0714	28	20	8	2	4	2	1	2
0.0724	202	26	14	1	4	2	1	2
0.0744	64	24	14	2	4	3	3	1
0.0769	26	16	10	1	4	2	3	3
0.0769	26	19	7	1	4	4	2	3
0.0786	64	23	13	1	3	1	2	2
0.0786	61	24	12	1	3	1	1	1
0.0794	233	25	12	1	2	2	1	3
0.0808	86	24	11	1	4	2	1	3
0.0833	24	15	9	2	4	1	1	2
0.0857	55	22	11	1	3	2	1	3
0.0901	89	23	12	1	1	2	3	3
0.0923	58	25	12	1	2	3	1	2
0.0948	64	24	12	1	2	1	3	2

Table A-16 (Cont.)

SQUARE ROOT OF AVERAGE ATTACK RATES FOR
TREATMENT COMBINATIONS OCCURRING IN KEARNS

<u>Square Root of Attack Rates</u>	<u>Number of Person-Days</u>	<u>Number of Males</u>	<u>Number of Females</u>	<u>SN</u>	<u>SS</u>	<u>S02</u>	<u>TSP</u>	<u>Min. Temp.</u>
0.1007	113	24	14	1	1	1	3	2
0.1026	66	25	14	1	1	2	1	1
0.1101	56	20	11	1	3	3	1	2
0.1111	36	23	13	1	2	4	1	1
0.1176	59	21	13	1	2	2	3	2
0.1248	94	24	13	2	4	4	3	1
0.1271	64	25	13	2	3	1	1	1
0.1329	142	26	12	1	3	1	1	3
0.1357	118	24	14	1	2	2	1	1
0.1379	29	17	12	2	4	4	2	1
0.1429	28	19	9	1	4	2	3	2
0.1431	135	26	14	1	1	2	3	2
0.1538	26	20	6	2	4	3	2	3
0.1547	128	23	14	1	3	2	1	1
0.1553	276	24	11	1	2	1	1	3
0.1600	25	16	9	2	4	4	4	1
0.1622	63	23	14	1	2	1	4	2
0.1681	125	26	14	1	4	1	1	2
0.1810	101	25	13	2	4	2	3	1
0.1818	33	21	12	1	4	3	1	1
0.1818	33	21	12	1	4	2	1	1
0.1834	342	26	14	1	1	1	2	3
0.1846	66	24	13	2	3	2	1	1
0.1855	189	26	14	1	2	2	1	2
0.1935	31	19	12	2	2	2	1	1
0.2000	30	18	12	1	4	4	3	1
0.2069	29	21	8	2	4	4	2	2
0.2080	477	26	14	1	1	1	1	1
0.2131	243	26	14	1	1	1	3	3
0.2169	231	26	14	1	3	1	1	2
0.2228	57	25	12	1	2	2	3	3
0.2353	34	24	10	2	4	4	1	2
0.2362	375	26	14	1	2	1	1	2
0.2387	402	25	14	1	2	1	1	1
0.2424	33	20	13	3	4	2	1	2
0.2500	32	22	10	1	2	2	2	3
0.2747	274	26	14	1	3	2	1	2
0.2816	330	26	13	1	1	2	1	2
0.2857	21	11	10	1	1	2	1	3
0.3149	1414	26	14	1	1	1	1	3
0.3161	1714	26	14	1	1	1	1	2

Table A-17

SQUARE ROOT OF AVERAGE ATTACK RATES FOR
TREATMENT COMBINATIONS OCCURRING IN MAGNA

<u>Square Root of Attack Rates</u>	<u>Number of Person-Days</u>	<u>Number of Males</u>	<u>Number of Females</u>	<u>SN</u>	<u>SS</u>	<u>SO2</u>	<u>TSP</u>	<u>Min. Temp.</u>
0.0000	22	11	11	2	4	3	3	2
0.0000	22	13	9	1	1	1	3	3
0.0000	25	15	10	1	1	2	1	1
0.0000	23	12	11	1	1	4	1	2
0.0000	23	12	11	1	3	1	1	2
0.0000	21	13	8	1	1	1	2	3
0.0000	23	15	8	1	4	1	2	2
0.0000	21	9	12	2	4	3	2	2
0.0000	21	12	9	1	4	3	2	3
0.0000	23	12	11	2	4	4	1	2
0.0000	45	15	11	1	3	3	3	2
0.0000	39	14	11	1	4	2	1	3
0.0000	67	15	11	2	4	4	3	1
0.0000	21	13	8	3	4	1	4	1
0.0000	26	15	11	1	4	3	3	2
0.0000	25	13	12	1	4	3	4	1
0.0000	20	11	9	1	3	3	1	1
0.0000	17	10	7	1	2	1	3	3
0.0000	27	17	10	3	4	1	2	1
0.0000	19	11	8	1	3	2	3	3
0.0000	18	9	9	1	2	4	1	1
0.0345	111	17	12	3	4	4	4	1
0.0412	77	17	11	1	3	4	2	2
0.0462	60	15	10	1	2	2	3	3
0.0505	51	17	11	1	3	2	1	1
0.0505	105	17	11	1	4	4	2	1
0.0566	42	15	10	1	4	1	1	2
0.0714	47	16	12	1	4	4	4	2
0.0714	81	17	11	1	1	2	1	3
0.0741	27	16	11	2	2	1	2	1
0.0741	45	16	11	1	1	2	2	2
0.0741	43	16	11	1	3	4	3	2
0.0796	122	17	12	1	1	1	3	2
0.0800	38	15	10	1	1	1	2	2
0.0800	25	15	10	1	4	2	2	1
0.0800	39	13	12	1	2	4	1	2
0.0833	24	14	10	2	4	2	2	2
0.0833	24	13	11	1	2	2	3	1
0.0833	24	14	10	1	4	1	3	2
0.0870	23	14	9	1	2	2	3	2
0.0870	23	12	11	2	4	4	4	2
0.0909	22	14	8	1	2	2	2	1
0.0909	22	11	11	1	4	4	1	3
0.0917	89	16	12	1	4	4	1	1
0.0917	75	16	12	1	4	3	1	1
0.0917	71	16	12	1	4	2	1	1
0.0924	62	15	10	1	3	2	3	2
0.0952	21	14	7	1	2	3	1	1
0.0952	21	12	9	2	1	4	3	1
0.0952	21	11	10	2	4	1	3	1
0.0962	62	15	9	1	1	2	3	3

