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A MODEL FOR REGIONAL AIR POLLUTION COST/BENEFIT ANALYSIS

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McLean, Virginia

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A Model for Regional Air Pollution Cost/Benefit Analysis

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A description of a cost/Benefit model is presented. This model is an extension of the Implementation Planning Program, a cost-effectiveness model which has been utilized in evaluating regional emission control strategies for the development of implementation plans. The specifications for the model for sulfur dioxide and particulate pollutants have been developed and are presented. The report also focuses on: 1. the need for analytical procedures to evaluate the economic consequences of air pollution control strategies; 2. the identification of additional research areas which need consideration; 3. a theoretical discussion of economic efficiency and equity considerations of air pollution control strategies; and 4. model utilization in the air pollution control decision-making process.

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1.0 EXECUTIVE SUMMARY

The Cost/Benefit Model described in this report is an extension of the Implementation Planning Program (IPP), a cost-effectiveness model which has been utilized in evaluating regional emission control strategies for the development of implementation plans. The specifications for the Model for sulfur dioxide and particulate pollutants have been developed over the past six months and are presented in this report. As a follow-on to this effort, the Cost/Benefit Model is now being developed and demonstrated in the National Capital Interstate Air Quality Control Region. The users' manual and demonstration results of the Model will be available by June 1971.

This report goes beyond the presentation of the Model specifications and also focuses on: (1) the need for analytical procedures to evaluate the economic consequences of air pollution control strategies; (2) the identification of additional research areas which need consideration; (3) a theoretical discussion of economic efficiency and equity considerations of air pollution control strategies; and (4) Model utilization in the air pollution control decision-making process.

The air pollution problem in the United States is now approached through a complex series of policies. The Nation is attempting to repair the damages caused by negative externalities from our expanding economy. Public pressures are forcing the development of rapid solutions. Air quality standards have been established on the basis of the best available information in the world. Nonetheless, the standard setting procedure is not based on comprehensive studies or complete data. It is possible that today's standards will be modified and improved as better decision-making information becomes available.

Unfortunately, regional air resource policies are being established without the required sensitivity to economic conditions. Since economic considerations are not included, the potential impact of these policies on the regional and national economy has not been evaluated. Analytical tools are needed to inform decision-makers of the economic consequences of air resource policies. Tools are needed to evaluate the economic efficiency and equity aspects of the impact of air pollution control policies on sources and receptors. Tools for evaluating strategies must be designed which will be compatible with the regional decision-making process and with regional environmental and urban-planning goals and objectives. There is clearly a need for a broader analytical approach, which includes the examination of long-term land-use plans and plans for regional economic growth.

At the present, the only analytical tools available for the development of regional emission control strategies are the "rollback technique" and the cost-effectiveness analysis approach of IPP. The "rollback technique" is used to estimate the required regional emission reduction but does not examine the spatial distribution of pollution concentrations within an air quality control region (AQCR). IPP predicts pollution concentrations at numerous geographical locations in an AQCR and predicts control costs for the major point sources. Yet, the procedure for determining the effectiveness of control strategies merely evaluates the difference between the predicted pollution concentration and the air quality standard. Considerations of regional and national economic impact are not directly included in the analysis.

This report outlines a basic framework for analytical procedures that may assist the air quality and emission standard-setting process, which has been used as a guide in the development of the Cost/Benefit Model. The Model represents an initial attempt to integrate economic, cost/benefit, and systems analysis into air pollution control decision-making.

The Cost/Benefit Model and it's relationship to IPP is illustrated in Figure 1-1. The major outputs of IPP used in the Cost/Benefit Model are the point source-control costs and the air quality display. The point source control costs are currently the only available measure of the social cost of air pollution control in the Model. Procedures for predicting area source control costs and control agency costs are described in this report but have, thus far, not been included in the Model.

The major portion of this study is devoted to the development of the Benefit Model (see Figure 1-1) which relates the predicted pollution concentration (i.e., air quality display) to receptor data and damage functions. The exposure of receptors to pollutants (a measure of dosage) is

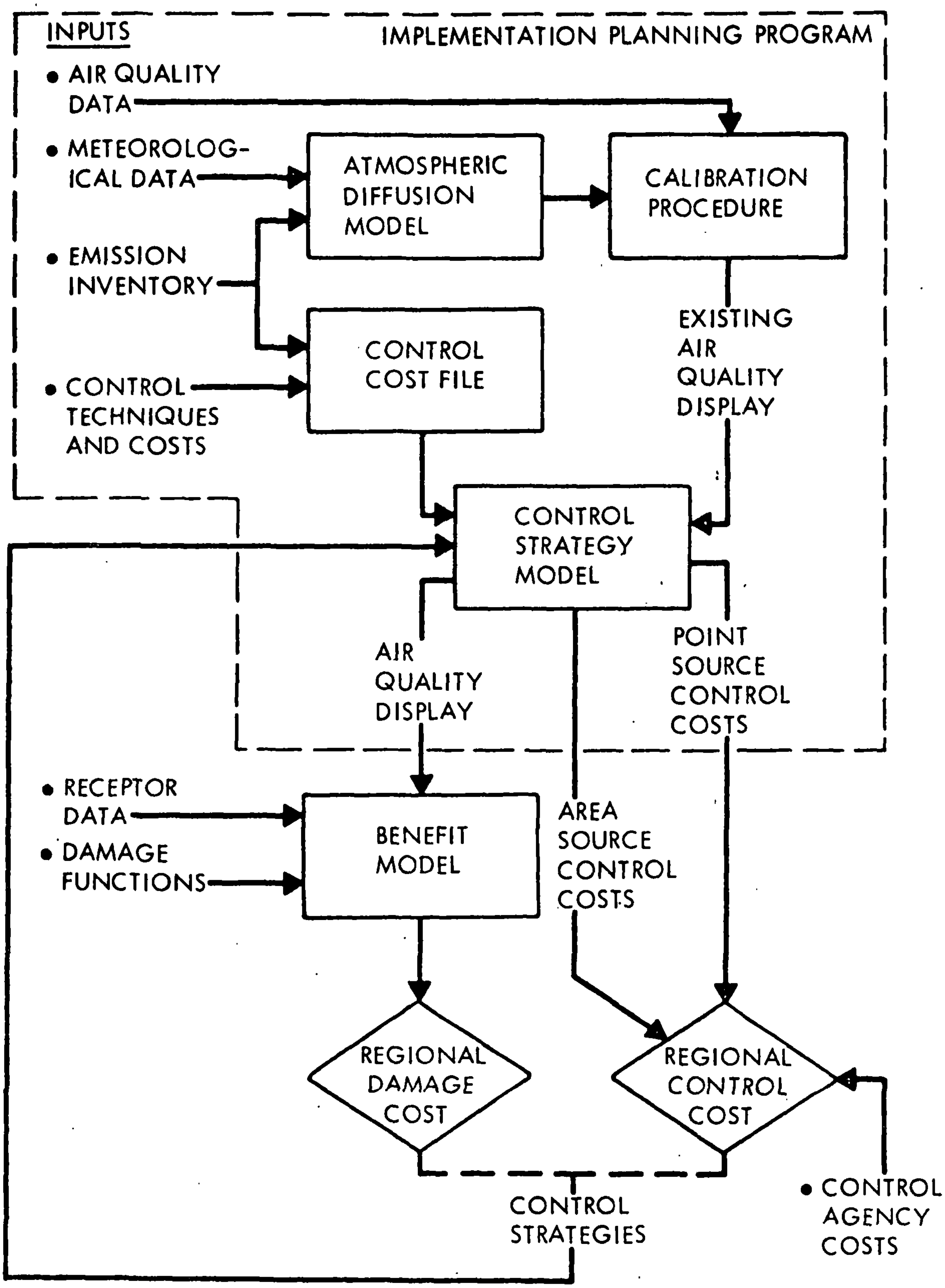

Figure 1-1. Regional Air Pollution Cost/Benefit Model

determined by the air quality-receptor relationship. The damage function (which relates the annual cost of air pollution damage to pollution concentration) when applied to the dosage estimate, determines the damage cost estimate desired. Estimates of benefits (i.e., a reduction in damages) are calculated by subtracting damage estimates for alternative strategies from the damages caused by existing atmospheric conditions.

Three categores of economic effects from air pollution can be evaluated with the Benefit Model. These are: (1) direct effects; (2) adjustments (or indirect effects); and (3) induced effects. Direct effects are immediate negative externalities borne by the receptor. Indirect effects are those which induce persons or firms to make certain adjustments in order to reduce the direct impact of pollutants. Induced effects are realized through the marketplace as a result of adjustments made.

The greatest deficiencies in the proposed analytical procedures are caused by the lack of acceptable damage functions. Damage functions relate one's "willingness-to-pay" to avoid air pollution (i.e., the social value of cleaning up the atmosphere) to the pollution concentration to which a person or thing is exposed. Such relationships are extremely difficult to develop. Documented results are just now appearing on the Horizon.

Even without damage functions, the Cost/Benefit Model can be used for "exposure" studies since knowledge of the relationship between pollution concentration and receptors (for alternative emission control strategies) is by itself valuable for decision-making. As damage functions are developed, they will play a greater role in the analysis. This report includes a discussion about the problems of damage function development and the application. The steps involved in developing damage functions include the identification, assessment, and evaluation of air pollution damages. The evaluation procedure is based on the economic concept of "shadow pricing."

Comprehensive evaluations of all costs and benefits of air pollution control strategies are not possible with the Cost/Benefit Model. The Model merely accounts for a part of the control costs and a part of the benefits. It should be understood that the results to be obtained from the Model demonstration will be considered tentative.

Such a model is possible at this time because economic research on air pollution is beginning to provide control cost estimates for individual plants, industries, and the nation. Such control cost estimates are annually reported in the Economics of Clean Air Report. Also, there is increased awareness of the economic effects of air pollution on health, materials, vegetation, soiling, esthetics, and residential property values. A major task for the future is the transformation of the economic data into the damage function form.

This report proposes that the Cost/Benefit Model be used in two separate ways. First, the Model can be used in intensive welfare economic studies of regional air pollution control strategies to provide a measure of the cost and benefits of control strategies and changes in the well-being of receptors in the region. Control costs and benefits are used directly in evaluating the economic efficiency and equity consideration of control strategies. Actual changes in well-being (i.e., welfare) can be compared with the desired changes (that is, compared to the goals or objectives of the regional decision-makers). The Model can be used to evaluate air quality standards, land-use plans, industrial development siting, and other regional plans. In this use, the Cost/Benefit Model is especially valuable in considering the impacts of control strategies on sources and receptors in different locations in the region. Figure 1-2 illustrates the use of the Model for this purpose.

This type of analysis, however, is limited in scope. The second proposed application of the Model is to provide data which can be used to estimate impacts of control costs and benefits on the economic activity of the region or the nation. Air pollution control policies stimulate a reallocation of resources which are reflected as changes in economic indicators. The Cost/Benefit Model does not include an analysis of such economic indicators. Policy analysis should include the identification of changes in employment, capital investment, regional income, value added, and other measures of economic activity.

To measure changes in regional and national economic activity, control costs and benefit estimates from the Cost/Benefit Model will serve as inputs to an economic model system developed as part of this contract by

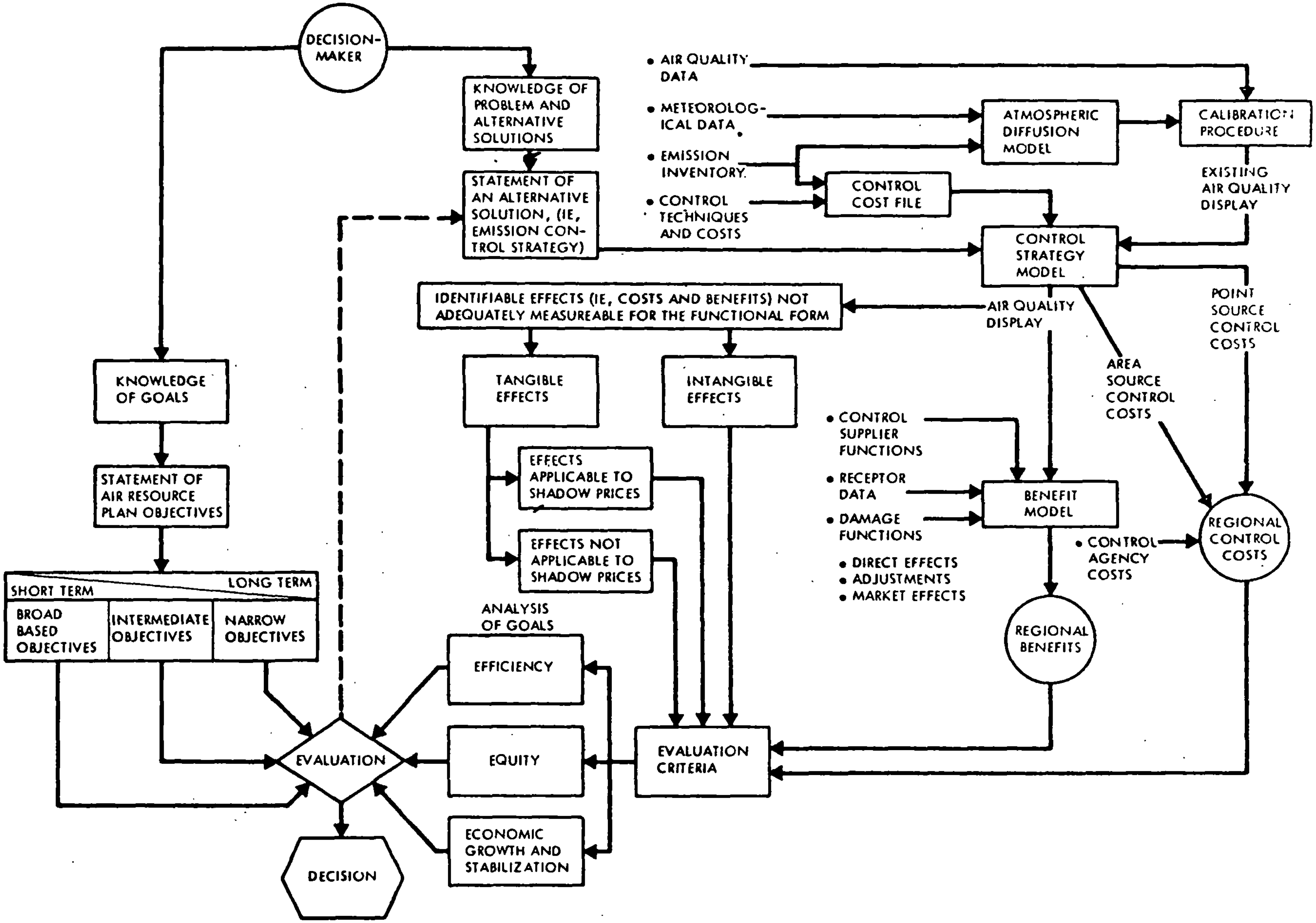

Figure 1-2. Direct Application of C/B Model in Strategy Analysis

CONSAD Research Corporation. The economic model system currently consists of two major components, namely, a regional economic model (which has been applied to 100 air quality control regions) and a national input/output mode. The regional economic model determines the economic effects of air pollution control costs and benefits flowing from the control strategies pursued in a region. The national input/output model system is introduced to provide external markets (i.e., provide feedback effects between that region and all other regions) for the regional economy, and also to measure the structural changes in the national economy following the application of air pollution control regulations to the 100 AQCRs. An illustration of the Cost/Benefit Model as used with the economic model system is presented in Figure 1-3.

The Cost/Benefit Model is a cross-sectional model, i.e., air pollution control policies can be evaluated at one point in time. Conventional cost/benefit analyses require that costs and benefits be traced over a predetermined period of time. Costs and benefits are then discounted back to the current year before the marginal costs and benefits of policies are evaluated. The current CONSAD economic model system is also cross-sectional. Longitudinal cost/benefit and other economic studies will be possible if and when a time series national economic model is incorporated into the CONSAD economic model system.

The overall objectives of this study have been accomplished through the following:

1. Investigating the theoretical literature on cost/benefit analysis and research reports on the application of cost/benefit analysis to public investment projects and social programs.

2. Examining the need for more advanced analytical procedures to support the air resource decision-making process.

3. Developing a conceptual design for incorporating analytical procedures into the decision-making process, including the techniques of systems analysis, cost/benefit analysis, and economic analysis.

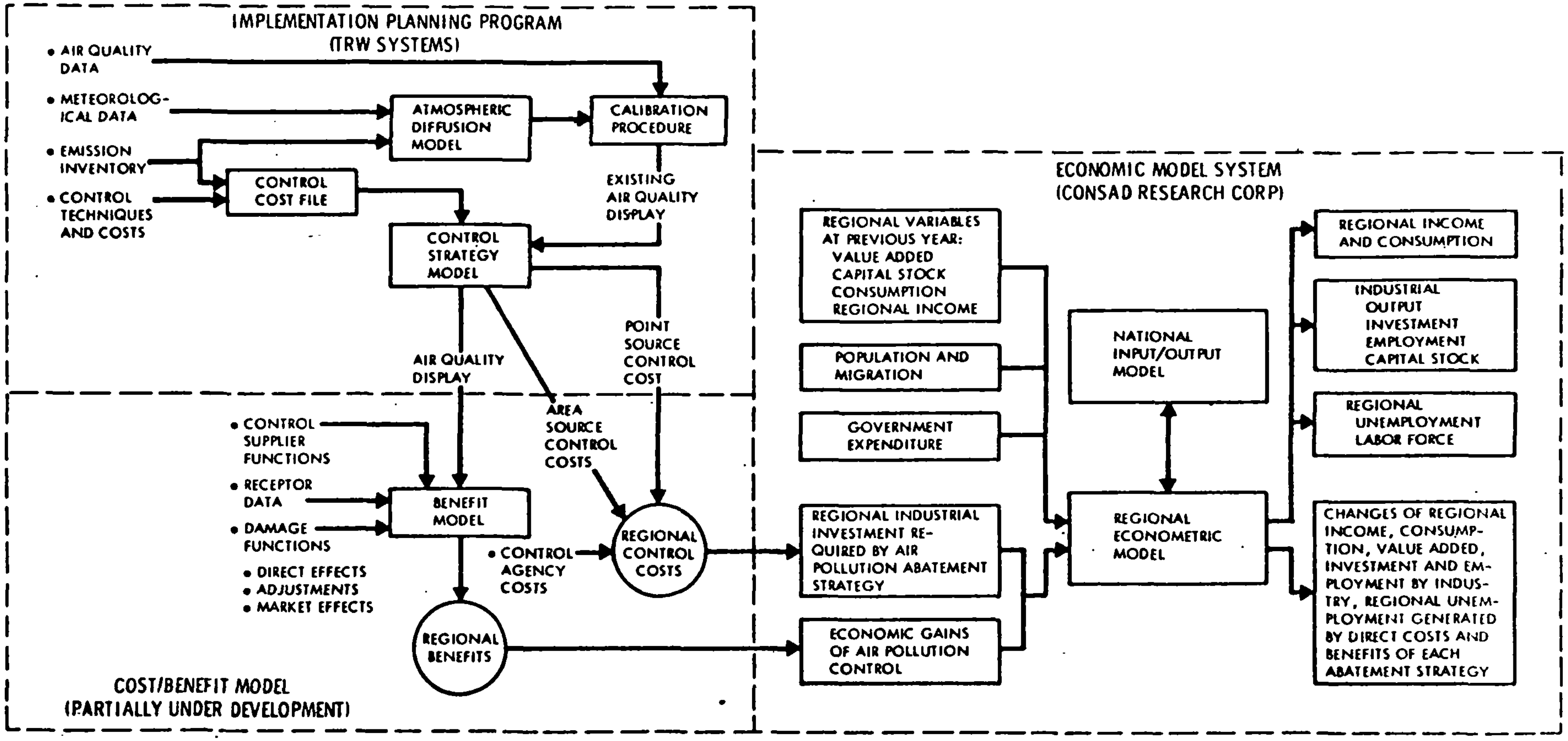

Figure 1-3. Use of C/B Model with Economic Model System

4. Preparing specifications for the development of a Benefit Model and other procedures which facilitate comprehensive evaluations of air resource policies.

5. Collecting data (i.e., census data, damage functions, etc.) and preparing a "pilot" Benefit Model for examining the feasibility of the approach.

6. Testing the use of census data in the present IPP design.

7. Identifying the types of analyses which will best utilize the capabilities of the Cost/Benefit Model. This includes;

   - examining economic efficiency and equity considerations of emission control strategies, and

   - examining new ways of developing regional emission standards.

Much additional work is required before a comprehensive, reliable model can be developed. This report identifies many of the gaps and deficiencies in the current version of the Model. Potential research areas have been identified to facilitate the evolution of analytical procedures for rational regional air pollution analyses. Some of the gap areas (and location in this text where the subject is treated) are:

- Damage functions (Section 7.2)
- Control supplier functions (Appendix D)
- Area source control cost functions (Section 6.3)
- Upgraded point source control costs (Section 6.2)
- Control agency costs (Section 6.4)
- Economic, social and impact indicators (Section 8.4)
- Regional decision-making framework, including,
  - evaluation criteria (Section 4.4)
  - regional objectives (Section 4.3)

Modeling and comprehensive analyses are likely to play an increasingly significant role in APCO activities. As the framework for comprehensive analyses is developed, it will serve as a guide for identification of the types of research and monitoring data that should be provided by Federal, State, and local air pollution control activities. The full value of research and surveillance data can only be realized through integrated analytical procedures designed to serve the decision-making process. Such procedures must be sensitive to quantitative and qualitative inputs from all professional disciplines which contribute to the problem solving process. The procedures must allow use of available data for current decision-making, and should also help in identifying data needed for the evaluation of policies aimed at meeting long-range goals.

This report leaves many gaps and unanswered questions. Hopefully, other researchers will evaluate this work and develop further procedures for analyzing the problem.

2.0 ECONOMIC ANALYSIS AND AIR RESOURCE PLANNING

The U. S. economy is now undergoing a shift in orientation, from an approach in which emphasis was placed upon the satisfaction of human wants without regard to environmental effects toward a sensitivity to the preservation of natural resources. Laws enacted to stimulate and protect the economic institutions which supply goods and services to our citizens have proved inadequate to maintain the quality of life, and externalities from our productive economy have begun to infringe upon the utility of the economy output itself. Legislation is now being rapidly enacted in an attempt to repair past damage. If rational judgments are made, a state of equilibrium will some day be reached in which the undesirable side effects of production and consumption will be minimal. In this connection, the present report examines the air resource decision-making process and provides an introduction to the development of a tool which will aid policy-makers in better determining the condition for the air resource.

The Air Quality Act of 1967 laid a framework for air resource decisions at the regional level. The Act provided for the establishment of air quality control regions, utilization of air quality criteria and control technology documents to set standards, and preparation of implementation plans for attaining these standards.

The Clean Air Amendments of 1970 modified the procedures by, among other things, establishing primary and secondary air quality standards. The entire nation was divided into a number of air quality control regions. A time schedule was determined for the development of implementation plans by the regions. Also, procedures were proposed for determining the adequacy of implementation plans in attaining air quality standards.

Additional tools and procedures are needed, however, if the air quality control regions are to properly evaluate their air resource problems and the regional impact which will result from alternative policies. Since knowledge of the total effects of atmospheric pollution and the precise economic relevancy of air resource policies to sources within a region is inadequate, decisions are being based primarily upon political considerations and limited amounts of scientific evidence and economic data. Improved decisions will be possible as more scientific evidence becomes available. For now, decisions must press forward toward advancement in pollution control.

Unfortunately, regional air resource policies are now being established without the required sensitivity to economic conditions. The air resource and the regional economy are interconnected, as shown in Figure 2-1. Regional policies are being established on the basis of an examination of pollution sources and related control technologies, specific pollutants and emission rates, ambient air quality in the region, and effects of air quality on the receptors. Since economic considerations are not included, potential impact on the regional and national economy has not been evaluated. Nonetheless, such effects as changes in fuel prices, added production costs, and increased cost of electrical power may influence such areas as unemployment, inflation, and the balance of payments. These factors must be examined.

From the standpoint of economics, efficiency considerations in relation to the air pollution problem may be portrayed as shown in Figure 2-2. After all relevant tangible and intangible effects are considered, primary concern is directed to the marginal cost of control and the marginal benefits (that is, the marginal reduction in air pollution damages), which are functions of regional pollution concentration. The goal of the decision-maker is to attain a level of pollution concentration where society's welfare is maximized. This conditions exists at the intersection of the marginal cost and marginal benefit curves in Figure 2-2.

In the political debate over desirable levels of air quality, it was argued that a moralistic approach to the problem does not lend itself to rational solutions.[1] Decision-makers have likewise been cautioned against proposing overly strict (i.e., uneconomical) solutions to the regional problem: "Recently air pollution control has become a major field for the practice of this art of one-upmanship by many of our political leaders."[2] Overly strict control may be uneconomical.

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[1] Henry Ford II, Washington Post, p. A16, November 23, 1970.

[2] D. A. Jenson, APCA Journal, p. 643, October 1970.

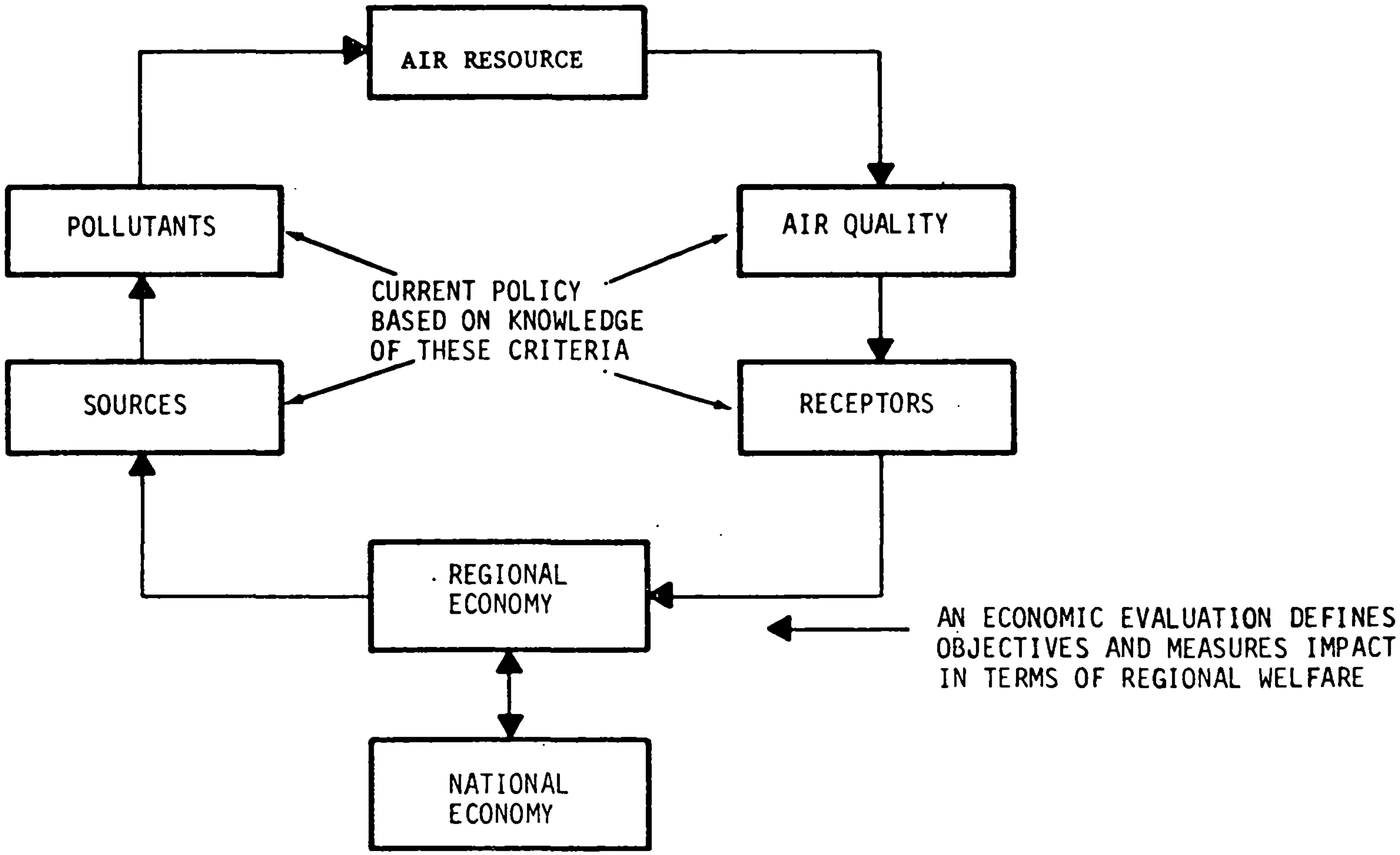

Figure 2-1. The Air Resource Loop

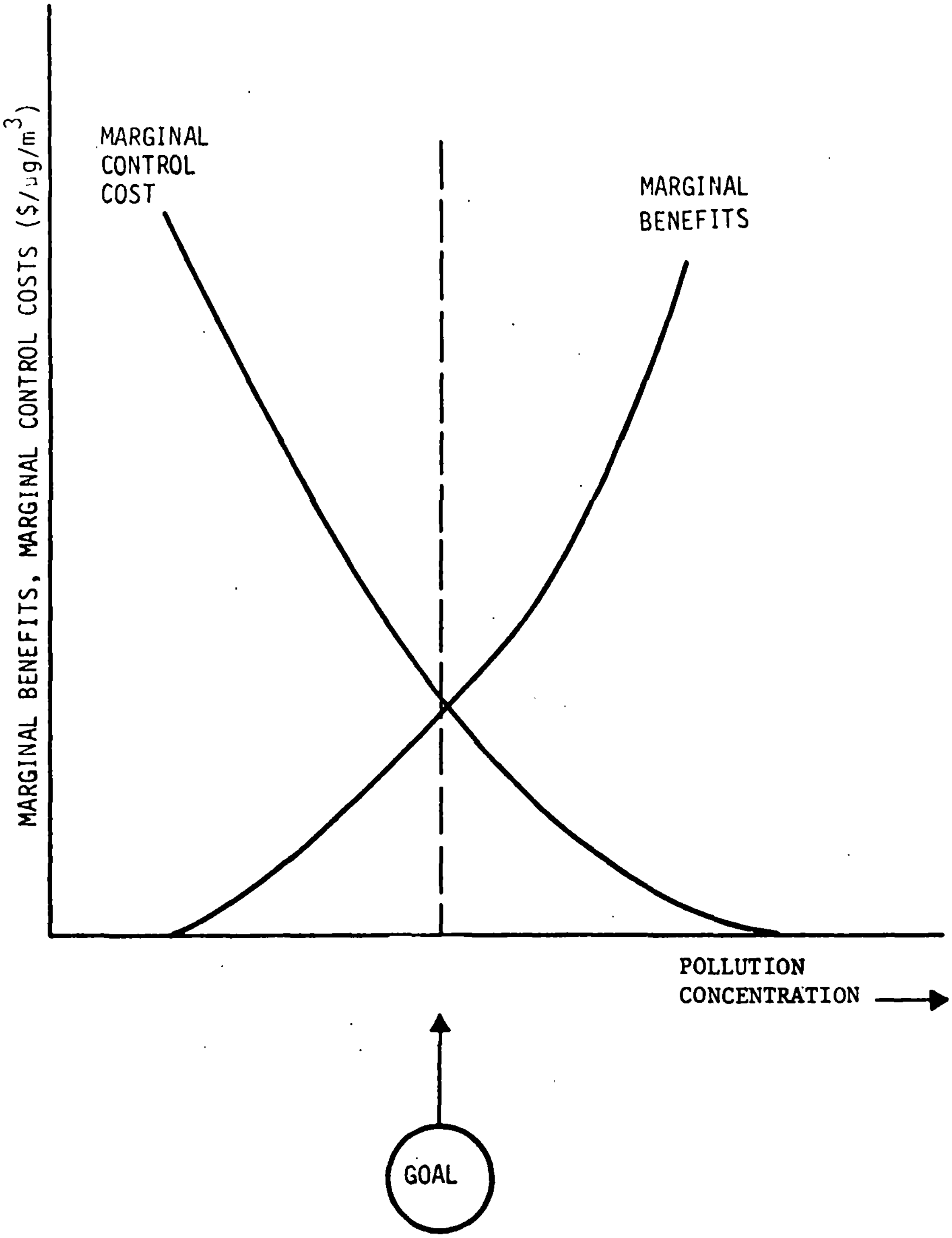

Figure 2-2. Air Pollution Efficiency Analysis

On the other hand, the use of effects criteria for setting standards may result in a plan which is not sufficiently stringent. If effects data are not integrated into the decision-making process, proposed emission standards will not adequately prevent the observed negative externalities and new standards will soon be required. Such changes in standards represent a costly process. Analytical tools are needed which will inform the decision-maker of the economic consequences of air resource policies. Such tools, will be useful now and of even greater value in the future, when air resources reach essentially steady-state conditions. At that time, changes within the regional economy (e.g., a major new pollution source, new products, or other innovations) will require intensive evaluation to determine their environmental impact. More formal and rigorous economic evaluations of air resource policies are necessary, for both present and future applications.

2.1 AIR RESOURCE PLANNING--ECONOMIC DECISIONS

Air resource management decisions can be made without the aid of "economics." Air quality improvements have been justified on the basis of such criteria as the satisfaction or dissatisfaction of those affected, scientific analysis of air pollution damage, etc. Economics merely attempts to place a value (i.e., a price) on the phenomena which cause or are affected by a polluted air resource. As the "science of choice," economics can be used in the decision-making process to reduce all effects of a policy to a common denominator (a common monetary unit). Even where all relevant values cannot be quantified, the "economic approach often provides a useful way of thinking about the problems and a useful way of organizing data for decision-makers."[1]

To analyze the economic aspects of the problem appropriate economic tools are required. In this report, welfare economics is applied in the form of a cost/benefit (C/B) analysis as a means of evaluating social well-being within a region. The procedures for air pollution C/B analysis are not unlike those used in other public investment decision, including

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[1] A. V. Kneese, and B. T. Bower, Managing Water Quality: Economics, Technology, Institutions, John Hopkins Press, Baltimore, Md., p. 8, 1968.

water resource analysis, although measurement of the extremely subtle effects of air pollution greatly complicates the analysis. The material presented here represents a step toward a comprehensive, systematic, and logical approach to the quantitative and qualitative evaluation of air resource plans.

2.2 APPLICATION OF ECONOMIC THEORY AND COST/BENEFIT ANALYSIS

Cost/Benefit analysis may be effectively applied in determining the optimum allocation of resources for a public project or program. Such an application is analogous to the use of financial or investment analysis by the private sector to evaluate corporate or private ownership investment projects. The analytical problem in the private sector is much less complex since market prices are available by which to measure the flow of costs and benefits over time. In the public sector, governments invest funds and make decisions where the forces of supply and demand break down (that is, where the economy alone does not provide the degree of well-being desired by the society). There is no marketplace where the externalities created by emission sources are corrected by the inherent demand of the receptors for clean air. When regional governments attempt to solve the problem, they are forced to consider causes and effects outside the marketplace and are left with no means for readily evaluating the costs and benefits of an investment decision or public program. C/B analysis of public programs is thus complicated by problems associated with both the measurement and the evaluation of effects.

Cost/Benefit analysis has long been used to evaluate public programs. Prest and Turvey[1] trace the development of C/B analysis from 1844, the year in which Dupuit's classic study on the utility of public works appeared in France. Dupuit's treatise represented a highly significant breakthrough in economics. Cost/Benefit analysis first achieved prominence in the United States, however, where it was found to be particuaarly applicable to navigation problems. The River and Harbor Act of 1902 required a board of engineers to report on the desirability of river and harbor projects under

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1 A. R. Prest, and R. Turvey, "Cost-Benefit Analysis: A Survey, "The Economic Journal, vol. 75, No. 300, p. 683, December 1965.

consideration by the Army Corps of Engineers, taking into account the benefits to commerce and the cost. Under the New Deal in the 1930's, the idea of a broader social justification for projects developed. The Flood Control Act of 1936 authorized Federal participation in flood control schemes "if the benefits to whomsoever they may accrue are in excess of the estimated cost." Other agencies soon accepted the concept of C/B analysis, and in 1950 an interagency committee produced the "Green Book," which attempted to codify and agree on general analytical principles. C/B analysis flourished in the 1960's, initially through Department of Defense acceptance of the planning-programming-budgeting (PPB) system and later as a result of President Johnson's desire that this tool be utilized throughout the government. It is now being applied to numerous socially oriented programs in such areas as urban renewal, transportation, and health.

2.3 USE OF THE REGIONAL AIR RESOURCE PLANNING MODEL

The analytical structure presented in this report combines systems analysis and C/B analysis to provide a formal structuring of causes and effects associated with the air pollution control problem. Such a framework provides a means for maximizing the utility of research findings and drawing attention to parameters not previously considered in the decision-making process. The approach can be used to identify future research needs and to prevent misallocation of resources. Finally, a computerized tool for C/B analysis offers opportunities to gain further knowledge by examining the interrelationships between relevant factors through trial and error or through sensitivity analysis.

In defining present and future environmental requirements, the Council on Environmental Quality (CEQ) recently stated: "The pressing need for tomorrow is to know much more than we do today. We lack scientific data about how natural forces work on our environment and how pollutants alter our natural world. We lack experience in innovating solutions. We lack tools to tell us whether our environment is improving or deteriorating. And most of all, we lack an agreed-upon basic concept from which to look at environmental problems and then to solve them"[1]

[1] U. S. Council on Environmental Quality, Environmental Quality (First Annual Report), U. S. Government Printing Office, Washington, D. C., p. 231, 1970.

Specifically, the need was expressed for: (1) a conceptual framework, (2) stronger institutions, (3) financial reform, (4) pollution control curb, (5) monitoring and research, (6) a system of priorities, and (7) comprehensive policies.[1]

A system directed toward the systematic evaluation of air pollution control strategies is proposed here. The proposed system can be used in the structuring and planning of such programs to ensure that the results of monitoring and research efforts are utilized to the maximum extent in the decision-making process.

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[1] Ibid., pp. 232-239.

3.0 CURRENT AIR RESOURCE PLANNING PRACTICES

In this chapter, existing air resource planning practices are briefly reviewed in order to place the proposed air resource decision-making and simulation tools in proper perspective. The proposed decision-making process builds upon air resource management procedures which have evolved over the past 20 years. Topics covered in this review include the need for regulations, the philosophy of air resource management, and air resource planning practices.

