East-West Environment and Policy Institute

Research Report No. 7

Air Quality Management: Quantifying Benefits

by Gordon L. Brady
Blair T. Bower

East-West Center
Honolulu, Hawaii

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Research Report No. 7 • November 1981
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Library of Congress Cataloging in Publication Data

Brady, Gordon L., 1945 -
Air quality management.

(Research report ; no. 7)
Bibliography: p.
1. Air quality management. I. Bower, Blair T.
II. Title. III. Series: Research report [East-West Environment and Policy Institute (Honolulu, Hawaii)]; no. 7.
TD883.1.B7 363.7'3925 81-17478
AACR2

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FOREWORD

The link between energy and environmental quality has been receiving increased attention over the past decade. The need to plan for a postpetroleum economy has provided additional impetus to studies of energy-environment problems, because the commercial energy sources most likely to supply additional energy during the rest of this century are coal and uranium, both of which have serious environmental problems. With this in mind, the East-West Environment and Policy Institute started a project on The Environmental Dimensions of Energy Policies. The major goal of this work is to provide policymakers with analyses that will be helpful in meeting the twin goals of adequate energy supplies and a sustainable environment.

An area of high priority in the Asia-Pacific region, and within the project, has been the analysis of the links between air quality management and energy policies. A Workshop on that theme was held at the East-West Center in March 1980, with participation from nine countries in the region. A paper dealing with the economic aspects of air quality management was prepared for the Workshop by Gordon Brady and Blair Bower. Participants in the Workshop believed that the economic approach discussed by them would be useful to a wider audience. The Institute requested them to revise their paper for publication by the Institute in its Research Report series. We believe that this report provides valuable insights to both the opportunities and the limitations of quantifying economic benefits of air quality management programs. In doing this, the paper can contribute to improving energy-environment policymaking in the Asia-Pacific region.

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ABSTRACT

The problems and potential of quantitative analysis as a tool in air quality management are explored. A status report is given on (1) decision making at the various governmental levels in the United States; (2) air quality measurement techniques and problems; and (3) factors that plague quantitative analysis with respect to air quality management. The problems occur both in measurement of air quality and in measurement of exposure of people and materials: inadequate mortality and morbidity statistics and the difficulty of establishing causality; exclusion of some pollutants from measurement, lack of historical data, and the unavailability, inaccuracy, and inadequate siting of instruments. Evaluation studies of monitoring equipment are cited. Measurement of exposure and of the effects of air pollutants on humans (dose-response function) and on nonhuman receptors are discussed, and the many variables involved are pinpointed. Methods of placing monetary values on these effects are described, including the valuing of improved visibility resulting from air quality management.

INTRODUCTION

> It is somewhat unusual to begin the treatment of a subject with a warning against attaching too much importance to it; but in the case of economics, such an injunction is quite as much needed as explanation and emphasis of the importance it really has. It is characteristic of the age in which we live to think too much in terms of economics, to see things too predominantly in their economic aspect; and this is especially true of the American people. There is no more important prerequisite to clear thinking in regard to economics itself than is recognition of its limited place among human interests at large (Knight, 1933).

This caveat is both appropriate and worthwhile. Interest in the use of quantitative analysis for the development and implementation of environmental health and safety laws is increasing. Both the U.S. Congress and the executive branch see quantitative analysis as a way of evaluating the allocation of public tax revenues among governmental programs as well as the expenditures these programs require of private entities. Assessing the cost-effectiveness of programs proposed by agencies to achieve environmental quality goals is another role of quantitative analysis.

Decisions in air quality management require making hard choices between or among often conflicting objectives. Achievement of one objective may come at the expense of particular industries or of regional interests. Distributional impacts may occur—with respect to both the costs of and the benefits from air quality management—on socioeconomic groups in relation to their income, employment, and race. It should be recognized that, in all societies, air quality is only a part of environmental quality, which is in turn only one part of the context in which decisions about air quality management are made.

Uncertainty surrounds air quality management decisions. The uncertainty begins with the less-than-complete understanding of pollutant quantities generated and discharged into the atmosphere and therefore of the abundance and distribution of chemicals in the environment (eg, the rate of diffusion of pollutants in the air, water, and soil, and the effects of changes in air quality on humans, plants, animals, and materials). The possible outcomes for each alternative air quality management program include health and visibility effects, climatic impacts, and the effects on materials and the reproductive cycle in plants, animals, and humans. These effects often are difficult to estimate because important variables relating to them are not completely known. Analysis must incorporate estimates of exposed populations of various types, as well as estimates of effects. Such uncertainties may be reflected quantitatively in terms of ranges of results and effects. Quantitative analysis also can pinpoint variables for which better information would be important, as well as variables that are unimportant.

This paper is a status report on the methods and approaches for estimating the benefits of air quality management and on the problems inherent in doing so. Decision making at the various governmental levels is discussed first. Then benefit estimation is described, including air quality measurement problems and techniques. Finally, comments will be made on some of the factors that plague quantitative analysis with respect to air quality management.