Table A-17 (Cont.)

SQUARE ROOT OF AVERAGE ATTACK RATES FOR
TREATMENT COMBINATIONS OCCURRING IN MAGNA

<u>Square Root of Attack Rates</u>	<u>Person-Days</u>	<u>Number of Males</u>	<u>Number of Females</u>	<u>SN</u>	<u>SS</u>	<u>S02</u>	<u>TSP</u>	<u>Min. Temp.</u>
0.1000	20	10	10	1	2	2	2	3
0.1048	49	15	12	2	4	2	3	1
0.1048	52	15	12	1	4	2	4	2
0.1053	19	12	7	1	3	3	4	2
0.1131	44	15	10	1	3	2	1	3
0.1219	55	16	12	1	4	3	3	1
0.1231	148	16	11	1	4	2	2	3
0.1265	45	15	12	1	3	1	2	3
0.1313	51	15	11	3	4	4	3	1
0.1433	91	17	12	2	4	4	4	1
0.1484	85	17	11	1	4	2	1	2
0.1489	65	14	11	1	4	2	2	2
0.1538	43	15	11	1	3	4	1	2
0.1539	66	17	11	2	4	4	3	2
0.1571	47	16	11	1	4	1	4	2
0.1661	133	17	12	1	4	4	2	2
0.1667	24	13	11	2	4	2	4	1
0.1667	24	15	9	1	3	1	1	1
0.1692	79	15	12	1	3	1	1	3
0.1695	204	17	12	1	2	2	1	2
0.1739	23	14	9	1	4	2	3	2
0.1739	23	13	10	1	3	2	2	1
0.1739	23	13	10	1	4	1	3	3
0.1807	62	15	12	1	2	2	1	3
0.1859	126	16	12	1	4	2	3	3
0.1903	69	16	11	1	1	1	1	1
0.1905	21	13	8	1	3	2	2	3
0.1920	111	17	12	1	1	2	1	2
0.1931	40	14	11	1	4	1	2	3
0.1951	74	16	12	1	3	3	1	2
0.2000	20	12	8	1	2	3	2	2
0.2082	40	15	11	1	1	2	2	3
0.2105	19	11	8	1	3	1	3	3
0.2128	360	17	12	1	4	4	3	1
0.2249	127	17	12	1	2	2	1	1
0.2308	26	15	11	1	3	4	2	1
0.2351	148	16	12	1	4	1	1	3
0.2378	185	17	12	1	2	1	1	3
0.2382	391	17	12	1	1	1	1	2
0.2402	843	17	12	1	1	1	1	3
0.2626	42	15	11	1	3	3	2	3
0.2680	119	17	12	1	3	2	1	2
0.2687	543	17	12	1	4	4	3	2
0.2720	69	16	12	1	4	4	3	3
0.2727	22	13	9	1	2	3	1	2
0.2727	22	11	11	2	4	4	2	2
0.2758	75	16	12	1	4	3	1	3
0.2857	14	8	6	1	1	2	3	2
0.2901	88	17	12	1	4	3	3	3
0.2967	134	17	12	1	4	3	1	2
0.3054	67	16	12	1	4	4	2	3
0.3313	422	17	12	1	4	4	1	2
0.3442	160	17	12	1	2	1	1	2

Table A-18

SUMMARY OF MULTIPLE REGRESSION ANALYSES OF OBSERVED DAILY ASTHMA ATTACK
RATES FOR OGDEN PANEL (156 PANELISTS). UTAH 1971-72 ASTHMA STUDY