The need for air pollution regulations is vividly expressed in the following passage by Otto A. Davis and Morton I. Kamien:

> Imagine for the sake of argument that the auto industry had developed an effective smog control device which it offered as optional equipment for all new cars. A person who was considering whether or not to order this optional for his new car might reason as follows: Suppose I purchase the smog control devices for my new car. If I purchase and everyone else also purchases, then we will have less smog in the city. On the other hand, my individual car can add only a negligible amount to the smog problem so that if everyone else purchases a device and I do not do so, then the smog will be diminished by almost exactly the same amount and I will have saved the cost of the device. Hence, if everyone else purchases a device, I will be better off if I do not get one installed on my car. Now presume that no one, with the possible exception of myself, purchases a device. Obviously, there will be a smog problem. However, if I purchase a device the problem will not be noticeably different, since my individual car contributes only negligibly to the situation and I will be out of the money which I paid for the smog control device. Hence, if no one else purchases, I should not purchase either. Obviously, the analysis is the same if some of the other people purchase and some do not. Conclusion: I will be better off, no matter what other people do, if I do not purchase a smog control device.
>
> Since all potential new car buyers will reason roughly as the representative individual above, the result is that there will be a zero demand for smog control devices. Hence, in the absence of some kind of regulation or collective decision, the automobile manufacturers will have no motivation to develop and market smog control devices. This conclusion holds even if--and it is an if--everyone would be better off if all cars were equipped with smog control devices. The point is that for each prospective purchaser of a device, the benefits from

his purchase are widely dispersed while the costs accrue to him. Thus the technological externality associated with the exhaust of a car prevent the unregulated market from leading the system to a Pareto optimum.[1]

3.1 PHILOSOPHY OF AIR RESOURCE PLANNING

A distinction is made in this report between air resource planning and air quality management in order to differentiate between the analytical studies which evaluate the desired characteristics of an air resource, including impact on the economy, and the broader responsibilities in the field of air quality management, which include development of an air resource policy as well as operation of a pollution control agency (see Figure 3-1). Air resource planning involves the development and analysis of air resource policies. Air qualtiy management involves the implementation and critical review of such a policy. The present report focuses on the problem of developing air resource policies and omits consideration of administrative procedures.

In discussing the air resource management concept, Schueneman notes that "little or no consideration has been given to long-range planning, or how proposed community or regional master plans might influence future ambient air quality."[2] He states that an air resource management program "must provide for the assimilation of information into goals and policies, and the subsequent enunciation of a public policy on the management of the community's air resource."[3] Essential elements of an air resource management program are as follows:

1. Development of a public policy on air conservation.
2. An organizational framework and staff capable of operating along functional lines (e.g., engineering, technical services, field services) and the funding support.

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[1] U. S. Congress, Joint Economic Committee, The Analysis and Evaluation of Public Expenditures: The PPB System, U. S. Government Printing Office, Washington, D. C., Vol. I, p. 76, 1969.

[2] J. Schueneman, "Air Pollution Control Administration," in Air Pollution, A, Stern, ed., (2nd Ed.), Vol. III, p. 721, 1968.

[3] Ibid., p. 722.

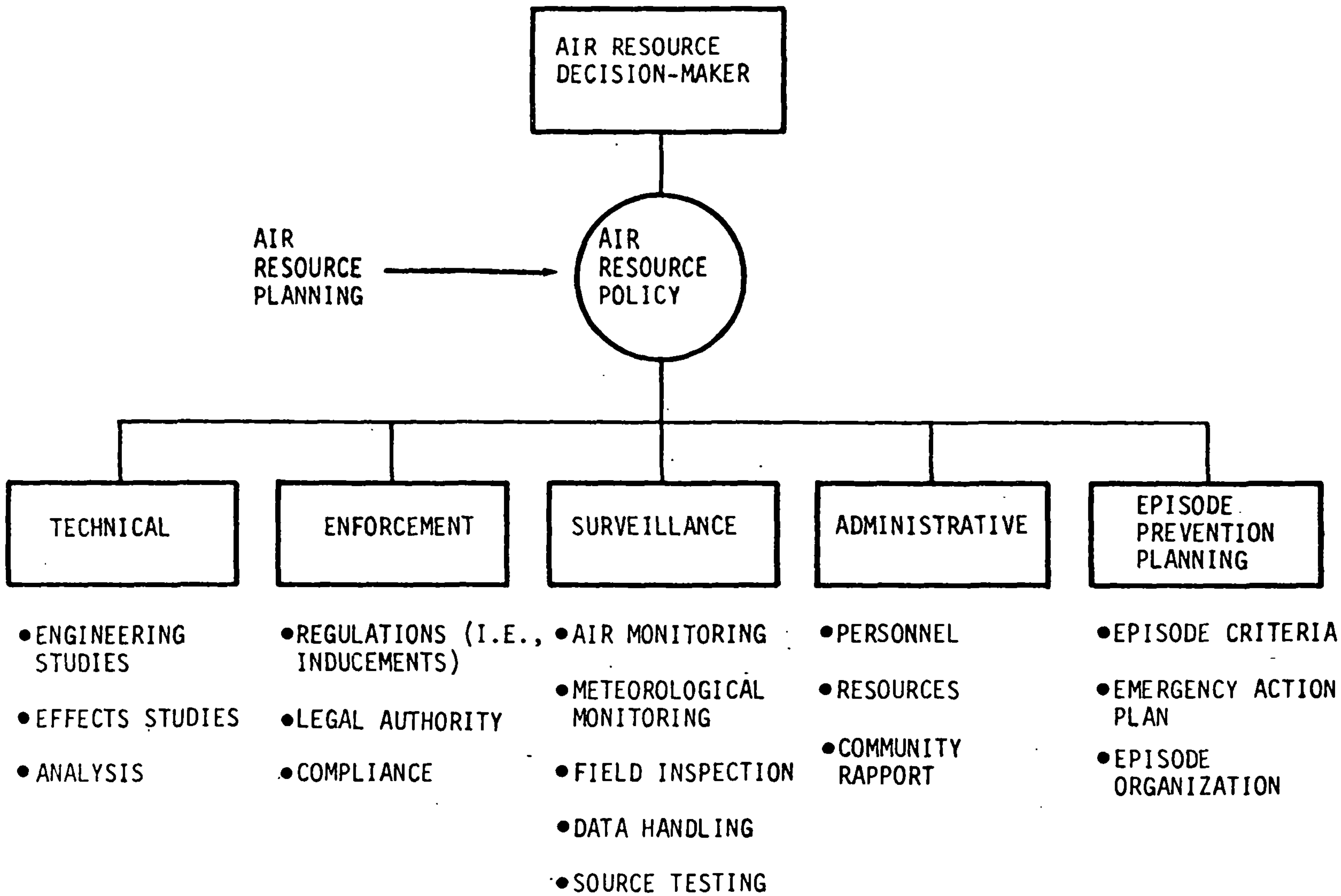

Figure 3-1. Scope of Air Quality Management

3. Delineation of realistic short-range goals that can be effectively met in a reasonable time period, say 5 years.

4. Continual assessment of existing air quality and preparation of estimates of the future situation.

5. Assessment in depth, on a continuing basis, of the emissions from all existing pollution sources and those expected to exist in the future.

6. Development of the necessary information about factors that influence the transport of air pollutants.

7. Assessment of the effects of ambient air quality of a community or region on man and his environment.

8. Establishment of ambient air quality goals (referred to by some as objectives or standards).

9. Design of remedial measures and programs calculated to bring about the air quality desired.

10. Development of long-range air use plans, fully integrated with other community plans for energy supplies, land use, transportation, recreation, refuse disposal, etc., to cope effectively with changes projected for the community.

11. Development of an understanding of the broad impact of changing science and technology on air resources and the potential effect on the social and economic character of modern society.

12. Development of an effective information and educational program to inform the community of the need to solve air pollution problems promptly and effectively.[1]

3.2 ESTABLISHED AIR RESOURCE DECISION-MAKING PROCEDURES

Ten years ago, before computer simulation had been applied to air pollution analyses, regional studies of pollutant concentrations, air pollution effects, emission sources, and other data were used in regional air resource planning. The "roll-back technique" developed by Dr. Ralph I. Larsen was used to calculate reduction in source emissions needed to meet air quality goals.

[1] Ibid., pp. 721-722.

With the development of the Implementation Planning Program (IPP), a mathematical simulation model is now available for evaluating the effectiveness of the emission control regulations contained in implementation plans. The model measures the effectiveness of emission regulations and compares predicted air quality to the air quality standards of a region.

3.2.1 Nashville Metropolitan Area Air Resource Management Plan

A major air pollution study was undertaken in the Nashville Metropolitan Area by the U. S. Public Health Service, in cooperation with Vanderbilt University and state and local agencies, between 1957 and 1959. The primary purpose of the study was to "assist the citizens and government of the Nashville Metropolitan Area in understanding the nature of air pollution problems and in developing a course of action to improve air quality and assure clean air in the future by establishing an air resource management program."[1] An extensive study was conducted of pollutant concentrations, pollution effects, community perception, sources of emissions, etc., ambient air quality goals were developed, and procedures for the development of an air resource management program were suggested.

In the report of the Nashville project, the state-of-the-art of air resource planning is defined as follows:

> The information presented in this report, although among the most complete for any community in the world, does not describe all aspects of the air pollution situation in absolute terms. This deficiency cannot be avoided because the resources of that basic data in the air pollution field are still limited, although they are expanding as a result of extensive, current research programs. In some matters, conclusions must be based on the best judgments possible in view of the factual information available. To delay action until all the decisions could be based on complete and exhaustive investigation would permit air pollution problems to become even more acute.[2]

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[1] J. D. Williams and N. G. Edmisten, An Air Resource Management Plan for the Nashville Metropolitan Area, U.S. P.H.S. Publication, No. 999-AP-18, p. 1, September 1965.

[2] Ibid., p. 9.

To calculate the percent of source reduction needed to meet the air quality goals, the Nashville study employed the Larsen roll-back technique, a method which is not necessarily sensitive to the geographical distribution of air pollutants within the region but focuses instead upon major emission reductions needed to lower regionwide air pollutant concentration. The technique is used to compare the actual percent reduction in emissions with the desired percent reduction (a level somewhere between the existing pollutant concentration and the background concentration). A somewhat simplified illustration of the procedure is shown in Figure 3-2. For more detailed information, the Nashville report cited previously and Larsen's paper in the APCA Journal[1] may be consulted.

3.2.2 Implementation Planning Under The Clean Air Amendments of 1970

Since the Nashville study, air pollution simulation modeling has reached a level of sophistication such that it can effectively assist the air resource planner in evaluating the distribution of pollutant concentrations within a region. The most important contribution of the model is its ability to predict the pollutant concentrations both before and after emission control.

Under the Clean Air Amendments of 1970, implementation plan guidelines recommend the use of either the rollback technique or diffusion modeling in evaluating the ability of emission control regulations to meet primary or secondary regional air quality standards. The rollback technique is still desirable in some AQCRs because of emission and air quality data limitations, the nature of the air pollution problem and the resources required to conduct the analysis. The Implementation Planning Program (IPP) is the most commonly used model for strategy analysis. In IPP, a Control Strategy Model analyzes the effectiveness of control strategies on sources by calculating the reduction in emissions from point sources, computing the annual costs for controlling point sources, and printing a visual display of predicted air pollution concentrations following application of a proposed control strategy.

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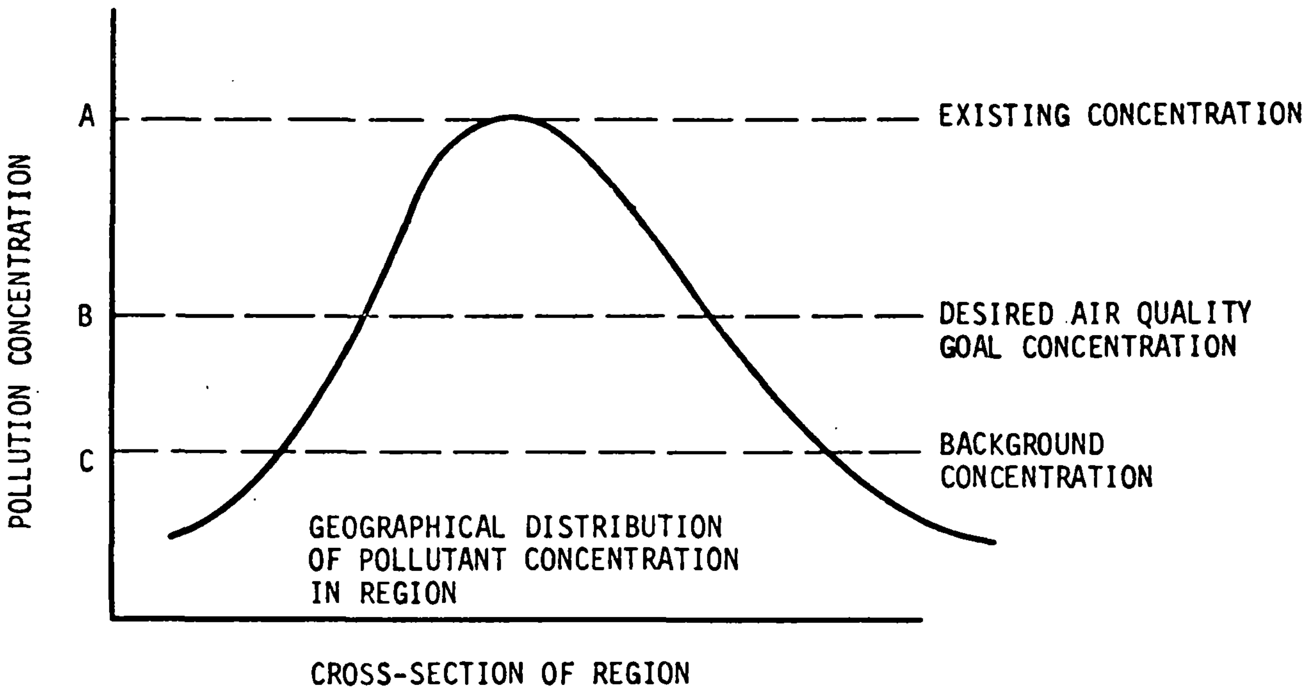
[1] R. I. Larsen, "A Method for Determining Source Reduction Required to Meet Air Quality Standards," Journal of the Air Pollution Control Association, Vol. II, No. 2, pp. 71-76, February 1961.



$$\text{(PERCENT OF SOURCE REDUCTION NEEDED)} = 100 \; \frac{(A-C) - (B-C)}{A-C}$$

WHERE:

A = EXISTING CONCENTRATION

B = DESIRED AIR QUALITY GOAL CONCENTRATION

C = BACKGROUND CONCENTRATION

Figure 3-2. Roll-Back Technique

Figure 3-3 illustrates the use of the Control Strategy Model in cross-sectional analyses. Alternative strategies are tested within the model, beginning with the most lenient control regulations (strategy 1) and progressing to the most stringent (strategy 5). Strategy 5, defined as "maximum technology," requires maximum feasible control technology for all sources, disregarding economic factors and availability of control hardware and fuels.

Figure 3-4 shows pollutant concentrations in the Metropolitan Cincinnati Interstate Air Quality Control Region as estimated by the IPP diffusion model before application of control strategies. Figure 3-5 shows the IPP-predicted pollutant concentrations resulting from the control strategy that was selected as a basis for preparing emission control regulations for the Cincinnati Region.*

The IPP model represents a significant improvement over earlier methods, in that regulations of greater or lesser stringency can now be compared for various political jurisdictions in an AQCR and the resulting distributions of pollutant concentrations analyzed. Acceptance of a control strategy is at present based only on the predicted pollutant concentration relative to the air quality standard, however, without regard to regional and national economic impact. The economic distribution of impact on sources and benefits to receptors are likewise not considered. Moreover, the strategies are not, in general, related to regional environmental and urban-planning goals and objectives. There is a need for a broader analytical approach which includes examination of long-term land use plans as well as plans for regional economic development.

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*A detailed description of IPP is presented in Chapter 6.0 of this report.

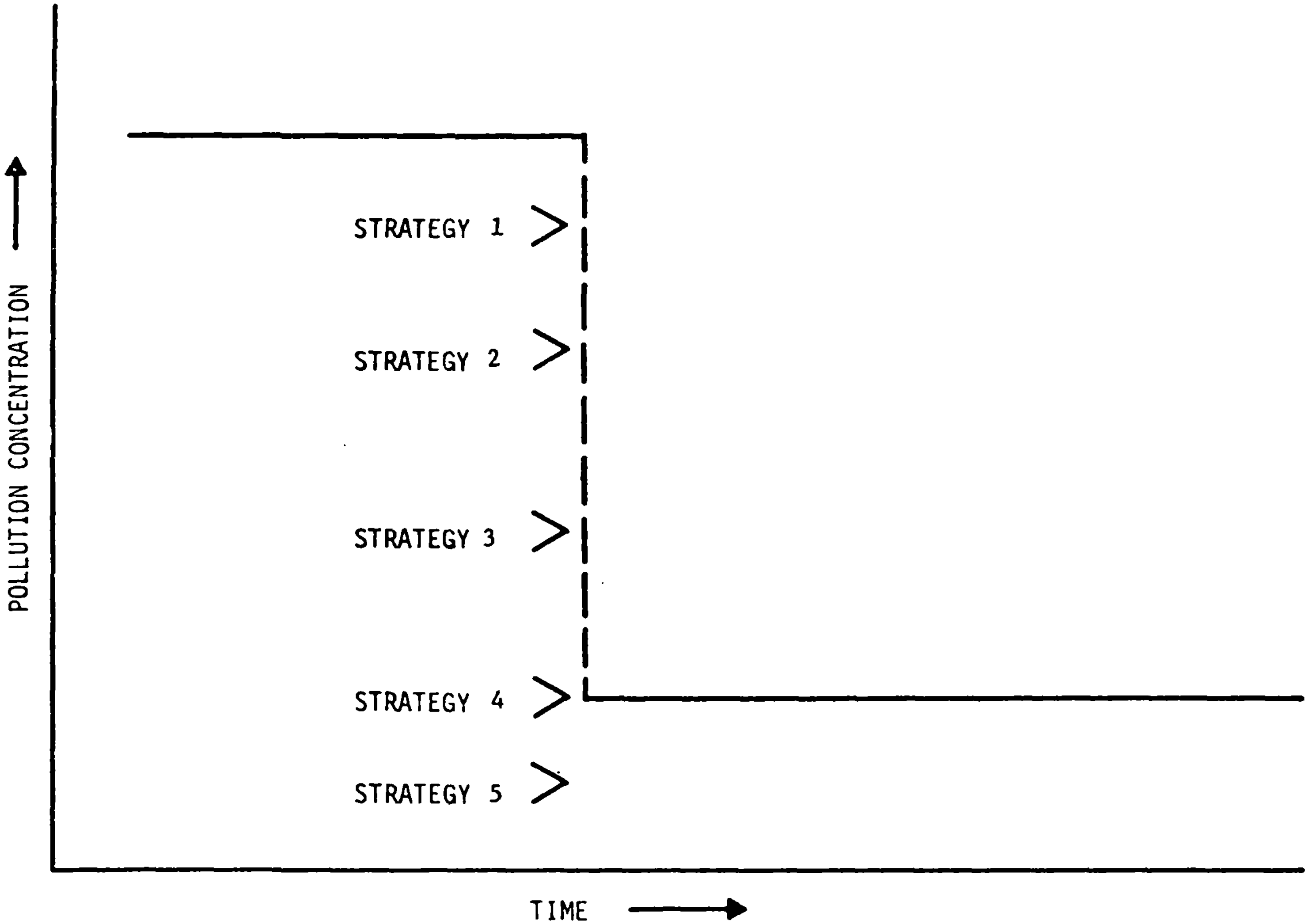
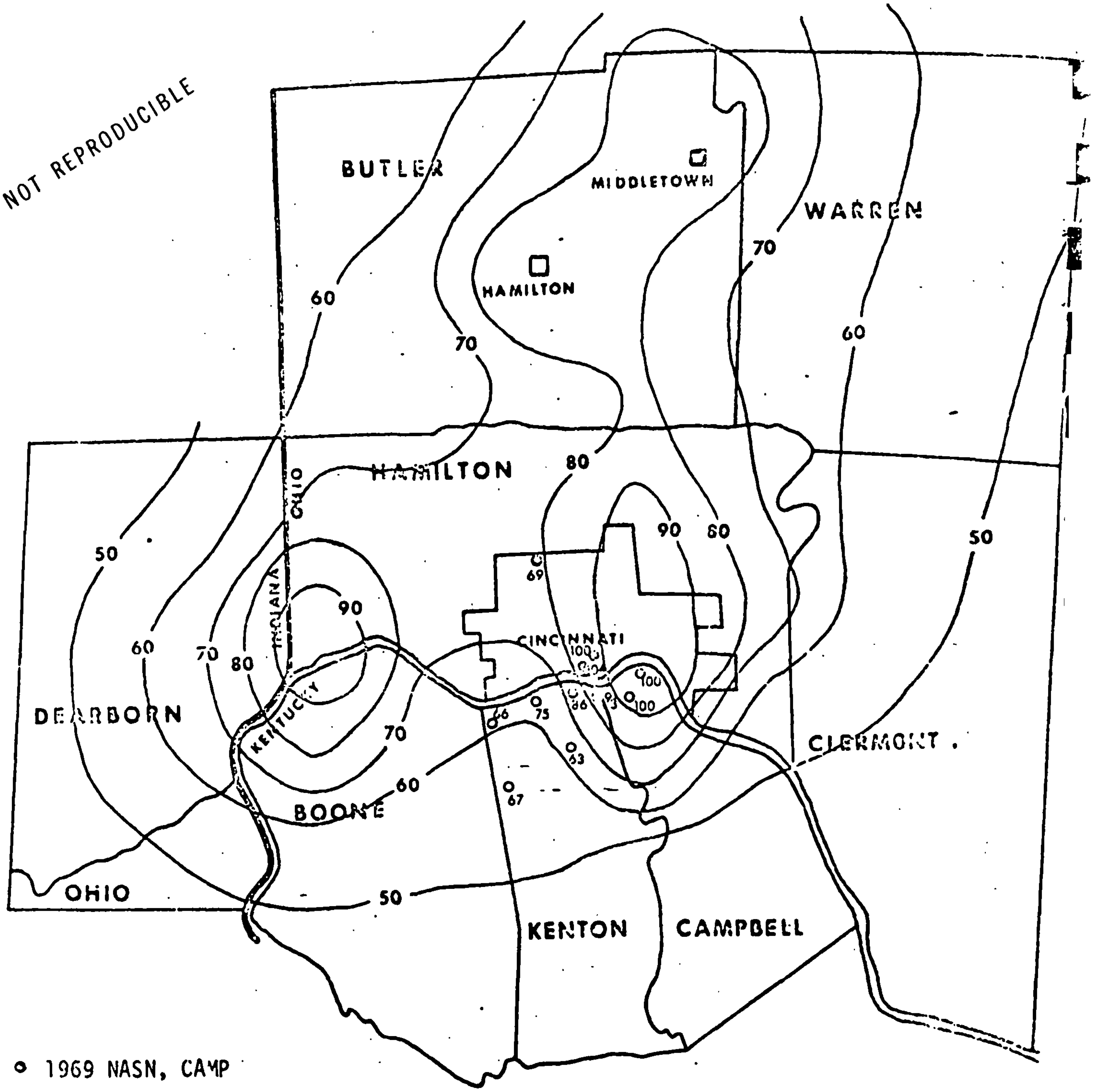


Figure 3-3. The Testing of Emission Control Strategies

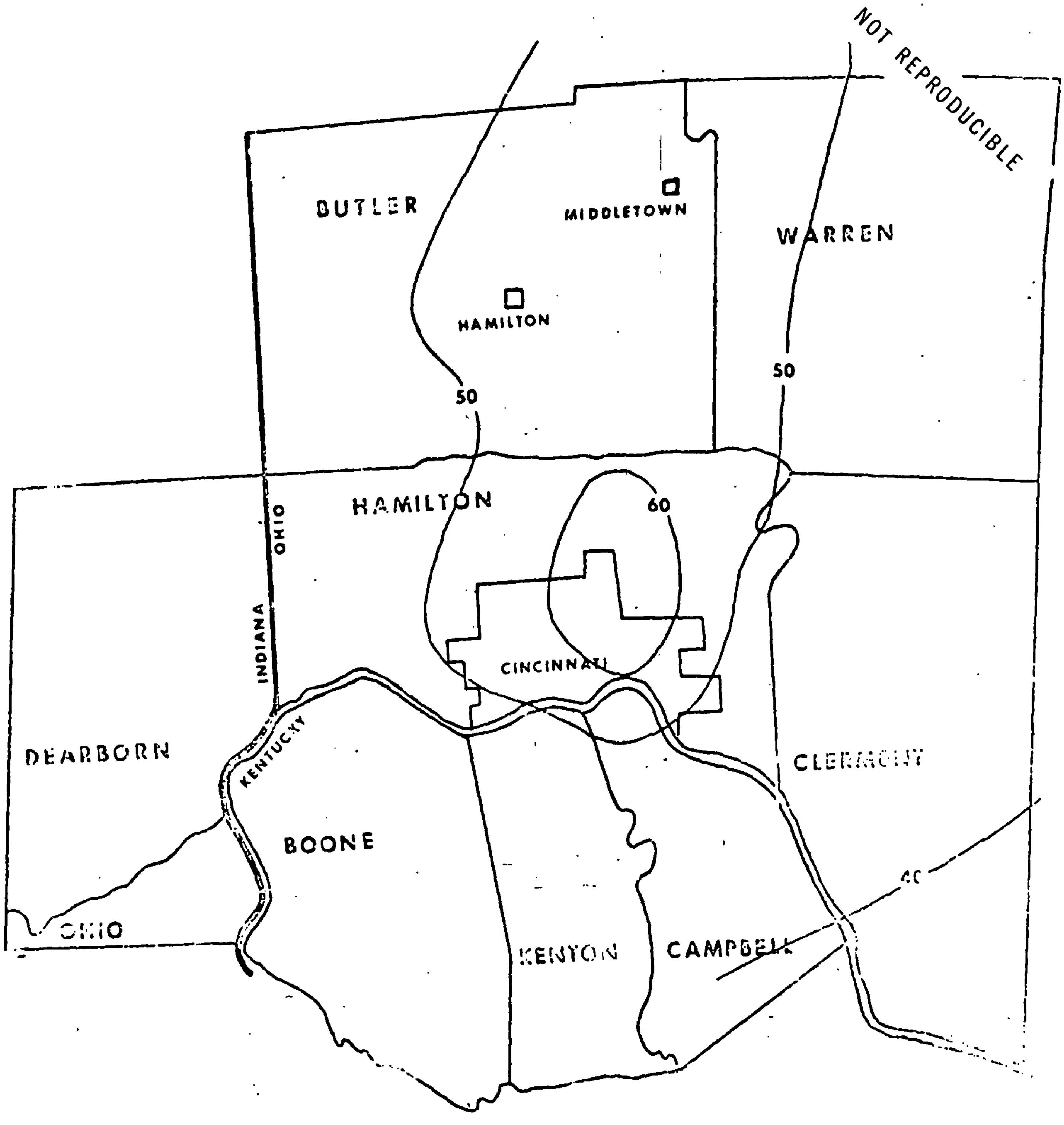


° 1969 NASN, CAMP

o 1968/1969 Northern Kentucky Network

Concentration in $\mu g/m^3$

Figure 3-4. Annual Arithmetic Mean Concentrations of Suspended Particulate Pollutants as Estimated by Diffusion Model for Existing Conditions.



Note: Annual Average Concentrations in $\mu g/m^3$

Figure 3-5. Predicted Ground-Level Concentrations Following Application of Proposed Control Strategy

4.0 CONCEPTUAL FRAMEWORK FOR REGIONAL AIR RESOURCE DECISION-MAKING

In the sections which follow, the decision-making structure of regional air pollution cost-benefit analysis is examined as a basis for the development of a cost-benefit model. The air resource problem, regional decision-making objectives, and types of criteria for evaluating changes in regional welfare are discussed. Relevant aspects of cost/benefit analysis theory are not discussed here but presented in Appendix A.

4.1 OVERVIEW

Deficiencies in the current air resource planning approach were noted in the preceding chapters. Particular emphasis was placed upon the need for evaluating the impacts of air resource plans as they directly and indirectly affect the welfare of society. The approach suggested in this section is designed to provide a framework for such an evaluation.

Two types of economic effects can be distinguished, those that increase the overall level of economic activity by reducing costs and/or increasing productivity (positive income effects), and those that redistribute resources without increasing the net economic level (redistribution effects).

Through a consideration of these effects, changes in the well-being of the individuals affected, the metropolitan area, and the society in general may be defined. In a cost/benefit evaluation, actual changes in well-being (i.e., welfare) are compared with desired changes (the goals or objectives of the region). These goals provide a useful framework for discussing cost/benefit analysis of air resource planning.

Figure 4-1 illustrates the air resource decision-making process and the role of economic analysis in evaluating the ability of alternative solutions to satisfy planning objectives.[1] The combined procedures of economic, cost/benefit, and systems analysis (such as the procedures

[1] This report treats the "decision-making process" in a very general sense. It does not investigate the alternative levels of decision-making within public and private sectors.

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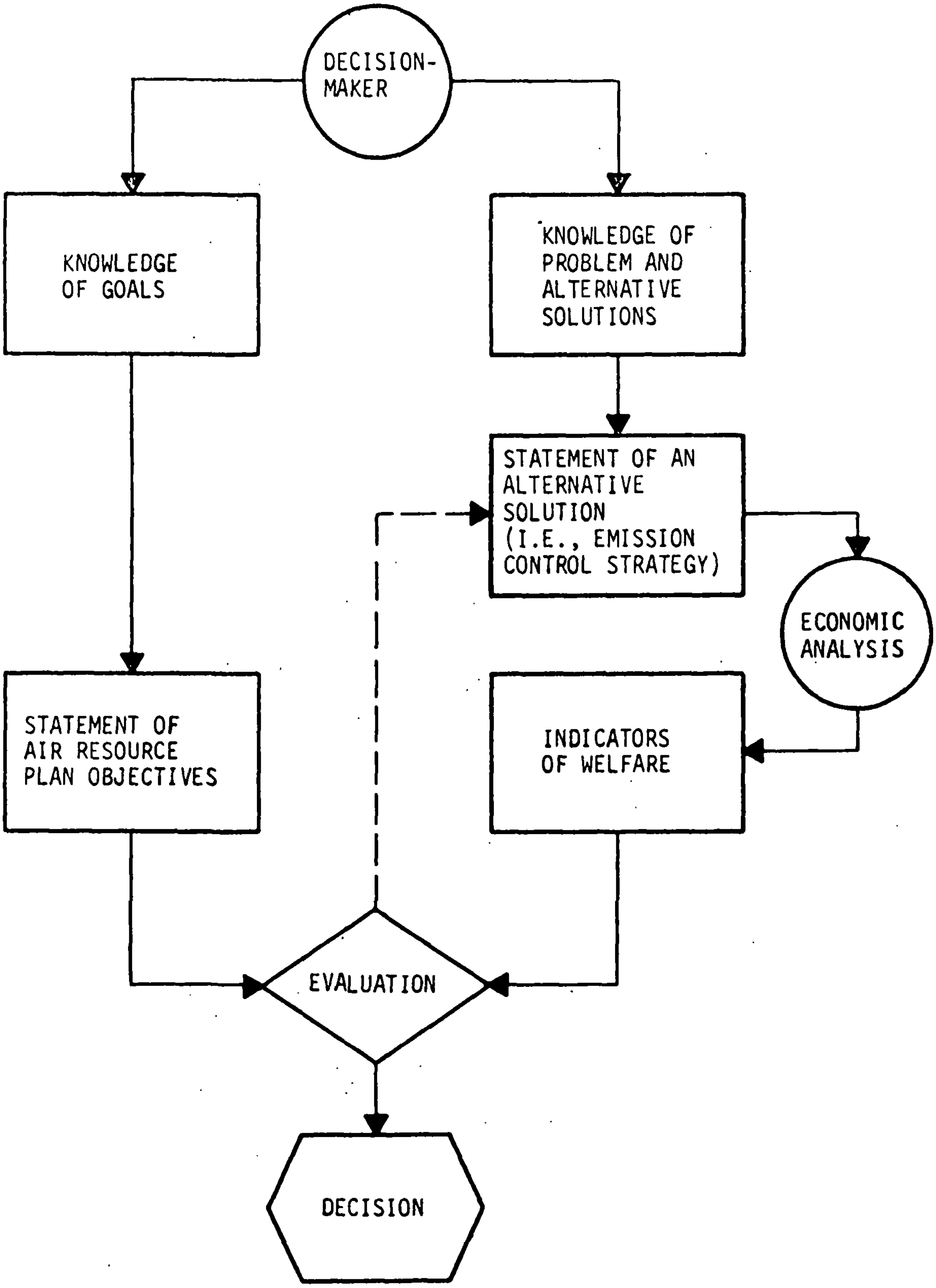

Figure 4-1. Air Resource Decision-Making Process

presented in this report and others) are directed toward the development of social and economic indicators (evaluation criteria). These indicators form a basis for evaluating goals in the following categories:

- Economic efficiency--Increased welfare for the region, i.e., increased aggregate income and productivity.
- Economic redistribution--The desirable distribution of benefits among income classes.
- Economic growth and stabilization--Stability of employment and regional product, as well as growth in regional income, employment, and other economic indicators.

Within the analytical framework, the constraints on an air resource program must be identified in order to ensure the development of correct assumptions and analytical techniques. Seven categories of constraints have been identified by one author.* The categories, followed by examples relevant to air pollution, are:

1. Physical--Fuel availability, control hardware, technological developments, etc.
2. Legal--Promulgation of proposed regulations.
3. Administrative--Staffing and enforcement of regulations once they have been promulgated; purchase and operation of surveillance equipment.
4. Distributional--Prevention of severe economic impact to small sources or the desirable allocation of clean burning fuels to certain source categories.
5. Political--Opposition to controls by sources, fuel suppliers, and other institutions.
6. Financial or Budget--Resource limitations of control agencies and emission sources which prevent instantaneous compliance.
7. Traditional, Social, and Religious--Opposition to certain control regulations (such as a ban on burning leaves) because of social custom.

*Categories applicable to all public programs; presented in O. Eckstein, "A Survey of the Theory of Public Expenditure Criteria," Public Finances Needs, Sources and Utilization, National Bureau of Economic Research, Princeton University Press, Princeton, N. J., pp. 439-494, 1961.

Political and other constraints which prevent immediate solution to air pollution problems should be identified. Such factors as the need for additional effects information, time of enforcement of regulations, and installation of control hardware must be taken into consideration.

The welfare indicators which are used in the evaluation of goals may be consistent with certain regional planning objectives and detrimental to others. The role of the decision-maker is to determine which of the regional objectives are most important in relation to both short-term and long-term goals.

The number of alternative solutions proposed by the analyst must be sufficient to permit marginal evaluations, that is, evaluations which consider the additional benefits (or increments of welfare) resulting from marginal reallocations of funds of marginal increases in the stringency of emission control regulations. Policy decisions will ultimately be based upon the evaluation of these objectives and welfare indicators.

4.2 PROBLEMS IN AIR RESOURCE PLANNING

The schedule of events specified in the air pollution control legislation for regions is shown in Figure 4-2. Air resource policy decisions are being based on guidelines established by the Air Pollution Control Office. A "crystal ball" forecast of future conditions in a hypothetical Air Quality Control Region (AQCR) is illustrated in Figure 4-3. To meet the primary and secondary air quality standards, the air resource planner must establish policies in the following areas:

1. General Stringency of Control--How efficient must emission control be in order to optimize the welfare of the region relative to the air resource and other urban goals?
2. Compliance Schedule--How quickly can the region move toward the optimum-welfare condition, taking into account the welfare of the regional economy?
3. Inducement Approach--What combination of emission regulations, emission taxes, land-use planning, product laws, etc., represents the most efficient and equitable approach in reaching the desired objectives?
4. Locational Aspects--What is the most efficient and equitable manner in which emission limitations can be applied relative to geographical location in the AQCR?