DECISION MAKING IN AIR QUALITY MANAGEMENT

National Air Quality Standards and Regulations

The Clean Air Act amendments of 1970 contained four major provisions for managing air quality as it is affected by stationary sources:[1]

1. The Environmental Protection Agency (EPA) established national ambient air quality standards for the so-called criteria pollutants. These standards include primary ones to protect human health and secondary standards to protect welfare (Section 109).
2. The EPA was required to establish emission standards for stationary pollution sources that were constructed after the issuance of regulations (ie, new source performance standards) (Section 111).
3. The EPA was required to establish national emission standards for hazardous air pollutants (Section 112).
4. Each state was required to prepare an implementation plan showing how the state would achieve and maintain the standards (Section 110).[2]

The formal regulatory process for air quality management at the federal level may be organized into nine steps (GAO 1979b):

1. Initiation by the EPA administrator—in response to a congressional statute or as a result of an EPA determination—of the process for setting an air quality standard for a specific pollutant;
2. Designation of an EPA lead office and of the project director(s) to formulate a work plan for developing the standard and for carrying out the necessary scientific, technological, and economic studies;
3. Organization of an EPA Working Group consisting of individuals from the major offices in charge of residuals management, EPA regional offices, and the offices of General Counsel, Legislation, Planning and Management, and Research and Development. The task of the group is to formulate the proposed standard and prepare the Action Memorandum for submission to the EPA Steering Committee, following approval by the assistant administrator to whom the lead office is accountable;
4. Formation of a Steering Committee to oversee the mechanics of the process and conduct the first internal review of materials prepared by the lead office;

5. Review involving all assistant administrators, general counsel, and principal staff office directors;
6. Review and approval by the EPA administrator;
7. Interagency review and comment, followed by clearance by the Office of Management and Budget;
8. Publication of the proposed standard in the *Federal Register* and the holding of public hearings as required to solicit public review and comment; and
9. Promulgation of the final standard after making appropriate revisions and repeating steps 5, 6, and 7.

Quantitative analysis can play an important role in steps 3 through 7 and in step 8, assuming that this step is used to generate additional information.

The first step of analysis is to specify the goals of a proposed decision. There may be more than one; for example, reducing detrimental health effects as well as preserving the natural environment. The alternatives available to achieve the goals must be listed and then arrayed in relation to their cost-effectiveness to enable a reasoned evaluation of the anticipated effects of the proposed standard.

The next phase of the analysis entails developing estimated relationships among air pollution concentrations, exposures, and effects. A considerable amount of judgment is needed to translate these relationships from scarce data on air quality; from, at best, crude data on the exposure of different segments of the population and of other receptors; and from poorly understood physiological and related systems. These are, however, the basis for the "criteria" document of a given air pollutant. (It should be emphasized that the criteria document for a pollutant apparently ignores other routes by which the individual may be exposed to and affected by the pollutant.) This criteria document in turn comprises the basis for establishing the air quality standard for the pollutant.

EPA decisions depend on a mix of scientific, engineering, legal, economic, and political factors. The issues are multifaceted, and their interpretation involves some bargaining among the principal contributors: scientists, engineers, lawyers, politicians, and social scientists. The bargaining takes place at various governmental levels. Not all levels will be concerned with the same issues. But the point is that the process results in air quality standards, which in turn become the force behind air quality management at the state, regional, and local levels.

State, Regional, and Local Responsibilities and the Use of Quantitative Analysis

Because state governments are the agents primarily responsible for the administration of EPA regulations, the EPA in actuality may have little direct control over the ways in which decisions are put into practice. Section 110 of the Clean Air Act requires that each state produce and submit to the EPA an implementation plan that shows how the primary air quality standards will be met within the state's boundaries in the specified period of time.[3] If a state shows that applying "reasonably available alternative" physical means for attaining the primary standards will not achieve them within the required time, however, the EPA administrator may extend the date of compliance. Quantitative analysis will be useful in debates about what can be done within a specific time period.

If the EPA disapproves the plan submitted by the state, the EPA administrator must prepare and make known promptly a state implementation plan. In addition, Section 113 allows the EPA to assume enforcement of the state plan provisions against any or all sources if the administrator determines that the state has failed to enforce the approved plan effectively. Section 116 allows a state to adopt and enforce more stringent emission standards than those in its state plan, but does not allow it to adopt and enforce less stringent emission standards.

Analysis of cost-effectiveness is—or should be—an essential ingredient in the preparation of state implementation plans. At least four types of cost-effectiveness analysis are relevant: (1) estimates of the "absolute minimum" social resource costs to a region of meeting the air quality standards; (2) estimates of the minimum costs, "as dischargers see them," of meeting the standards; (3) estimates of the minimum regional costs of meeting the standards subject to possible constraints on distributional effects, such as no more than 10 percent increase in home-heating costs; and (4) estimates of the minimum regional costs of meeting the standards under alternative regulatory systems, for example, regulation of individual stacks, a "bubble" over each activity, emission offsets, and marketable permits.[4] Benefit-cost analysis could be used when there are questions about costs or when certain benefits appear to have been excluded. These analyses call for considerable skill, ingenuity, and flexibility.

The state plan framework allows state, regional, and local governments to determine the means for achieving the federal goals. Cost-effectiveness analysis is the most likely type of quantitative analysis in evaluating alternative ways of achieving specific—or alternative—air quality standards. Cost-effectiveness, however, refers not just to determining the least cost, but also includes practical elements in the calculations of the individual air quality management agencies. The least-cost solution for society may not be the least costly solution for the agency with limited resources and incentives to apply to activities. Some pressures will be of a local political nature, whereas others may come from the EPA. State and local officials often are critical of the EPA for writing regulations that require more field resources than are available. States vary in their ability to attract competent employees and in the analytical expertise available to support air quality management programs.