Regression Parameters and Indicators	Scenario											
	1	2	3	4	5	6	7	8	9	10	11	12
Regression Summary Measures												
Days of Observation	327	327	327	386	386	387	382	375	327	327	327	327
R ² (%)	21	24	16	15	14	14	14	14	16	20	16	20
Residual Std. Dev.	0.057	0.056	0.058	0.057	0.057	0.057	0.057	0.059	0.058	0.057	0.058	0.057
Statistical Significant β -weights and Associated β -weight Signs*												
<u>Experimental Design</u>												
Day of Study	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
Day of Week Var 2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Day of Week Var 3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Day of Week Var 4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Day of Week Var 5	NS	NS	NS	<0.10+	NS	NS	NS	NS	NS	NS	NS	NS
Day of Week Var 6	<0.01+	<0.01+	<0.05+	<0.05+	<0.05+	<0.05+	<0.01+	<0.01+	<0.05+	<0.05+	<0.05+	<0.05+
Day of Week Var 7	<0.05+	<0.05+	<0.05+	<0.05+	<0.05+	<0.05+	<0.01+	<0.01+	<0.05+	<0.05+	<0.05+	<0.05+
Base Rate Total	NS		<0.01+	<0.001+	<0.001+	<0.001+	<0.01+	<0.01+	<0.01+		<0.01+	
Base Rate Quarterly		<0.001+								<0.001+		<0.001+
Age	NS	NS										
Adult/Juvenile	NS	NS										
Male/Female	<0.10+	NS										
Smoking	<0.01-	<0.05-										
Education	NS	NS										
<u>Aerometry</u>												
TSP	NS	NS	NS	NS					NS	NS	NS	NS
SN	NS	NS	NS		NS				NS	NS	NS	NS
SS	NS	NS	NS			NS			NS	NS	NS	NS
SO ₂	NS	NS	NS				NS		NS	NS	NS	NS
NO ₂	NS	NS	NS					NS	NS	NS	NS	NS
Max. Temp.	NS	NS										
Min. Temp.	NS	NS	<0.001-	<0.001-	<0.001-	<0.001-	<0.01-	<0.001-	<0.01-	<0.05-	<0.01-	<0.05-
Relative Humidity	NS	NS							NS	NS	NS	NS
Min. Temp. Lag	NS	NS										

*Blank indicates variable not included in regression. Significance is indicated at 0.10, 0.05, 0.01, 0.001 and NS, not significant. Significance based on individual t-value in full multiple regression equation.

Table A-19

SUMMARY OF MULTIPLE REGRESSION ANALYSES OF OBSERVED DAILY ASTHMA ATTACK
RATES FOR SALT LAKE CITY PANEL (156 PANELISTS). UTAH 1971-72 ASTHMA STUDY

Regression Parameters and Indicators	Scenario											
	1	2	3	4	5	6	7	8	9	10	11	12
Regression Summary Measures												
Days of Observation	307	307	308	403	403	404	340	358	308	308	308	308
R ² (%)	22	31	10	8	8	7	9	8	11	23	10	21
Residual Std. Dev.	0.052	0.049	0.054	0.055	0.055	0.056	0.055	0.056	0.054	0.051	0.054	0.051
Statistically Significant β -weights and Associated β -weight Signs*												
<u>Experimental Design</u>												
Day of Study	<0.05+	NS	NS	<0.05+	NS	<0.10+	NS	<0.10+	NS	<0.05-		
Day of Week Var 2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Day of Week Var 3	NS	NS	NS	<0.10+	NS	NS	NS	<0.10+	NS	NS	NS	NS
Day of Week Var 4	<0.01+	<0.01+	<0.01+	<0.05+	<0.05+	<0.05+	<0.01+	<0.05+	<0.01+	<0.01+	<0.05+	<0.01+
Day of Week Var 5	<0.10+	<0.05+	NS	<0.05+	<0.10+	<0.10+	<0.10+	<0.10+	NS	<0.10+	NS	<0.10+
Day of Week Var 6	<0.05+	<0.01+	<0.05+	<0.05+	<0.05+	<0.05+	<0.05+	<0.05+	<0.05+	<0.05+	<0.05+	<0.05+
Day of Week Var 7	<0.01+	<0.01+	<0.01+	<0.01+	<0.05+	<0.01+	<0.01+	<0.01+	<0.01+	<0.01+	<0.01+	<0.01+
Base Rate Total	NS		NS	NS	NS	NS	NS	NS	NS		<0.10+	
Base Rate Quarterly		<0.001+								<0.001+		<0.001+
Age	<0.05-	<0.05-										
Adult/Juvenile	<0.10+	NS										
Male/Female	NS	NS										
Smoking	<0.05-	<0.05-										
Education	<0.001+	<0.001+										
<u>Aerometry</u>												
TSP	<0.10-	<0.10-	NS	<0.10-					NS	NS	NS	NS
SN	NS	NS	<0.10-		<0.05-				<0.10-	NS	<0.05-	NS
SS	NS	NS	<0.05+			NS			NS	NS	<0.10+	NS
SO ₂	NS	NS	NS				NS		NS	NS	NS	NS
NO ₂	NS	NS	NS					NS	NS	NS	NS	NS
Max. Temp.	NS	NS										
Min. Temp.	NS	NS	NS	<0.05-	<0.05-	NS	<0.05-	NS	NS	NS	NS	NS
Relative Humidity	NS	<0.10+							<0.10+	<0.001+	NS	<0.01+
Min. Temp. Lag	NS	NS										

*Blank indicates variable not included in regression. Significance is indicated at 0.10, 0.05, 0.01, 0.001 and NS, not significant. Significance based on individual t-value in full multiple regression equation.

Table A-20

SUMMARY OF MULTIPLE REGRESSION ANALYSES OF OBSERVED DAILY ASTHMA ATTACK
RATES FOR KEARNS (156 PANELISTS). UTAH 1971-72 ASTHMA STUDY