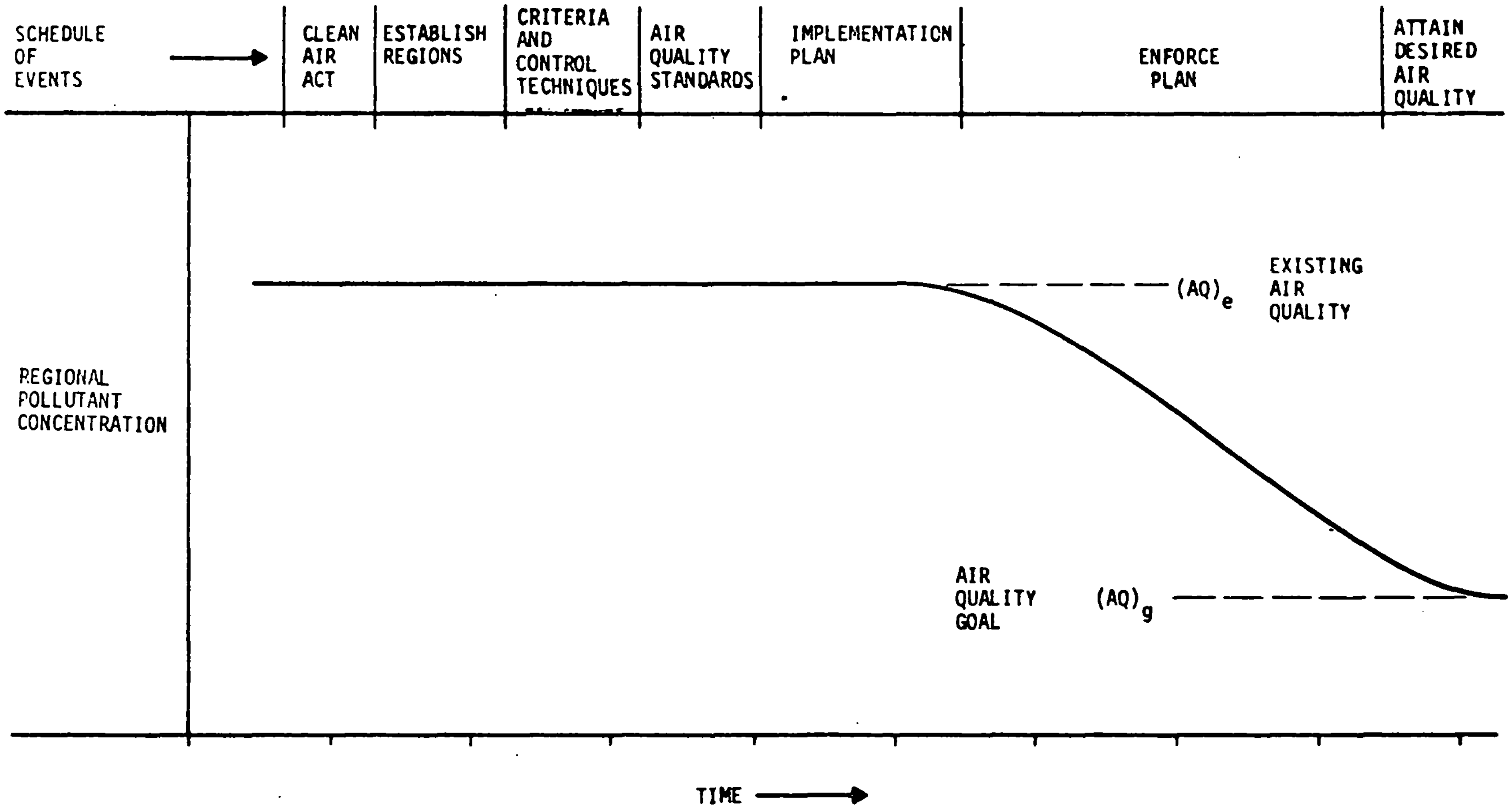

Figure 4-2. The Path to Clean Air

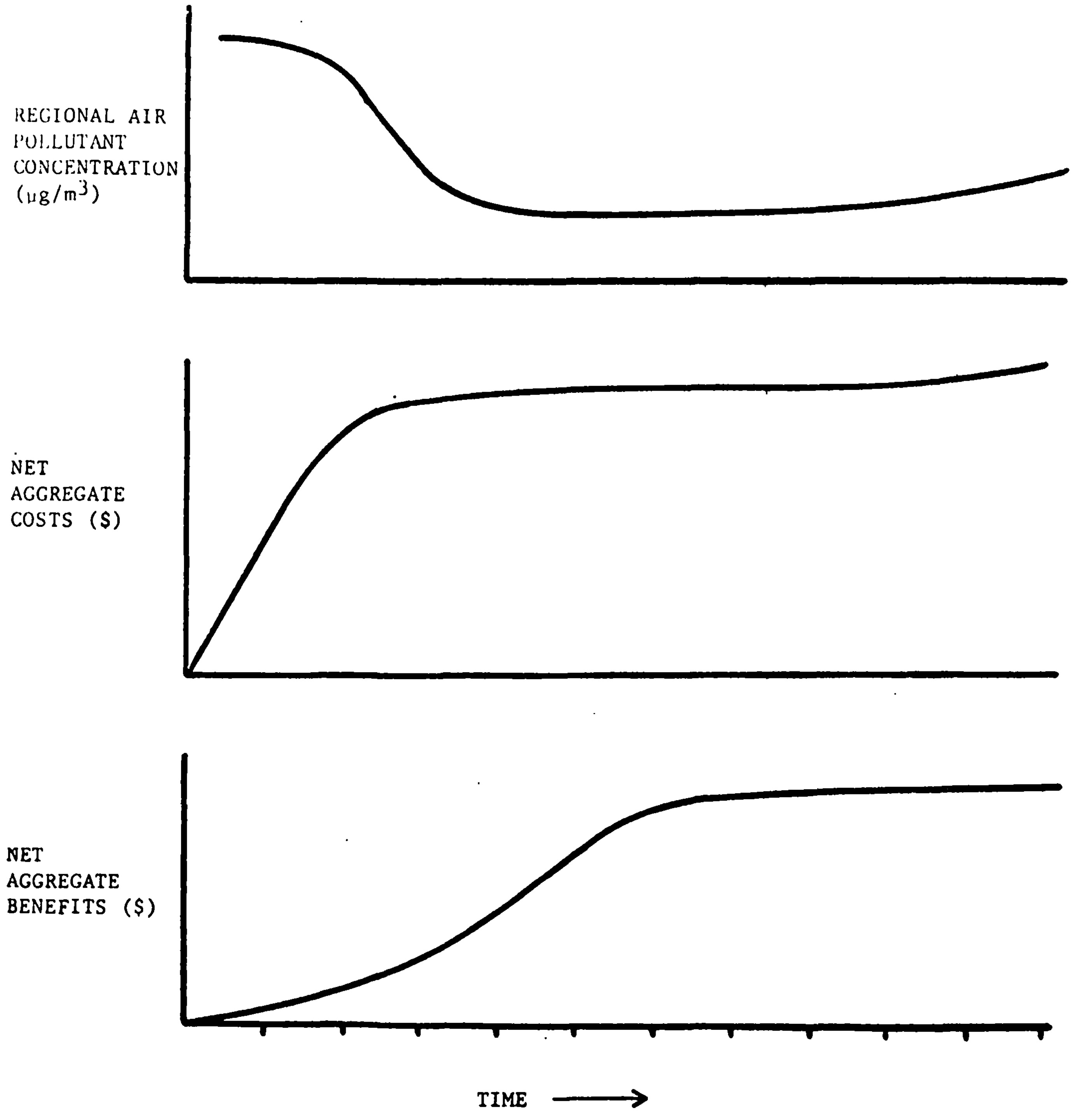

Figure 4-3. Flow of Costs and Benefits Over Time

Effective air resource planning will require more sophisticated tools to answer these questions than have thus far been available.

4.3 DECISION-MAKING OBJECTIVES

Once regional goals have been defined, the air resource decision-maker will decide upon essential planning objectives. Different levels of objectives will be identified, perhaps as follows:

- Air resource planning objectives.
- Environmental planning objectives
- Urban planning objectives

The objectives of the air resource planner may or may not be consistent with those of other government planners. Total regional welfare which is difficult, if not impossible, to determine should be the deciding factor when conflicts in objectives arise.

The formal procedure currently recommended for the development of implementation plans fails to provide for sufficient consideration of the various regional planning objectives. Although outside the scope of the present project, the development of more sophisticated guidelines for regional objectives by APCO is encouraged. Some objectives which might be considered in the AQCR decision-making process include:

- Regional economic growth.
- Increased public and private investment.
- Creation of new job opportunities.
- Net inducement of private investment in labor into the region.
- Decrease in social cost of living in region.
- Increase in fiscal capacity of central-city tax base.
- Enticement of moderate-income households into central city.
- Revitalization of commercial core (Central Business District).
- Expansion and support of central-city institutions.
- Increased aesthetic appeal of central-city and region as a whole for residents and tourists.

4.4 EVALUATION CRITERIA

Regional planning objectives and evaluation criteria will influence the selection of air resource analytical procedures. Welfare criteria may be used to reflect the changes in community well-being that result from air resource planning activities. These welfare indicators must be designed to detect and, in some cases, measure advances toward the various goals of the air resource program.

Procedures for identifying specific criteria for analyses of government programs are outlined by H. T. Hatry,* as part of an attempt to clarify the basic concepts of governmental program planning analysis. Hatry also identifies specific criteria for use in evaluating alternative program proposals for carrying out major state and local governmental functions.

It is important that each criterion be relevant to the specific problem under consideration. Criteria applied in the solution of a specific problem should cover all major effects relative to the objectives. Ideally, each of the criteria should be capable of meaningful quantification, although for air resource programs it may be necessary to utilize purely qualitative measures. The criteria selected must relate to governmental objectives.

In the study cited above*, criteria are grouped into seven major program areas:

- Personal safety
- Health
- Intellectual development, personal enrichment
- Satisfactory home and community environment
- Economic satisfaction and satisfactory work opportunities
- Satisfactory leisure time opportunities
- Transportation - communication - location

*H. T. Hatry, "Criteria for Evaluation in Planning State and Local Programs," In H. H. Hinrichs and G. M. Taylor, eds., Program Budgeting and Benefit - Cost Analysis, Goodyear Publishing Co., Pacific Palisades, Calif., pp. 94-119, 1969

Most governmental programs can be evaluated by criteria that fall within one or two of these categories. For air pollution problems, however, relevant criteria may be found in all seven categories.

Monetary criteria are essential in the evaluation of air pollution programs, but the problems encountered in developing such criteria are quite complex since most air pollution effects are intangible (i.e., not readily measured). Monetary criteria which can be used to evaluate changes in gross income and economic activity in a region include:

- Manufacturing value added
- Retail and wholesale sales
- Amount of bank deposits
- Industrial capital expenditures

Due to the complexities associated with identification, assessment, and evaluation of air pollution effects, it is assumed that air resource decision-making in the near future will be based primarily on qualitative criteria and non-monetary quantitative criteria (such as documented effects as listed in the pollutant "criteria documents"). Evaluation criteria must be developed which are based on the criteria documents and other pertinent literature.

4.5 APPLICATION OF COST/BENEFIT ANALYSIS TO AIR RESOURCE DECISION-MAKING

The aim of cost/benefit analysis is to maximize the present value of all benefits less that of all costs incurred, subject to specified constraints. Cost/benefit analysis has been considered for use in the evaluation of transportation systems, criminal rehabilitation programs, urban renewal projects, and other social programs. Economists Prest and Turvey have stated that "cost/benefit analysis can also be applied to proposed changes in laws or regulations, to new pricing schemes and the like."[1]

In air pollution control, C/B analysis can be employed to compare the social costs and benefits resulting from a potential air resource

[1] Op. Cit. P. 686.

policy with those to be expected from a continuation of the existing level of effort (the "base alternative"), as shown in Figure 4-4. After defining the project life (the period of time over which costs and benefits will be measured), the costs and benefits of alternative air resource policies are computed and discounted back to the base year for purposes of comparative analysis. The resulting data may then be used in the evaluation of alternative policies.

Determination of the project life is an important factor in the design of a cost/benefit analysis study, since various costs and benefits are frequently realized at substantially different points in time. Project life is estimated rather subjectively, on the basis of an assessment of such factors as physical lifespan, technological change, shifts in demand, and emergence of competing products. For water resource projects involving the construction of dams, project life may be defined as 50 or 100 years for dams that are expected to perform for 150 years. In air pollution planning, a shorter project life is desirable because of the following factors:

- Frequent changes, in air resource requirements
- Rapid depreciation of control equipment (15 years or so)
- Obsolesence of current control equipment because of technological innovations
- Rapid technological and conceptual changes throughout the relatively new field of air resource management.

In conclusion, there are numerous other characteristics of the cost/benefit analysis framework which have been studied elsewhere in the application of C/B to other public programs. An investigation of such other factors is not within the scope of this report but is recommended for future research. Hopefully, this chapter has served to identify a few of the more important aspects which must be considered in the development of cost/benefit procedures for the analysis of air pollution control strategies.

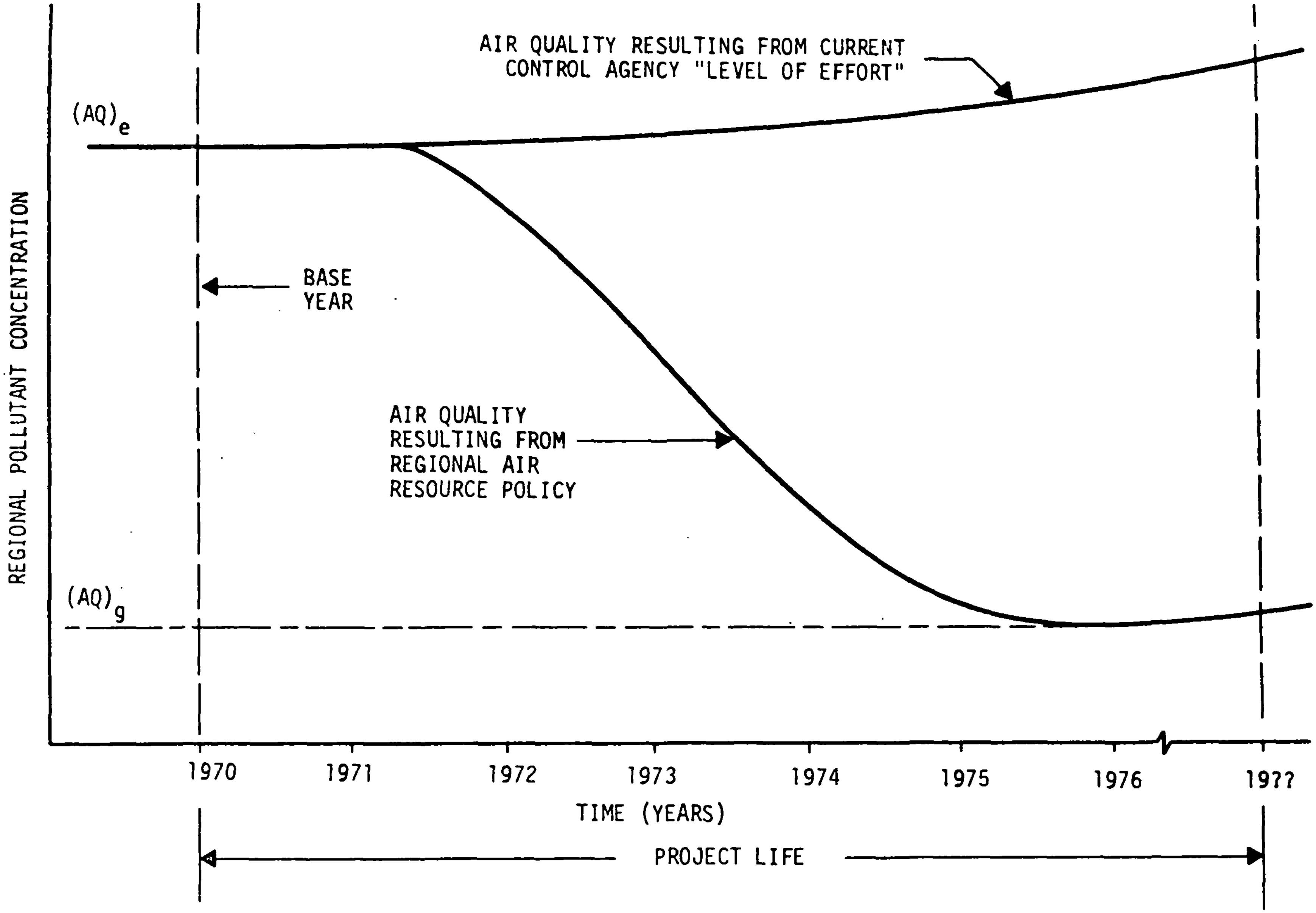

Figure 4-4. The Concept of Air Pollution Cost/Benefit Analysis

5.0 OVERVIEW OF THE COST/BENEFIT MODEL

The preceding chapters have focused on the need for improved analytical procedures to support air resource planning. The conceptual framework of the decision-making process has been identified, and the use of cost/benefit analysis in this process has been discussed.

The cost/benefit model is introduced in this chapter and alternative methods of model utilization are identified. The introductory material provided here serves as a transition from the previously cited needs for a conceptual framework for analytical studies to the practical procedures presented in Chapter 7.0 (Control Cost Estimating Procedures) and Chapter 8.0 (Benefit Model). Some applications of the C/B Model are presented in Chapter 9.0.

The C/B Model is an outgrowth of the Implementation Planning Program (IPP). The C/B Model is the last module of the Regional Air Pollution Analysis (RAPA) system as it was initially envisioned in 1968. A simple flow diagram of the C/B Model and its relation to IPP is shown in Figure 5-1. A general description of the model will serve as an introduction to the C/B system.

Two outputs of IPP now being used in regional air quality decision-making are: (1) point source control costs, and, (2) air quality display (as previously cited in Chapter 2.0). Point source control costs are estimated for each identified pollution source with particulate or sulfur dioxide emission rates greater than 24 tons per year (the commonly accepted cut-off point). The control costs are calculated on a source-by-source basis by hypothetically applying to each source the control system needed to comply with the emission strategy under investigation. The air quality display is a two dimensional plot of pollution concentration (in the form of isopleths) within an AQCR. The outputs of IPP serve as inputs to the C/B Model, as shown in Figure 5-1.

The efforts of this study (and the follow-on demonstration of the C/B Model) have been directed at the development of the Benefit Model. Procedures for estimating control agency and area source control costs are identified in Chapter 7.0 but have not been developed as part of this project. Thus, point source control costs (which are generally a significant

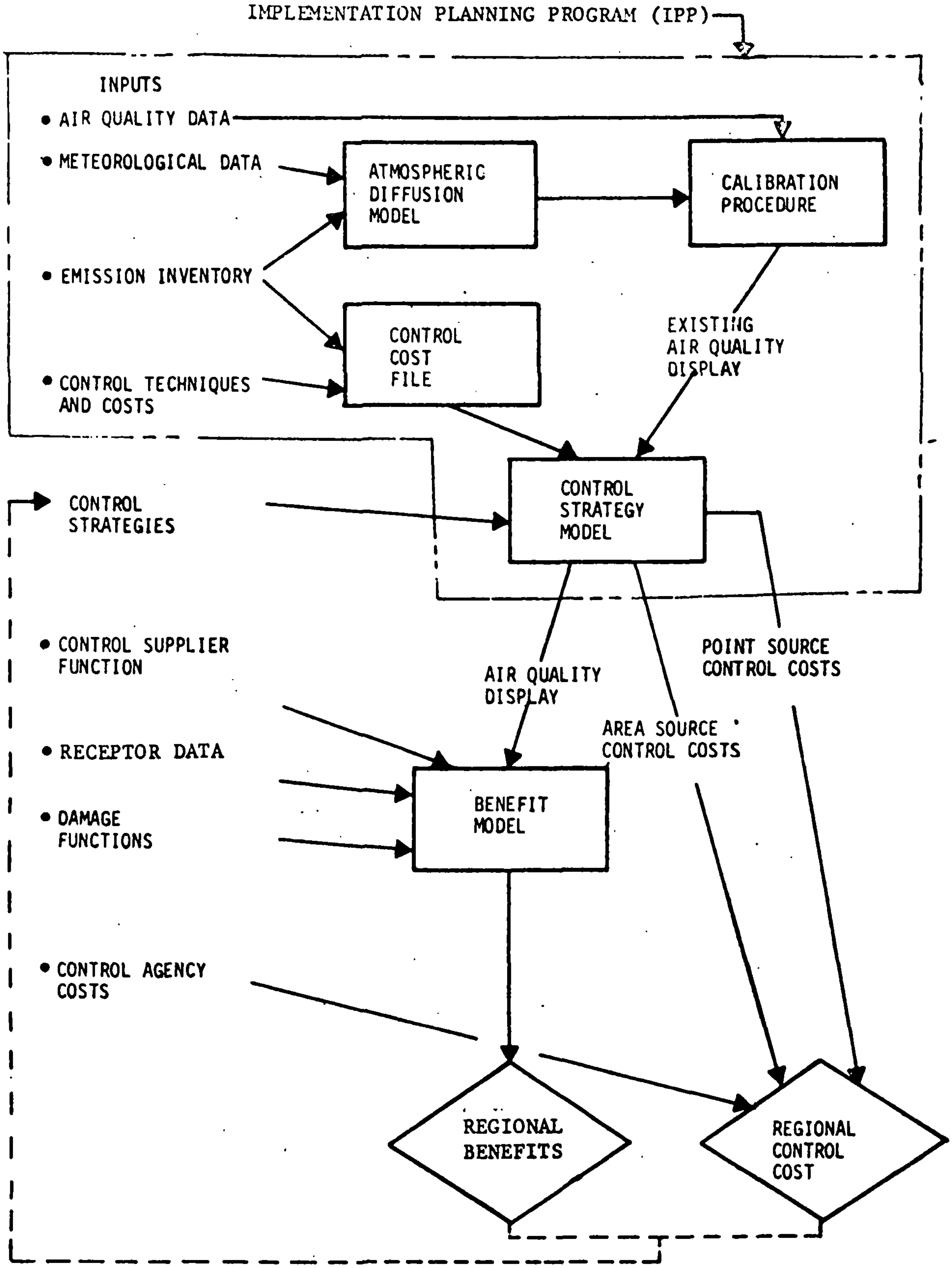

Figure 5-1. Regional Air Pollution Cost/Benefit Model

portion of the total regional control cost) are the only estimates of the cost of air pollution control available at this time.

The Benefit Model relates predicted control strategy pollutant concentrations to receptors and damage functions. The air pollutant-receptor relationship is an estimate of receptor exposure (i.e., dosage). The damage function, which relates the annual cost of air pollution damage to pollution concentrations, applied to the exposure estimate determines the damage cost estimate.

The Control Supplier Function, drawn in Figure 5-1, is a procedure for estimating the type and quantity of resources demanded for the control of air pollution for each strategy. Such an estimate of resources demanded is important for economic modeling. The need for this procedure has been identified and an elementary method of developing such data is presented in Appendix D.

5.1 VALUE OF THE COST/BENEFIT MODEL

The design philosophy of the Cost/Benefit Model has been based on the use of data which are either readily available or which are identifiable and capable of being collected within a reasonable period of time. The models are thus practical devices which use the best decision-making information available.

As a simulation tool, the Cost/Benefit Model will be useful for analysis of economic efficiency and economic redistribution of factors associated with alternative emission control strategies for an Air Quality Control Region (AQCR). The model may be used in sensitivity analyses to test various inputs such as damage functions. The effectiveness of alternative land use policies may also be determined for individual political jurisdictions within a region. Finally, the model can be used in simulation tests of research data on air quality and pollution effects.

As the design of the system progresses, problems concerning the sensitivity of data and other related considerations will arise. Analysis of these problems will improve the accuracy of regional air resource decision-making. The simulation model will make a significant contribution to the understanding of the decision-making process and of the total impact of air pollution control policies.

5.2 ALTERNATIVE TYPES OF MODELS

Two types of simulation models can be applied in evaluating alternative control strategies, cross-sectional models and longitudinal models. Cross-sectional models of which the IPP and regional econometric models are examples are somewhat simpler than longitudinal models.

The concept of a cross-sectional model is illustrated in Figure 5-2. As is shown, the conditions resulting from a control strategy are analyzed at one given point in time. Existing conditions (i.e., the base alternative) are first analyzed, and the effects of alternative policies are then evaluated, with the sssumption that all responses will occur instantaneously. This method of evaluation, however, is not consistent with the theoretical framework of C/B analysis, which requires that the costs and benefits of a proposed policy be evaluated over the defined project life and measured relative to the base alternative. There is, nonetheless, a great deal to be gained by cross-sectional analysis. The effort and cost involved in forecasting conditions and the uncertainty of these forecasts, especially in such areas as fuel availability, process and control technologies, etc., can make the use of longitudinal models impractical. Finally, the IPP model has the capability of analyzing future conditions and, in fact, has been used to evaluate 1980 conditions in the development of implementation plans for AQCRs.

Longitudinal C/B analysis traces costs and benefits to some future time and discounts cost estimates back to a base year (see Figure 5-3). The analysis may, for example, estimate costs and benefits annually from 1970 through 1975, assuming a project life of 5 years. The analysis should be sensitive to progress (in the form of improved air quality, thus, benefits which will occur during specified increments during the project life), as well as to variations in control costs.

Such an analysis is more realistic than the cross-sectional analysis, since costs and benefits do not occur instantaneously in real situations. Sources initially spend large sums for the analysis of emissions control problems, research, and equipment installation. The benefits from a control strategy are not immediately evident, since control systems must be designed, installed, and put into operation before benefits to receptors will be noted. The procedure of analyzing costs and benefits over time

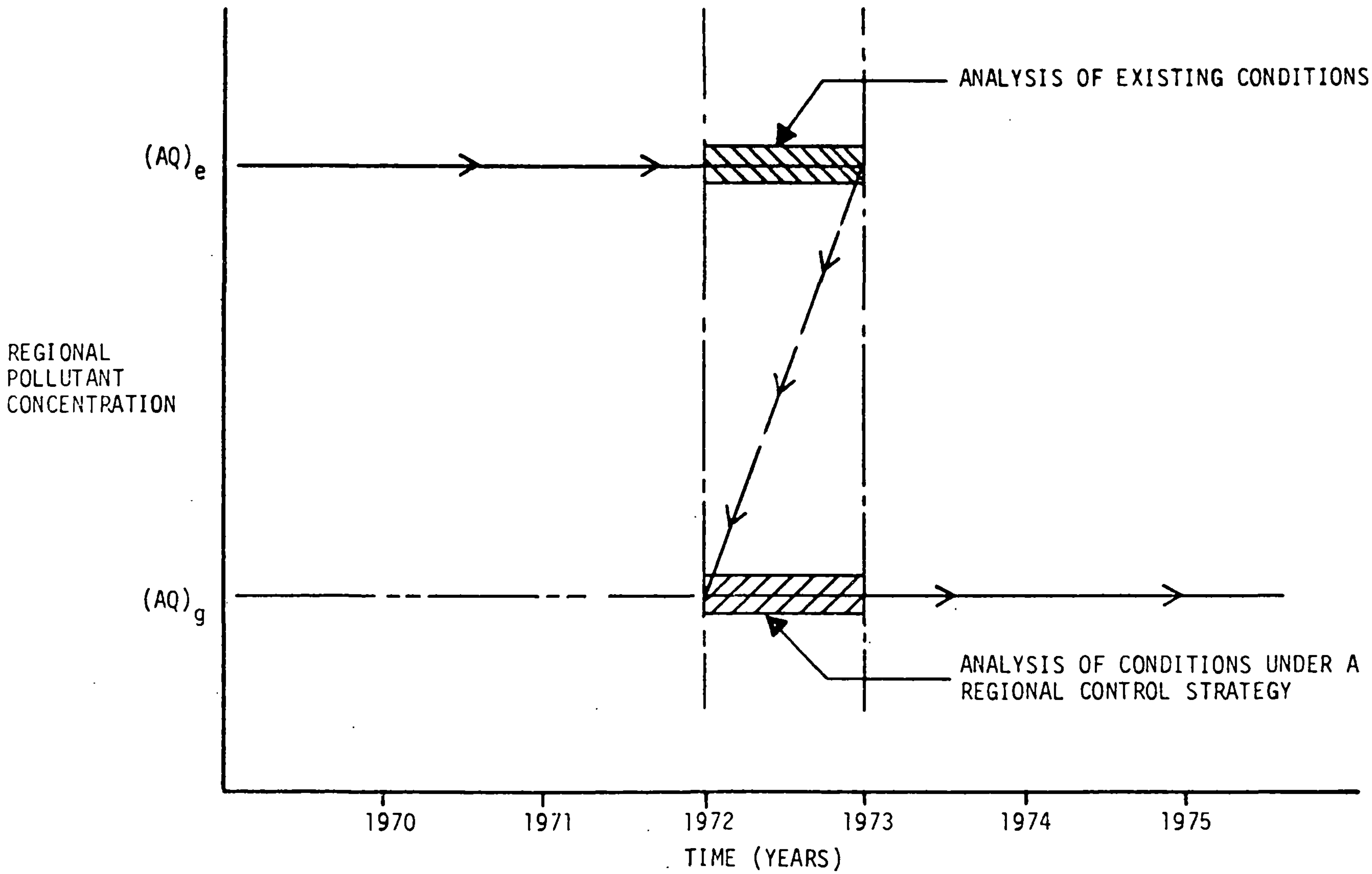

Figure 5-2. Form of Regional Cross-Sectional Analysis

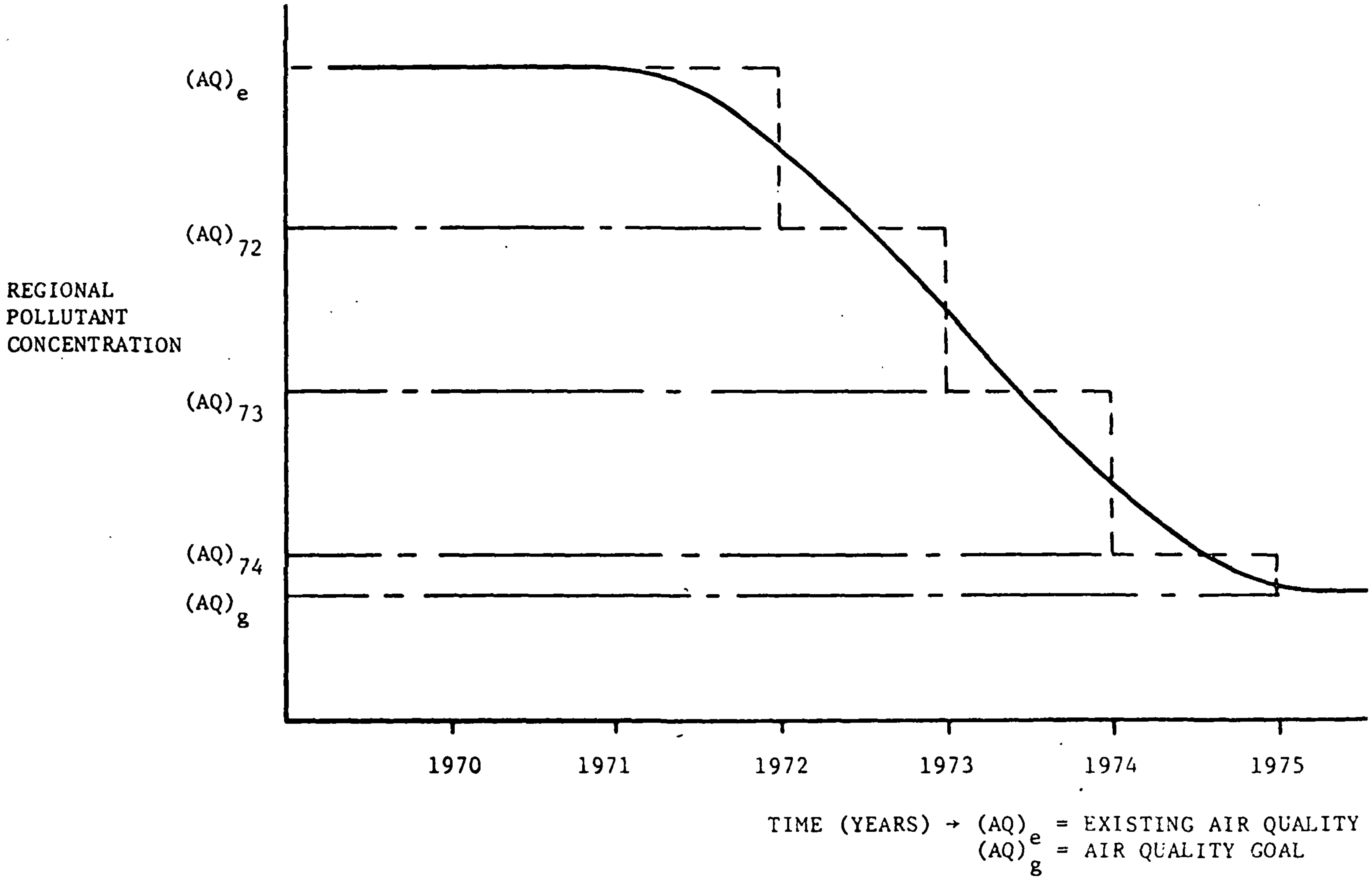

Figure 5-3. Longitudinal Cost/Benefit Study of Air Quality

and discounting these values back to a base year is utilized because of the time discrepancy in the flow of costs and benefits.

In addition to the data needed for a cross-sectional analysis, a longitudinal model will require forecasts of (1) population, (2) control technology, (3) control hardware and fuel prices, (4) sources, and, (5) emissions. A method must also be developed whereby the schedule for source compliance may be estimated. This method must evaluate the constraints which prevent instantaneous compliance by sources, including availability of control hardware and alternative fuels, political lobbying, enforcement procedure, and other factors. Longitudinal analysis thus involves repeated use of the cross-sectional model in combination with additional technical and economic forecasts.

The decision was made during this effort to concentrate on initial development of a cross-sectional C/B Model, due to limitations in the availability and accuracy of data on sources, emissions, damage functions, etc. On the basis of an evaluation of this cross-sectional model, a decision will be made concerning the additional development of a longitudinal C/B Model.

5.3 COST/BENEFIT MODEL UTILIZATION

The Cost/Benefit Model was designed with two immediate end-uses in mind. The first end-use is in welfare economic studies of air pollution control strategies in an AQCR. Control cost and benefit estimates, which are the outputs of the model, can be used directly for evaluating efficiency and equity considerations of control strategies. In this application, the cost/benefit ratios of alternative strategies may be weighed. The distribution of benefits and costs among certain groups of receptors within the AQCR can also be examined. The model can be used in this manner to evaluate air quality standards, land-use plans, industrial development siting and other regional plans.

A flow diagram of the C/B Model as used directly in decision-making is illustrated in Figure 5-4. The model, as shown in the Figure, has been integrated into the decision-making process cited earlier in this report. The direct application of C/B analysis represents one type of economic evaluation for alternative strategies.

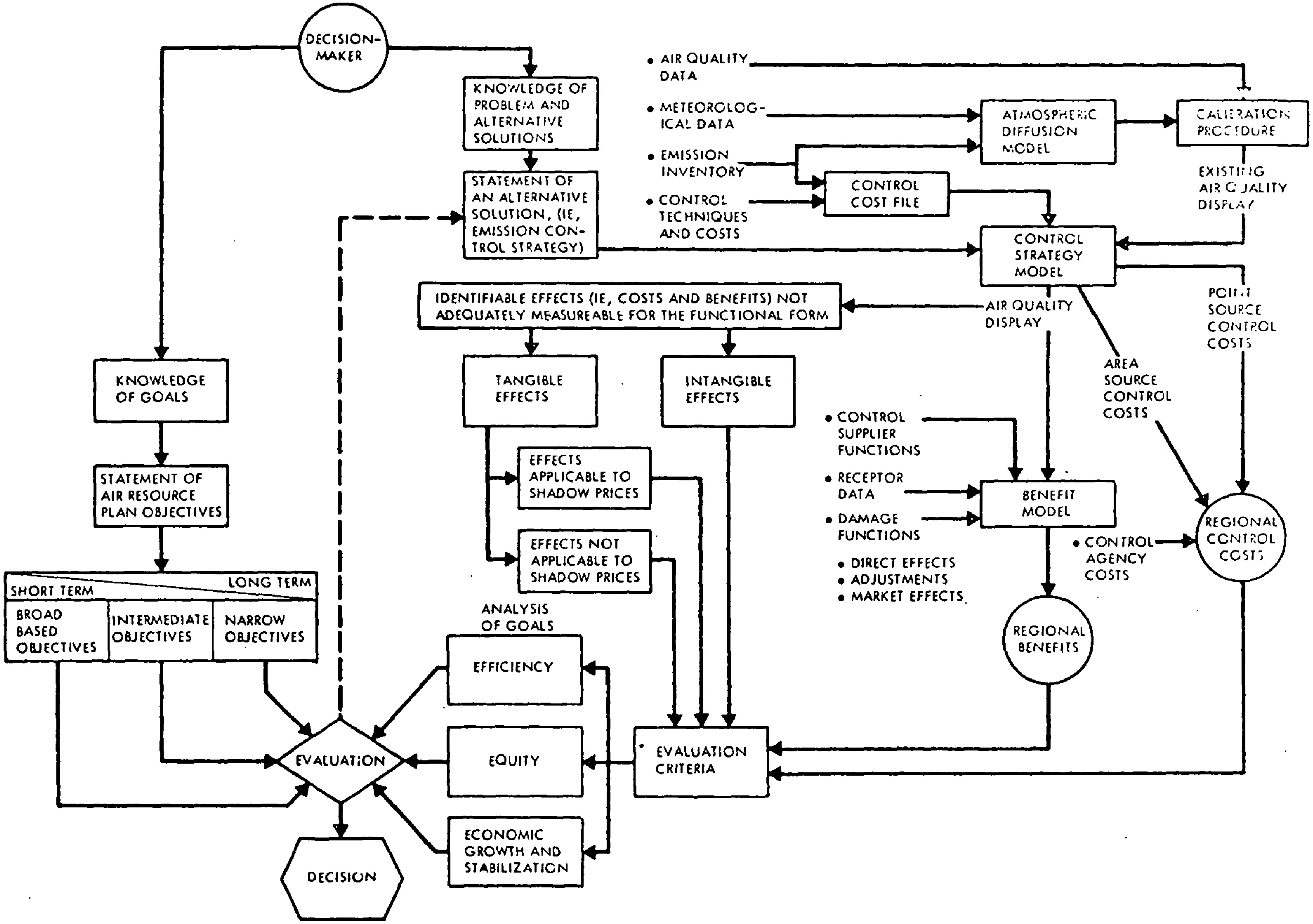

Figure 5-4. Direct Application of C/B Model in Strategy Analysis

But, this type of economic evaluation is limited in scope. The resulting estimates of control costs and benefits derived from the direct utilization of the model are not reflected as impacts on the economic activitiy of the region or the nation. The reallocation of resources in the economy, which is expected from an air pollution control policy, is not reflected in the C/B Model. Impacts on such economic indicators as employment, capital investment, regional income, value added, and others are not measured. Air pollution policies have an effect on such indicators on the region and the nation and should be evaluated.

To measure the impacts of control policies on the economy, the control cost and benefit estimates from the C/B Model must be evaluated in a series of economic models. CONSAD Research Corporation has developed an economic model system for this purpose (see Figure 5-5). The CONSAD model system has been designed to determine the economic effects of air pollution policies on regions and the nation. The economic model system currently consists of two major components, namely, a regional economic model (applied to 100 of the Nation's AQCRs) and a national input/output (I/O) model (see Figure 5-6). The regional economic model determines the effects of air pollution control costs and benefits on an open regional economy. The national I/O system is introduced to serve the role of the external markets (provide inter-regional feedback) for the regional economy, and also to measure the structural change of the national economy upon air pollution control to the 100 AQCRs.[1] The economic model system measures effects of air pollution strategies in terms of changes in unemployment, value added, income, and other measures of economic activity.

This report focuses on the utilization of the C/B Model by itself. In this manner, the costs and benefits are used directly in decision-making. When the economic model system is utilized, the benefits must be converted into a form which reflects changes in disposable income and productivity of labor and capital. This report does not focus on such economic evaluations. See referenced document[1] for a discussion of the principles and procedures of the economic model system.

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[1] For a complete description of the economic model system, see An Economic Model System for the Assessment of Effects of Air Pollution Abatement, CONSAD Research Corporation, Pittsburgh, Pa., April 15, 1971.