IMPROVING AIR QUALITY: ESTIMATING BENEFITS

Estimating the benefits from improving air quality requires quantification of the adverse effects avoided by the improvement. Thus, benefits become equal to the amount of damage reduction or avoidance. Of traditional concern have been the effects of air quality on human health, plant and animal life, and physical structures. Of increasing concern are its effects on visibility (aesthetics).

The appropriate place for estim. 'ing benefits and costs is the region: an airshed, a metropolitan area, o' ι multicounty area.[5] Estimating the monetary benefits to a region from improved air quality begins at the micro, or individual, level. Four steps are involved. First, the time patterns of air quality at specific locations within a region must be measured. Second, the time patterns of exposure for different receptors must be estimated. Third, estimates are needed of the physiological, physical, psychological, chemical, and biological effects resulting from the exposure time patterns at various levels of air quality. Finally, the effects observed and predicted in the third step must be translated into monetary terms.

Measurement of Ambient Air Quality

Several problems connected with measuring ambient air quality have implications for estimating benefits. First of all, the concentrations of only a limited number of pollutants are measured currently. For those that are measured, historical data are limited, although in some areas from 5 to 15 years of data exist for some 'ollutants. Even where historical data exist, they normally do not reflect changes over time in the compositio f aggregate pollutants, such as total suspended particulates (TSP). Nor o measurements separate respirable and nonrespirable fractions o! TSP in urban or rural areas.

Second, the extent to which the indicators measured encompass the effects of air quality indicators that are not measured is not clear. Further, difficulties of interpretation may stem from correlation among measured indicators. In addition, what is monitored may be used, in some instances, only as an index of a pollutant that is not directly measured or measurable; for example, SO_2 is used as an index of sulfates or H_2SO_4.

Third, how the data were obtained must be understood. Three points must be considered: (1) the accuracy of the measuring instruments; (2) the availability of instruments for continuous monitoring; and (3) the adequacy of the measuring site.

The *accuracy* of instruments for measuring concentrations of different gaseous materials varies significantly. Even if the sampling instrument is accurate, the laboratory analyses to obtain concentration levels often have been found to be inaccurate and unreliable.

The *availability* of continuous monitoring equipment is related to the time period that a measuring instrument is actually in operation. If continuous monitoring equipment is not available for the given indicator, the readings may represent random occurrences of short duration not necessarily charateristic of the long-term event sequence. Episodic conditions may well impart an upward bias to the distribution of concentrations obtained from periodic but noncontinuous measurements.

The *adequacy* of the measuring site is important. The physical surroundings of the site may change over time and affect the accuracy of the measurements. Or the actual location of the instrument may change over time, although the site designation remains the same.

Fourth, the number of measuring sites necessary to yield a reasonably accurate picture of ambient air quality in a given region is a relevant issue, because each measurement represents air quality in a relatively small area. A related question is: How many measuring sites are necessary to yield frequency distributions of ambient air quality for various sections of an entire metropolitan area?

In 1978, US$62 million in federal money was granted to state and local agencies for air quality management, of which about US$16 million was used for monitoring air quality. As of 1977, about ninety-five hundred monitors were located throughout the United States and its territories. The number of monitors for each pollutant is shown in Table 1.

The General Accounting Office (GAO 1979a) studied the air quality monitoring networks in Boston, New York, San Francisco, Washington, D.C., and Butler County, Ohio. For each monitoring location, GAO personnel analyzed the adequacy of sites, equipment, and quality assurance procedures. GAO personnel visited randomly selected monitoring sites from which data normally are reported to state and local agencies for

Table 1. Ambient Air Quality Monitors in the United States[a] (GAO 1979a)

Pollutant Measured	Number of Monitors
Total suspended particulates	4,234
Sulfur dioxide	2,618
Nitrogen dioxide	1,579
Ozone	527
Carbon monoxide	450
TOTAL	9,408

[a]Monitors from which data were reported to EPA's national data bank in 1977.

Table 2. Evaluation of Ambient Air Quality Monitors, 1977 (GAO 1979a)

Pollutant Monitored	Number of Monitors Evaluated	Number with No Problems	Number Not Meeting Siting Criteria	Percent Not Meeting Siting Criteria
Total suspended particulates	81	33	48	59
Sulfur dioxide	56	7	49	88
Nitrogen dioxide	30	2	28	93
Ozone	43	3	40	93
Carbon monoxide	33	1	32	97
TOTALS	243	46	197	81

developing state implementation plans and sites identified as potential locations for the national air quality monitoring system. As shown in Table 2, approximately 81 percent of the 243 monitors evaluated had problems (one or more) that could affect adversely the accuracy and reliability of the data generated; the percentages ranged from 59 percent (total suspended particulates) to 97 percent (carbon monoxide).

Of the 243 monitoring sites evaluated in the GAO study, approximately 72 percent did not meet one or more of the EPA's proposed site specifications for the national monitoring system (Table 3).