Regression Parameters and Indicators	Scenario											
	1	2	3	4	5	6	7	8	9	10	11	12
Regression Summary Measures												
Days of Observation	325	325	327	396	397	396	331	353	327	327	327	327
R ² (%)	26	27	18	22	22	23	19	17	18	24	18	22
Residual Std. Dev.	0.042	0.042	0.043	0.044	0.044	0.044	0.044	0.043	0.044	0.042	0.044	0.042
Statistically Significant β -weights and Associated β -weight Signs*												
<u>Experimental Design</u>												
Day of Study	NS	NS	<0.10-	NS	NS	NS	NS	NS	<0.10-	<0.05-		
Day of Week Var 2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Day of Week Var 3	<0.01+	<0.01+	<0.05+	<0.01+	<0.01+	<0.01+	<0.01+	<0.01+	<0.05+	<0.01+	<0.05+	<0.01+
Day of Week Var 4	<0.05+	<0.05+	<0.10+	<0.05+	<0.05+	<0.05+	<0.10+	<0.10+	<0.10+	<0.05+	<0.10+	<0.10+
Day of Week Var 5	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+
Day of Week Var 6	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+
Day of Week Var 7	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+
Base Rate Total	<0.001+		<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+		<0.001+	
Base Rate Quarterly		<0.001+								<0.001+		<0.001+
Age	NS	NS										
Adult/Juvenile	<0.10+	NS										
Male/Female	NS	NS										
Smoking	NS	NS										
Education	<0.01-	NS										
<u>Aerometry</u>												
TSP	NS	NS	NS	NS					NS	NS	NS	NS
SN	NS	NS	NS		NS				NS	NS	NS	NS
SS	NS	NS	NS			NS			NS	NS	NS	NS
SO ₂	NS	NS	NS				NS		NS	NS	NS	NS
NO ₂	NS	NS	NS					NS	NS	NS	NS	NS
Max. Temp.	NS	NS										
Min. Temp.	NS	NS	NS	<0.001+	<0.01+	<0.01+	<0.01+	NS	NS	NS	NS	NS
Relative Humidity	NS	NS							NS	NS	NS	NS
Min. Temp. Lag	NS	NS										

*Blank indicates variable not included in regression. Significance is indicated at 0.10, 0.05, 0.01, 0.001 and NS, not significant. Significance based on individual t-value in full multiple regression equation.

Table A-21

SUMMARY OF MULTIPLE REGRESSION ANALYSES OF OBSERVED DAILY ASTHMA ATTACK
RATES OF MAGNA PANEL (156 PANELISTS). UTAH 1971-72 ASTHMA STUDY

Regression Parameters and Indicators	Scenario											
	1	2	3	4	5	6	7	8	9	10	11	12
Regression Summary Measures												
Days of Observation	323	323	325	397	400	401	365	362	325	325	325	325
R ² (%)	30	35	20	13	15	15	16	15	22	27	20	26
Residual Std. Dev.	0.052	0.050	0.055	0.055	0.055	0.055	0.055	0.056	0.054	0.053	0.055	0.053
Statistically Significant β -weights and Associated β -weight Signs*												
<u>Experimental Design</u>												
Day of Study	NS	<0.05-	<0.01+	<0.01+	<0.01+	<0.01+	<0.01+	<0.01+	<0.01+	NS		
Day of Week Var 2	NS	NS	NS	NS	<0.10+	<0.10+	<0.10+	NS	NS	NS	NS	NS
Day of Week Var 3	<0.10+	<0.10+	<0.10+	<0.10+	<0.10+	<0.10+	NS	NS	<0.10+	<0.10+	<0.10+	<0.10+
Day of Week Var 4	<0.10+	<0.10+	NS	<0.10+	<0.05+	<0.05+	<0.05+	<0.10+	<0.10+	<0.10+	<0.05+	<0.10+
Day of Week Var 5	<0.05+	<0.05+	<0.05+	<0.01+	<0.01+	<0.01+	<0.05+	<0.05+	<0.05+	<0.05+	<0.05+	<0.05+
Day of Week Var 6	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+
Day of Week Var 7	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+	<0.001+
Base Rate Total	<0.05+		<0.10+	NS	<0.10+	NS	<0.05+	<0.10+	<0.10+		<0.01+	
Base Rate Quarterly		<0.001+								<0.001+		<0.001+
Age	NS	NS										
Adult/Juvenile	<0.05+	NS										
Male/Female	NS	NS										
Smoking	<0.001-	<0.001-										
Education	<0.10+	<0.001-										
<u>Aerometry</u>												
TSP	NS	NS	NS	NS					NS	NS	NS	NS
SN	<0.05-	<0.05-	<0.01-		<0.05-				<0.01-	<0.05-	<0.01-	<0.05-
SS	<0.10+	NS	<0.05+			<0.05+			NS	NS	NS	NS
SO ₂	NS	NS	NS				<0.05+		NS	NS	NS	NS
NO ₂	<0.05+	NS	NS					<0.10+	NS	NS	NS	NS
Max. Temp.	NS	NS										
Min. Temp.	NS	NS	NS	<0.01-	<0.001-	<0.10-	NS	NS	NS	NS	NS	NS
Relative Humidity	<0.05+	NS							<0.05+	<0.05+	<0.05+	<0.05+
Min. Temp. Lag	NS	NS										

*Blank indicates variable not included in regression. Significance is indicated at 0.10, 0.05, 0.01, 0.001, and NS, not significant. Significance based on individual t-value in full multiple regression equation.