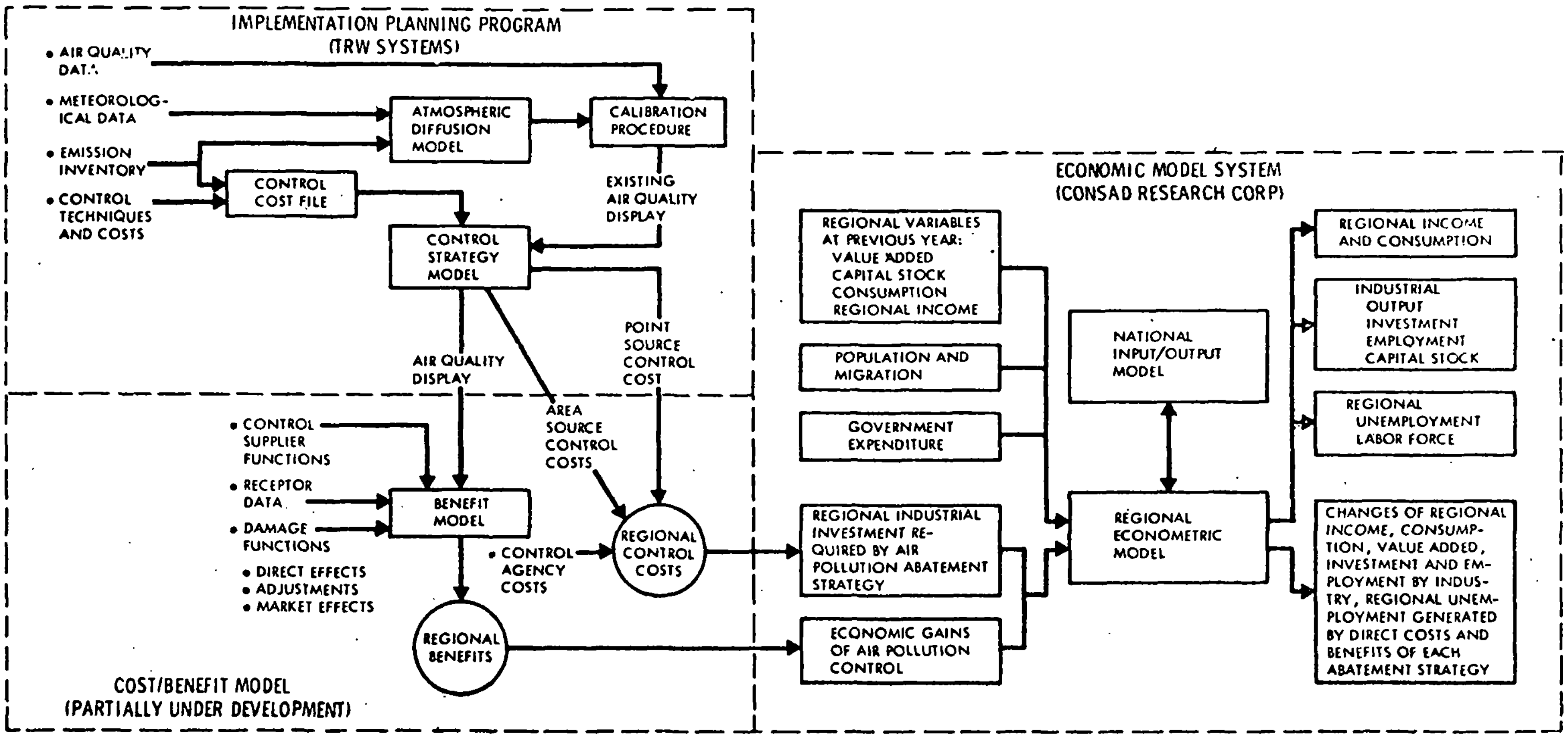

Figure 5-5. Use of C/B Model with Economic Model System

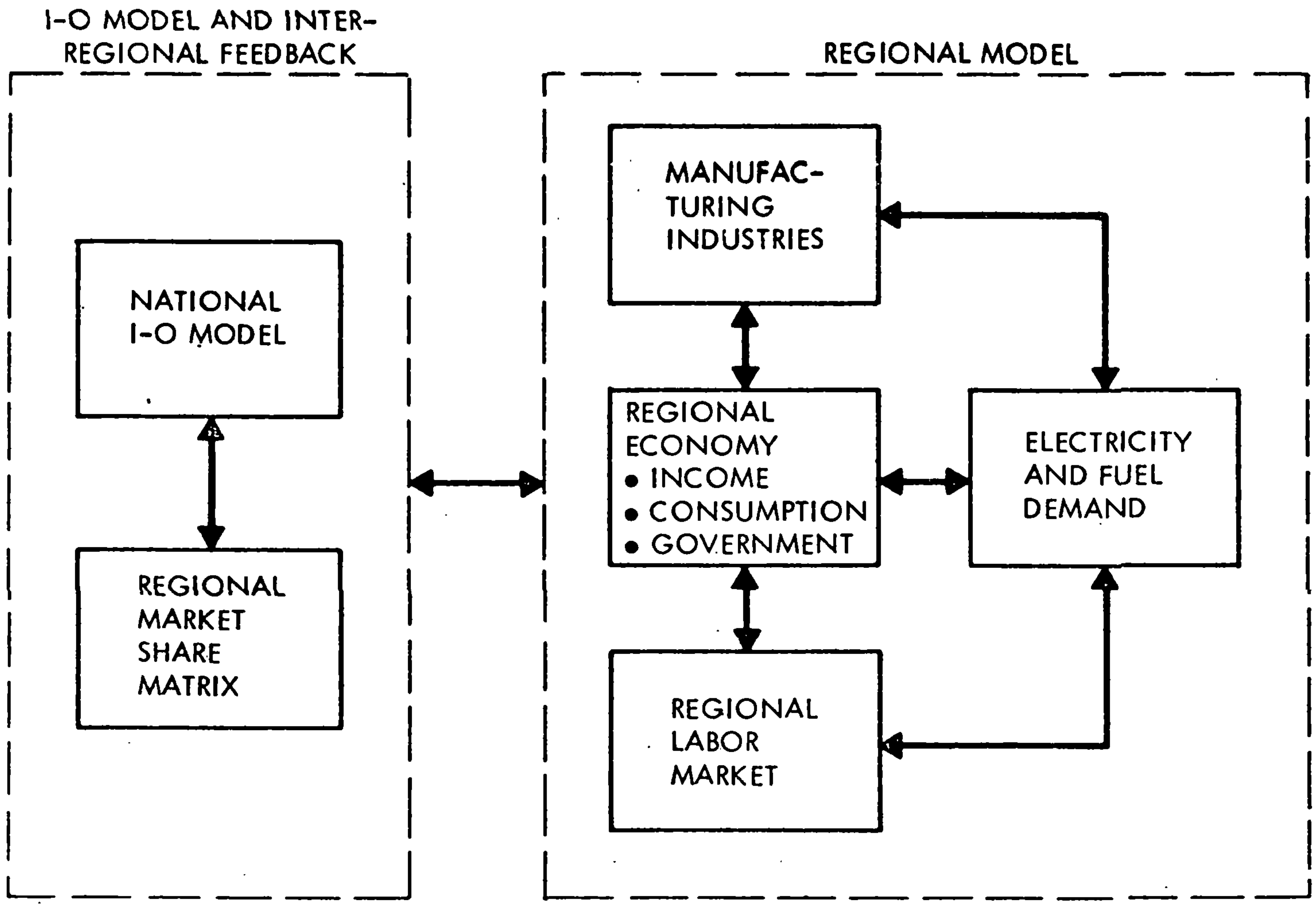

Figure 5-6. Major Components of the Model

6.0 CONTROL COST ESTIMATING PROCEDURES

The IPP model currently predicts only control costs for point sources (see Section 5.0 for a discussion on this limitation). Since the social cost of controlling air pollution includes more than point source control costs, this chapter focuses on the development of other cost estimating procedures which may, in the future, supplement the point source control costs. The major cost categories recommended for inclusion in the model are identified as "area source control costs" and "control agency costs."

In addition, this chapter presents a detailed description of the Implementation Planning Program (IPP) and its uses. This presentation is important because IPP provides the control cost estimates and the air quality display which are the inputs to the Benefit Model (Chapter 7.0).

6.1 IMPLEMENTATION PLANNING PROGRAM

The Implementation Planning Program is illustrated in Figure 6-1. The heart of the IPP is the Atmospheric Diffusion Model, which predicts ambient concentrations of pollutants in an AQCR by mathematically determining the dispersion of pollutants from sources. Input to the model is in the form of an emission inventory which lists the major sources of pollutants and gives detailed engineering parameters for the sources of pollution and the emissions generated. Emission contributions from sources that cannot be identified individually are aggregated to form "area sources." Meteorological data are included on wind speed, wind direction, mixing depth, and other phenomena characterizing the transport mechanism whereby pollutants are transmitted from sources to receptors.

To improve the accuracy of the diffusion model, a calibration procedure is used to compare predicted pollutant concentrations with measured air quality values. The procedure adjusts for errors in the diffusion model which result from inaccuracies in the mathematical diffusion equation, inaccurate source-emission and meteorological data, irregularities in the topography of the region (which the model assumes to be a flat plain), and other deviations. The Atmospheric Diffusion Model thus predicts the concentration and distribution of pollutants for the AQCR with reasonable accuracy.

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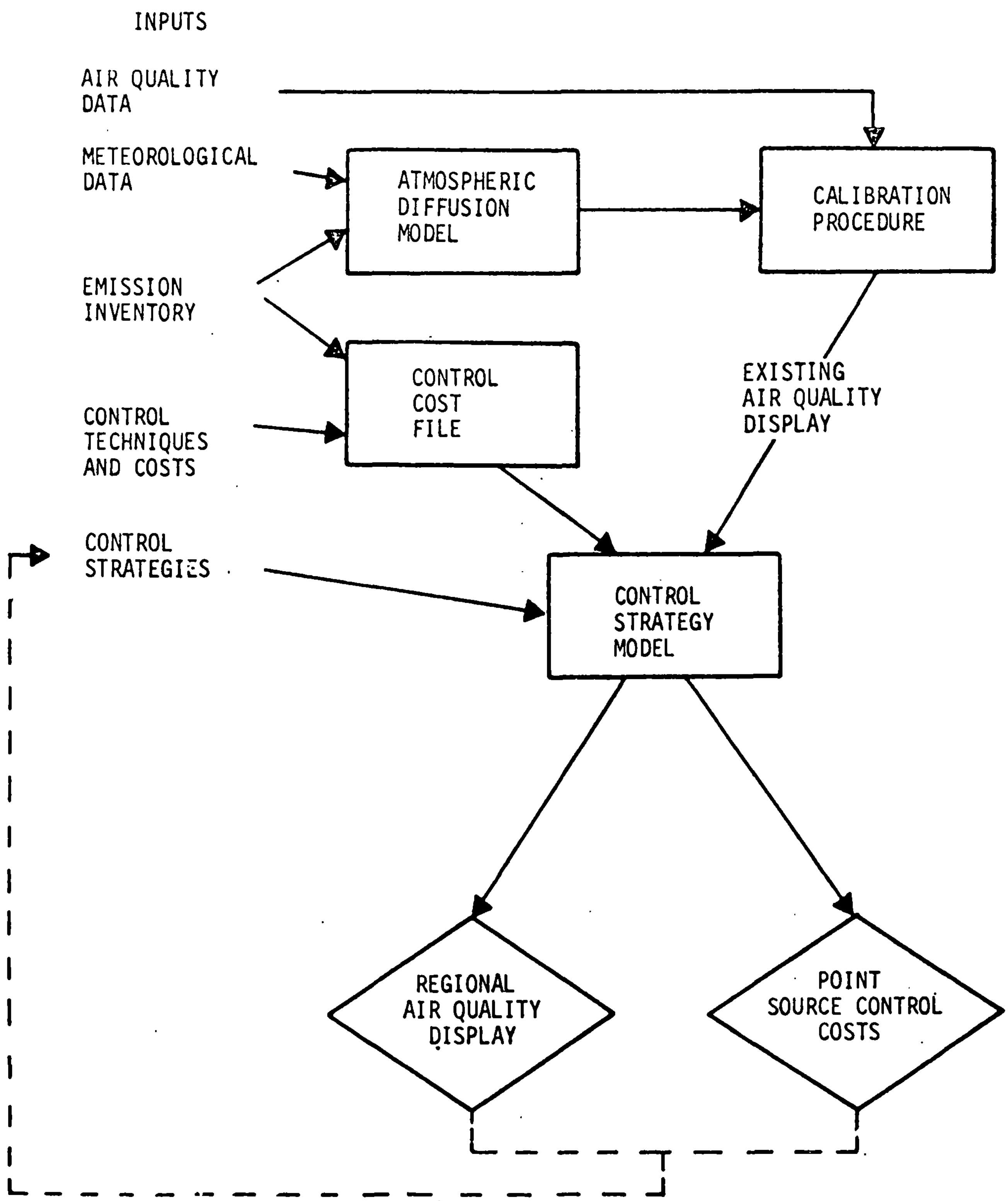


Figure 6-1. Implementation Planning Program

Before regional emission control strategies are tested, a Control Cost File is prepared by the computer. Each major source (i.e., point source) is assigned all control devices which may reasonably be used for reducing emissions from that source. For particulate emissions, control devices generally take the form of emission control equipment applied externally to the polluting process. For sulfur dioxide emission, either low sulfur fuel substitutions or flue gas desulfurization techniques are entered into the file. The Control Cost File thus takes the form of a list of all point sources and the appropriate control devices for each source, with each alternative device representing a different level of control efficiency for a given source.

The IPP model is used to evaluate the effectiveness of alternative control strategies for a region. A control strategy is a combination of emission control standards for specific categories of emission sources.[1] Different emission standards are normally applied to three major source categories: solid waste disposal, industrial processes, and fuel combustion. An additional emission standard uniformly reduces the emissions from area sources by a specified amount.

When the effectiveness of a control strategy is analyzed, the Control Strategy Model applies the designated emission standards to each of the point sources in the AQCR. The reduction in emissions from point sources generally lowers the pollutant concentrations within the region. The Control Strategy Model recomputes the pollution concentration distribution and calculates the emission control costs for sources affected by the emission standards. The most significant output of the Control Strategy Model is a regional display of pollutant concentrations and an estimate of the annual control cost for all sources in the region which must comply with the control strategy.

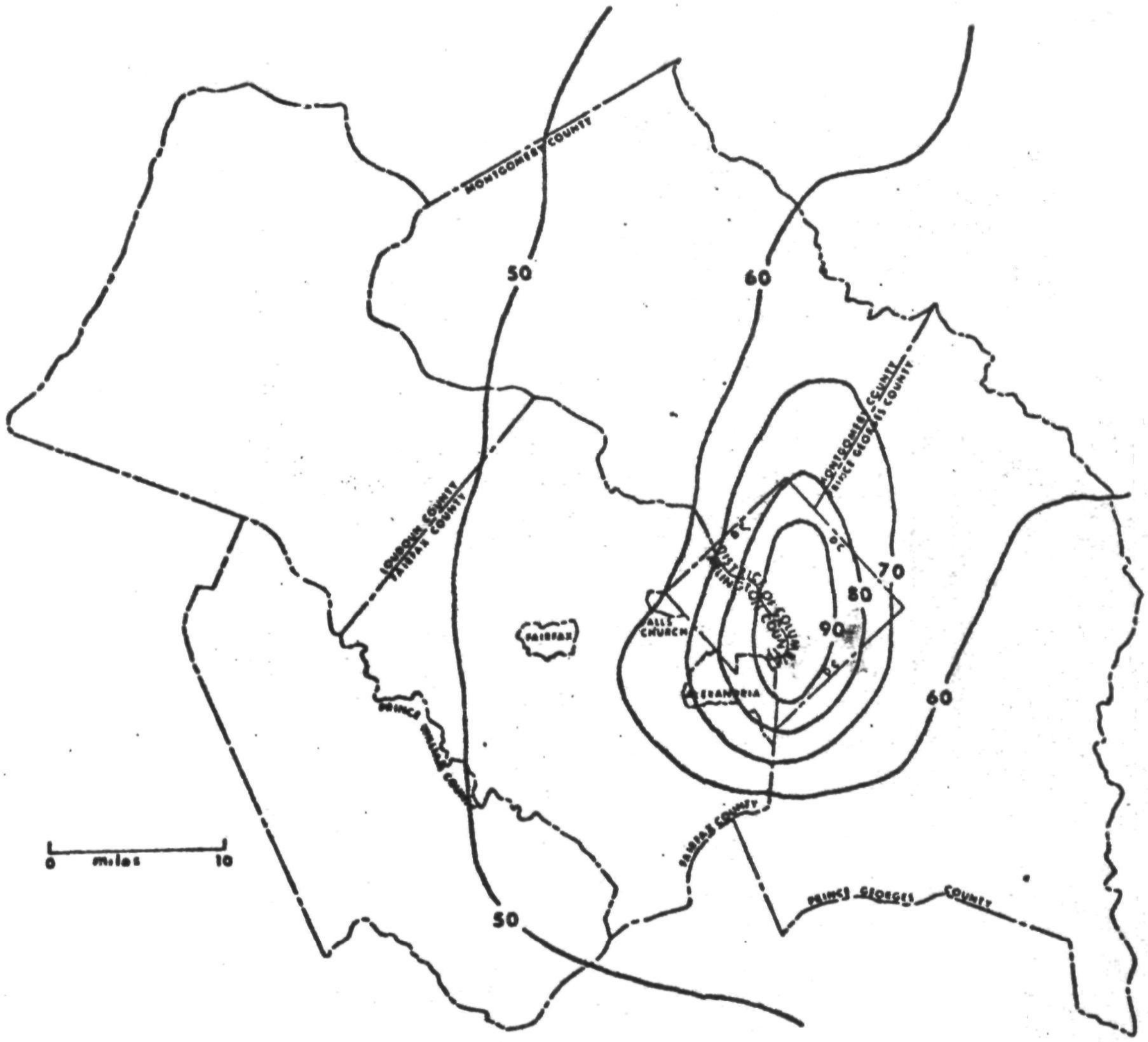
The IPP model is now being used by APCO to evaluate emission control strategies in implementation plans. TRW has utilized the IPP model in evaluating emission standards for the District of Columbia portion of the National Capital Interstate Air Quality Control Region (NCIAQCR) and the model implementation plan for the Metropolitan Cincinnati Interstate Air

Quality Control Region (NCIAQCR). The use of the IPP model in evaluating the effectiveness of alternative particulate control strategies in the NCIAQCR is briefly described in the following paragraphs.

Figure 6-2 illustrates the existing ground-level particulate concentrations in the NCIAQCR as predicted by the calibrated Atmospheric Diffusion Model. In this region, the goal of the implementation plan was to attain an annual arithmetic average of particulate concentrations of 86.6 $\mu g/m^3$ as an interim standard and 65.2 $\mu g/m^3$ as a long-term standard. In testing the acceptability of a strategy, the IPP model is used to ascertain the annual average concentration does not exceed the long-term air quality standard at any point in the AQCR.

To meet the above standards, a control strategy for reduction of the particulate concentration was required. The isopleths in Figure 6-2 indicate that annual average concentrations above 90 $\mu g/m^3$ were observed in the NCIAQCR. Concentrations of up to 107.7 $\mu g/m^3$ could be expected within this 90 $\mu g/m^3$ isopleth (the 100 $\mu g/m^3$ isopleth was too small to be drawn on the map). Analytical results for 10 control strategies are presented in Table 6-1. The reduction in emissions from point and area sources is indicated, as well as the control cost expected and the pollutant concentrations at the maximum receptor in the region. Strategy 18 was selected for the District of Columbia, on the basis of (1) control costs, (2) expected air quality (which, within experimental error, approximated the air quality standard), and (3) the assumption that the emission control technologies required to meet the strategy were technically feasible and economically reasonable. Particulate levels expected after the application of the proposed control strategy are illustrated in Figure 6-3.

In summary, the IPP model is a tool which measures the effectiveness of alternative control strategies. The display of expected air quality is the most valuable evaluation criterion available for resource decision-making. The calculated control costs represent only an estimate of the direct cost of emission control to the major point sources, however, and have not been utilized in economic analyses. Costs have thus had only a general effect on air resource decision-making.



NOTE: **Annual Concentration in $\mu g/m^3$**

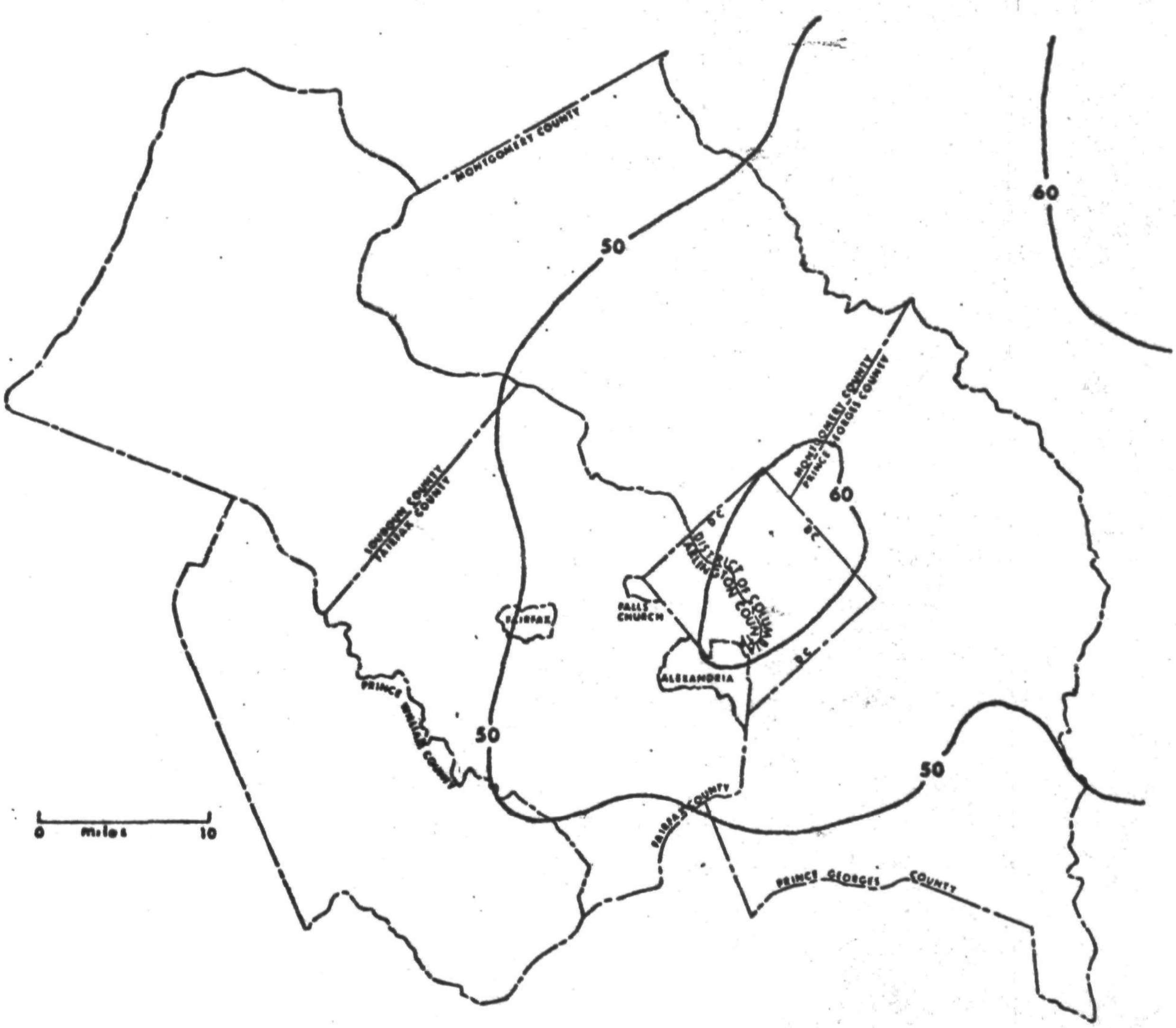
Figure 6-2. Existing Ground Level Particulate Concentrations in the NCIAQCR as Computed by the Verified Diffusion Model

TABLE 6-1

PARTICULATE CONTROL STRATEGIES - NATIONAL CAPITAL INTERSTATE AIR QUALITY CONTROL REGION

	POINT SOURCES		AREA SOURCES		CONTROL COST		
Strategy Number	Percent Reduction	New Emission Rate (tons/day)	Percent Reduction	New Emission Rate (tons/day)	$\$ \times 10^6$	$/ton removed	Maximum Receptor ($\mu g/m^3$)
		(84.7)**		(75.6)**			
1	36.3	54.0	18.0	62.0	0.5	47	107.7
2	87.4	10.7	51.4	36.7	13.9	514	92.2
3	62.2	32.0	47.5	39.7	4.0	210	90.0
4	52.7	40.1	48.6	38.9	4.4	267	76.0
5	86.4	11.6	51.4	36.7	11.8	471	69.4
6	78.2	18.4	51.4	36.7	11.6	489	69.7
7	76.0	19.9	51.4	36.7	11.6	489	69.7
8	36.3	54.0	36.3	48.2	0.5	47	89.8
9	41.0	50.0	18.6	61.6	0.6	44	81.8
10	77.0	19.5	51.4	36.7	11.6	489	70.0
18	70.4	25.0	51.4	36.7	10.8	498	68.2

**Existing conditions based on the 1969 inventory collected for the NCIAQCR and the validated diffusion model.



Note: Annual Concentrations in μg/m³

Figure 6-3. Predicted Particulate Concentrations After the Enactment of the Proposed Emission Control Strategy in all Political Jurisdictions

6.2 POINT SOURCE CONTROL COSTS

The IPP model computes the expected emission control costs for both public and private point sources. Control technologies are hypothetically applied to point sources as a basis for the cost-estimating procedures.[1] These costs are generally acceptable for cross-sectional C/B analyses. For greater accuracy, some fuel prices and control technique assumptions should be upgraded, since the costs are based on 1967 data.

6.3 AREA SOURCE CONTROL COSTS

Emission sources in an AQCR that are not considered point sources are represented in the IPP model as area sources. The area source category includes residential and small commercial fuel combustion, residential and commercial solid waste, automobiles, and process sources not large enough to be identified as a point source. Area sources are not identified individually in the IPP model, and emission control cost estimates are not prepared for these sources.

The task of identifying control techniques and control costs for area sources has not been a high-priority item under the present RAPA contract because of other priorities. As cost/benefit analysis techniques are developed, however, greater emphasis must be placed on determining rigorous cost estimates for all important sources. The resources invested in such cost estimates must, of course, be weighed against the benefits derived. Since cost estimates for point sources alone are inadequate for regional C/B evaluations, it appears the expenditure of resources in developing a cost-estimating procedure for area sources is justifiable.

No set procedure was developed during this study for determining area source control costs. The following guidelines were defined, however, as a basis for future research:

- A uniform reduction in area source emissions throughout a region will affect individual jurisdictions differently because of differences in density and the mix of sources. Area source cost functions should thus be developed on a

[1]For a full description of the control cost estimating procedure, see TRW Systems Group, Air Quality Implementation Planning Program - Volume I, Operators Manual, Contract No. PH 22-68-60, November 1970.

census tract or grid basis so that cost functions can be related to characteristics of the local community or neighborhood.

- Crude linear approximations of area source control cost functions may be sufficiently sensitive for the model (the function being determined by only one or two cost-effectiveness data points and the origin). The functions may be based on census tract or other data and economic data from the Economics of Clean Air Report.[1] The following relationships may be developed:

    - Residual heating control costs, based on number and size of households per census tract.
    - Auto exhaust control costs, based on number of automobile miles travelled.
    - Solid waste disposal control costs, based on population per census tract.

6.4 CONTROL AGENCY COSTS

Another cost category which must be evaluated in a C/B analysis is the cost associated with implementation of the control program by the public sector. For purposes of the analysis, control agency costs can be taken as an allocation of the control agency budget for all jurisdictions in an AQCR for control of the specific pollutants under analysis. In evaluating the cost of a specific control strategy, the relevant control agency costs are the incremental costs determined from the budget required for the current level of effort and the budget required to support the agency under the proposed control strategy. Figure 6-4 shows the format used for reporting control agency costs in the NCIAQCR.

Most of the current air pollution control legislation is based on the concept of controlling pollutant emissions through direct regulation (in the form of an emission standard). The Tax Reform Act of 1969, on the other hand, includes inducements in the form of a provision for a 5-year

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[1] U. S. Senate, The Economics of Clean Air, Third Report of the Administrator of the Environmental Protection Agency to the Congress of the United States, U. S. Government Printing Office, Washington, D. C., January 1971

JURISDICTION	1970 BUDGET* ($)		BUDGET FOR COMPLIANCE** ($)	
POLLUTANTS	TOTAL	SO_x & PART.	TOTAL	SO_x & PART.
MARYLAND				
● MONTGOMERY CTY.				
● P. GEORGES CTY.				
STATE OF VIRGINIA				
● ARLINGTON CTY.				
● FAIRFAX CTY.				
● LOUDOUN CTY.				
● PRINCE WILLIAM CTY.				
● ALEXANDRIA CITY				
● FAIRFAX CITY				
● FALLS CHURCH				
DISTRICT OF COLUMBIA				
TOTAL				

*CURRENT "LEVEL OF EFFORT."

**BUDGET NEEDED TO SUPPORT AIR RESOURCE PROGRAM FOR AN IDENTIFIED CONTROL STRATEGY.

Figure 6-4 . Accounting for Control Agency Costs write-off on pollution control equipment installed in industrial plants which were in operation on December 31, 1968. Some states have likewise recognized the need for and desirability of some form of mechanism to help companies absorb the heavy initial control costs. Such relief generally takes one of three forms. The purchaser of control equipment may be allowed to accelerate the depreciation write-off (over a period of 1 to 5 years) for income tax or franchise tax purposes. Purchases of pollution abatement equipment may be exempted from sales and use taxes, or pollution abatement installations may be exempted from property taxes.

In cost/benefit analysis, it is important to include the social costs to the public sector which result from financial incentives, credit subsidies, and other inducements for private sector emission control. When air pollution control strategies in a region are based on direct regulation, the social cost of the inducement is not substantial (but should nonetheless be evaluated). When tax write-offs, direct payments, and other forms of financial inducements are utilized, the social cost to the public sector is substantial. More intensive study of such schemes is recommended.

7.0 BENEFIT MODEL

The social costs of air pollution control include all economic effects resulting from the allocation of resources to administration, research, enforcement, measurement, and implementation in connection with the control of pollutant emissions. Social benefits, on the other hand, are those increases in welfare which result from improved air quality. To measure the benefits resulting from the application of control strategies, a Benefit Model has been developed (see Figure 7-1). The Benefit Model determines damage costs by relating air quality data to receptor data and to damage functions which express the social value of air quality data to receptor data and to damage functions which express the social value of air quality effects on receptors. The difference in air pollution damage cost between existing air quality and the control strategy air quality is the value of the strategy "benefit."

The control supplier function, also shown in Figure 7-1, is a relationship (not yet developed) which predicts the stimulus to the regional economy resulting from the demand for air pollution control equipment and services. Benefits to control equipment suppliers are an important input in regional econometric modeling and, although not part of the present contract, have definite economic significant and are briefly discussed in Appendix D.

To put the Benefit Model in perspective, a flow diagram of a cross-sectional C/B model (without the Control Supplier Function) is presented in Figure 7-2. As illustrated, control strategy air quality is first related to receptor information (census tract data). Damage is determined for each census tract by means of a damage function which expresses damage cost as a function of air quality and census data. The regional damage cost is computed by summing overall census tracts in the AQCR.

The design of the Benefit Model is described in the following sections.

7.1 RECEPTOR DATA

In cost/benefit analysis, the consequences of government policies are traced back to the fulfillment of individual (or household) wants.

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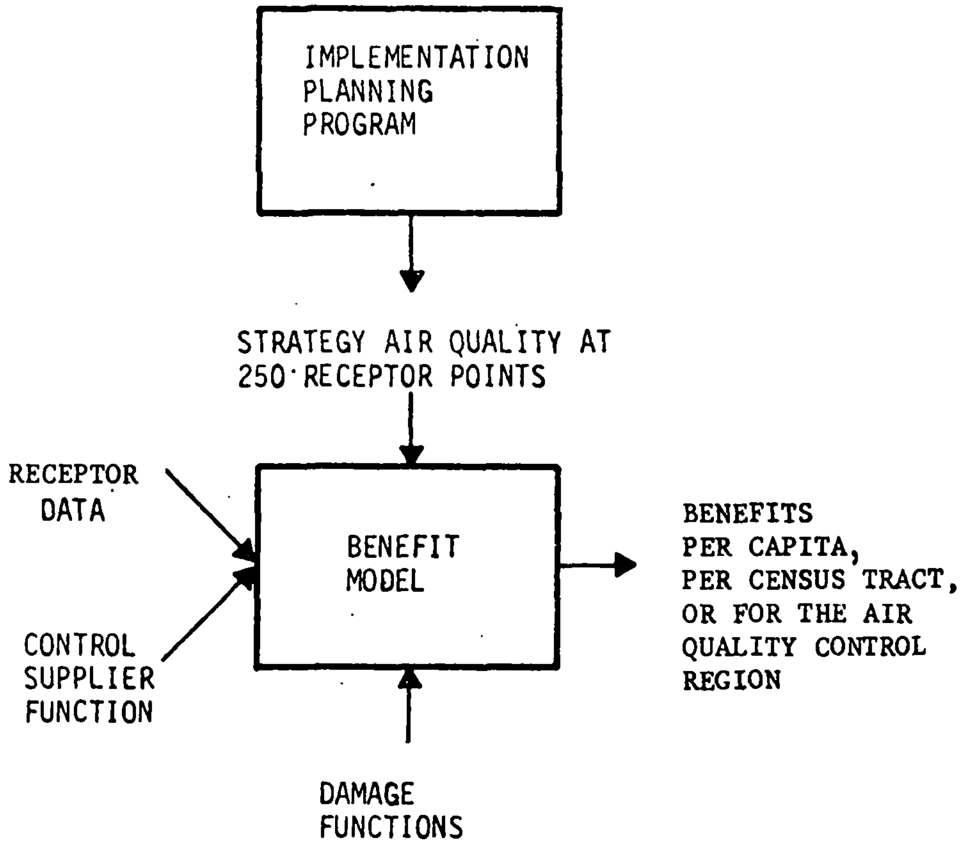


Figure 7-1. Benefit Model Design

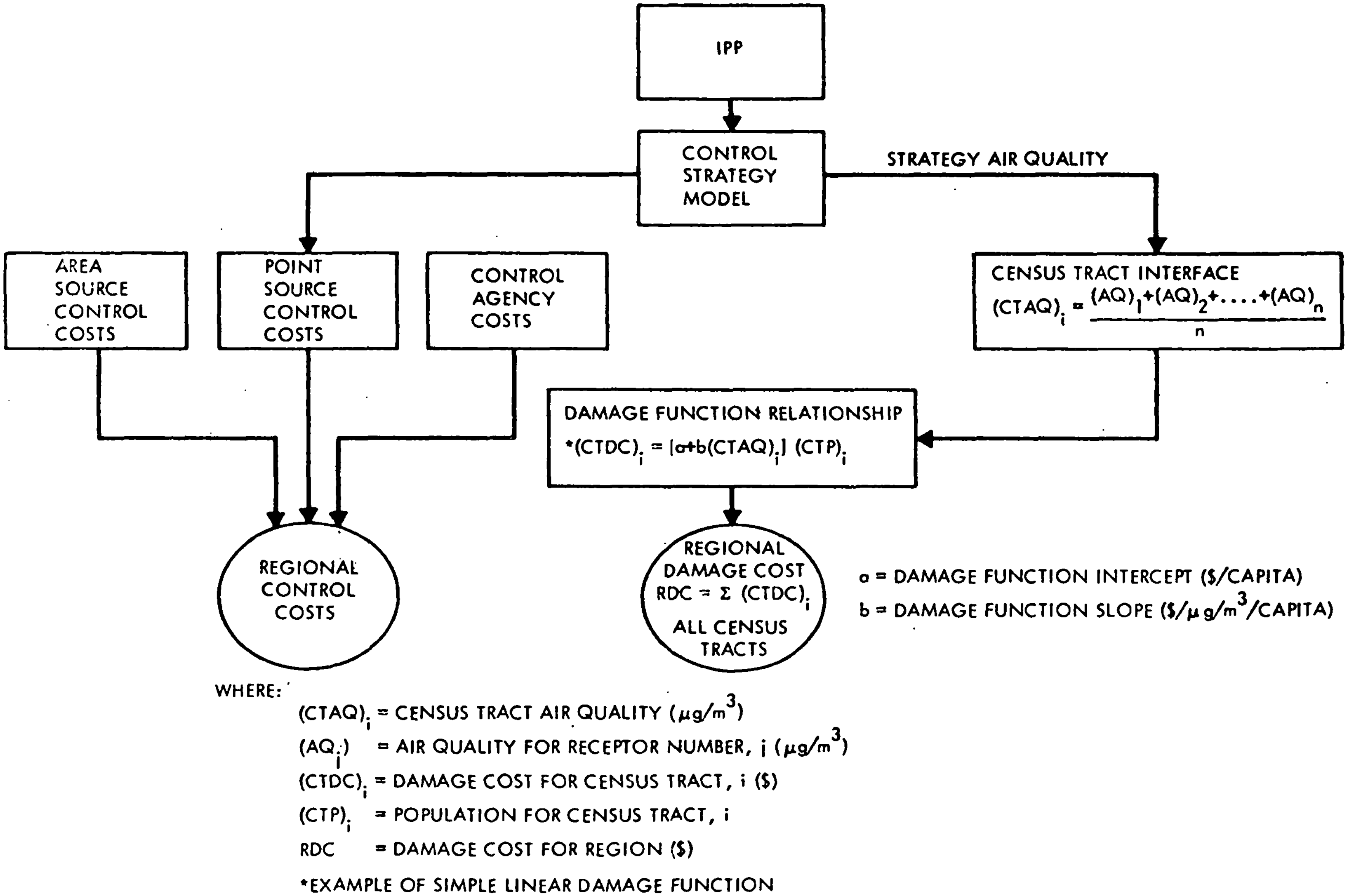


Figure 7-2. Cross-Sectional Cost-Benefit Model for Given Pollutant and Damage Function

This rule of cost/benefit analysis was the determining factor in the selection of census tract information to describe air pollutant receptors at this time (additional data descriptive of receptors may be added at some later time). In addition to obtaining extensive information on the population of a region, the Bureau of the Census tabulates significant information on individual and household characteristics. The Department of Commerce defines census tracts as follows:

> "Census tracts are small, permanently established, geographical areas into which large cities and their environs have been divided for statistical purposes. Tract boundaries are selected by local committee and approved by the Bureau of the Census. They remain the same for a long time so that statistical comparisons can be made from year to year and from census to census. The average tract has over 4,000 people and is originally laid out with attention to achieving some uniformity of of population characteristics, economic status, and living conditions. In each decennial census, the Bureau of the Census tabulates population and housing information for each tract--hence, the name "census tract"."[1]

It is important to know the criteria used in defining census tracts. The Census Bureau has found that certain definitive criteria should be applied in order to make the tract statistics useful to as many interests as possible and to facilitate enumeration. These standards limit the populations, specify the best types of boundaries, and indicate the type of homogeniety needed. The criteria* are as follows:

- Population Size - Census tract should contain between 2500 and 8000 inhabitants, but may contain somewhat more. Tracts covering a large population are desirable if the population is homogeneous. The average size for all tracts should not be less than 4000.