The following examples of improper site conditions provide ample reason for critical scrutiny of the accuracy and representativeness of air quality data. In some instances, the monitors used to measure the concen-

Table 5. Evaluation of Monitoring Sites (GAO 1979a)

Pollutant Measured	Number of Monitors Evaluated	Number Not Meeting EPA's Proposed Siting Specifications	Percent Not Meeting EPA's Proposed Siting Specifications
Total suspended particulates	81	47	58
Sulfur dioxide	56	39	70
Nitrogen dioxide	30	26	87
Ozone	43	37	86
Carbon monoxide	33	25	76
TOTALS	243	174	72

tration of TSP were surrounded by trees or enclosures that prevented a proper flow of air and increased the potential screening of particulate matter. Numerous air inlets and probes were found positioned on top of multistory buildings, far above the height limit in regulations proposed by the EPA. In addition, many air inlets and probes contained dirt and other foreign matter. Bird nests were sometimes found in air intake probes. From discussions with officials, it was learned that siting of instruments was often based on the location's convenience to an energy source (to operate the monitors), its accessibility for servicing, and its security from vandalism. In addition to these problems, 58 percent of the monitoring installations contained unacceptable or uncertified equipment (Table 4).

The use of acceptable equipment, sited in proper locations and operated by well-trained personnel, does not guarantee accurate and reliable data, however. In 1977, the EPA evaluated the state and local laboratories where the samples collected at monitoring stations were analyzed. Only 10 percent analyzed accurately the samples that the EPA sent them.

Based on EPA criteria, the EPA found only 56 percent of monitoring records adequate for statistical analysis. The percentages ranged from 33 percent (ozone) to 64 percent (TSP) (Table 5). A similar conclusion was reached in a study conducted for the National Academy of Science (NCR, 1977). The study concluded that the EPA did not apply scientific principles strictly enough to the design, operation, and evaluation of air quality monitoring programs.

Table 4. Evaluation of Monitoring Equipment (GAO 1979A)

Pollutant Measured	Number Evaluated	Number Using Unacceptable or Uncertified Equipment	Percent Using Unacceptable or Uncertified Equipment
Total suspended particulates	81	19	23
Sulfur dioxide	56	40	71
Nitrogen dioxide	30	26	87
Ozone	43	31	72
Carbon monoxide	33	26	79
TOTALS	243	142	58

Table 5. Evaluation of Statistical Adequacy of Ambient Air Quality Records, 1977 (GAO 1979a)

Pollutant	Number of Monitors Having Records (Table 1)	Number of Monitoring Records Considered Complete for Statistical Averaging	Percent Monitoring Records Considered Complete for Statistical Averaging
Total suspended particulates	4,234	2,707	64
Sulfur dioxide	2,618	1,354	52
Nitrogen dioxide	1,579	874	55
Ozone[a]	527	176	33
Carbon monoxide	450	173	38
TOTALS	9,408	5,284	56

[a]EPA guidelines to state and local agencies permit them to discontinue monitoring for ozone during the winter (nonozone-producing) months.

Table 6. Comparison of Indoor and Outdoor Concentrations for Selected Pollutants[a] (GAO 1979a)

Pollutant Measured	Ratio of Indoor Concentration to Outdoor Concentration
Total suspended particulates	approximately 1
Sulfur dioxide	less than 1
Nitrogen dioxide	greater than 1
Ozone	less than 1
Carbon monoxide	greater than 1
Respirable particulates	greater than 1

[a]Simultaneous measurements were obtained in cities in Massachusetts, Tennessee, Ohio, Missouri, Wisconsin, and Kansas.

Measurement of Exposure

Even if air quality is measured accurately, measuring the exposure of receptors is another problem. For receptors that remain relatively stationary (eg, plants, physical structures), the problem is less severe than for humans, animals, and migratory fish. The actual exposure of humans will be a function of the geographic location of their activities, that is, at home, at work, in transit to and from work, in recreation, and in other activities. Mobility, changing place of residence, also can affect exposure significantly.

For example, the World Health Organization (WHO) found that most people spend approximately 85 percent of their time indoors. Indoor air pollution concentrations, in the few detailed studies undertaken, typically have been found to exceed outdoor concentrations for several air pollutants; therefore, measurements of outdoor air quality can no longer be relied upon to estimate total exposure. For most of the individuals studied, the average exposure was closer to those levels in the home than to those at other sites. The data in Table 6, which are based on one set of measurements, show that the ratio of indoor to outdoor air pollutant concentrations exceeded 1.0 for CO, respirable particulates, NO_2, and CO_2.

Similar results were obtained by Moschandreas, et al. (1978) in measurements of indoor and outdoor air pollutant concentrations for 16 buildings. Indoor concentrations generally exceeded outdoor concentrations for NO, hydrocarbons, CO, aldehydes, and CO_2. Measurements were either higher or lower for NO_2, TSP, and respirable suspended particulates. Indoor concentrations were usually lower than those outside for SO_2, O_3, SO_4, NO_3, and Pb.

Measurement of Effects

Even if the time patterns of exposure to pollutants could be determined, the next problem is to identify the resulting effects on humans, plants, animals, and materials. This step requires the development of dose-response relationships between exposure and effects. Some examples of such relationships are discussed here.

Effects on Nonhuman Receptors.

Damage estimates can be made for agricultural and horticultural crops. The susceptibility of plants to air pollution, or other stresses, is a function of the quality of the soil—including availability of nutrients and trace elements—and the water supply. Healthy plants and trees are less susceptible to stresses of all kinds, including air pollution. But one of the problems in estimating damages is the fact that some of the effects on plants of adverse air quality are similar to the effects of trace element deficiencies.