Table A-22

SCENARIO 3 MULTIPLE REGRESSION OF OBSERVED DAILY ATTACK RATES FOR SELECTED
SUBSETS OF PARTICIPATING PANELISTS IN EACH COMMUNITY. UTAH 1971-72 ASTHMA STUDY

Community Panel Subset	N	Percent R ²	Res. Std. Dev.	Day of Study	2	3	4	5	6	7	B(T)	Min. Temp.	TSP	SN	SS	SO ₂	NO ₂
Ogden																	
All Panelists	327	16	.058	NS*	NS	NS	NS	NS	<.05+	<.05+	<.01+	<.001-	NS	NS	NS	NS	NS
All: Home Neighborhood	327	30	.053	NS	NS	NS	NS	NS	NS	<.10+	<.001+	<.001-	NS	NS	<.10-	NS	NS
All Adults	327	16	.080	NS	NS	NS	NS	NS	NS	NS	<.05+	<.01-	NS	NS	NS	<.05+	NS
All Juveniles	327	9	.073	NS	NS	NS	NS	NS	<.05+	<.10+	<.01+	<.01-	NS	NS	NS	NS	NS
No Fumes on Job	327	22	.056	<.05-	NS	NS	NS	NS	<.10+	<.05+	<.01+	<.001-	NS	NS	NS	NS	NS
No Hay Fever	327	33	.087	<.01+	NS	NS	NS	NS	NS	NS	<.001+	<.001-	NS	NS	NS	NS	NS
Original Panelists	327	15	.060	NS	NS	NS	NS	<.10+	<.01+	<.01+	<.001+	<.05-	NS	NS	NS	NS	NS
Salt Lake City																	
All Panelists	308	10	.054	NS	NS	NS	<.01+	NS	<.05+	<.01+	NS	NS	NS	<.10-	<.05+	NS	NS
All: Home Neighborhood	308	12	.052	NS	NS	NS	<.01+	NS	NS	NS	<.10+	NS	NS	<.05-	<.05+	NS	NS
All Adults	308	9	.071	NS	NS	NS	<.10+	NS	NS	NS	<.001+	NS	NS	NS	NS	NS	NS
All Juveniles	308	12	.077	NS	NS	<.10+	<.05+	<.10+	<.10+	<.01+	<.10+	NS	<.10-	<.10-	<.10+	NS	NS
No Fumes on Job	308	15	.058	<.10+	NS	NS	<.01+	NS	<.10+	<.01+	<.05+	NS	NS	NS	NS	NS	NS
No Hay Fever	308	9	.069	<.05+	NS	NS	<.05+	NS	NS	<.05+	NS	<.10-	NS	NS	NS	NS	NS
Original Panelists	308	12	.063	NS	NS	NS	<.01+	NS	<.05+	<.01+	NS	NS	NS	<.01-	<.05+	NS	NS
Kearns																	
All Panelists	327	18	.043	<.10-	NS	<.05+	<.10+	<.001+	<.001+	<.001+	<.001+	NS	NS	NS	NS	NS	NS
All: Home Neighborhood	327	31	.042	<.10-	NS	<.01+	NS	<.001+	<.001+	<.001+	<.001+	NS	NS	NS	NS	NS	NS
All Adults	327	15	.083	<.05-	NS	NS	NS	<.001+	<.001+	<.01+	<.05+	NS	NS	NS	NS	NS	NS
All Juveniles	327	14	.046	NS	NS	<.01+	<.05+	<.001+	<.05+	<.05+	<.01+	NS	NS	NS	NS	NS	NS
No Fumes on Job	327	21	.046	NS	NS	<.01+	<.10+	<.001+	<.001+	<.001+	<.001+	NS	NS	NS	NS	NS	NS
No Hay Fever	327	26	.084	<.01-	NS	<.05+	<.10+	<.001+	<.001+	<.001+	<.001+	<.05-	NS	NS	NS	NS	NS
Original Panelists	327	16	.046	NS	NS	<.05+	<.10+	<.001+	<.001+	<.01+	<.01+	NS	NS	NS	NS	NS	NS
Magna																	
All Panelists	325	20	.055	<.01+	NS	<.10+	NS	<.05+	<.001+	<.001+	<.10+	NS	NS	<.01-	<.05+	NS	NS
All: Home Neighborhood	325	27	.056	NS	NS	NS	NS	NS	<.10+	<.01+	<.001+	<.01-	NS	NS	NS	NS	<.05-
All Adults	325	23	.081	<.10+	NS	NS	<.05+	<.10+	<.001+	<.01+	<.01+	<.01-	NS	<.01-	NS	NS	NS
All Juveniles	325	20	.063	<.05+	NS	NS	NS	<.10+	<.05+	<.05+	<.001+	<.05+	<.05-	NS	NS	NS	NS
No Fumes on Job	325	17	.054	NS	NS	NS	NS	NS	<.05+	<.01+	<.001+	NS	NS	<.10-	NS	NS	NS
No Hay Fever	325	12	.072	<.001-	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	<.10+	NS	NS
Original Panelists	325	14	.057	<.05+	NS	NS	NS	NS	<.01+	<.001+	<.10+	NS	NS	<.05-	NS	NS	NS

*Significance is indicated at 0.10, 0.05, 0.01, 0.001 and NS, not significant. Significance based on individual t-value in multiple regression equations. Signs indicate direction of association, i.e., sign of regression coefficient.