- Boundaries - Census tract boundaries should follow permanent and easily recognized lines (state lines,

[1] U.S. Department of Commerce, Census Tract Manual, Washington, D.C., U.S. Government Printing Office, p. 1, January 1966.

*These descriptions have been condensed from the Census Tract Manual (Ibid) pp. 32-38.

highways, railroads, rivers, streams, channels, and the like). Alleys are normally not used and should not be unless named.

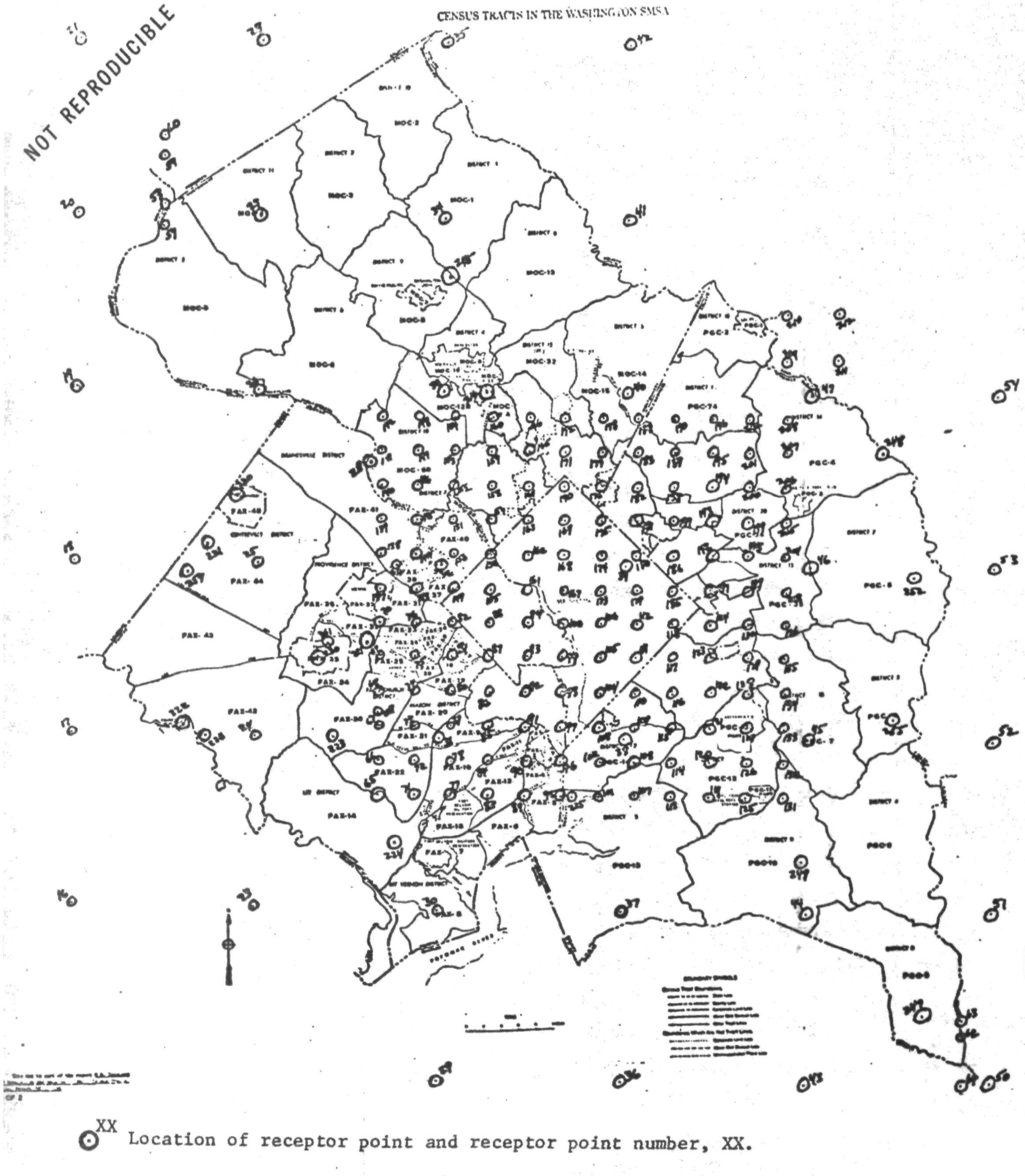
- Homogeniety - Census tracts should contain, insofar as is practicable, persons of similar racial or nationality characteristics, of similar economic status, and of similar housing. If a tract includes both expensive homes and slum dwellings, for example, average statistics for the tract as a whole will not reflect the condition of either group.

- Geographic Shape and Size - In general, a census tract should be compact. It is desirable to avoid panhandles, L's, dumbbells, and other elongated shapes. Irregular boundaries should be avoided wherever possible.

As part of this effort, a procedure was developed for relating air quality data (as calculated by the Atmospheric Diffusion Model) to census tracts. The Atmospheric Diffusion Model is currently designed to compute air pollutant concentrations at approximately 250 receptor points (located on a grid) within an AQCR. Figure 7-3 shows the relationship between receptor points and census tracts for the Washington, D. C. Standard Metropolitan Statistical Area (SMSA). The procedure uses the existing receptor grid and census tract data, since reorienting the receptor grid to the centroid of each census tract would have been costly initially and would have likewise led to increases in operational computer time. Instead, an analytical procedure was developed to form the interface. This procedure will be described in detail in the follow-on report. Briefly, the procedure involves the selection of specific receptor points to represent each census tract. This operation is conducted once for each AQCR by a researcher before the regional analysis is begun. Each census tract is identified by one or more receptor points which represent that tract (see Figure 7-4). The computer then calculates a simple arithmetic average of the pollutant concentrations at the receptor points. This average is referred to as the "census tract air quality" (CTAQ).

7.2 DAMAGE FUNCTIONS

Damage functions are the most complicated and least clearly defined inputs to the Benefit Model, owing to the lack of knowledge of the cause-and-effect relationship between air pollutants and receptors and the current inability to place a value on the effects.



XX Location of receptor point and receptor point number, XX.

Figure 7-3a. Receptor Points Superimposed on Census Tracts of the NCIAQCR (Macroscopic view)

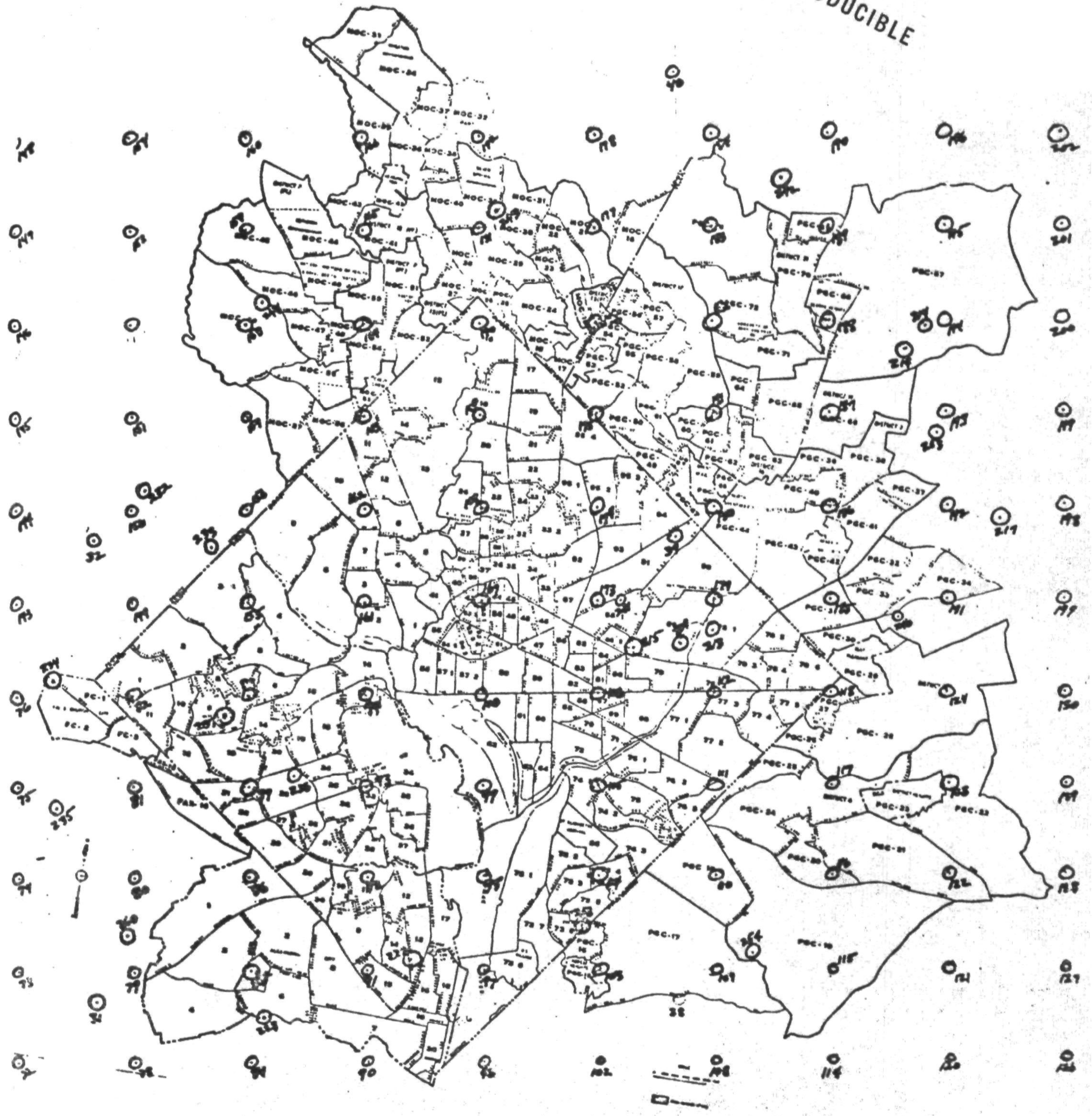


Figure 7-3b. Receptor Points Superimposed on Census Tracts of the NCIAQCR (Microscopic view)

INPUTS

RECEPTOR NUMBER	AIR QUALITY ($\mu g/m^3$)	
	PART.	SO_x
045	73.6	52.1
067	72.5	54.3
163	70.1	50.5

CENSUS TRACT NUMBER	RECEPTOR POINTS REPRESENTING CENSUS TRACT
0109502	045, 067, 163

OUTPUTS

CENSUS TRACT NUMBER	AIR QUALITY ($\mu g/m^3$)	
	PART.	SO_x
0109502	72.1	52.3

Figure 7-4 . Receptor Point - Census Tract Interface

In the following subsections, some of the characteristics of damage functions are described and problems associated with their measurement are noted. The literature contains little information on the development of air pollution damage functions, but references are cited whenever possible.

7.2.1 Description of a Damage Function

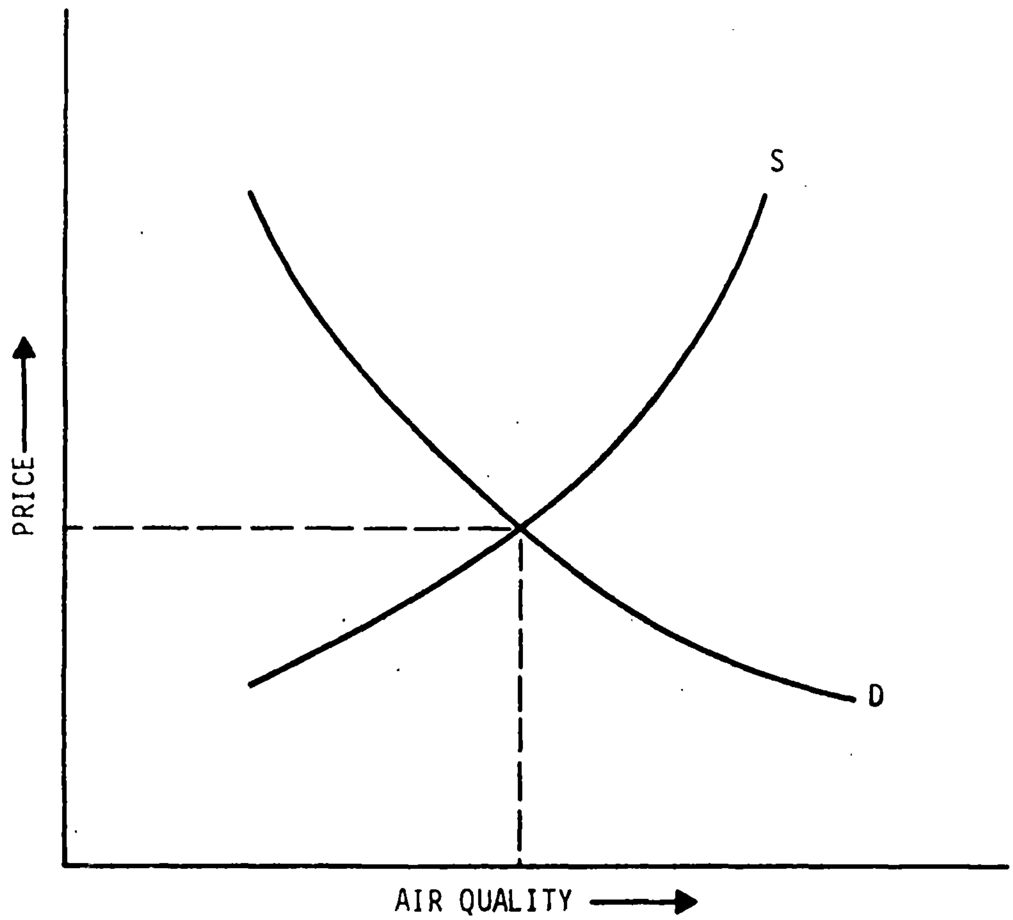
In an economic sense, supply and demand exist for air quality just as they do for goods and services in the private sector. In the private sector, price is a function of the effects of supply and demand for goods and services in the marketplace. Since there is no marketplace for the air resource, the price of clean air will depend upon society's willingness to pay for improved air quality. Figure 7-5 illustrates a conceptual supply-demand relationship for air quality.

In Figure 7-6, a parallel is drawn between the demand for goods and services in the private sector and that for air quality in the public sector. An air pollution damage function is in essence a demand function for air quality, an aggregation of the citizens' willingness to pay for a collective good. Willingness to pay for air quality is the damage function expression that is applicable to cost/benefit modeling. Individuals may pay to avoid such damages as corrosion of materials and soiling of property for example. Many people likewise prefer to avoid intangible air pollution effects which are detrimental to aesthetic pleasure or which produce general sluggishness.

In cost/benefit analysis, the consequences of government actions are all traced back to the fulfillment of wants of individuals. Individuals feel the effects of air pollution directly and indirectly in the form of:

- Actual outlays,
- Reduction in his income, health or satisfaction, or
- Complete foreclosure of some opportunities.

In practical terms, a damage function represents a dose-response relationship in which the damage cost is the price an individual (or individuals) will pay to avoid the response. Damage functions are

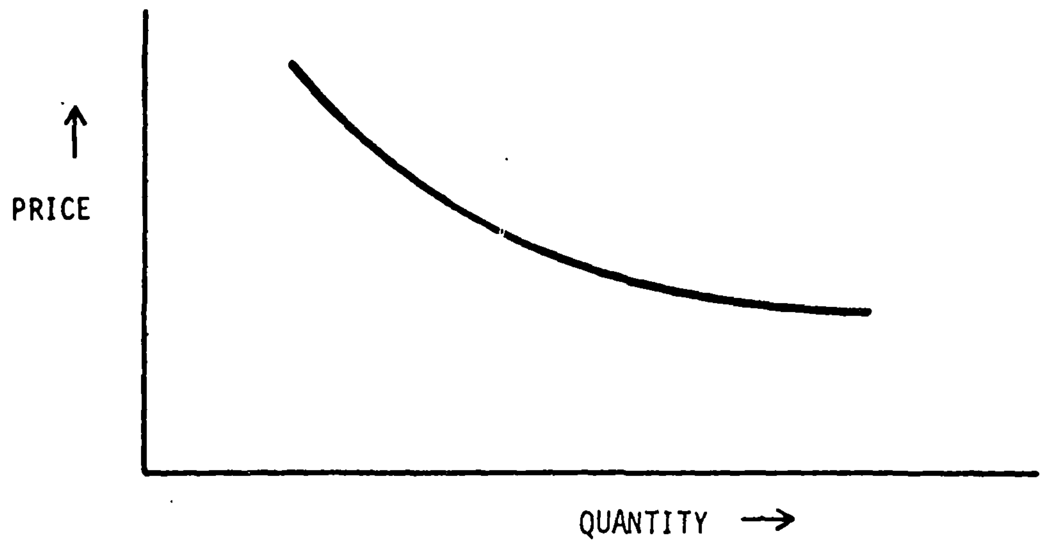


SUPPLY = MARGINAL CONTROL COST

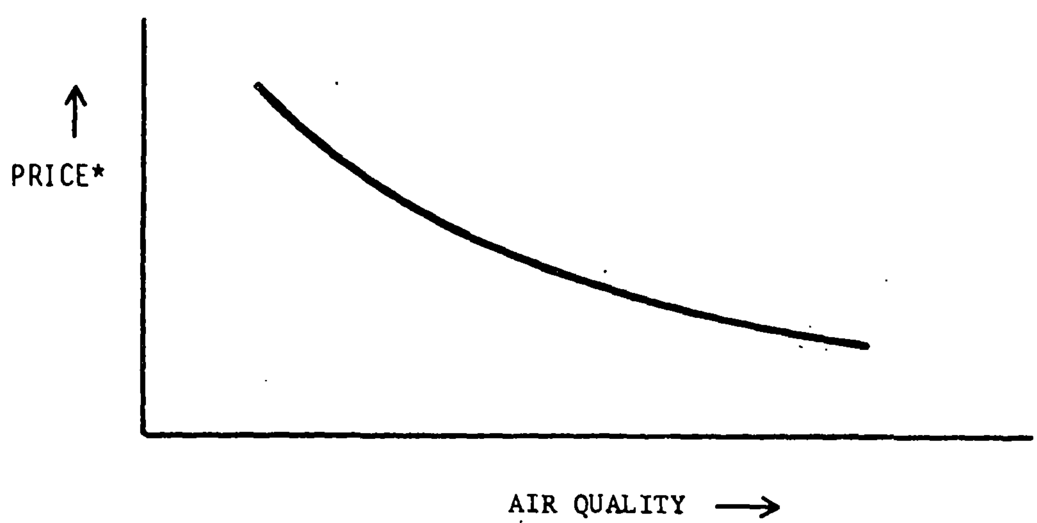
DEMAND = MARGINAL BENEFITS

Figure 7-5 . Supply - Demand Relationship for Air Quality

• DEMAND FUNCTIONS CAN BE DETERMINED FOR GOODS AND SERVICES IN THE MARKETPLACE, THAT IS ...



• A DAMAGE FUNCTION MAY BE CONSIDERED AN AIR QUALITY DEMAND FUNCTION... THAT IS, A "WILLINGNESS TO PAY" FOR QUALITY OF THE AIR RESOURCE (AS COMPARED TO QUANTITY OF PRODUCT) ...



*THE PRICE ONE IS WILLING TO PAY TO HAVE IMPROVED AIR QUALITY

Figure 7-6. What is a Damage Function?

expressed in the form of a rate (i.e., value of damage allocated over a fixed period of time). Figure 7-7 shows the variables used in measuring the rate of damage. The valuation of damage is expressed as the cost factor K.

7.2.2 Identification of Air Pollution Effects

The social benefits associated with improved air quality and the economic concepts used to describe these effects are discussed in Appendix A. In this section, attention is focused on the identification and classification of effects for the practical purpose of developing benefit estimates. It is hoped that the material presented here will stimulate the development of methods of classifying air pollution effects and will aid in the structuring of research on effects and damage functions.

Air pollution effects may be categorized as follows:

- Direct Effects - The direct and immediate externalities borne by the receptor.
- Adjustments (Indirect Effects) - Effects which induce persons and firms to make certain adjustments in order to reduce the direct impact of the pollutant.
- Market Effects - Effects realized through the marketplace as a result of adjustments made to reduce the direct impact of pollutant concentrations.[1]

Air pollution effects are felt by the individual, the corporate sector, and the public sector. (See Figure 7-8). As may be seen from the figure, effects realized by the corporate sector are passed along to the consumer in the form of price increases. The effects of air pollution on the public sector are likewise usually passed along to the taxpayer in the form of increased taxes. Figure 7-9 gives examples of effects on the individual, the private sector, and the public sector. Benefits to the individual are divided as follows:

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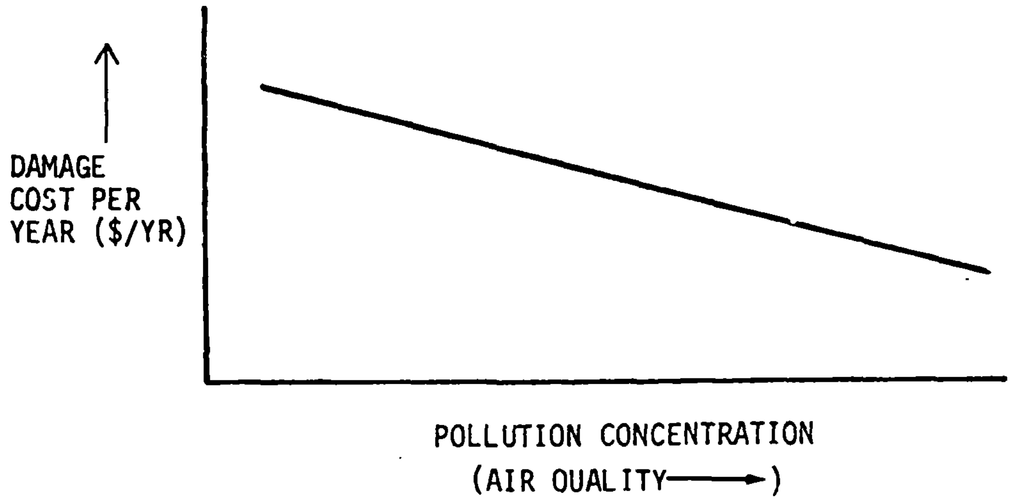
[1] Ridker, Ronald G., Economic Costs of Air Pollution - Studies in Measurement, Frederick A. Praeger, New York, p. 14, 1967.



<u>RATE OF DAMAGE</u>

$$D = f[\ a,\ t,\ AQ,\ RC,\ PP\ ]$$

where:

D = Damage per period of exposure.
a = Concomitant conditions, such as temperature, pressure, humidity, etc.
t = Exposure duration(ie, 1 year)
AQ = Pollutant concentration
RC = Receptor characteristics
PP = Properties of pollutant

<u>ANNUAL DAMAGE COST</u>

$$C = (K)(D) = g[\ K,\ a,\ t,\ AQ,\ RC,\ PP\ ]$$

where:

K = Cost per unit damage
C = Damage cost per period of exposure

Figure 7-7. Damage Function - A Rate

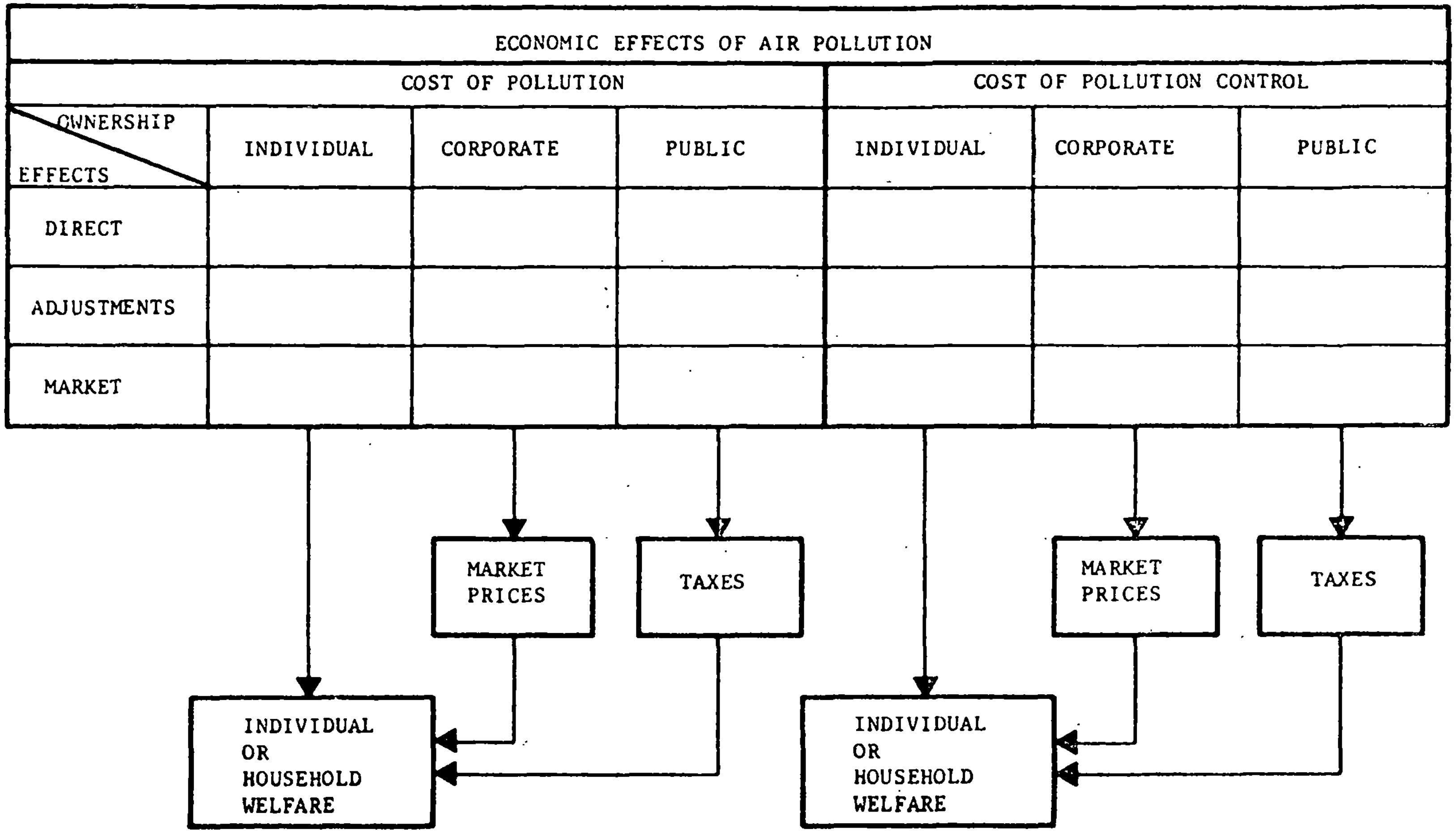


Figure 7-8. Structuring the Economic Effects of Air Pollution

SOCIAL BENEFITS = B_t = $B_h + B_p + B_i + B_u$

WHERE:

B_h = INDIVIDUAL HEALTH BENEFITS

- INCREASED NET AGGREGATE PRODUCTIVITY BENEFITS FROM ENHANCED:
  - JOB PERFORMANCE
  - PRODUCTIVE LIFE SPAN
  - ALERTNESS, PSYCHOLOGICAL SATISFACTION, ETC.
- INCREASED NET AGGREGATE CONSUMPTION BENEFITS FROM REDUCED:
  - MEDICAL CARE
  - PREVENTIVE MEDICINE, ETC.

B_p = INDIVIDUAL PROPERTY BENEFITS

- INCREASED NET AGGREGATE PRODUCTIVITY BENEFITS FROM PROPERTY, I.E.,
  - MATERIALS
  - ANIMALS
  - VEGETATION
  - LAND, ETC.
- INCREASED NET AGGREGATE CONSUMPTION BENEFITS FROM REDUCED PROPERTY MAINTENANCE, I.E.,
  - LAUNDRY
  - AUTO WASHING
  - WINDOW CLEANING, ETC.

B_i = PRIVATE SECTOR BENEFITS

- NET AGGREGATE PRODUCTIVITY BENEFITS OF GOODS AND SERVICES PURCHASED FROM THE PRIVATE SECTOR RESULTING FROM PRICES WHICH DO NOT INCLUDE THE COST (TO THE FIRM) OF:
  - CLEANLINESS
  - PROPERTY DISUTILITY
  - INCREASED WORKER PRODUCTIVITY, ETC.

B_u = PUBLIC SECTOR BENEFITS

- NET AGGREGATE PRODUCTIVITY BENEFITS OF PUBLIC SECTOR SERVICES DUE TO COSTS TO THE GOVERNMENTS FOR:
  - CLEANLINESS
  - PROPERTY DISUTILITY
  - INCREASED WORKER PRODUCTIVITY, ETC.

Figure 7-9. Social Benefits Resulting from Air Pollution Control

- Effects relating to the individual's person (i.e., health, welfare, productivity etc.).

- Effects relating to property owned by the individual.

Information on air pollution effects can be found in APCO's criteria documents for specific pollutants,[1] which contain comprehensive reviews of specific pollutant effects as well as extensive bibliographies.

7.2.3 Assessment of Air Pollution Effects

Once the effects have been identified, the next step in developing damage functions is to assess the magnitude of these effects. This procedure will require an analysis of the chemical reactions between pollutants and receptors, as well as a determination of the physiological, pathological, psychological, and other effects of the pollutants on living organisms. The dose-response relationship between pollutant and receptor must also be examined. As is indicated in the criteria documents, the analyst must be concerned with the following factors:

- Concentration
- Chemical composition
- Mineralogical structure
- Absorbed gases
- Co-existing pollutants
- Physical state of pollutant
    - Solid
    - Liquid
    - Gaseous

In addition, the characteristics of the receptor must be evaluated. Relevant characteristics include:

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[1] RAPA model evaluates particulate and sulfur dioxide emission. Criteria documents for these pollutants are: Air Quality Criteria for Particulate Matter (AP-49) and Air Quality Criteria for Sulfur Oxides (AP-50), U.S. DHEW, NAPCA, Washington, D. C., January 1969.

[2] Ibid. p. XIV.

- Physical characteristics
- Individual susceptibility
- State of health
- Rate and sight of transfer of receptor

The measurement of pollution effects is greatly complicated by the fact that such effects are quite subtle and vary according to both pollutant concentration and duration of exposure. Degree of exposure is expressed in terms of dosage (duration of exposure times pollution concentration). Because of changing atmospheric conditions the pollutant concentration to which an individual is exposed varies significantly over a relatively short period of time. In addition, there are numerous pollutants which affect receptors, and the aggregate mix of pollutants at any one location is constantly changing. As human beings move from place to place in the course of a day, they are exposed to an even greater variety of combinations of pollutants. Finally, the effects of pollutants on health and property remain unclear owing to the lack of a full understanding of synergistic phenomena. Much additional research is needed if the total effects of air pollution are to be determined.

7.2.4 Evaluation of Air Pollution Effects

The third and final task in the process of producing a damage function is an evaluation of the effects which have been identified and assessed. Problems arise, of course, in placing a price on effects such as those outlined above. Welfare economists consider the value of social benefits to be a function of the individual's personal preference for the benefits (i.e., the individual's willingness to pay). In preparing damage functions, the analyst is faced with such complex problems as determining society's willingness to pay when society itself is unable to clearly identify the effects of air pollution, or attempting to determine the value which society places on one of a number of synergistic effects resulting from air pollution, cigarette smoking, natural oxidation, etc. The need to evaluate the aesthetic consequences of air pollution further complicates matters, since such effects are perceived by the individual, on both the conscious and subconscious levels.

The task of evaluating public undertakings involves working in the absence of market prices for most analytical inputs and outputs. The job of the analyst is to develop values for inputs and outputs which are consistent with those found in the marketplace.

The price placed on a public good is referred to as a "shadow price." Shadow pricing has been discussed in some detail by Margolis* and McKean.** Margolis states that "the process of forming the shadow values is made difficult not only because of market limitations, but also because there is no widespread agreement on the basis for generating social values. Should one try to aggregate the preference of people in a society or should one attempt to rely on the preferences of program planners or adminstrators?"*** Margolis also argues that it is the willingness to pay for government outputs which signifies their values.

The purpose of evaluating air pollution costs and benefits is to assist the decision-maker in determining a policy. Shadow prices are utilized so that the effects of a public program (as it affects society) can be evaluated in monetary terms (i.e., on the basis of a common unit for comparing effects). Shadow prices are useful means of expressing utility, but unless the decision-maker is confident of the monetary values assigned to the effects, little is gained through the analytical process.

The question of how shadow prices are determined is, of course, highly relevant. Margolis discusses techniques for estimating "willingness to pay."*** Figure 7-10 summarizes the shadow pricing program and identifies three methods of determining shadow prices. The various literature on the analysis of public expenditures contains theoretical discussions of this topic.

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*J. Margolis, "Shadow Prices for Incorrect or Nonexistent Market Values," in Joint Economic Committee, U.S. Congress, The Analysis and Evaluation of Public Expenditure: The PPB System, Vol. I, U.S. Government Printing Office, pp. 533-546, 1969.

**R. N. McKean, "The Use of Shadow Prices," in S. B. Chase, Jr. ed., Problems in Public Expenditure Analysis, The Brookings Institution, Washington, D. C. pp 33-77, 1968.

***J. Margolis, op. cit., pp. 541-546.

- WHY IS THERE A VALUATION PROBLEM? ----- BECAUSE THERE IS NO MARKET WHERE SUPPLY AND DEMAND FOR THIS PRODUCT (THAT IS, QUALITY AIR) DETERMINES A PRICE

- HOW THEN IS A PRICE PLACED ON SUCH A PUBLIC GOOD? ----- THE MEASUREMENT RULE USED IS AS FOLLOWS:

  ESTIMATE WHAT THE USERS OF THE PUBLIC PRODUCT ARE WILLING TO PAY ----- SUCH A MEASUREMENT IS CALLED A "SHADOW PRICE"

- HOW ARE SHADOW PRICES DETERMINED?

METHOD #1 CONSIDER THE PRODUCT AS AN INTERMEDIATE GOOD AND THEN ESTIMATE THE VALUE OF THE MARGINAL PRODUCT OF THE GOOD IN FURTHER PRODUCTION, THAT IS, ASSUME THE USER IS A PRODUCER AND THEN ASK: BY HOW MUCH DOES THE PUBLIC OUTPUT INCREASE HIS INCOME?

METHOD #2 MEASURE THE COST SAVINGS OF THE PUBLIC SERVICE, THAT IS, THE REDUCTION IN THE COSTS THAT THE INDIVIDUAL WOULD HAVE INCURRED IF THE PUBLIC SERVICE WERE NOT SUPPLIED.

METHOD #3 ESTIMATE DIRECTLY THE USERS PRICES BY APPEAL TO MARKET INFORMATION, THAT IS, LOOK FOR NEAR SUBSTITUTES FOR COLLECTIVE CONSUMPTION.

Figure 7-10. How to Value Air Pollution Effects?

7.2.5 Types of Air Pollution Damage Functions

Although there have been various attempts at determining air pollution damage functions, this section will concentrate upon two examples, a damage function which valuates the direct effect of particulate soiling, and an analysis in which residential property values are estimated as a function of sulfur dioxide and particulate concentrations.

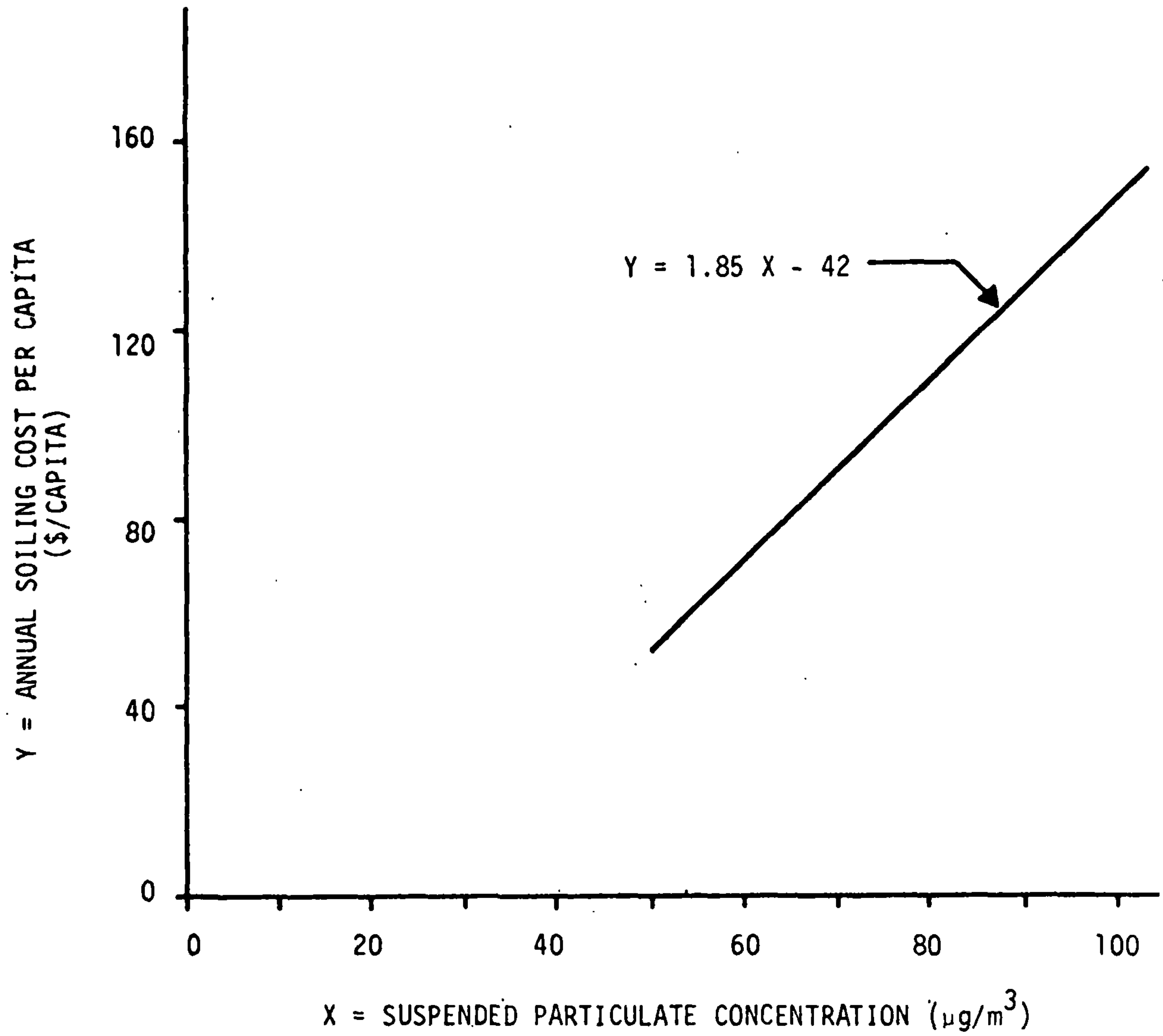
The damage function developed by Wilson and Minnottee* for the Washington, D. C., metropolitan area is presented in Figure 7-11. The damage function relates per capita annual soiling cost to concentrations of suspended particulates. The authors utilized the results of air pollution statistical studies in the Washington, D. C., area conducted by Irving Michelson. Michelson's study used responses to a questionnaire to determine the frequency of certain household cleaning chores in areas of high and low air pollution within the metropolitan area.** Wilson and Minnottee applied shadow prices to the "frequency of cleaning" function determined by Michelson. Method #3 (Figure 7-10) was utilized, that is the prices of cleaning services in the private sector were determined and then applied to the specific chores identified by Michelson. The soiling damage function was utilized to estimate savings (benefits) from reduced soiling for residential households. Studies of a similar nature have been conducted in Kansas City, and the Ironton-Ashland-Huntington metropolitan area. The procedures used in developing the damage functions were those previously outlined in this section (identification, assessment, and evaluation).