Once the reduction in tree growth or crop yield due to adverse air quality has been estimated, it is relatively simple to translate such reductions into monetary terms. Where a national market for a product is involved, however, some loss of productivity in one geographic area may or may not affect product price, depending on yields in other areas.[6]

Conceptually, it is even possible to estimate damage reduction, and, hence, benefits to lake fisheries from improving air quality. For example, damage caused by the deposition of airborne acid residuals—in terms of decreased fish yield—possibly could be estimated in relation to fish species in a given lake in the northeastern United States. This would require (1) water quality and associated productivity data for the lake over two or three decades, (2) the assumption that productivity was not decreasing as a result of normal geomorphological and ecological processes, and (3) the certainty that lake acidity affects the productivity of some of the lake's fish species.

The EPA has supported research on damage to materials from various levels of air pollutions. Consequently, reasonable estimates of damage to materials can be made if reasonably accurate measurements of exposure are possible. Measurements must allow for normal deterioration of materials, a function of weather and use. As in the situation of agricultural and horticultural crops and forests, separating air pollution damage from damage caused by other factors seems possible for materials, with the present level of knowledge.

Effects on Human Health.

The effects of air pollution on human health can be defined in terms of (a) acute mortality, (b) progressive deterioration of the human system, and (c) temporary discomfort. Acute mortality effects generally occur in individuals who are already in poor physical condition. Progressive deterioration occurs with such diseases as bronchitis and cancer and eventually leads to death. (Death may or may not be a result of the disease that caused the deteriorization; that is, the individual might be "pushed over the brink" by a disease such as pneumonia.) Eye irritation is an example of a temporary health effect. The human system returns to normal after the episode is over because its capacity to function does not deteriorate as a result of the temporary exposure to air pollution.

The dose-response function for a given segment of the population is the relationship between different levels of air quality and their effects in terms of one or more pollutants. Various procedures have been used to estimate dose-response relationships. They include: (1) extrapolation from laboratory studies on animals; (2) biochemistry studies of the human system, such as the effect of SO_2 on cellular structure; (3) clinical studies of small populations exposed to similar and well-known conditions, such as those in work places (eg, textile mills, chemical plants, asbestos factories); (4) epidemiological studies of a population in a given area over time; and (5) cross-sectional studies of standardized metropolitan statistical areas. The last four reflect a continuum of analysis from the submicro level to regional aggregates. Some of the problems of developing dose-response relationships, as well as some of the results, are reflected in Lave and Seskin (1977), Crocker et al. (1979), and Mendelsohn and Orcutt (1979).

Estimating the effects of pollutants on humans is extremely complicated. Even when pollutant concentrations are high enough to produce acute effects, isolating the cause of the effect is still not completely straightforward. A persons' exposure to a pollutant occurs in a variety of ways, for example, through the skin, digestive system, and respiratory system. Depending on the pathway and the chemical nature of the pollutant, a number of systems within the body may be affected before expulsion or excretion occurs. Causality is difficult to establish when exposure is light; the effect may take place over a period of years, at different locations, and in combination with other stressors on the human system.

The physiological mechanisms by which air pollutants affect health may be examined through laboratory experiments. Such experiments are limited to those on small animals, on cultures of human cells, and on microorganisms. To conduct experiments that expose human subjects to high concentrations of air pollution is considered unethical. The effects of exposure to low concentrations of long duration, however, are not likely to be uncovered in laboratory experiments. At best, animal bioassays can only suggest quantitative dose-response relationships.

Epidemiological studies are based on time-series or cross-sectional observations of human populations in their environments. These studies identify and determine the extent of exposures and their effects. In combination with laboratory findings, epidemiological studies may provide a basis for programs designed to limit various types of exposures. Because such studies rely on statistical data, the limitations of the data must be recognized.

Mortality Statistics. Mortality statistics reflect a mixture of long-term and short-term disease processes. The accuracy of death certificates—for causes of death—is not known. Records of deaths are kept primarily for legal and paralegal purposes and secondarily for such public health purposes as charting the causes of death and the changes in mortality rates. More than half of the "cause-of-death" certifications contain two or more medical terms. The one used in tabulating cause of death is the "underlying cause," that is, the cause that initiated the sequence of events leading to death. The underlying cause may be a disease of long duration or one that occurred recently; this is particularly true for elderly people where the cause of death often is attributed to pneumonia or other infectious disease. The occurrence of a disease and the subsequent death of the person may have been due to different sets of factors that have exerted their influences at different times and even at different places during the person's life. The reported cause of death is documented by autopsy evidence in only about 15 percent of deaths. Thus, the accuracy of an observed correlation between time and place of an exposure and a death attributed to a particular cause is usually impossible to evaluate.

The situation is complicated further by the fact that the age distribution of deaths varies substantially among causes of death. For all causes combined, 62 percent of deaths occurred in the 65-and-over age group (1971 US data). The corresponding proportions for some of the major causes of death were: cerebrovascular disease, 83 percent; coronary heart disease, 75 percent; This suggests that if mortality data are to be used in benefit studies, they should be both age and cause specific, even though this is only a minor step toward distinguishing between short-term and long-term effects of exposure to air pollution.

Morbidity Statistics. Two major types of morbidity statistics are: (1) self- or proxy-reported health conditions and their effects on the functioning of people; and (2) data derived from the work of physicians, clinics, and hospitals. The first type reflects self-perceptions of health, general information, and recommendations received about health care. The completeness and accuracy of this information are affected strongly by the person's interest in reporting and willingness to do so. These, in turn, are influenced by the person's knowledge, which is affected strongly by the ease of access to health care.