Table A-23

TEMPERATURE-SPECIFIC RELATIVE RISKS BASED ON ODDS RATIO FOR
INDIVIDUAL POLLUTANTS AND COMMUNITIES: UTAH 1971-72 ASTHMA STUDY

Pollutant	Temperature Range	Pollutant Concentration $\mu\text{g}/\text{m}^3$	Ogden		Salt Lake City		Kearns		Magna	
			Odds Ratio (O_i)	s.e. (O_i)	Odds Ratio (O_i)	s.e. (O_i)	Odds Ratio (O_i)	s.e. (O_i)	Odds Ratio (O_i)	s.e. (O_i)
TSP	$\leq 30^\circ\text{F}$	≤ 60	1.000	-	1.000	-	1.000	-	1.000	-
		60-75	0.923	0.126	0.939	0.202	0.888	0.187	1.090	0.149
		75-260	0.961	0.097	0.949	0.154	0.888	0.094	0.956	0.096
		>260	0.697	0.341	0.663	0.207	-	-	1.156	0.293
	30-50°F	≤ 60	1.000	-	1.000	-	1.000	-	1.000	-
		60-75	1.075	0.159	0.840	0.103	0.909	0.121	1.000	0.109
		75-260	1.121	0.092	1.046	0.099	1.070	0.103	1.006	0.074
		>260	0.912	0.254	0.937	0.324	-	-	0.913	0.308
	>50°F	≤ 60	1.000	-	1.000	-	1.000	-	1.000	-
		60-75	0.951	0.127	1.215	0.214	1.305	0.142	1.408	0.152
		75-260	1.169	0.143	1.000	0.181	1.278	0.160	1.210	0.143
		>260	-	-	-	-	-	-	-	-
SS	$\leq 30^\circ\text{F}$	≤ 6	1.000	-	1.000	-	1.000	-	1.000	-
		6-8	1.000	0.116	1.073	0.197	1.121	0.149	1.044	0.198
		8-10	0.914	0.125	1.073	0.219	0.991	0.152	1.089	0.225
		>10	0.980	0.106	0.837	0.132	1.000	0.116	0.951	0.147
	30-50°F	≤ 6	1.000	-	1.000	-	1.000	-	1.000	-
		6-8	0.986	0.104	1.195	0.120	0.962	0.088	1.248	0.149
		8-10	1.138	0.195	1.355	0.182	1.031	0.100	1.076	0.125
		>10	0.972	0.173	1.291	0.146	0.939	0.089	1.160	0.103
	>50°F	≤ 6	1.000	-	1.000	-	1.000	-	1.000	-
		6-8	0.891	0.125	1.123	0.198	0.841	0.090	1.439	0.191
		8-10	1.272	0.396	1.221	0.419	0.870	0.160	1.715	0.247
		>10	1.138	0.286	1.055	0.319	0.779	0.133	1.652	0.169
SO ₂	$\leq 30^\circ\text{F}$	≤ 60	1.000	-	1.000	-	1.000	-	1.000	-
		60-80	-	-	1.108	0.379	0.853	0.134	0.884	0.155
		80-365	-	-	0.772	0.257	1.102	0.154	1.000	0.101
		>365	-	-	-	-	-	-	0.932	0.254
	30-50°F	≤ 60	1.000	-	1.000	-	1.000	-	1.000	-
		60-80	-	-	0.478	0.349	1.159	0.168	0.914	0.106
		80-365	-	-	1.794	0.826	0.961	0.147	1.000	0.075
		>365	-	-	-	-	-	-	0.987	0.322
	>50°F	≤ 60	1.000	-	1.000	-	1.000	-	1.000	-
		60-80	-	-	-	-	0.666	0.250	1.486	0.249
		80-365	-	-	-	-	1.352	0.571	1.451	0.290
		>365	-	-	-	-	-	-	-	-
SN	$\leq 30^\circ\text{F}$	≤ 2	1.000	-	1.000	-	1.000	-	1.000	-
		2-4	0.940	0.116	1.020	0.167	1.094	0.141	0.951	0.108
		4-6	0.921	0.144	0.759	0.164	1.059	0.181	0.910	0.147
		6-8	1.131	0.220	0.825	0.199	0.892	0.198	-	-
		>8	1.000	0.110	0.759	0.124	0.967	0.111	0.904	0.105
	30-50°F	≤ 2	1.000	-	1.000	-	1.000	-	1.000	-
		2-4	1.036	0.098	1.094	0.096	0.954	0.093	1.097	0.119
		4-6	0.922	0.139	0.872	0.160	0.924	0.166	1.064	0.238
		6-8	0.950	0.466	0.863	0.221	1.264	0.343	0.758	0.263
		>8	1.332	0.333	0.863	0.201	1.046	0.258	0.987	0.223
	>50°F	≤ 2	1.000	-	1.000	-	1.000	-	1.000	-
		2-4	0.869	0.087	0.764	0.127	0.780	0.064	0.827	0.089
		4-6	0.519	0.145	0.943	0.191	0.753	0.258	0.581	0.356
		6-8	-	-	-	-	-	-	-	-
		>8	-	-	-	-	-	-	-	-
NO ₂	$\leq 30^\circ\text{F}$	≤ 50	1.000	-	1.000	-	1.000	-	1.000	-
		50-100	1.000	0.091	1.011	0.147	0.967	0.127	0.962	0.117
		>100	1.134	0.186	1.043	0.179	1.172	0.258	1.157	0.225
	30-50°F	≤ 50	1.000	-	1.000	-	1.000	-	1.000	-
		50-100	0.965	0.086	1.201	0.115	0.063	0.226	0.071	0.272
		>100	0.647	0.201	1.114	0.306	-	-	-	-
	>50°F	≤ 50	1.000	-	1.000	-	1.000	-	1.000	-
		50-100	0.960	0.146	0.909	0.206	-	-	1.574	0.054
		>100	1.791	0.780	-	-	-	-	-	-

Table A-24

AVERAGE LEVELS OF SELECTED POLLUTION, TEMPERATURE AND DESIGN VARIABLES FOR
STATISTICALLY SIGNIFICANT TEMPERATURE-SPECIFIC SCENARIOS: UTAH 1971-72 ASTHMA STUDY