In the basis of a statistical analysis, economists Robert J. Anderson, Jr., and Thomas D. Crocker have determined a negative correlation between particulate and sulfur dioxide concentrations and residential property values.*** The authors evaluated the combined effects of suspended

* R. D. Wilson and D. W. Minnottee, "A cost-Benefit Approach to Air Pollution Control", Journal of the Air Pollution Control Association, Vol. 19, No.5, p. 306, May 1969.

** I. Michelson, "The Household Cost of Living in Polluted Air in the Washington, D. C. Metropolitan Area", A Report to the U.S. Public Health Service.

***R. J. Anderson, Jr., and T. D. Crocker, "Air Pollution and Housing: Some Findings" Paper No. 264, Institute for Research in the Behavioral, Economics, and Management Sciences, Purdue University, Lafayette, Indiana, January 1970.



Source: Wilson and Minnotte

Figure 7-11. Example Damage Function for Direct Effects particulates and sulfur dioxide (as measured by sulfation) on residential property in the following Census Bureau classifications: (1) owner-occupied; (2) renter-occupied, gross rent; and (3) renter-occupied, contract rent. The most significant independent variables which affect property values were identified and are shown in Figure 7-12. It should be noted that sulfaction rate and suspended particulate concentration are included as significant variables. The statistical results of the Anderson and Crocker work for the Washington, D. C., SMSA are presented in Table 7-1.

The benefits measured by the Wilson/Minnotte and the Anderson/Crocker damage functions represent only a small portion of the "benefits" that are desired by society. The Wilson/Minnotte function measures only the direct effects of soiling resulting from suspended particulates. Numerous other direct effects have been identified for particulates as well as other pollutants. The Anderson/Crocker functions estimate only the market effects resulting from society's preference to reside in cleaner rather than dirtier air. The market effects result from the conscious and subconscious perception of direct effects. The impact of the effects and adjustments are reflected in the values of properties as established in the marketplace.

During this study, the Anderson/Crocker results for the Washington, D. C., SMSA were examined to determine their potential as a damage function for estimating air pollution market effects. The analytical results of the Washington study will be tested as a predictive function in the demonstration of the C/B Model.

7.2.6 Application of Air Pollution Damage Functions

Damage functions are generally expressed in relation to number of households (or population) and pollution concentration. In the Cost/Benefit Model, damage functions are applied to each census tract in an AQCR to determine the census tract damage cost. The sum of the damage costs for all census tracts in an AQCR determines the AQCR damage cost.

The damage estimates of the direct effects of pollution are estimated as a function of particulate and/or sulfur dioxide concentrations for the base alternative (i.e., the existing condition) as well as for predicted concentrations under a given emission control strategy. Social benefit is considered to be the difference between the damages from the base alternative and damages after application of the control strategy (see Figure 7-13.)

PROPERTY VALUE FUNCTION: PV = f(a, PSN, PPT, MFI, DLP, OLD, NWT, DIS, MRM)
WHERE PROPERTY VALUE IS QUANTIFIED FOR EACH CENSUS TRACT AS: • TYPE I: MEDIAN PROPERTY VALUE - OWNER-OCCUPIED • TYPE II: MEDIAN PROPERTY VALUE - OWNER-OCCUPIED - 75% OR MORE SINGLE FAMILY DWELLINGS • TYPE III: MEDIAN GROSS RENT - RENTER-OCCUPIED • TYPE IV: MEDIAN CONTRACT RENT - RENTER-OCCUPIED
THE INDEPENDENT VARIABLES OF SIGNIFICANCE ARE AS FOLLOWS: • a = CONSTANT • PSN = ANNUAL ARITHMETIC MEAN SULFATION • PPT = ANNUAL ARITHMETIC MEAN SUSPENDED PARTICULATES • MFI = MEDIAN FAMILY INCOME • DLP = PERCENT OF LIVING UNITS DILAPIDATED • OLD = PERCENT OF HOUSES OVER TWENTY YEARS OLD IN 1959 • NWT = PERCENT OF HOUSING OCCUPIED BY NONWHITES • DIS = DISTANCE OF CENSUS TRACT FROM CENTRAL BUSINESS DISTRICT • MRM = MEDIAN NUMBER OF ROOMS IN HOUSING UNIT

*SEE TABLE 4-2 FOR QUANTITATIVE RESULTS

SOURCE: ANDERSON AND CROCKER

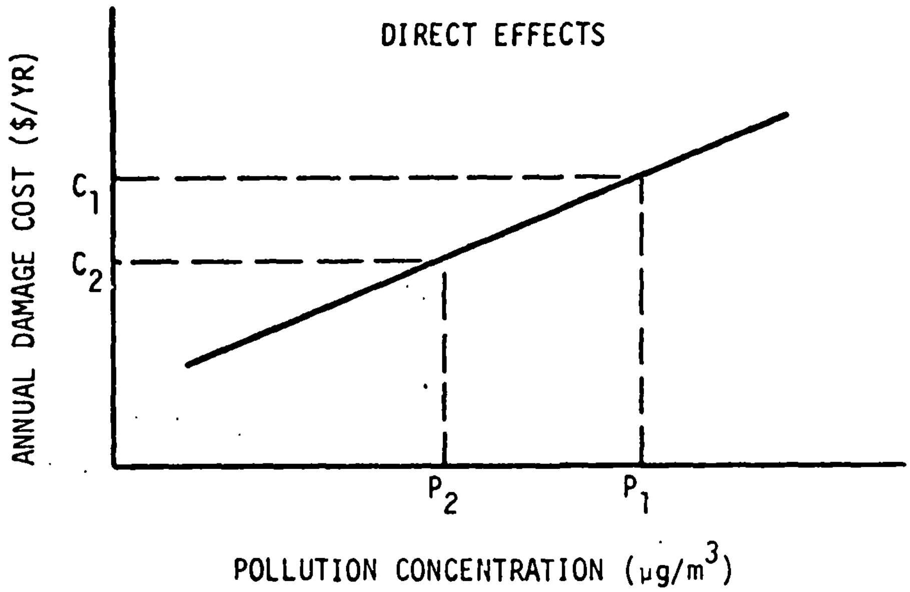
Figure 7-12. Example Damage Function for Market Effect*

Table 7-1

REGRESSION RESULTS OF ANDERSON-CROCKER STUDY FOR THE WASHINGTON, D. C., SMSA

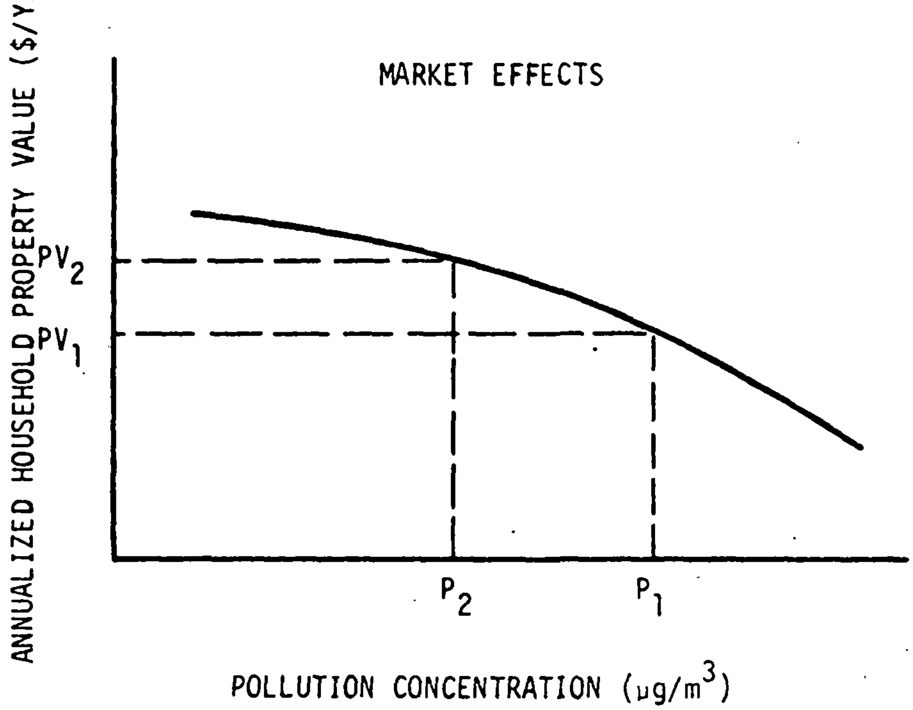
INDEPENDENT \ DEPENDENT	Regression Coefficients Type I	Type II	Type III	Type IV
Const.	3.3901 (.4012)	1.1617 (.5622*)	.2428 (.4441**)	.4705 (.3859**)
In (PSN)	-.0712 (.0222)	.0010 (.0270**)	-.0905 (.0239)	-.0727 (.0207)
In (PPT)	-.0610 (.0318**)	-.1698 (.0509)	.0049 (.0316**)	-.0302 (.0275**)
In (MFI)	.7677 (.0447)	.9970 (.0587)	.5109 (.0492)	.4650 (.0431)
In (DLP)	.0044 (.0059**)	.0113 (.0079**)	.0121 (.0055*)	-.0054 (.0048**)
In (OLD)	-.016 (.0103)	-.0213 (.0107*)	-.0606 (.0125)	-.0408 (.0108)
In (NWT)	.0251 (.0064)	.0321 (.0080)	-.0043 (.0066**)	-.0124 (.0058*)
In (DIS)	-.0582 (.0158)	-.0312 (.0097)	-.0216 (.0152**)	-.0111 (.0132**)
In (MRM)		.9064 (.1948)		
R^2	.6966	.7897	.6963	.7549
S^2	.0222	.0179	.0181	.0136
T	275	121	218	218

* Not significantly different from zero at the .01 level.
** Not significantly different from zero at the .05 level.



C_1 = (DAMAGE COST)P_1; C_2 = (DAMAGE COST)P_2

SOCIAL BENEFIT = $C_1 - C_2$



SOCIAL BENEFIT = $PV_2 - PV_1$

Figure 7-13. Application of Damage Functions

The social benefits from market effects are the differences between the annualized household property values under the two strategies (also shown in Figure 7-13).

In cross-sectional cost/benefit studies, problems arise when air quality measurements for the current year are not representative of air quality in previous years (see Figure 7-14). Air quality may have improved as a result of the implementation of emission regulations, as is the case for sulfur dioxide concentrations in the District of Columbia (Figure 7-15). On the other hand, conditions may have deteriorated. Analytical problems arise because air pollution effects are not short-term phenomena, but are rather a function of historical air pollutant concentrations. Air pollution effects such as soiling are immediate effects and cleaning costs are a function of particulate concentrations for the base year. Other effects, (such as those on health), result from long-term exposure to pollutants and damage functions in these cases must theoretically be determined on the basis of pollutant concentrations calculated over a number of years. Also, the reduction in damage cannot generally be assumed to be effective instantaneously, that is, an instantaneous reduction in pollutant concentration does not bring about an instantaneous improvement in human health or productivity. Although beyond the scope of the present study, such problems must be examined in future cost/benefit research.

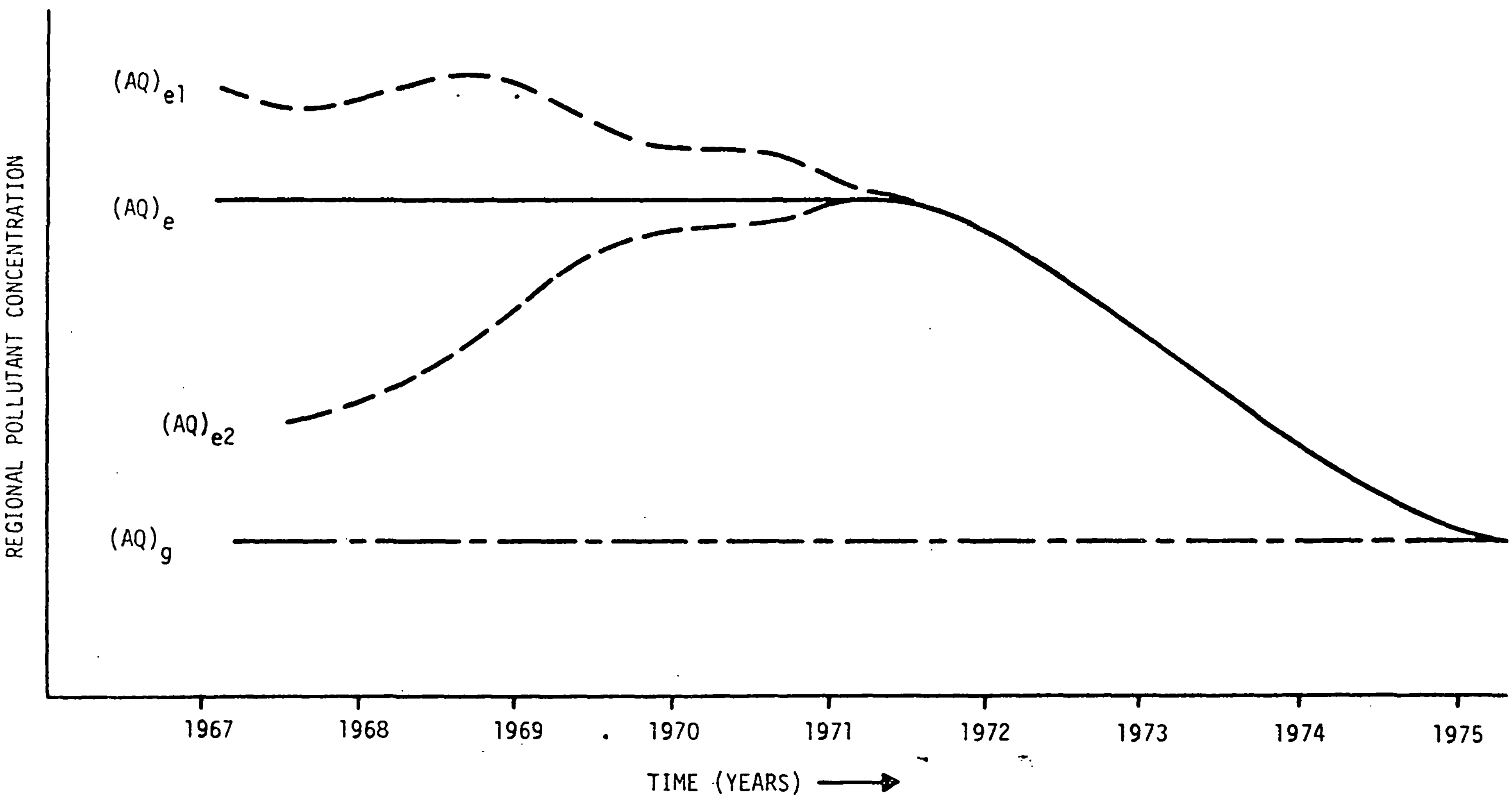


Figure 7-14. Historical Trends in Pollution Concentration

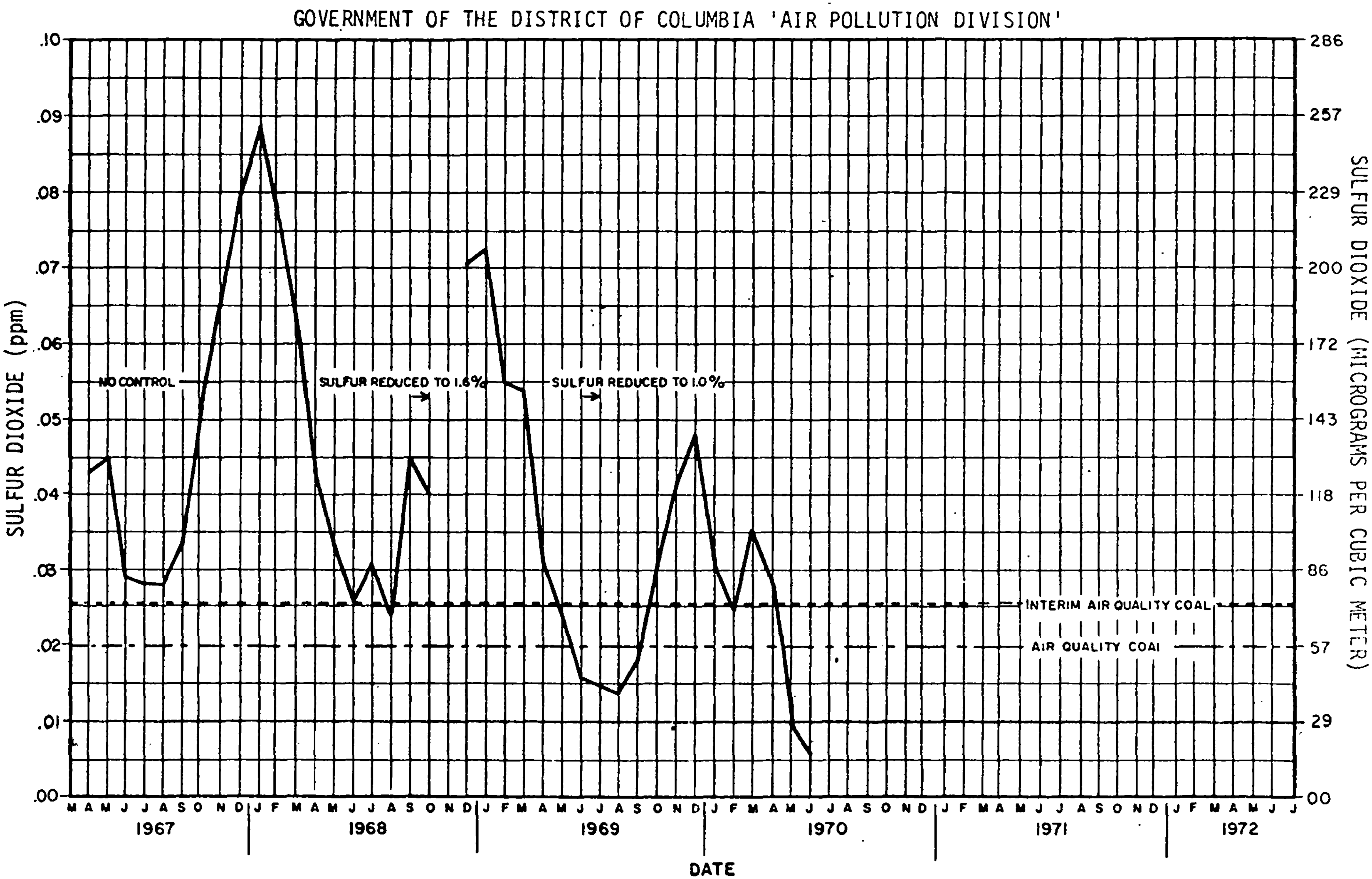


Figure 7-15. Monthly Average Sulfur Dioxide Concentrations in the District of Columbia

7.2.7 Development of Damage Functions

There is a dire need for additional research on the effects of air pollution. As an interim measure, however, the development of methods which transform available data into useful damage functions can be tested. One of the advantages of a cost/benefit simulation tool is that it may be used in sensitivity analyses to determine the reasonableness of proposed damage functions. Brain-storming sessions can be useful in determining how the damage functions are to be created. A modification of the Delphi procedure may also be applicable as a means of estimating "personal preferences."

Many different approaches can be taken in the development of damage functions. The analyst may look at damages to individual classes of receptors (pinto beans, electrical contacts, guinea pigs, etc.) and then aggregate these damages by means of statistical techniques in order to project total damage costs. Another approach is to use analytical techniques in the development of "comprehensive damage functions" based on the best available data (see Figure 7-16).

Many questions arise in evaluating methodologies for the development of damage functions. Must all effects be identified and evaluated, or can knowledge of specific effects be the basis for decision-making? Can a comprehensive damage function be developed as a function of personal income, residential location, occupation, health status, or other variables? Can health data such as those obtained by Lave and Seskin (see Table 7-2) be used in the development of broad-based health functions?[1] Can "personal preference" be defined on the basis of intensive surveys and congressional polls (i.e., do such polls indicate willingness to pay for solutions to society's problems)? How can sociologists, psychologists, economists, and statisticians contribute to a comprehensive study of damage functions?

Such questions must be examined in relation to the air resource decision-making process and the needs of the decision-maker.

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1 Lave, Lester B., and Seskin, Eugene P., "Air Pollution and Human Health," Science, 21 August 1970, Volume 169, Number 3947, pp. 724-734.

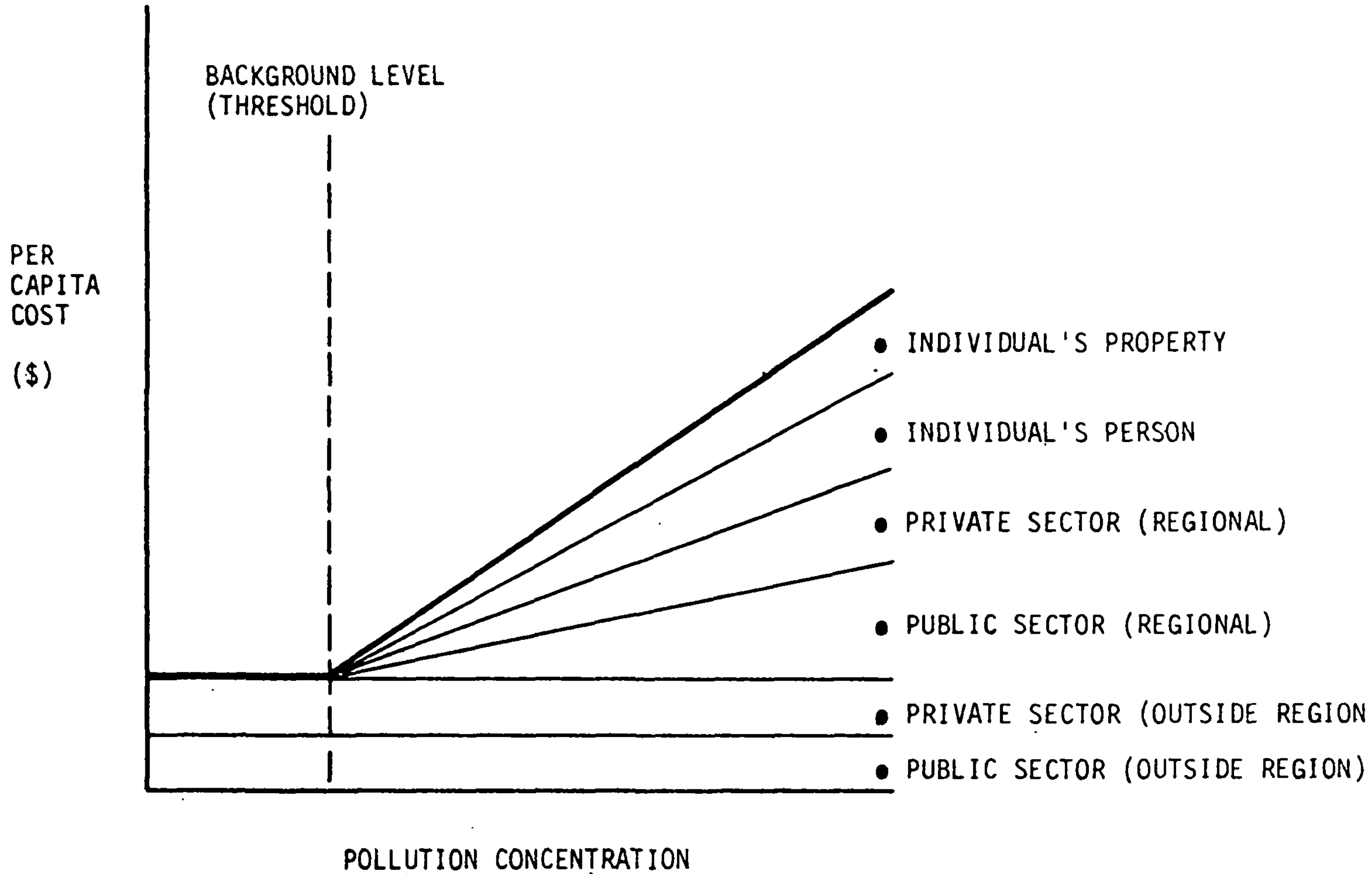

Figure 7-16. Comprehensive Damage Function for an AQCR

Table 7-2

EXAMPLE DATA FOR THE DEVELOPMENT OF
DAMAGE FUNCTIONS FOR HEALTH EFFECTS

DISEASE	POLLUTION REDUCTION	EXPECTED ANNUAL SAVING ($ MILLIONS)
• All Respiratory Diseases	50%	1,222
• Cardiovascular Diseases	50%	468
• Cancer	50%	390
TOTAL		2,080

Source: Lave and Seskin

8.0 SOME APPLICATIONS OF THE COST/BENEFIT MODEL

The Cost/Benefit Model will be service tested during the follow-on efforts of this study. The capabilities of the model will be tested through numerous evaluations. The present section reviews a few of the model's capabilities.

Economic evaluations of regional air pollution control strategies should focus on the efficiency and distribution of costs and benefits to society. Measures of economic efficiency indicate the effectiveness of a policy which requires a reallocation of resources. Equity studies evaluate the distribution of effects relative to various income groups. The desired goal relative to the equity criteria in the fair distribution of benefits and costs to all sectors of a given population (e.g., an AQCR).

To illustrate the flexibility and capabilities of the C/B Model, this chapter presents a discussion on a collection of alternative uses, which include:

1. Emission Control Regulation Development
2. Analysis of the Distribution of Benefits
3. Practical Model Application in AQCRs
4. Criteria for Evaluating Strategies
5. Other Uses of the C/B Model

8.1 EMISSION CONTROL REGULATION DEVELOPMENT

Theoretical discussions of air pollution cost/benefit applications generally concentrate on measurements of economic efficiency, that is, the determination of the strategy under which the total cost of air pollution disposal is minimized. There has been no discussion in this report of procedures which may be used to evaluate the geographical distribution of air pollution costs and benefits within an AQCR.

If cost/benefit analysis can be used to evaluate the impact of the effects of an emission control strategy in AQCR, it is reasonable to assume that it can be applied in the development of emission control standards (or regulations). Emission standards have thus far been based on engineering analyses of sources and available control technology. The allowable emission rate is frequently expressed as a function of process or boiler

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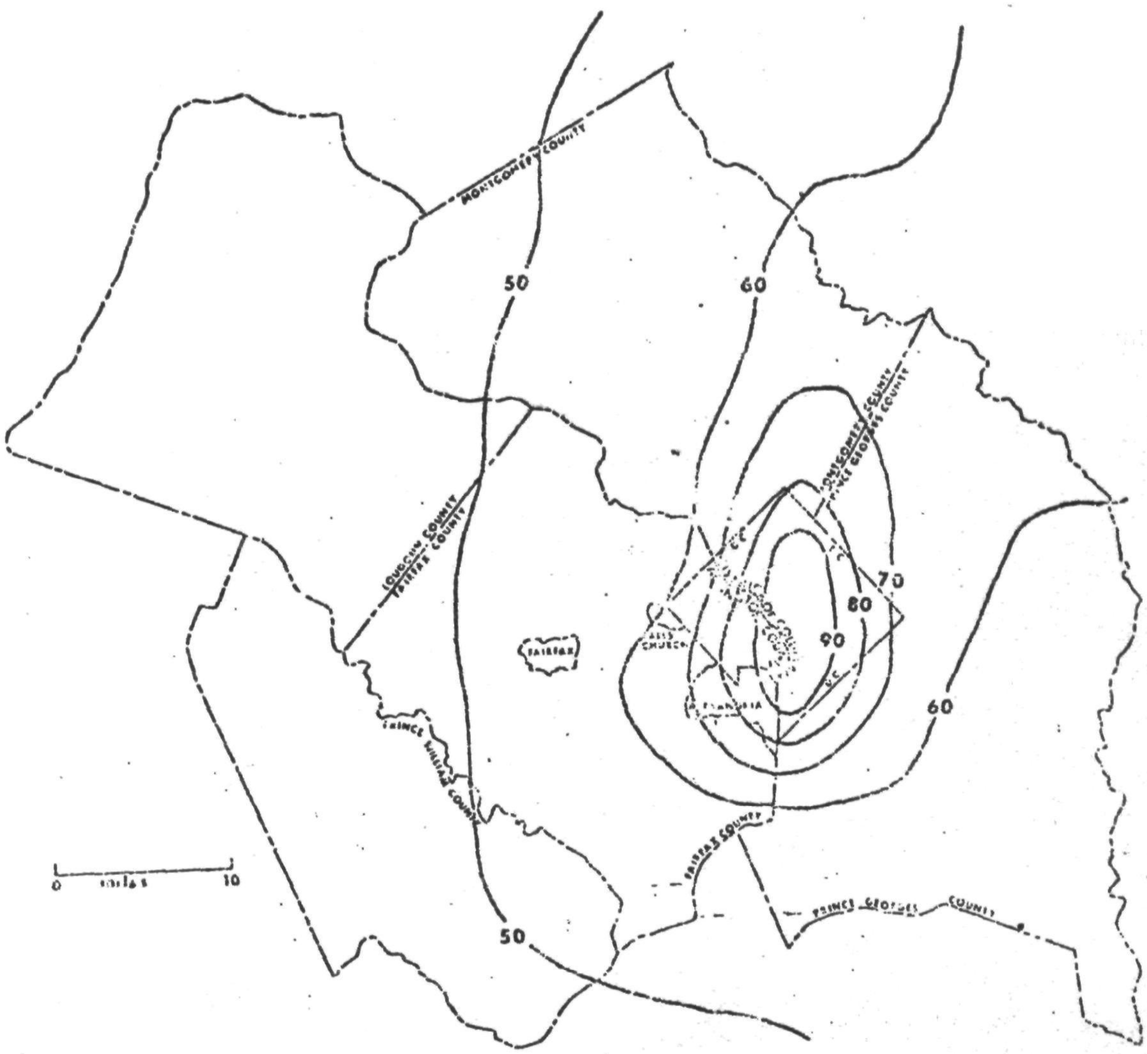
size. So that no firms will be placed in an advantageous or disadvantageous economic position relative to other competitive firms, emission standards are generally applied uniformly to all sources in a region (i.e., all firms bear the same burden).

Such emission standards are generally promulgated and applied without regard to the planning objectives of the AQCR, however. Emission standards currently tend to be economically inefficient because they are uniformly applied to all sources in the AQCR. For critically located sources, such emission standards are needed to satisfy air quality standards. For sources in other locations, such emission standards may be too stringent, as will be seen in the following example.

Particulate concentration distributions in the NCIAQCR before and after application of emission standards are shown in Figure 8-1 and 8-2. A cross-sectional view of pollution concentration relative to geographical location is presented in Figure 8-3. The upper and lower curves in Figure 8-3 represent pollutant concentrations before and after enactment of an emission control strategy respectively. The criterion for determining the acceptability of an emission control strategy is that air quality at any point in the region must meet or surpass the proposed air quality standard.

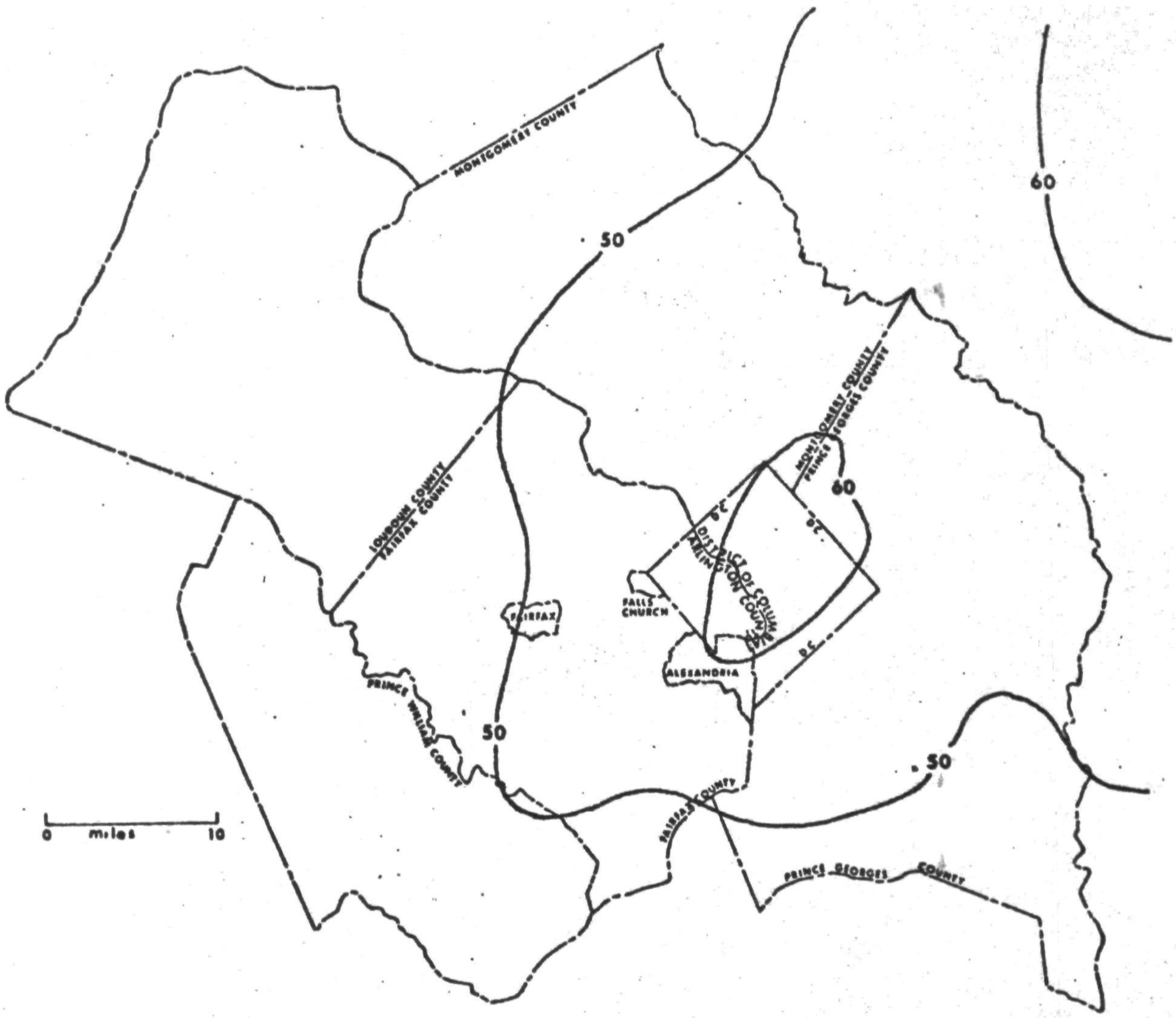
Due to the uniform application of emission standards, the same level of control is required for sources affecting the pollution concentration in areas outside the center city as is required for sources affecting the center city. Since the long-term standard is based on the removal of all identifiable effects which lower the welfare of society, it may be asked whether there is a need for further reduction in pollutant concentrations at the perimeter of the region (that is, whether "non-degradation" is essential when existing pollutant concentrations are far below levels at which effects are observed or welfare decreased). The sources are being treated equitably, but the receptors are not. An economically inefficient solution thus exists.