The second type, data from health care units, also reflect, to some extent, the symptoms that people report. These data, however, are affected by the information obtained through diagnosis and treatment of the person. Such data also would not reflect unattended illness. The data coverage is affected strongly by health care costs and the income level of the person. Costs, and other limitations on health care availability and use, will influence the completeness of morbidity statistics of both types.

In contrast to the universal coverage of mortality statistics, the morbidity statistics used in U.S. benefit studies are derived from surveys in which the samples used were usually not large enough to provide useful data, even for populations of the largest standardized metropolitan statistical area. The only morbidity statistics used in any of the studies are from a national survey of work-loss days. The number of work-loss days incurred by an individual are influenced by various fringe benefit and insurance provisions which protect income loss. Another shortcoming in the work-loss data used to reflect the incidence of disease is its applicability only to the insured segment of the population. A significant portion of the work force is not employed in the sectors from which these data are derived. Also, the data do not reflect the days of low productivity when workers should have stayed at home, but did not because they could not afford the loss of wages.

Concluding Comments on Measuring Effects on Human Health. In addition to the problems associated with air quality data and estimations of exposure, there are other difficulties in establishing correlations between air pollution and its effects on human health. Relationships among the many stressors of the human system make it difficult to determine the effect of any one variable on death and the incidence of disease. Environmental and behavioral factors modulate the physical, chemical, and biological responses of the human system to air pollution. These modulators may increase or decrease the person's adverse response.

Unique as they are to the individual's body and environment, the variables also include socioeconomic factors. Age and such behavioral variables as smoking, diet (including food additives and water quality), amount and type of exercise, occupation, indoor and outdoor exposures, and migration history all affect the body's reactions. Climate is also an important modulator. Information on these variables is costly to obtain. Consequently, the use of such information has been limited in efforts to develop dose-response relationships.

The dose-response relationship implies causality; the typical method of estimating the relationship is multiple regression, which does not imply causality. To date, all the data used have been either general purpose or data collected for another reason. Although the inadequacies of the data are acknowledged, these inadequacies rarely prevent attempts at analysis. Caution in interpreting results is clearly necessary.

Translation of Dose-Response Relationships into Monetary Values

Even if we assume that dose-response relationships can be defined, the next hurdle is that of translating improvements or declines in air quality into monetary terms.

Effects on Human Health.

Many analysts and policymakers question placing a monetary value on human death or disease probabilities (Lave and Seskin, 1979; Mendelsohn, 1979; Crocker et al., 1979). The implication is that some type of trade-off is being made between changes in exposure and therefore between the probability of death or disease and goods traded in the market place. These types of trade-offs do occur, however. Individuals in their daily activities and governments in their decision making both engage in such calculations.

Several ways of placing monetary values on human health effects have been proposed, including: (1) income foregone; (2) reductions in health care costs; (3) increases in productivity, both through reduced absenteeism and through improved performance; (4) willingness to pay for reducing risk of disease (eg, health insurance); and (5) willingness to pay as deduced from game models. Changes in property values have been used in a regional context, but such values reflect the effects of factors other than — or in addition to — air pollution related health effects.

To obtain monetary measures of human health benefits from improved air quality, a basis for placing values on marginal changes in health status, both for death and for disease, is necessary. In economic theory, the conceptual basis for assigning such values is the "willingness to pay" to reduce the probability of dying in a given period and to avoid days — or years — of illness prior to dying.

A problem arises when wage-rate data are used to estimate willingness to pay for reduced probabilities of death. To the extent that there is a correlation between the risk of death and the risk of injury, sickness, or disability and the type of job, wage-rate differences will tend to reflect both types of risks. Therefore, use of wage-rate differences overestimate the willingness to pay to reduce the probability of death alone.

Related to this question is the problem of determining the value people place on the reduced probability of death by a particular disease. Analytically, the distinction must be made between willingness to pay to postpone death by *any* cause and willingness to pay to avoid illness and the pain, anxiety, and medical costs associated with *some* forms of death. Most models assume individuals are indifferent to cause of death (Lave and Sesker, 1979; Mendelsohn, 1979; Crocker et al., 1979); yet, empirical observations suggest that is not the case. Estimates of the willingness to pay for reduced probability of death that are derived from data on accidental deaths are likely to understate the willingness to pay to avoid the combination of illness and death associated with environmentally induced effects. Proper estimation requires that the length of the latency period must be taken explicitly into account in estimating the benefits of reduced death probability.

The time lag between exposure and death creates theoretical and empirical problems for estimating monetary values. When wage-rate data are related to the risk of accidental death, they yield an estimate of the willingness to pay now to reduce the probability of death now. What may be more relevant, however, is the willingness to pay now to avoid a present exposure to harmful substances, thereby decreasing the probability of extended illness and of death in the future. The willingness to pay in the latter case may be greater or lesser depending on the length of the latency period, the probabilities of dying because of other causes now and in the future, and the time pattern of expected income and consumption.

A critical factor in willingness to pay is people's perception of the possibilities for and potential effects of exposure to air pollution. Various studies in the United States and England have shown that individuals generally recognize air pollution only when and where it is visible. To what extent recognition of air pollution has been increased by air quality indexes in daily weather reports is not clear.

Very little empirical research has been done on estimating the benefits accruing from reduced incidence of disease. Several problems must be addressed if empirical estimation is to be successful. First, if monetary values are to be based on wage-rate differences or other market information, adequate information about the incidence of disease in the sample groups or individuals is necessary. Questionnaires or bidding games may be useful here because disease, at least from the more common causes, has been experienced by most people. The survey instrument's design, biases, and accuracy must be taken into account.