Scenario	Pollutant Categories	Attack Day	Observation Days	Pollutant Concentration ($\mu\text{g}/\text{m}^3$)					Max. Temp.	Min. Temp.	Relative Humidity	Adult/Juvenile Ratio	Male/Female Ratio	O/B(T)	O/B(Q)
				TSP	SN	SS	SO ₂	NO ₂							
Magna	<60	0.152	78	45.4	1.6	6.1	13.0	10.6	88.1	59.4	35.6	1.26	1.00	0.828	0.886
	Min. Temp. >50°F	0.199	25	66.4	1.7	13.2	43.0	24.9	86.3	59.9	35.3	1.21	1.05	1.072	1.072
	TSP	0.177	22	94.8	1.4	13.0	46.0	19.6	82.3	57.9	35.2	1.15	1.06	0.989	0.968
Magna	<6	0.132	58	50.6	1.5	4.3	8.7	9.6	87.0	59.1	34.1	1.23	0.99	0.728	0.783
	Min. Temp. >50°F	0.177	19	57.4	1.3	7.0	24.8	11.8	83.8	59.9	34.6	1.22	1.00	1.008	1.015
	SS	0.205	13	64.5	1.8	9.0	30.2	17.4	84.8	58.4	38.7	1.20	1.04	1.103	1.128
	>10	0.199	37	68.1	1.7	16.4	44.1	24.1	88.0	59.4	37.6	1.23	1.06	1.059	1.068
Magna	<60	0.160	102	55.3	1.5	7.5	17.3	13.3	86.8	59.5	35.8	1.24	1.01	0.862	0.894
	Min. Temp. >50°F	0.219	7	75.1	1.6	19.7	68.4	30.1	81.6	56.3	41.8	1.19	1.06	1.212	1.239
	SO ₂	0.214	5	72.4	1.8	20.1	100.9	16.0	89.6	57.6	36.7	1.24	1.02	1.156	1.215
Kearns	<60	0.145	96	43.8	2.1	5.8	10.7	18.2	87.6	59.4	36.9	0.57	1.31	1.024	1.013
	Min. Temp. >50°F	0.179	19	66.9	1.8	5.5	16.4	16.8	82.2	58.2	34.9	0.62	1.14	1.169	1.079
	TSP	0.171	15	92.3	1.5	5.6	14.3	18.9	80.5	58.1	33.7	0.62	1.14	1.132	1.096
Salt Lake City	<6	0.111	100	75.6	1.8	4.2	11.3	35.2	67.8	41.1	45.3	0.84	1.07	1.046	1.033
	Min. Temp. 0-50°F	0.133	49	94.7	2.6	7.0	14.6	44.9	62.1	39.5	55.5	0.84	1.04	1.211	1.132
	SS	0.147	20	112.6	2.7	8.9	13.7	44.5	61.7	38.5	51.6	0.88	0.98	1.318	1.198
	>10	0.141	32	122.4	7.3	17.4	27.7	56.0	61.7	38.1	56.0	0.83	1.02	1.361	1.311

Table A-25

SIMPLE CORRELATION COEFFICIENTS BETWEEN STUDY VARIABLES BASED ON
DAILY OBSERVATIONS INCLUDED IN STATISTICALLY SIGNIFICANT
TEMPERATURE-SPECIFIC SCENARIOS: UTAH 1971-72 ASTHMA STUDY

TSP	SN	SS	SO ₂	NO ₂	Day of Study	B(T)	B(Q)	Age	Smoking	Educa- tion	Adult/ Juvenile	Male/ Female	Max. Temp.	Min. Temp.	Relative Humidity	Attack Rate	O/B(T)	O/B(Q)	
Magna: Min. Temp. >50°F																			
1.00	-0.05	0.44	0.49	0.36	0.28	-0.15	0.21	-0.28	-0.59	0.03	-0.42	0.18	-0.29	-0.14	-0.06	0.26	0.29	0.21	TSP
	1.00	0.14	-0.05	-0.02	-0.63	0.01	-0.26	0.14	0.33	-0.27	0.19	0.45	0.58	0.19	-0.14	-0.23	-0.25	-0.16	SN
		1.00	0.63	0.64	-0.12	0.10	0.34	-0.04	-0.01	-0.06	-0.01	0.23	0.03	0.03	0.21	0.38	0.34	0.29	SS
			1.00	0.47	0.20	-0.22	0.11	-0.18	-0.30	0.17	-0.17	0.07	-0.31	-0.25	0.11	0.41	0.46	0.44	SO ₂
				1.00	0.16	0.16	0.52	-0.09	-0.16	-0.17	-0.03	0.13	-0.11	0.12	0.10	0.41	0.37	0.25	NO ₂
Kearns: Min. Temp. >50°F																			
1.00	-0.14	0.02	0.21	0.03	0.45	0.18	0.29	0.44	-0.07	-0.09	0.37	-0.39	-0.26	-0.10	-0.17	0.22	0.18	0.11	TSP
	1.00	0.27	0.13	0.12	-0.64	-0.30	-0.27	-0.46	0.12	0.02	-0.24	0.46	0.55	0.17	-0.11	-0.32	-0.25	-0.24	SN
		1.00	0.57	0.48	-0.19	-0.08	-0.25	-0.27	-0.22	0.14	-0.19	0.08	0.11	0.06	0.17	-0.12	-0.10	-0.01	SS
			1.00	0.31	-0.01	-0.03	-0.13	0.02	-0.14	-0.09	0.10	-0.17	-0.07	-0.04	-0.01	-0.04	-0.02	-0.02	SO ₂
				1.00	0.09	0.07	-0.14	-0.09	-0.28	0.18	-0.15	-0.08	-0.03	0.21	0.09	-0.19	-0.23	-0.15	NO ₂
Salt Lake City: Min. Temp. 30-50°F																			
1.00	0.54	0.43	0.39	0.53	0.37	0.31	0.26	0.35	-0.03	0.17	0.30	-0.01	-0.12	-0.22	-0.05	0.05	-0.02	-0.09	TSP
	1.00	0.73	0.62	0.56	-0.02	0.03	-0.13	-0.04	-0.04	-0.07	-0.03	-0.08	-0.16	-0.18	0.15	-0.06	-0.07	0.01	SN
		1.00	0.44	0.37	0.12	0.03	0.04	0.02	-0.05	0.01	-0.01	-0.02	-0.25	-0.24	0.23	0.16	0.16	0.12	SS
			1.00	0.50	-0.04	-0.05	-0.15	0.02	0.11	-0.06	0.08	-0.16	-0.07	-0.14	0.11	-0.08	-0.07	0.01	SO ₂
				1.00	0.27	0.17	0.10	0.24	-0.05	0.06	0.20	-0.14	-0.12	-0.31	0.08	0.03	-0.02	-0.03	NO ₂