This situation can be illustrated as in Figure 8-4, where source equity (i.e., uniform application of emission standards for all sources in an AQCR) is plotted as a function of receptor equity (i.e., equal pollution concentration exposure for all receptors). The curve shows situations in which the condition of source equity is matched by receptor



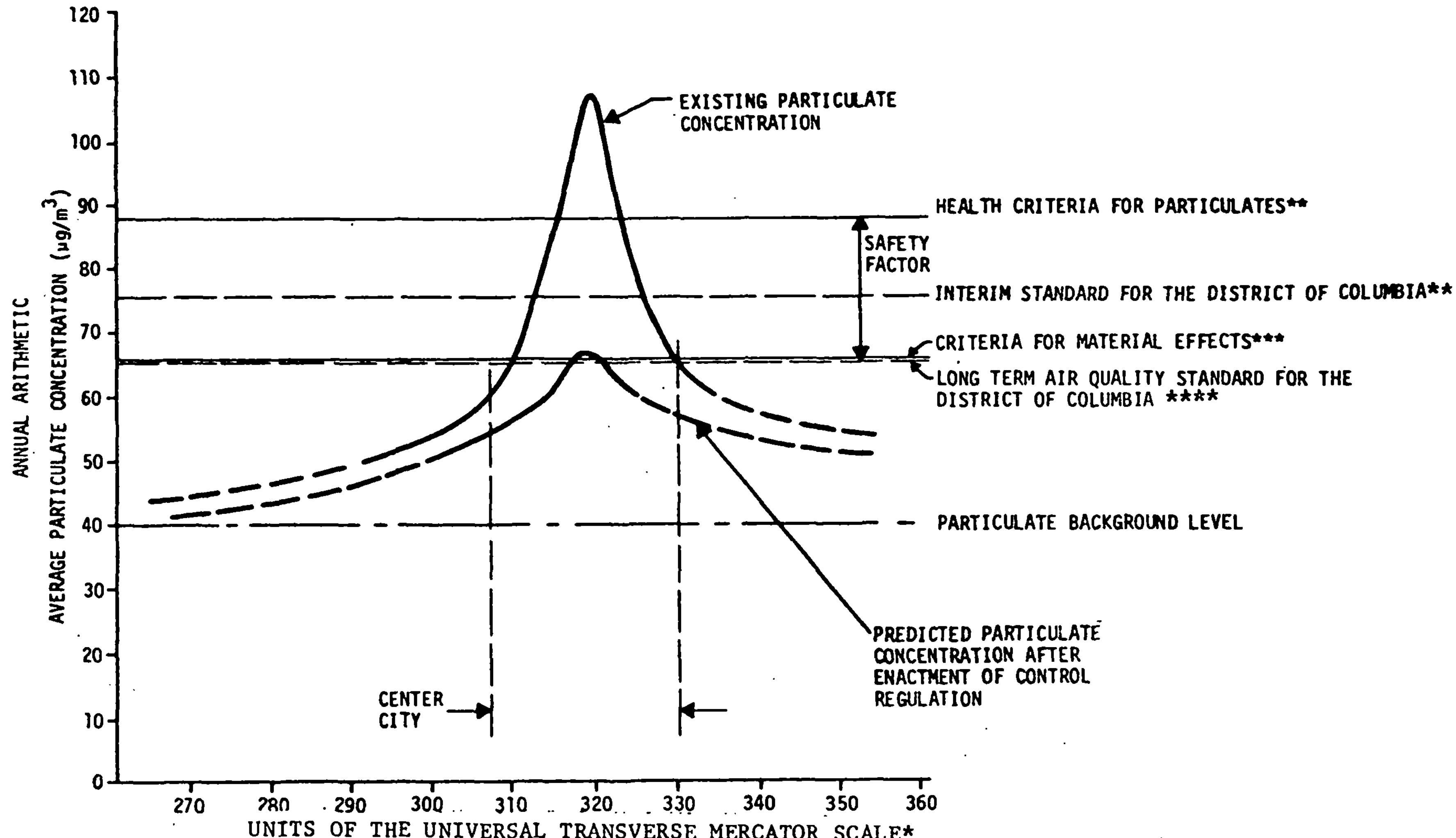
Note: Annual Concentrations in $\mu g/m^3$

Figure 8-1. Existing Ground Level Particulate Concentrations in the NCIAQCR as Computed by the Verified Diffusion Model



Note: Annual Concentrations in $\mu g/m^3$

Figure 8-2 . Predicted Particulate Concentrations after Enactment of the Proposed Emission Control Strategy in all Political Jurisdictions (Strategy 18)



*Measurements taken along the plane 4305 of the Universal Transverse Mercator Scale.

**Annual Geometric Mean = 80 μg/m³. Annual Arithmetic Annual Mean = 86.8 μg/m³.

***Annual Geometric Mean = 60 μg/m³. Annual Arithmetic Mean = 65.2 μg/m³.

****Standards proposed under procedures established by the Air Quality Act of 1967. The National Primary and Secondary Air Quality Standards of the Clean Air Amendments of 1970 would also apply.

Figure 8-3. Predicted Air Quality Improvement in the NCIAQCR

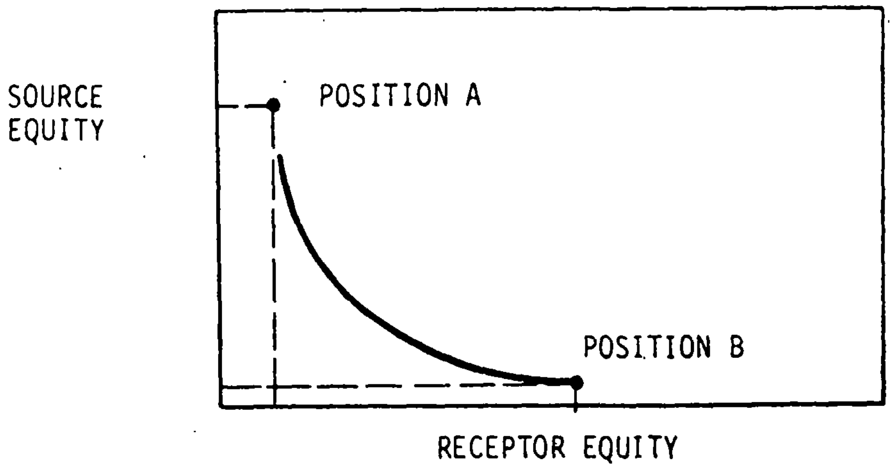


Figure 8-4. Source Equity vs. Receptor Equity.

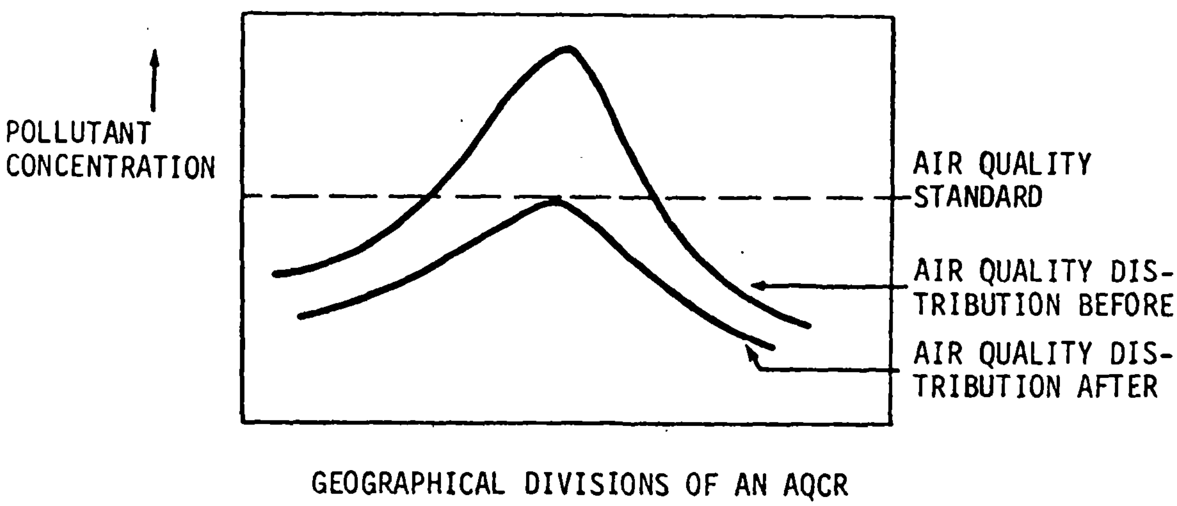


Figure 8-5. Source Equity (Position A)

inequity and vice versa (souce inequity and receptor equity). Position A on the curve corresponds to a situation involving source equity and receptor inequity. Such a situation is further shown in Figure 8-5. A hypothetical situation for Position B is shown in figure 8-6.

The current application of emission standards is represented by Position A. Position B is typical of an emission standard based on geographical location in the AQCR. Figure 8-7 illustrates such an emission standard, with control being more stringent in Zone W than in Zone X and so on (an example of such a regulation would be the prohibition of automobile traffic in the center city). An emission standard which varies with geographical location within an AQCR is likely to be more economically efficient for society since, relative to a uniform standard, there is a control cost saving with a negligible reduction in benefits. The practicality of emission standards such as the one illustrated in Figure 8-7 should be determined. There is likewise the need to re-examine the basis for developing emission standards. If an urban growth objective is to enhance the quality of the downtown area through commercial development and construction of middle-income residences, and at the same time to relocate industry outside the center city, then emission standards based on a policy oriented toward Position B would be compatible with regional goals.

The above presentation has been designed to indicate ways in which cost/benefit analysis can be used to examine new policy alternatives. The model is likewise useful as a means of evaluating existing policies. The important contribution made by the development of the C/B Model is the ability to look at benefits (and damages) relative to specific geographical areas in an AQCR.

8.2 ANALYSIS OF THE DISTRIBUTION

The Cost/Benefit Model is capable of evaluating the distribution of effects on the sources and receptors. Equity evaluation of air pollution control costs to firms affected is important in a competitive economy. The distribution of benefits resulting from cleaner air must likewise be evaluated for purposes of urban planning, land use, etc. Some equity evaluations which are possible with the Cost/Benefit Model are:

1. Compare the absolute pollutant concentration to income. Although benefits (measured in dollars)

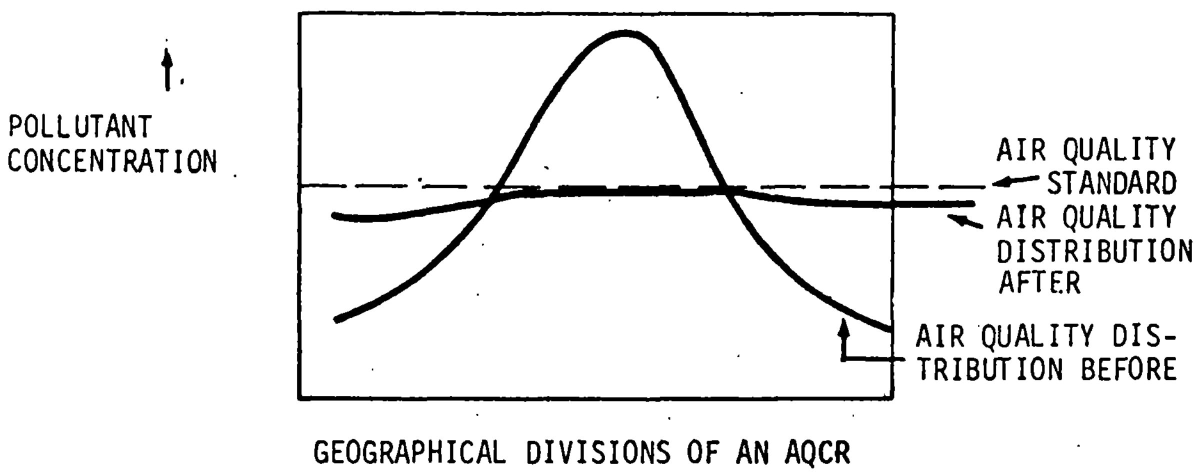
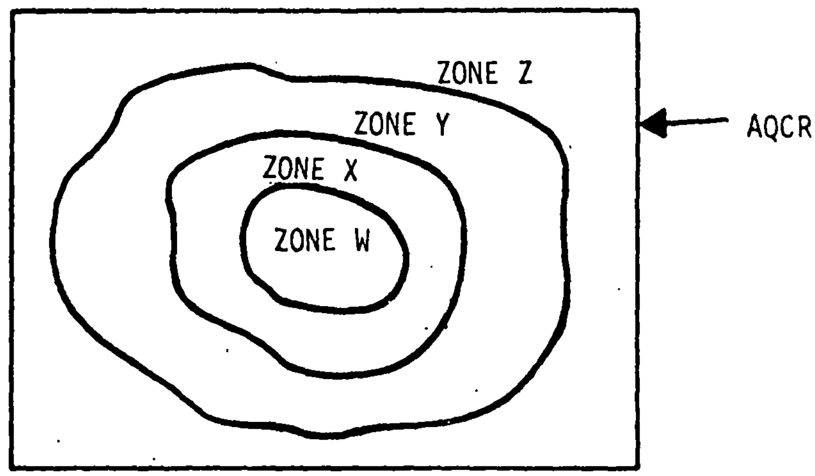


Figure 8-6. Source Equity (Position B)



- EMISSION STANDARD IN ZONE W MORE STRINGENT THAN IN ZONE X; ZONE X STANDARD MORE STRINGENT THAN ZONE Y; AND SO FORTH

Figure 8-7. An Emission Standard Based on Geographical Location are not being considered here, the relationship between actual air quality and income class will be valuable to a regional decision-maker who evaluates long-term air quality trends and is cognizant of air pollution interim. Essentially the relationship in question is:

$$I = f(AQ) \qquad \text{where: } I = \text{Income}$$

This relationship can be measured for existing conditions as well as under alternative regional control strategies.

2. Compare the change in air quality resulting from a regional control strategy to income class. This comparison answers the question: What improvement in air quality was obtained for each income class? The relationship is as follows:

$$AQ = g(I)$$

The change in air quality can be measured in two ways:

a. Absolute improvement in air quality (e.g., $\mu g/m^3$) where:

$$(AQ)_A = (AQ)_b - (AQ)_a$$

$(AQ)_A$ = absolute change in air quality

$(AQ)_b$ = air quality before strategy

$(AQ)_a$ = air quality after strategy.

b. Relative improvement in air quality (e.g., %) where:

$$(AQ)_R \frac{(AQ)_b - (AQ)_a}{(AQ)_b}$$

$(AQ)_R$ = relative change in air quality.

3. Comparison of benefits (in dollars) resulting from a regional control strategy to each income class, i.e.,

$$B = f(I)$$

4. Comparison of benefits per income (i.e., B/I) resulting from a regional control strategy for each income class, i.e.,

$$(B/I) = g(I)$$

This procedure will measure the improvement in aggregate consumption and productivity benefits resulting from a given strategy for each income class. This is the most significant measure for equity analyses, since it relates the importance of benefits to individual consumption levels (i.e., an additional dollars worth of well-being for an individual earning $10 per year is far more significant than an additional dollars worth of well-being for an individual earning $10,000). These data may be presented as follows:

Income ($)	Benefit ($)	$\left(\frac{\text{Benefit}}{\text{Income}}\right)$ (%)
2,000	80	4
4,000	120	3
.	.	.
.	.	.
.	.	.
25,000+	500	2

5. Analysis of benefits and benefit/income ratios for non-white (NWT) and white (WT) sectors of a regional population. The procedure used could be as follows:

   - Divide census tracts into WT and NWT, where a NWT tract is defined as one having 50% or more non-white residents.
   - Develop comparative data on these tracts, as follows:

I($)	WT(B) ($)	NWT(B) ($)	WT(B/I) (%)	NWT(B/I) (%)
2,000	90	70	4.5	3.5
4,000	110	130	5.5	6.5
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
25,000	600	400	400	1.6

6. Analyses for an entire region as well as by individual political jurisdiction.

8.3 PRACTICAL MODEL APPLICATION IN AQCRs

The Cost/Benefit Model will be initially applied as a research tool. It is possible that the products of future research on damage functions and in other related areas may strengthen the capabilities of the Model to the extent that it will greatly enhance the sophistication of decision-making by regional control officers. Development of the Model capabilities should be in line with potential practical applications in the field.

Once the Model becomes operational, it is necessary to determine how it may be used most advantageously as part of a specific decision-making process. Figure 8-8 identifies possible points of Model application relative to various stages in air resource planning. Initially, the Model could be used for developing desirable air resource strategies consistent with existing and projected economic activity and technology. As air resource plans are implemented, it could be used to monitor the effectiveness of the program and identify needed policy alterations. After attainment of a desirable air resource, the Model could be used in evaluating the steady-state conditions and in establishing policies for future industrial growth, land-use plans, etc. Issues such as power plant siting and solid waste disposal techniques could be examined with the aid of the Model and appropriate policies developed.

The quality of the Model outputs will improve as the quality of the input data improves. Administrative programs such as source permit systems and air quality monitoring networks should provide more accurate input data than are now available. The future role of modeling should be examined in light of the significant increase in data resources that will be available. Any air resource program should have as an objective the optimum utilization of all data collected. An analytical model such as proposed represents one method of extracting maximum value from data developed in the field. Additional research on the capabilities and practical uses of such a model would be of considerable value.

8.4 CRITERIA FOR EVALUATING STRATEGIES

In Chapter 3.0, the use of impact indicators (or, evaluation criteria) in the decision-making process was discussed. Currently, regional control officers use a few quantitatively determined criteria in control strategy decision-making (such as estimates of the probability of success in complying with air quality standards and rough estimates of control costs) but rely greatly on qualitative factors. The field of air resource management will improve as more reliable criteria are developed and used in the decision-making process. This section briefly identifies some criteria and discusses the need for additional criteria development.

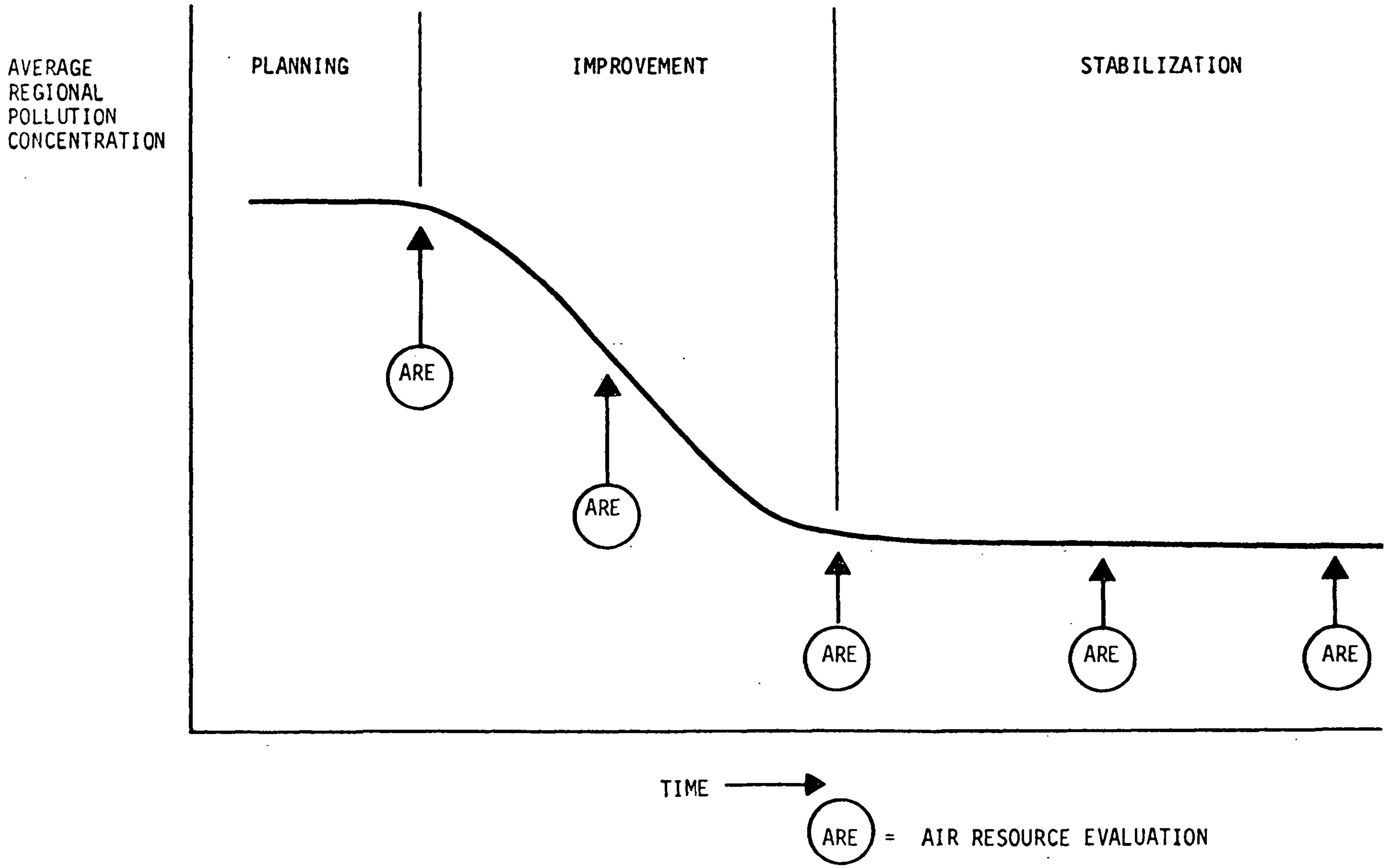


Figure 8-8. Use of the Cost/Benefit Model in an AOCR

The Cost/Benefit Model produces indicators which, by themselves, are useful in evaluating control strategies. Such indicators may be developed from the model's control cost and benefit estimates and can be referred to as "control impact indicators" and "effects impact indicators." When an economic model system is used to determine the effects of control costs and benefits on regional economic activity, indicators on unemployment, regional output, investment and consumption are produced. These are the traditional economic indicators. Finally, there has been developing in this country an interest in creating and utilizing "social indicators" in the evaluation of public programs. The state-of-the-art in devising social indicators to measure the well-being of society is still very rudimentary. This section briefly discusses the different types of indicators.

Control impact indicators are useful tools for evaluating efficiency and equity aspects of air resource policies as they affect sources in an AQCR. Woodcock and Barrett have discussed the development of impact indicators and their application in the gray iron foundry industry.[1] Such indicators make it possible to compare impacts for various emitters and can be used in judging the efficiency of an air resource management program and determining whether emission control regulations distribute air pollution control expenditures equitably among the firms affected.

Effects impact indicators are developed by converting social benefits to incremental changes in labor and capital productivity. Examples of such indicators are:

- The change in productivity of an industrial activity resulting from the social benefit derived from reduced plant maintenance, reduced absenteeism of labor, more productive labor (because of improved health and mental attitude), less corrosion of facilities exposed to the atmosphere, increased value of plant property (which could be rented or put to other economic uses), etc., and,

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[1] Woodcock, K. R., and Barrett, L. B., "Economic Indicators of the Impact of Air Pollution Control; Gray Iron Foundries: A Case Study," Journal of the Air Pollution Control Association, Vol. 20, No. 2, pp. 72-77, February 1970.

- The change in productivity of an agricultural activity because of reduced plant damage, livestock illness, etc.

Such indicators are useful in evaluations of relative benefits received by sectors of a region from air resource policies (e.g., rich vs. poor, whites vs. non-whites, inner city vs. suburbia).

Economic modeling is required to develop economic indicators for the air resource decision-making process. Economic indicators reflect the impacts from control costs, the demand for air pollution control equipment, the resulting increase in regional welfare (from benefits), etc. Such effects create a shift in the economic structure of the region. Air pollution control policies lead to changes in economic output, labor markets, availability of capital, and distribution of capital within the economy.

The economics model system developed by CONSAD is capable of estimating such impacts in the economy. The model system was designed to provide the following types of information for use in public-policy analyses:

1. Regional economic changes expected to result from application of various emission standards to major polluters.

2. Regional economic effects expected to result from reduction of industrial damage and growth in air pollution equipment industries.

3. Changes in regional output, investment, employment, income, and consumption associated with various emission standards.

4. Fiscal effects of regional implementation of air quality control programs. Such effects include the tax base impacts of economic change and the rate of achievement of emission standards specified in the implementation plan.

5. Statistical indicators, including industry-specific ratios of air pollution control costs to total investment and to value added in production.[1]

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[1] A Cross-Sectional Regional Economics Model for RAPA-II Air Pollution Control Analysis, CONSAD Research Corporation, Pittsburgh, Pennsylvania, pp. 3, June 1970.

The system produces some of the following economic indicators:

- Gross regional product
- Employment change by industry
- Investment change and capital stock by industry
- Industry value added.

Raymond A. Bauer[1] has defined social indicators as "yardsticks by which to know if the social condition is getting better or worse." Such indicators are recommended for the air resource decision-making process. They should not merely reflect measures of air quality, but must represent social welfare resulting from the costs and benefits of pollution control policies. The President's Task Force on Economic Growth has stated that, in order to improve the environment and facilitate economic growth and progress, "the appropriate Federal agency should develop indicators of social and economic well-being to guide long-term public policy."[2] The report of the National Goals Research Staff states:

> "While we have come to appreciate the complexity of social and environmental processes, our present knowledge of those complex processes is extraordinarily incomplete. From this, it follows that for the long range we must vigorously pursue the extension of our knowledge in these processes. And, for the short range, since our ability to anticipate exactly what will happen is so limited, we must sharpen our ability to detect as rapidly as possible that which has already happened. This requires the development of new improved methods for the measurement of social change."[3]

A list of readings on social indicators is included in the Bibliography.

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1 Bauer, R. A., Social Indicators, MIT Press, Cambridge, Mass. 1966.

2 Policies for American Economic Progress in the Seventies, Report of the President's Task Force on Economic Growth, May 1970, p. 2.

3 Toward Balanced Growth: Quantity with Quality, Report of the National Goals Research Staff, Washington, D. C., 4 July 1970.

8.5 OTHER USES OF THE C/B MODEL

The simulation capabilities of the C/B Model will be applicable in a wide variety of investigations of the impact of air resource policies on the regional economy and citizen welfare. Some research with the Model will be oriented toward the further development of Model inputs such as damage functions. Oth[illegible] [illegible]ications of the model can be more directly related to policy rec[illegible]tions. Areas in which the Model will be of particular value incl[illegible]

- <u>Damage f[illegible] development</u> - The evaluation of damage functio[illegible] [illegible]athematical forms such as

  - DC = [illegible] + [illegible]
  - DC [illegible] b [illegible]
  - DC = [illegible] -b [illegible]
  - DC = [illegible] + cX^2
  - DC [illegible] bX + cY + . . . + nZ, etc.

  (where DC [illegible]als annual damage cost per capita or annual damage cos[illegible] [illegible]er household). In addition, data may be fitted into the [illegible]ge-function forms and tested (e.g., the analytical res[illegible] [illegible] Anderson and Crocker, Lave and Seskin, and others[illegible]

- <u>Political jurisdiction evaluations</u> - Evaluations of the costs and benef[illegible]ts resulting from policies affecting different p[illegible] jurisdictions in an AQCR, for example,

  - str[illegible] [illegible]trol only in the center city
  - strict control only outside the center city
  - strict control in one jurisdiction only
  - strict control in all but one jurisdiction, etc.

- <u>Source category evaluations</u> - Evaluations of the costs and benefits resulting from the control of

  - area sources only
  - power plants only
  - steel mills only
  - combinations of industrial groups, etc.

- Control system evaluations - Evaluations of the results of control by
    - fuel switching only
    - fuel switching with specific fuels only
    - maximum feasible technology on certain sources only, etc.

The role of the analyst will be to develop situations which are relevant to more efficient and equitable policies and, by testing the situations, to gain further knowledge for decision-making purposes.

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APPENDIX A

THEORETICAL CONSIDERATIONS OF AIR POLLUTION COST/BENEFIT ANALYSIS

This section briefly reviews some theoretical considerations of air pollution cost/benefit analysis. Various sources in the welfare economics literature have been reviewed to better understand the manner in which cost/benefit analysis is applied in other public programs. The discussion here attempts to relate the principles of cost/benefit analysis to air pollution.

The social costs of air pollution control affect the individual, the corporate sector, and the public sector. Individual costs represent an incremental portion of the consumption benefits. Such costs might take the form of annual incremental costs of products that are altered for air quality purposes (i.e., fuels for home heating, gasoline for automobiles, etc.) or annual incremental costs of activities which replace activities that are outlawed by air pollution control regulations (e.g., the cost of solid waste removal and disposal when backyard burning is prohibited).

The corporate sector feels the impact of air pollution control costs through emission reduction activities, air quality monitoring and research and development on process innovations or pollution controls. The impact of these costs may be passed on to the individual in the form of an increase in the price of the goods and services marketed. Without emission control, the cost of air pollution is transferred to the community in the form of damages in this case referred to as external diseconomies or negative externalities, since the costs are negative benefits and are external to the firm. The justification for air pollution control is based on the premise that it is socially cheaper to control emissions at the source (i.e., to increase the internalities) than it is to bear the cost of a polluted air resource (i.e., to live with the externalities).

Public expenditures for pollution control are associated with (1) enforcement of individual and corporate control activities, (2) reduction of emissions from public facilities, (3) regional and nation-wide monitoring of pollution concentrations, (4) research and development on new control techniques and instruments, and (5) research on air pollution effects.

When evaluating the cost of air pollution control to the public sector, allocation of annual revenues at the federal, state, and local levels of government must be measured. The impact of these costs is felt by the individual in the form of increased taxes.

Social benefits, like social costs, have an impact on the individual, the corporate sector, and the public sector. The social benefits to be measured in cost/benefit analysis are the technological or "real" effects which alter the total production possibilities and total welfare opportunities for consumers in the economy. The economic effects of air pollution have been grouped as follows:

- Direct effects - the direct and immediate externalities borne by the receptor
- Adjustments (Indirect effects) - effects which induce persons and firms to make certain adjustments in order to reduce the direct impact of the pollutants.
- Market effects - effects realized through the marketplace as a result of the adjustments made.

One classification of the direct effects of air pollution is shown in Figure A-1.* The concept of the social cost of adjustment is illustrated in Figure A-2. Adjustments result from the direct effects of air pollution on property and the individual. Society is willing to pay a price to avoid the inconvenience or dissatisfaction resulting from these effects. Figure A-3 illustrates the manner in which the individual feels the effects of air pollution. A structure of the type shown in Figure A-3 is required as a starting point for classification of the social costs and benefits of emission control strategies.

In discussing the effects of public programs, a major economic distinction is drawn between pecuniary effects and technological effects. Pecuniary effects are the result of changes in relative prices in the economy. They involve a redistribution of goods and services among people. "Technological effects" (also called "real" effects) alter the total production possibilities or total welfare possibilities for consumers in the

*Barrett, L. B. and T. E. Waddell, "The Cost of Air Pollution Damages: A Statur Report," (unpublished paper).

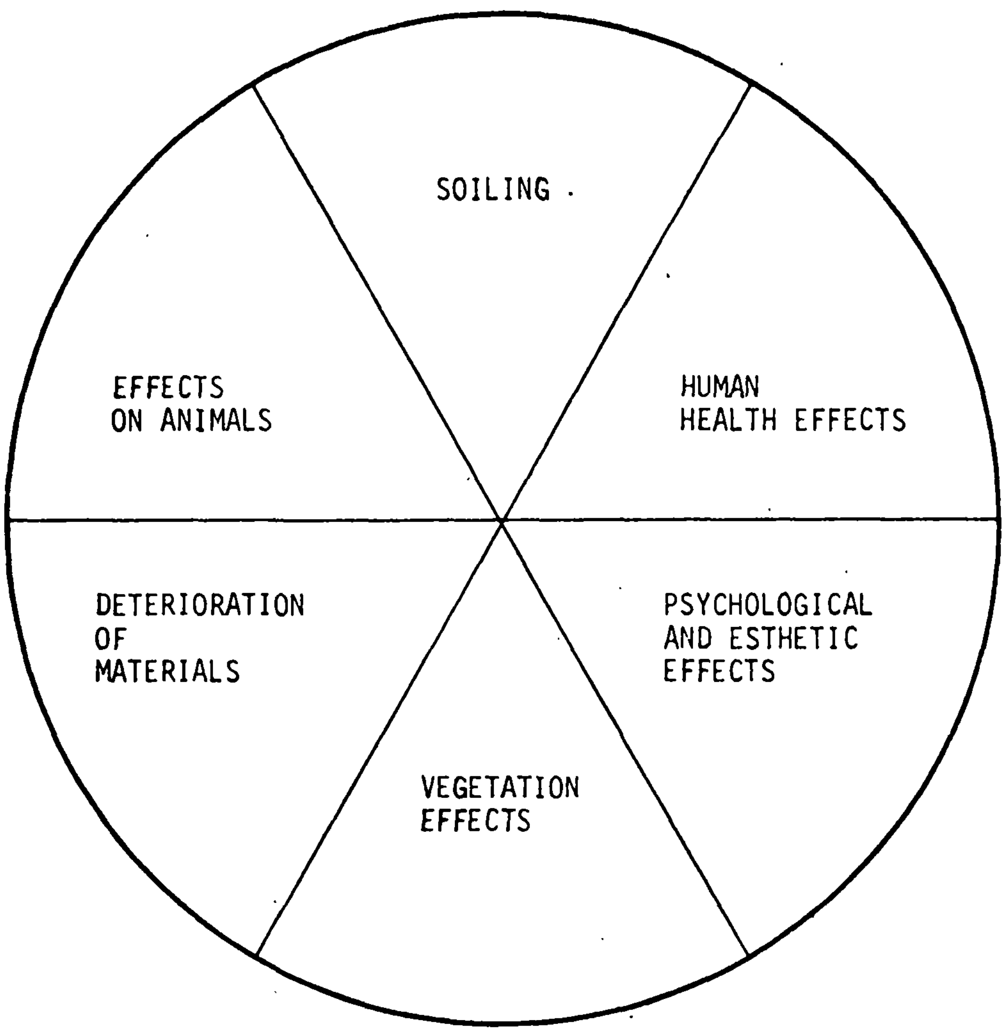

Figure A-1. Classification of Direct Effects

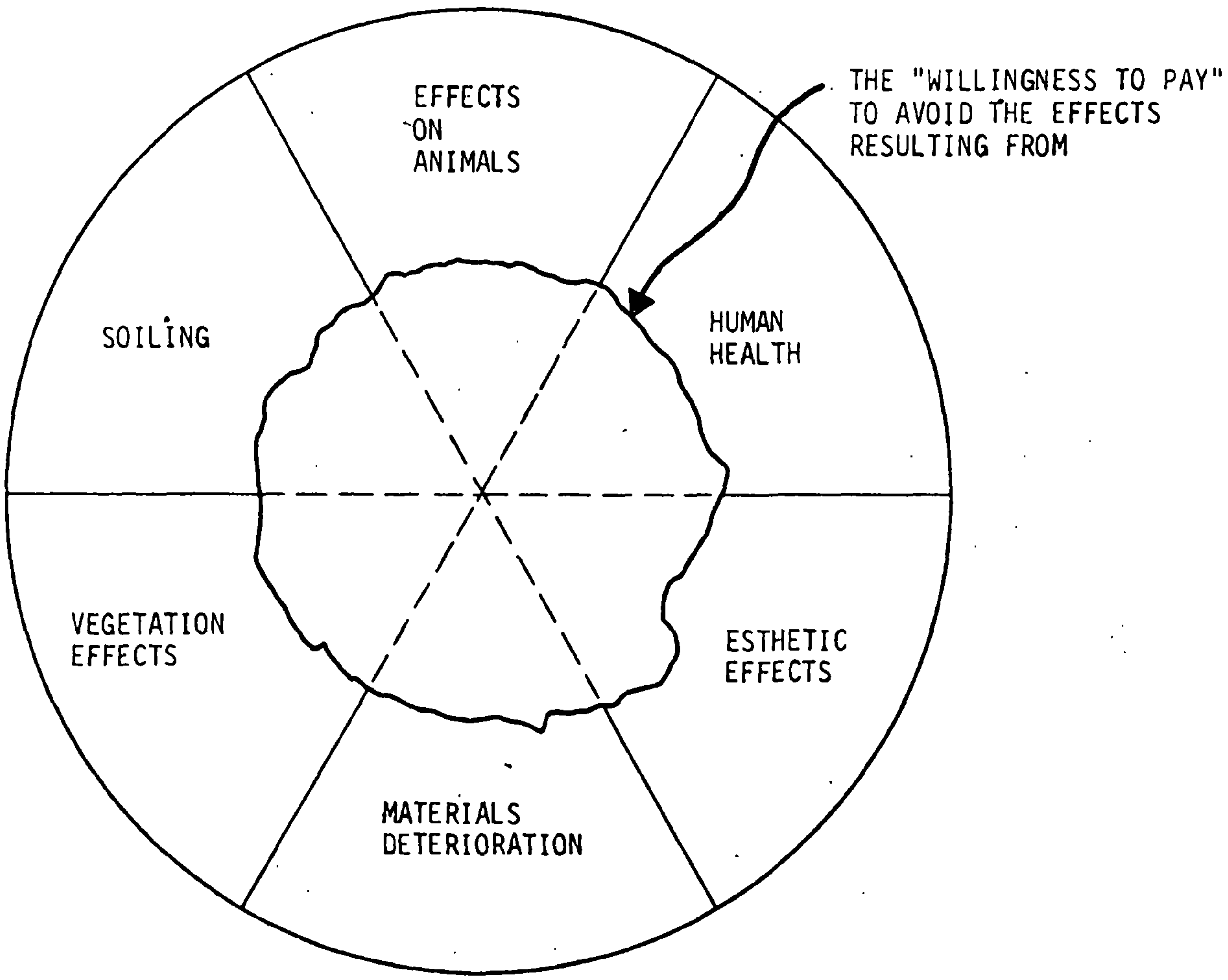

Figure A-2. Identification of Adjustments

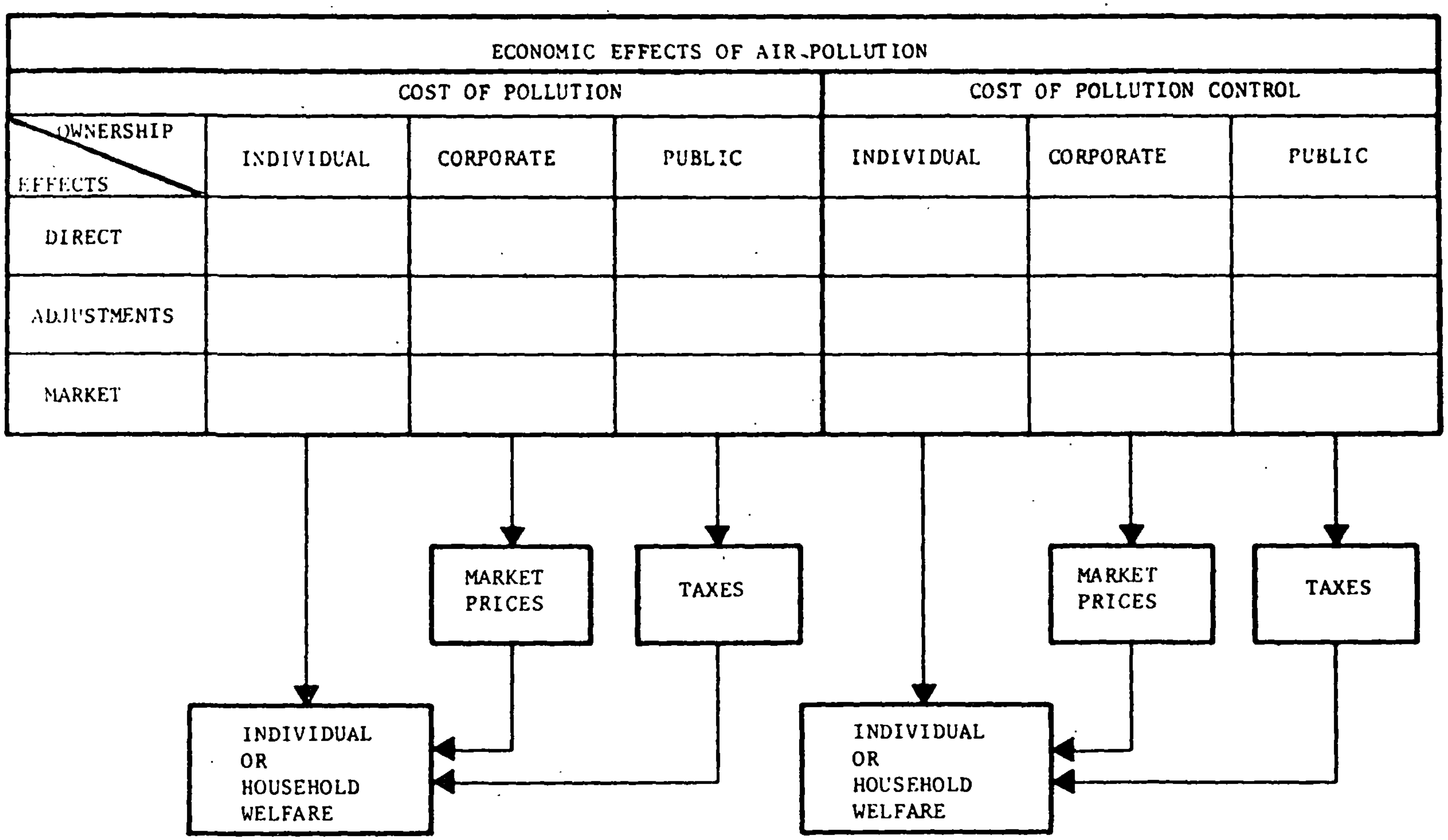

Figure A-3. Structuring the Economic Effects of Air Pollution economy. These effects are termed "economies" when they are favorable and "diseconomies" when they are unfavorable. Thus, manpower training programs produce real benefits for trainees insofar as they increase the workers' productive capabilities. Once the trainee is part of the training program, the benefits are classified as internal real benefits or economies ("internal" because the effects are borne by the firm that does the training).