Second, empirical studies must deal explicitly with the fact that disease, as a concept, includes health states of differing severity and duration. Therefore, separate estimates for different types of illnesses of specific intensity and duration must be made.

Third, an individual's willingness to pay to avoid one day of a certain type of illness is affected by the social institutions that govern the sharing of medical care costs, lost output, and lost wages. Complete medical insurance may reduce to zero the incremental costs of illness that would be borne by the individual. Paid sick leave and other ways of maintaining income may mean that the costs of lost output from sick leave are not borne by the individual in the form of lost wages. Consequently, an individual's willingness to pay to avoid a day of illness may understate significantly the social cost of preventing that illness.

Effects on Visibility.

A common argument states that such factors as visibility cannot be given a dollar value because, as with human health, they are intangible. Individuals are conscious of decreased visibility, however, and appear willing to pay to improve it because visibility is thought of as a positive attribute of environmental aesthetics. In fact, it is likely that people more often connect air pollution with poor visibility than they do with adverse health. Several methods for estimating the monetary value of visibility benefits from improving air quality hold possibilities.

Brookshire, et al. (unpublished) and others have attempted to value the aesthetic elements of visibility by direct and indirect methods. Figure 1 gives the structure of a process for this valuation.

The first step, using an atmospheric dispersion model, links emissions with the ambient concentrations recorded by one or more air-quality indicators in a given region. The second correlates changes in concentration(s) to reductions in visibility. The third translates the actual reductions in visibility into visibility changes as seen by individuals. In the fourth step, either direct or indirect methods are used to ascribe monetary values to people's preferences for different levels of visibility.

The direct approach requires the following steps:

1. Alternative levels of the public good (visibility) are described in terms of quantity, location, and time.

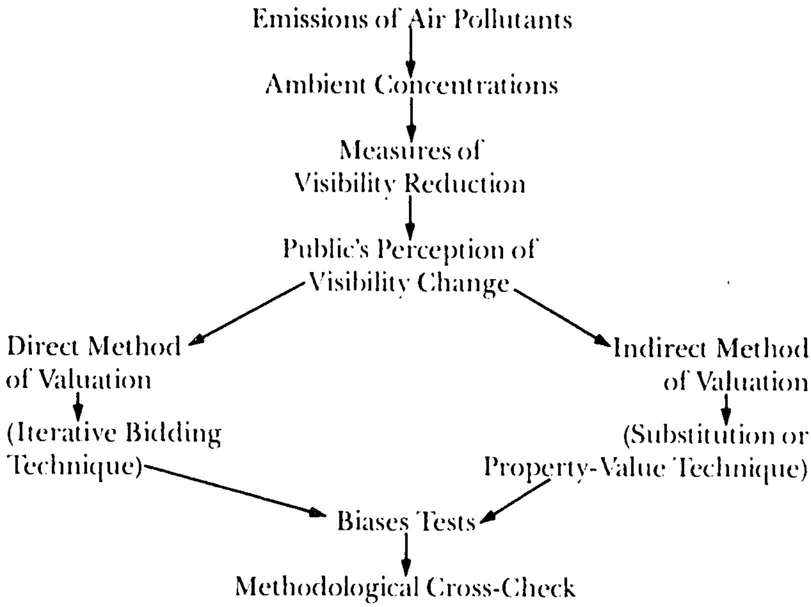

Figure 1. Steps in a process for valuing changes in visibility in monetary terms.

2. Where possible, respondents are given pictures and other visual information to increase the likelihood of uniform perceptions.
3. The market for the good is described in detail (eg, respondents are assured that all users of the good will pay equally).
4. The method of payment is specified (eg, taxes, access fees) and one is chosen for its administrative feasibility and familiarity.
5. Respondents react to the prices fixed for the alternative levels of the public good; that is, when confronted with a specific level of visibility and its associated conditions at a certain price, a respondent is forced to decide whether to "buy" or not.

In the indirect approach, survey techniques are employed to collect information that relates different activities to location, duration, frequency, and expenditures for individuals and households. The individual is viewed as a "utility maximizer" who combines purchases of private goods, including place of residence, and the use of public goods to achieve various levels of usefulness while constrained by budgets of time, money, and household technology.

Both direct and indirect methods of placing monetary values on visibility are subject to criticism, particularly because of information biases and those introduced by survey instrument design. It has been argued that direct revelation of consumer preferences for public goods, such as environmental quality, would be impossible (Brookshire). The problem most often cited is people's desire to be freeriders. This desire, it is argued, underlies the tendency to misstate preferences. For example, if residents suspected they would be taxed for improving the quality of water in a stream or lake by an amount equal to their willingness to pay, they would have an incentive to understate their preferences. Or, if outdoor enthusiasts are told that the average of their bids to prevent construction of a power plant will be used to set an entrance fee or user charge, they may have the incentive to overstate their willingness to pay to prevent construction in order to impose their true preferences on others.

Another criticism of the survey approach is that responses to hypothetical situations may not be as complete as those based on real experiences. For example, an individual might respond to a hypothetical decrease in air quality at one location with a low bid, believing that other sites would make equally good substitutes. Other problems with surveys concern how payment or compensation for hypothetical changes in environmental quality would be obtained by the participants in experiments. Despite these problems, the methodologies outlined can provide at least a rough estimate of benefits from improving visibility.