Section 1

SUMMARY AND BACKGROUND OF STUDY

The objectives of the project "Evaluation of Statistical Methods and Databases for Utah 1971-72 Asthma (CHESS) Study" were to review and evaluate relevant air pollution literature, to acquire the original 1971-72 Utah asthma data, to assess the quality of the data and its impact on the study results and to apply selected statistical methodologies to the data. The Utah 1971-72 asthma study refers to data collected by the Environmental Protection Agency (EPA) from March 7, 1971 to June 17, 1972 in four Salt Lake Basin communities. These data were part of EPA's Community Health and Environmental Surveillance System (CHESS) program to identify associations between air pollutants and the aggravation of asthma symptoms among subjects with pre-existing asthma. The Utah study design was conceived as monitoring asthmatic panels in four communities using a daily mailed diary format accompanied by daily aerometric measurements and a preliminary baseline health questionnaire.

A review of air pollution literature directly related to asthma panel studies was completed. Emphasis was given to other EPA CHESS asthma studies, including original analyses and subsequent reanalysis. Asthma panel studies conducted prior to the series of CHESS studies were reviewed to place the Utah 1971-72 study design in historical perspective. A brief review of the clinical and biological characteristics of asthma and factors that can trigger asthma attacks was undertaken to provide background information useful in evaluating the results of the Utah 1971-72 asthma study.

After acquiring the original data, the data quality and its impact on study results was assessed. This was accomplished by identifying the field procedures used to collect the data and the procedures used to incorporate the data into a data base, by reviewing relevant literature concerning these procedures and by statistically investigating characteristics of the data itself.

Four separate statistical methodological approaches were applied to the Utah 1971-72 asthma data. Previous asthma panel studies relied extensively on multiple regression of daily panel attack rates and on temperature specific relative risk analyses. These person-day based analyses were applied to the Utah data and methodological limitations were identified. An approach using a multiple logistic regression for

each panelist's attack data was applied and the methodological approach was evaluated. A new approach to the analysis of asthma panel studies was devised which took into account some of the problems identified with prior analyses and also the quality of the data. The latter approach requires further testing and refinement before its results can be considered definitive. The ensemble of approaches does, however, allow some conclusions to be drawn from the data set.

adst. This report is divided into five main sections. The first reviews the use of asthma as a health indicator in environmental epidemiology, including a review of selected asthma panel studies. The next two sections consider the impact of the data quality: the limitations and characteristics of the aerometric data and of the panelists' data, respectively. The last two sections contain statistical analyses: analyses correcting for variation among panelists and analyses based on person-days.

1.1 BACKGROUND OF STUDY

The Utah 1971-72 asthma study was conducted in four Salt Lake Basin communities. The four communities are located immediately west of the Rocky Mountain Wasatch Range. The study areas were sections of Ogden, Salt Lake City, Kearns and Magna. The principal point source of sulfur dioxide emissions, a copper smelter, was located within 2 miles of Magna. The relative locations of the study areas from Salt Lake City were Ogden 33 miles due north, Magna 12 miles southwest and Kearns 9 miles south southwest. Magna and Kearns are approximately 6 miles apart with Kearns located to the southeast of Magna. Pollution exposure levels for sulfur oxides were expected to be highest in Magna, lowest in Ogden and intermediate for Kearns and Salt Lake City.

Asthmatics living in these communities were identified using a common CHES protocol (1). A School and Family Health Questionnaire administered through a chosen school in December 1970 provided the initial sample of asthmatics. This questionnaire was supplemented by other sources of information. All identified asthmatics living within a 2-mile radius of an air monitoring station were interviewed and if eligible were asked to participate. To be eligible they must have had a history of wheezing and shortness of breath with each asthma attack and had two or more attacks in the previous year. No clinical verification of asthma or other verifications of panelist's responses were made as part of the study protocol. The age and sex composition of the panels as analyzed are described in Table 1-1. In regard to smoking status among adults, 26% were smokers, 9% were former smokers and 65% were nonsmokers who had never smoked. Also, 79% of the panelists lived in households where the head of household graduated from high school.