Property-Value Studies

Property values for a single urban housing market have been analyzed in a number of studies to try to estimate the implicit price function for air quality. One of the main questions associated with this approach is: What is captured by it and what omitted? Residential property values reflect conscious choices by individuals among locations with specific characteristics. As such, property values should capture the people's willingness to pay to avoid the perceived adverse consequences of air pollution and all the other factors leading to choice of residence (eg, access to work, recreation, public transportation, schools). Obviously, many factors affect an individual's choice among locations.

It is doubtful that most air quality effects on mortality statistics would be captured by residential property value data. Nor would property values capture the willingness to pay to avoid the consequences of air pollution experienced in the work place, while shopping, or during travel. On the other hand, such data may be capable of capturing less tangible subjective values as aesthetics, the nuisance of dirt, and differences in home maintenance costs.

CONCLUDING COMMENTS

This report began by stating that substantial uncertainties are associated with estimating the state of air quality and the effects on receptors of different levels of air quality. Some recapitulation and extension would be useful.

The accuracy of existing estimates of air quality is not known and has not been assessed explicitly. That many monitoring sites and instruments are inadequate and many laboratory analyses inaccurate is clear, however.

Air quality is only one of the factors that affects the incidence of human disease and death. Particularly difficult to estimate are the effects on disease and death of long-term exposures to low levels of toxic substances. Long latency periods for carcinogenic substances complicate both the problems of determining effects and of estimating the damages associated with the adverse effects.

Despite the uncertainties, decisions have been and will continue to be made that allocate resources to improve air quality. This poses an important and a difficult question for analysts: How should data surrounded by uncertainties be presented to decision makers? To be effective, the analyst must understand the legal and political context of the decision-making process as well as the underlying theory or the basic mechanisms that yield the observed or imputed effects. The latter is especially true in the analysis of health benefits. Otherwise, relationships among empirically observed, seeming regularities may be misinterpreted. The analyst should forego vague statements of possible relationships; instead, the theory of underlying mechanisms should be presented. Statistically significant relationships are suggestive and are not indications of cause and effect. False correlations also are a problem; that is, some other factor or set of factors that may cause the observed "statistically significant" relationships may exist. If factors are missing that affect the phenomenon being explored, biased parameter estimates may occur.

Decision makers often are as interested in the distributional consequences of an air quality management program as they are in total regional benefits. In benefit analysis, the present value of a properly discounted dollar's benefit is "socially equivalent" to any other dollar's benefit. It makes no difference who obtains the benefit. This assumption ignores an important criterion in air quality management decision making. There are few decisions in air quality management that will not have differential effects on a particular industry, type of labor, capital, racial or income group, or region of the country.

Because complete protection of the entire human population is impossible, the analyst must make explicit the criteria and bases for decisions. For example, to know the nature of the calculations and assumptions inherent in a decision to protect 99.5 percent of the population from exposure to certain levels of a specific pollutant is important.

Given the federal air quality standards, analysis at other governmental levels is directed toward generating information. The information is used to select specific action programs to achieve the specified air quality standards in the required context. At a minimum, this involves cost-effectiveness analysis to determine the least-cost set of physical measures and associated incentives to meet the standards. But the cost-effectiveness framework also can be used to analyze both the costs of achieving alternative levels of air quality and the costs of achieving different distributions of costs and air quality in a given region.

Exposure to adverse air quality represents but one of the stresses imposed on the human body. Whether it is as important or more or less so than other stresses is not known. A major problem facing quantitative analysts in air quality management, and more broadly, in environmental quality management, is the splintered nature of the regulatory development processes and management systems in contrast to the integrated nature of the human system. Administratively, it may be efficient for specialists to deal with a single pollutant: (a) in isolation from other pollutants; and (b) without consideration of the intermedia residuals management problems of individual dischargers. The response of the human system to various stresses, however, occurs regardless of institutional responsibility for the stresses. The attempt must be made to compare the benefits achieved from improving air quality at different levels of expenditure in relation to a given substance in a given environment, and among solid, gaseous, and liquid residuals.

NOTES

1. The Clean Air Act was being amended again by the U.S. Congress in 1981 and 1982.
2. The state implementation plans must consider stationary and mobile sources of discharges.
3. Developing a state implementation plan requires the use of air quality (dispersion) models. Such models translate the estimated present or future discharges into the spatial pattern of air quality in a given region. The limitations of such models and the problems in their application are not within the scope of this report, even though they are critical to the analysis of benefits and costs in air quality management.
4. In December 1979, the EPA announced the use of the "bubble" concept, which subjects an aggregation of point sources within certain types of activities to a single aggregate emission limitation. This is in contrast to requirements that each individual point source (stack) within an activity meet an emission limitation. Emission offsets may be used in nonattainment areas in order to allow new sources or modifications of existing sources. Growth is allowed to the extent that equal or greater reductions may be obtained from existing sources in the region.
5. Where cross-boundary flows of pollutants are significant, costs to achieve air quality goals in a given region may be incurred outside as well as inside the particular region.
6. In the long run, it may be less expensive for society, in real resource terms, to shift resources to growing crops or trees in another area rather than improving air quality in the original target area.
7. The computation is complicated wherever cross-boundary flows are involved, so that costs must be incurred in another region in order to achieve standards in a given region.
8. For a description of implementation incentives see B. T. Bower, et al., 1977, Incentives in environmental quality management, *Environmental Science and Technology* 11 (3): 250–254.

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