Classic examples of external real economies are air and water pollution. These effects are classified as "external" because they are borne by persons other than those who caused the pollution. They are considered "real" because production or consumption opportunities elsewhere in the economy are reduced, since polluted water is a detriment to other uses of water (i.e., commercial, drinking, swimming, etc.).

The concepts of pecuniary and real effects would be applicable, for example, to a shift in output from firms which liquidate because of excessive costs of air pollution control (as well as other firms) to firms which supply control equipment. The resulting increase in revenues to the suppliers of control equipment is a pecuniary effect (i.e., a redistribution). The important consideration is that only a shift within the economy exists, without an increase or decrease in the productivity of the economy as a whole.* Technological effects are felt by firms which must purchase hardware, switch fuels, install monitoring devices or perform research. When the responsibility for pollution control is placed upon the pollutant emitter, costs are internalized and measured on the balance sheet of the firm, instead of being passed along as an externality to the community. Such costs are felt as a net decrease in productivity for the total economy, since the same quantity of product is being produced at an increased cost. This decrease in net productivity is a real social cost for cost/benefit analysis.

As was the case with social costs, effects are identified as either pecuniary or technological in the evaluation of social benefits. For example, air pollution control may reduce demand for certain products and

*This discussion assumes a market economy without serious imperfections.

services in some sectors of the economy (e.g., window-washing, house-painting), thus causing a shift in output from these sectors to the rest of the economy. The reduction in revenues for the sector in which demand is reduced and the corresponding increase in demand and in revenues for the rest of the economy are pecuniary effects. The net increase in aggregate consumption or aggregate production benefits which the society realizes from improved air quality represents a technological effect and a social benefit. For example, as an individual becomes more productive (because of improved health or enhanced psychological attitude) or as he derives more satisfaction from a given income (i.e., through increased welfare or income utility), social benefits for society increase accordingly.

Another concept employed in cost/benefit analysis is that of the so-called "secondary effect" of a project.[1/] As the term is generally used, such effects represent the external pecuniary effects of the project. They include the results of changes in demand for particular resource inputs used by the project and the accompanying changes in income of the resource owners. The results of changes in the demand pattern for particular outputs as well as the accompanying changes in incomes of their sellers, as the initial beneficiaries spend their added income and the initial cost-bearers reduce their spending, are likewise considered to be secondary effects. Such "re-spending" is essentially a byproduct or side-effect of a project and does not reflect any increase in the economy's total productive capability, since such increases are already counted in the real benefits. Secondary effects reflect shifts in relative demand patterns which produce increased income for some persons and decreased incomes for others.

Secondary benefits thus represent the values added by incurring secondary costs in activities stemming from or induced by the project (i.e., indirect contributions of public investment to aggregate consumption). The principle sources of secondary benefits are:

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[1] The discussion here on secondary effects and intangible effects is based on B. A. Weisbrod's, "Concepts of Costs and Benefits," in S. B. Chase, Jr., ed., Problems in Public Expenditure Analysis, Brookings Institution, Washington, D. C., pp. 257-262, 1968.

- Departures from competition in the further processing of goods and services produced by means of public project outputs.

- Changes in consumption sufficient to produce changes in the price of consumer goods.

- External economies associated with public projects.

- Private investment induced by public projects.

It is common in cost/benefit analyses to distinguish between costs and benefits that are "tangible" and those that are "intangible." Tangible effects can be measured and priced for decision-making purposes, intangible effects cannot. In other words, tangible effects include those for which, at a particular point in time, data are available whereby the effects may be assessed a value placed on them (in the form of shadow prices). In this connection, Weisbrod comments as follows: "In short, what is tangible or intangible, measurable or non-measurable, is less a matter of what is abstractly possible than it is of what is pragmatically, and at reasonable costs, feasible."[1] He emphasizes the point that what is intangible today because of data limitations may be tangible tomorrow as a result of research efforts aimed at quantification of effects, citing the following analogy: "In the Middle Ages and earlier it must surely have been argued by some that one's feeling of warmth or cold was intangible, unmeasurable, and so on. Fortunately, Gabriel Fahrenheit did not agree."[2]

The concept of intangible and tangible effects is of great importance in air pollution control. Since most of the effects of a polluted atmosphere are now considered intangible, qualitative considerations will influence decisions concerning the development of a regional air resource plan. For decision-making purposes, such intangible effects must be identified and ranked according to their importance. As planned research efforts are implemented, more data will become available and additional air pollution effects may be quantified.

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1 Ibid. pg. 261

2 Ibid. pg. 261

The distinction between tangible and intangible effects has been made. It should be noted that intangible effects can and do affect the decision-making process. As research progresses, there should be a trend toward more complete identification and evaluation of effects, with a corresponding decline in the influence of intangible effects upon policy decisions.

Having identified the relevant costs and benefits and some of the essential terminology of cost/benefit analysis, additional aspects of economic efficiency are now reviewed. This material should serve as a guide for some of the analyses that are possible with the Cost/Benefit Model.

The use of cost/benefit analysis to determine the economic efficiency of alternative control strategies is illustrated in Figure A-4. The upper graph shows one way of plotting pollution and control cost curves for a hypothetical AQCR. These theoretical curves are based on the control costs and pollution damage costs for five increasingly stringent emission control strategies (S_A through S_E). As the stringency of the control strategies increases, there is a corresponding reduction in the regional pollution concentration.

Costs of pollution damage and control are determined for each strategy (e.g., $CC_{(E)}$ and $CP_{(E)}$ for strategy S_E). Above the two cost curves is a "total cost to society" curve which is a summation of control and damage costs. The marginal cost of control increases as control efficiency increases, and the marginal cost of pollution increases as pollution concentration increases, as shown in the lower graph. The minimum cost to society thus corresponds to the intersection of the control cost and cost of pollution curves.

Control costs, and benefits are illustrated in Figure A-5. The control cost curve in this illustration is identical to that in Figure A-4. The benefits curve represents the differences, in pollution costs under existing conditions (S_0) and under various emission control strategies. The benefit, B, for strategy S_1 for example is the difference between pollution costs under strategies S_0 and S_1. The optimum welfare condition for society is represented by strategy S_2, where the absolute difference between benefits and costs reaches its maximum value. From the lower

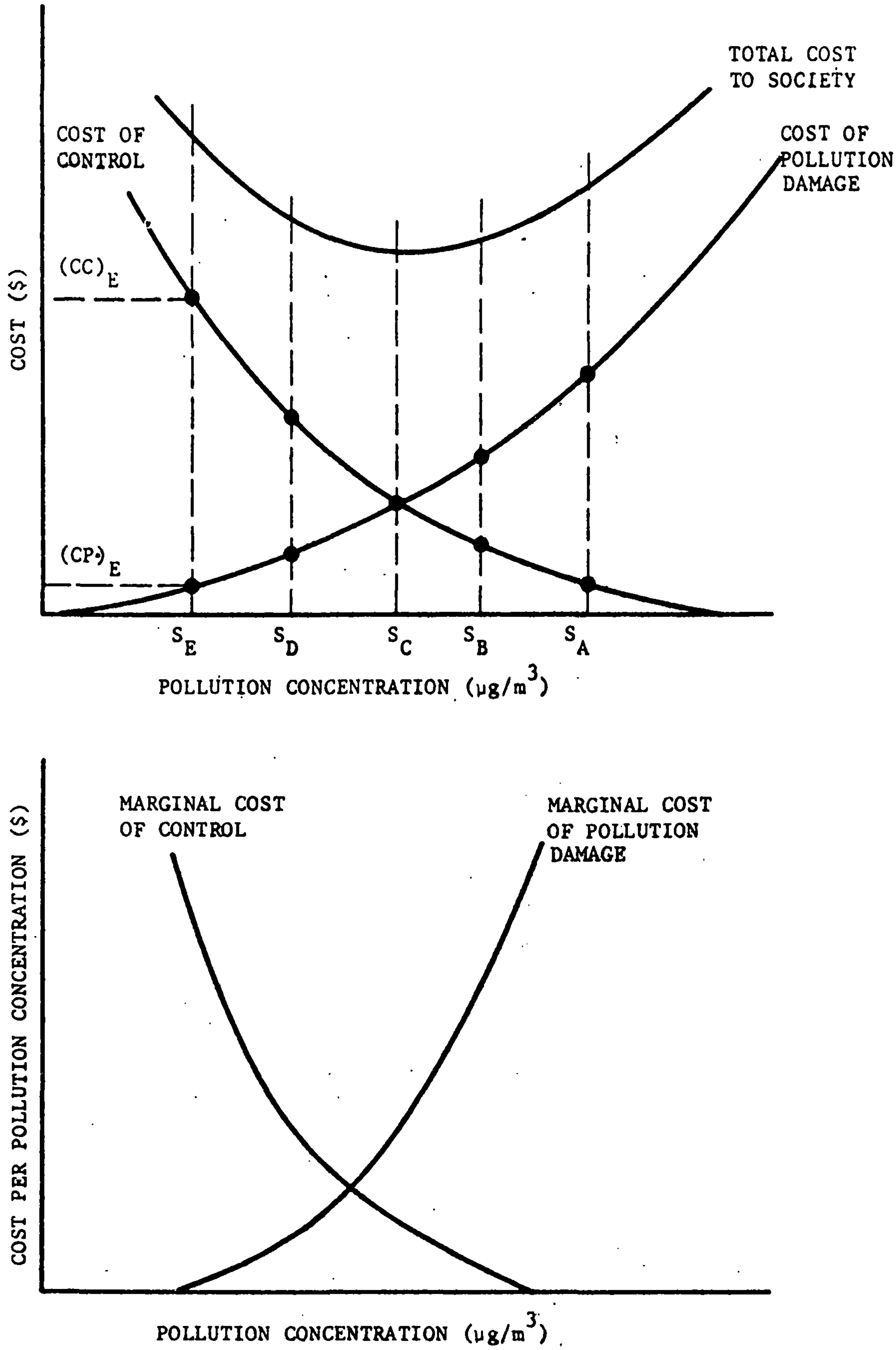


Figure A-4. Cost of Control and Cost of Pollution

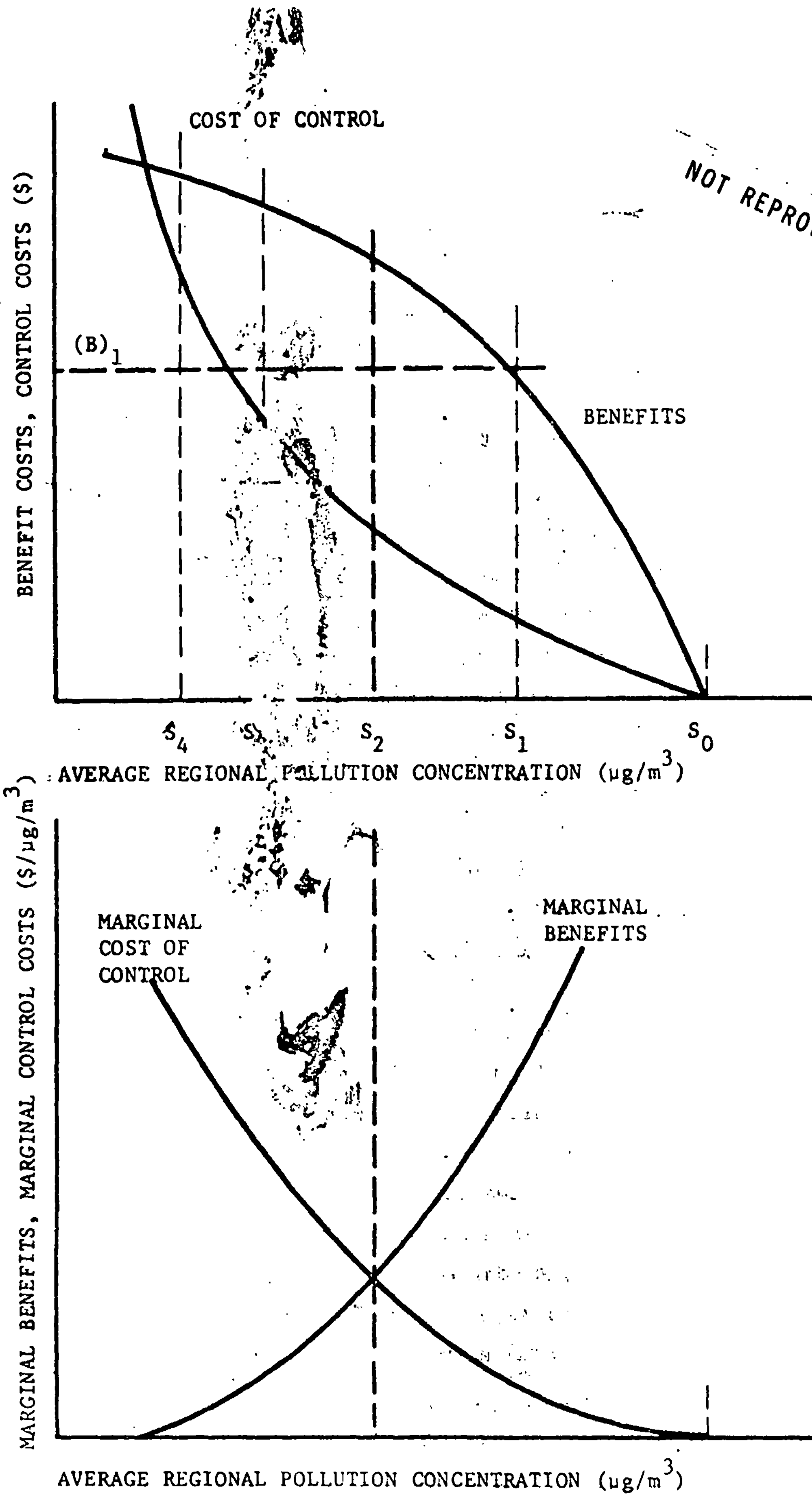


Figure A-5. Cost of Control and Benefits graph it is evident that for strategy S_2 marginal benefits equal marginal costs. This condition of maximum welfare, referred to in economics as the Pareto optimum, exists when one more dollar spent on improving the welfare of one individual necessarily detracts from the welfare of another. Thus under strategy S_2 if one dollar more is spent on the control of emissions, benefits valued at less than a dollar will be gained. On the other hand, if one dollar less is spent on control, more than a dollar's worth of benefits will be lost.

This concept is further illustrated in Figure A-6, where the abscissa represents "tons of emissions removed" (under various emission control strategies) rather than "regional pollution concentration" (this change reverses the location of the marginal cost and marginal benefit curves - see Appendix B for a discussion of a iterative "measures of pollution" for plotting costs and benefits. As in Figure A-5, the Pareto optimility condition exists where welfare is maximized.

As Figure A-6 indicates, the goal of the air resource decision-maker is to remove the Pareto-relevant damages. No plans will be included for elimination of Pareto-irrelevant damages, since for these, the benefits derived from pollution control will be less than the costs of controlling the pollutants. For maximum efficiency, it is important that a pollution control policy provide for removal of Pareto-relevant damages only. Benefits under the Pareto-optimum strategy are represented by quadrangle AECB and the cost of pollution control, by triangle BEC. The net benefit to society is thus represented by triangle AEB. As shown in Figure A-7, it is desirable to internalize the Pareto-relevant externalities (i.e., by making the polluting sources pay the control cost) without infringing upon the Pareto-irrelevant externalities. In other words, it is desirable to control pollution at the source up to a point where the next dollar spent on pollution control is equal to the resulting incremental social benefits obtained by the community.

The shaded area under the marginal control cost and marginal benefit functions in Figure A-8 represents total air pollutant disposal cost to society at the maximum welfare condition. This total cost may be reduced

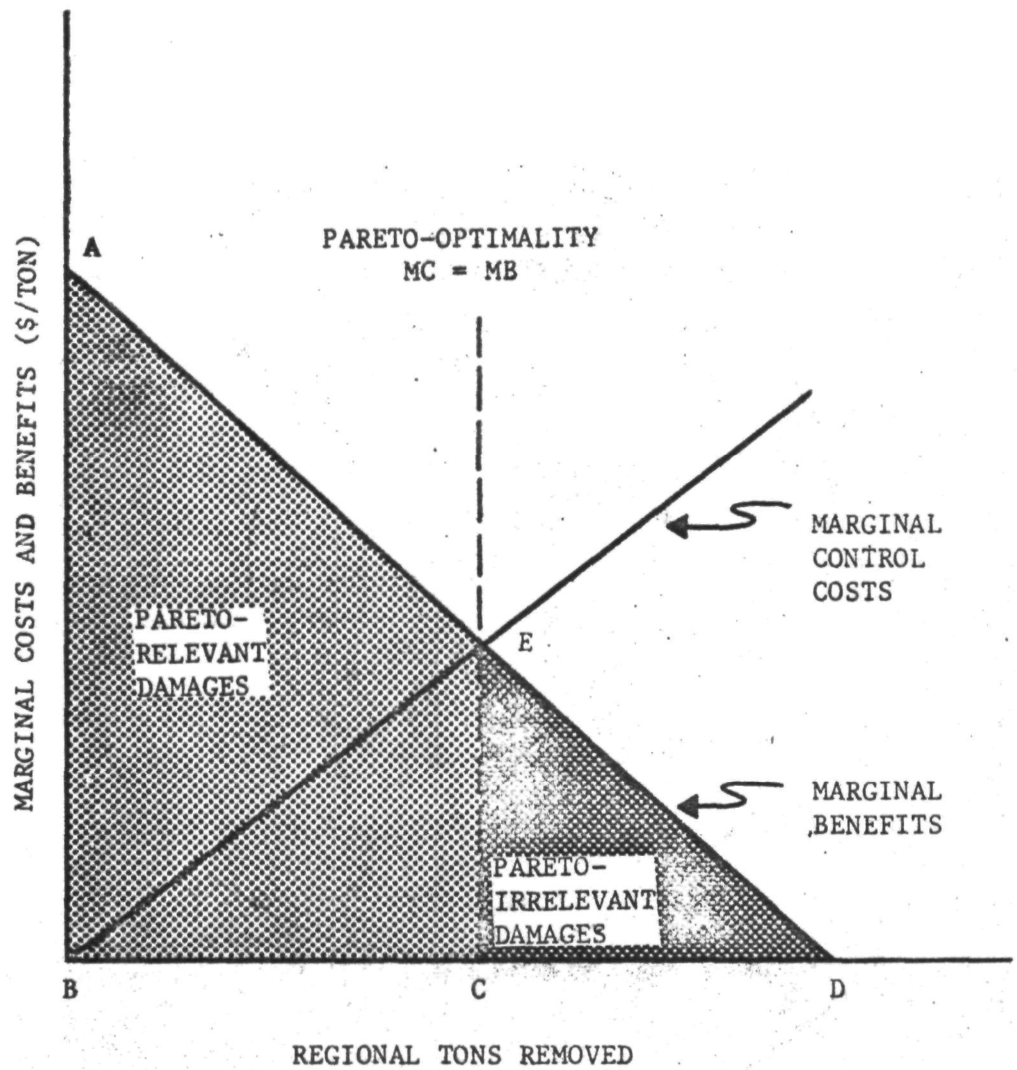


Figure A-6. Pareto-Relevant and Pareto-Irrelevant Externalities

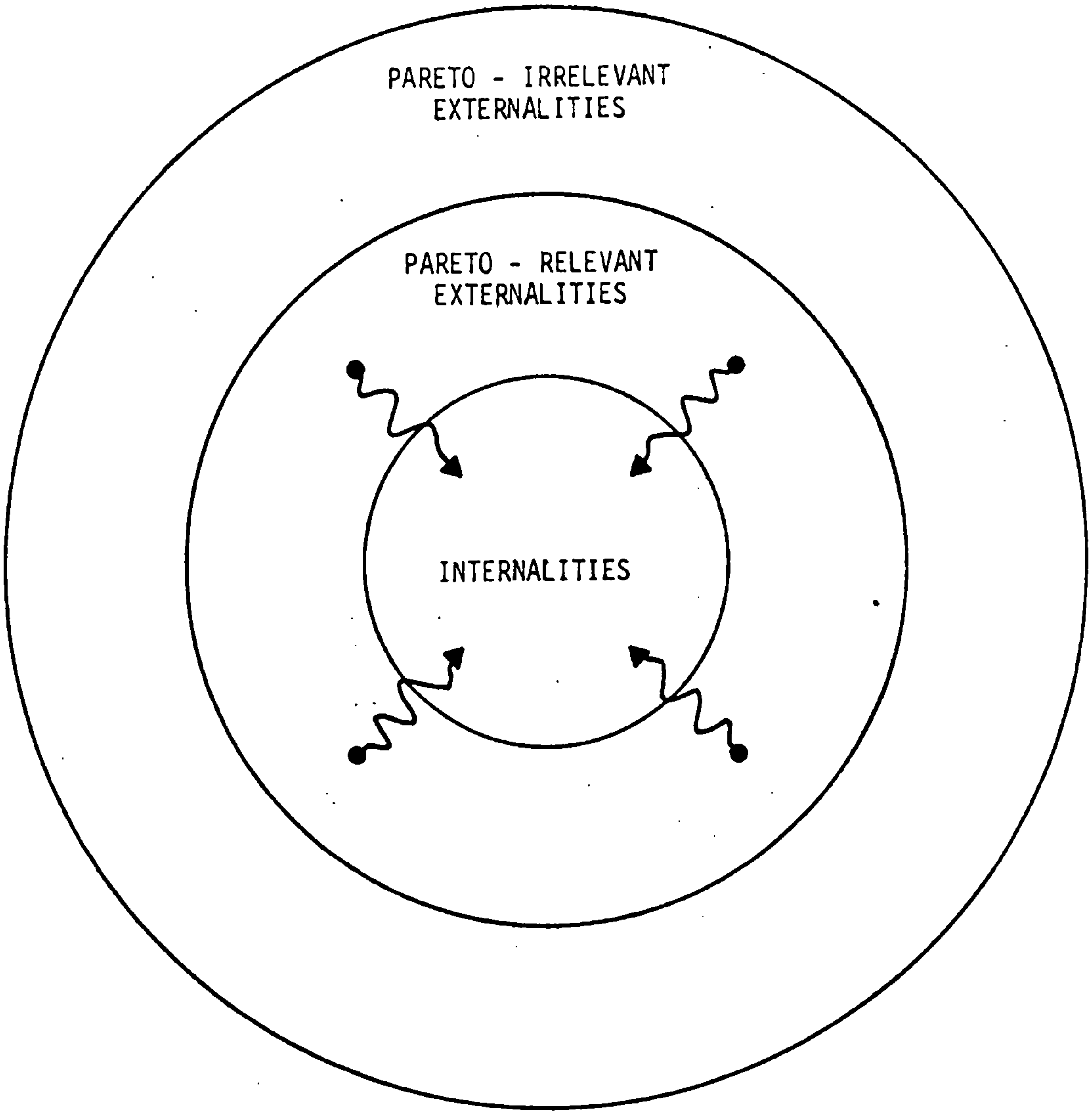


Figure A-7. Internalization of the Cost of Pollution

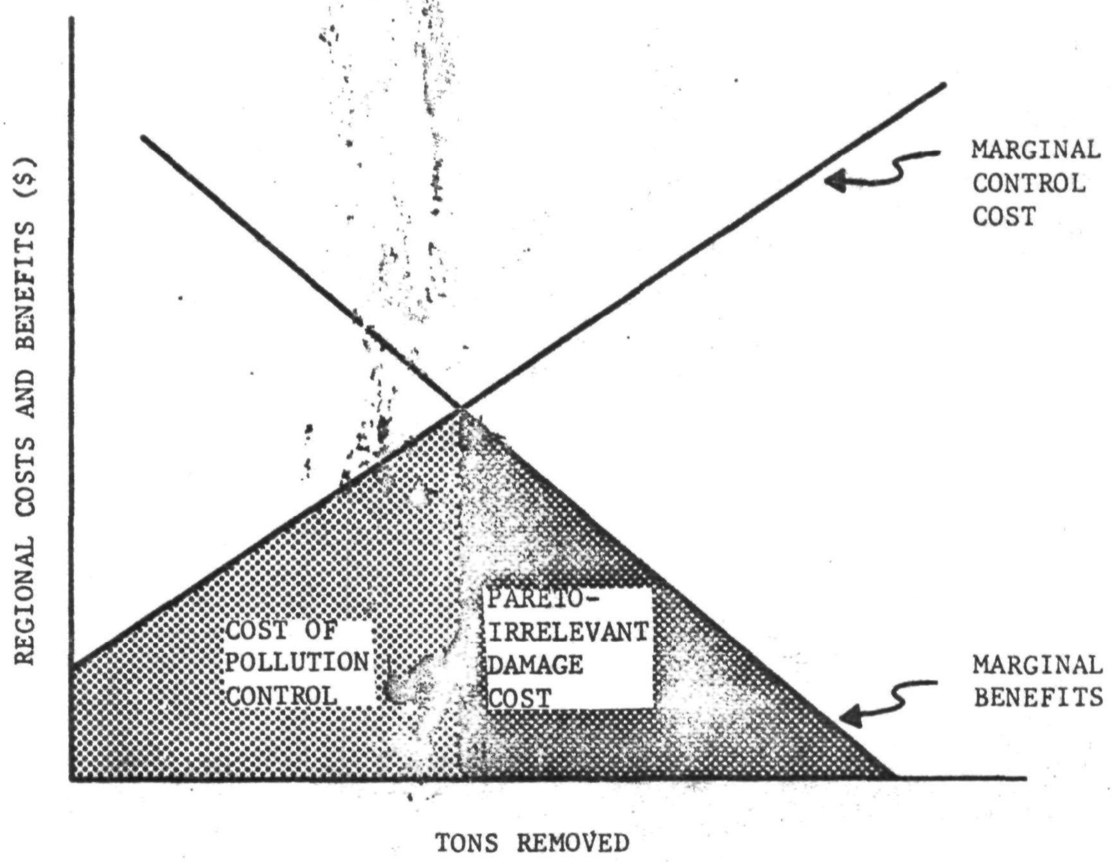


Figure A-8. Relevant Costs of Air Pollution Disposal once the maximum welfare condition has been obtained (see Figure A-9). Through technological advances in air pollution control systems, society will experience an effect that may be portrayed as a shift of the marginal control cost curve to the right. Such advancement is a classical case of a technological effect. Society benefits by a more efficient mode of operation, that is, a net increase in productivity.

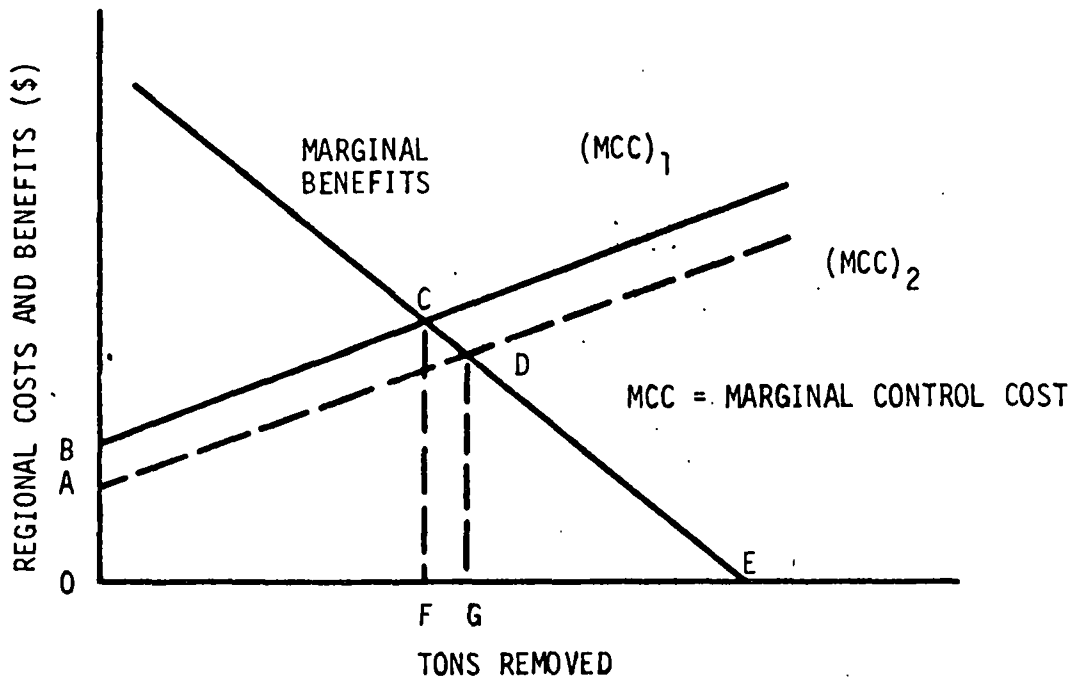
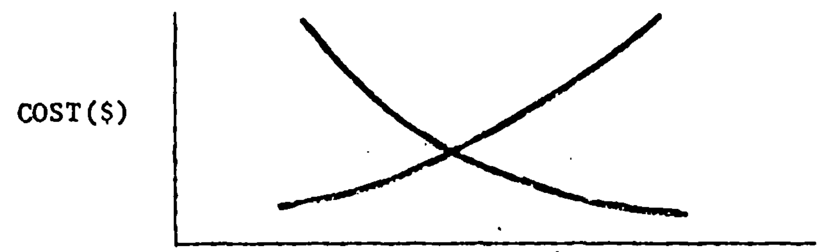


Figure A-9. Reduction of the Relevant Costs of Air Pollutant Disposal

APPENDIX B

PRACTICAL MEASURES FOR OBSERVATIONS OF COSTS AND BENEFITS

In the analysis of emission control strategies costs and benefits are plotted on rectangular coordinates for purposes of clarity (see Appendix C for illustrative plots of costs and benefits for alternative strategies). Control costs and benefits are normally plotted against some measure of pollution, with costs on the ordinate and the measure of pollution on the abscissa, as in the sketch below.



The measures of pollution which are most meaningful for the analysis must be identified. Some pollution measures which indicate the effectiveness of control strategies are:

- Maximum concentration anywhere in the AQCR,
- Regional emission rate from point and area sources,
- Average concentration for all census tracts in the AQCR, and
- Average concentration for the center city portion of the AQCR.

Various other measures may also be used, but these four are adequate as a beginning.

The "maximum concentration" in an AQCR is now used by APCO to determine the acceptability of an emission control strategy. Although this measure is valuable as a means of ensuring that air quality is acceptable at all points in an AQCR, it is not a good indicator of overall air quality. Certain high-concentration points may remain unchanged, for example, while overall regional air quality is improving. Maximum concentration is thus an inadequate measure for purposes of cost/benefit analysis.

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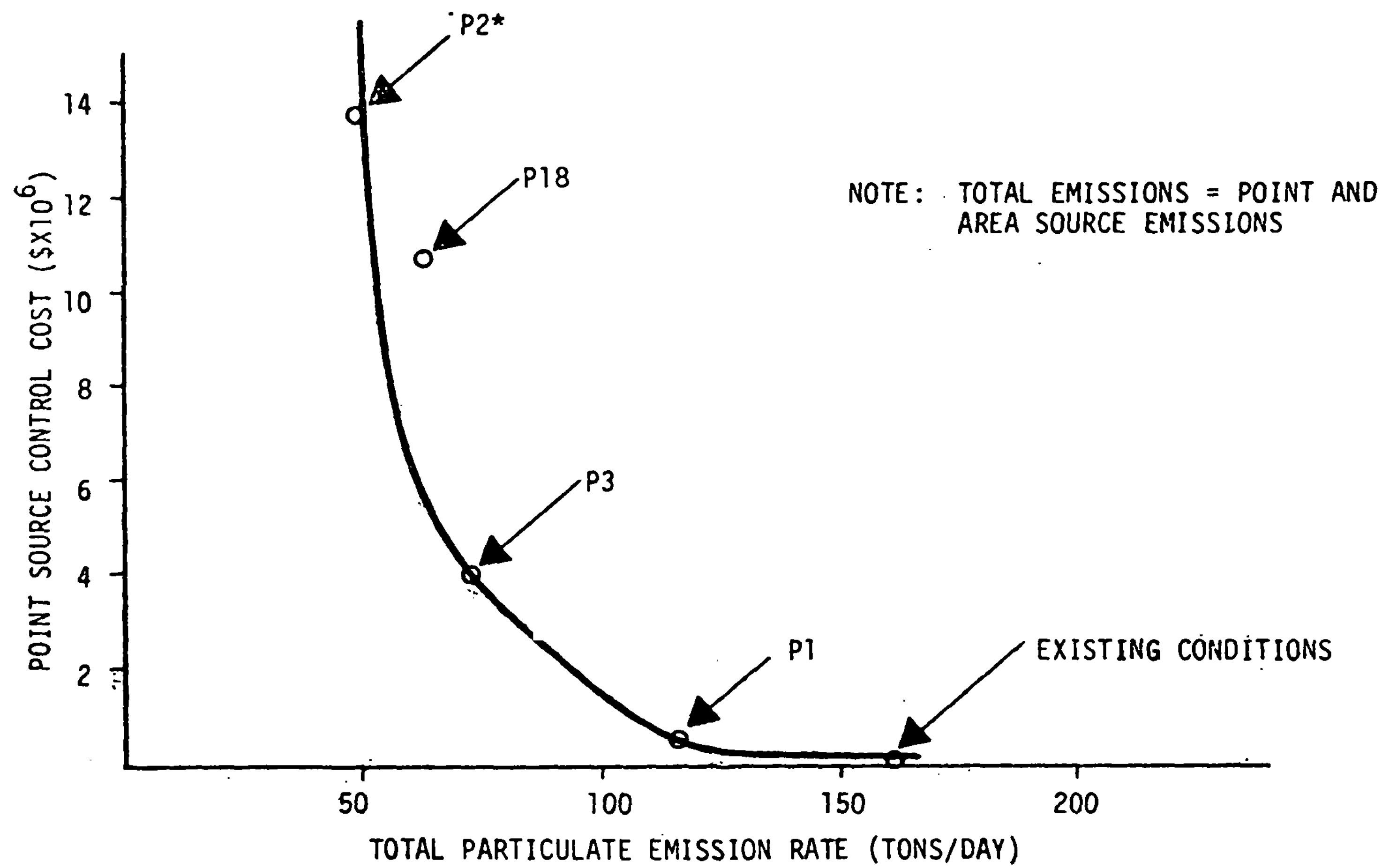
The "emission rate" from sources in a region is a measure of the total pollutant contribution and indicates the degree of emissions control. Emission rate is not as closely related to benefits as is a measure of region-wide air quality, but it does represent the effectiveness of source control. Typical emission rate data are shown in Figures B-1 through B-4, which plot the costs and marginal control cost of strategies tested in the NCIAQCR.

Average "regional pollution concentration" (ARPC) is an excellent indicator for cost/benefit analyses purposes, since pollution concentration is the independent variable in damage functions. ARPC is the arithmetic average of predicted pollutant concentrations for all census tracts in an AQCR. Essentially, the measure is a weighted average relative to regional population. In other words, since the average census tract contains approximately 4000 people, pollutant concentrations in the area of greatest population density will be most heavily weighted.

"Average center city pollution concentration" represents a compromise between the "point of maximum concentration" and measures "regionwide average." It is valuable as a measure of improvement in the zone of poorest air quality.

In summary, various "measures of pollution" are available for use as the abscissa in C/B presentations, and a comparative analysis of the advantages of these measures would be highly desirable.



*SEE TABLE B-1 FOR DESCRIPTION OF PARTICULATE AND SULFUR DIOXIDE CONTROL STRATEGIES.

Figure B-1. Point Source Control Cost vs. Total Regional Particulate Emission Rate for NCIAQCR --- for Selected Strategies

Table B-1.

SELECTED CONTROL STRATEGIES FOR THE NCIAQCR

Particulate Strategies

P 1. Existing Control Regulations Throughout the Region. This strategy displays the air quality resulting from complete compliance with existing control regulations in the Region.

P 2. Maximum Control Technology. Under this strategy the best available control device or measure (as defined in the Control Cost Model) is applied to each pollution source. This strategy may be neither economically nor technically feasible but does give a potential lower limit on pollutant emissions.

P 3. Existing Regulations in the District and Virginia - No Emissions in Maryland. Area source emissions were eliminated and point sources were substantially reduced by the application of maximum control technology.

P 18. Proposed Particulate Control Strategy. District of Columbia sources were controlled to 0.03 grains/scf for industrial process sources, 0.06 grains/scf fuel combustion and 0.20 grains/scf for incineration. Maryland and Virginia sources were controlled to the levels specified by their respective implementation plans.

Sulfur Dioxide Strategies

S 11. Existing Regulations. Complete application of existing regulations affecting sulfur oxide emissions throughout the region.

S 12. Maximum Control Technology. The strategy requires the application of the best available control technology to all sources; in most cases, this requires fuel burning sources to switch to natural gas.

S 15. Maximum of 0.7 Percent Sulfur Content Fuel in Region. This gives a small reduction from the current 1.0 percent sulfur restriction now in effect in most of the Region. (Major exceptions are the Dickerson and Chalk Point power plants.)

S 19. Proposed Sulfur Oxide Control Strategy. A fuel sulfur content limitation of 0.5% was imposed on District of Columbia sources. Maryland and Virginia sources were controlled in accordance with their implementation plans."

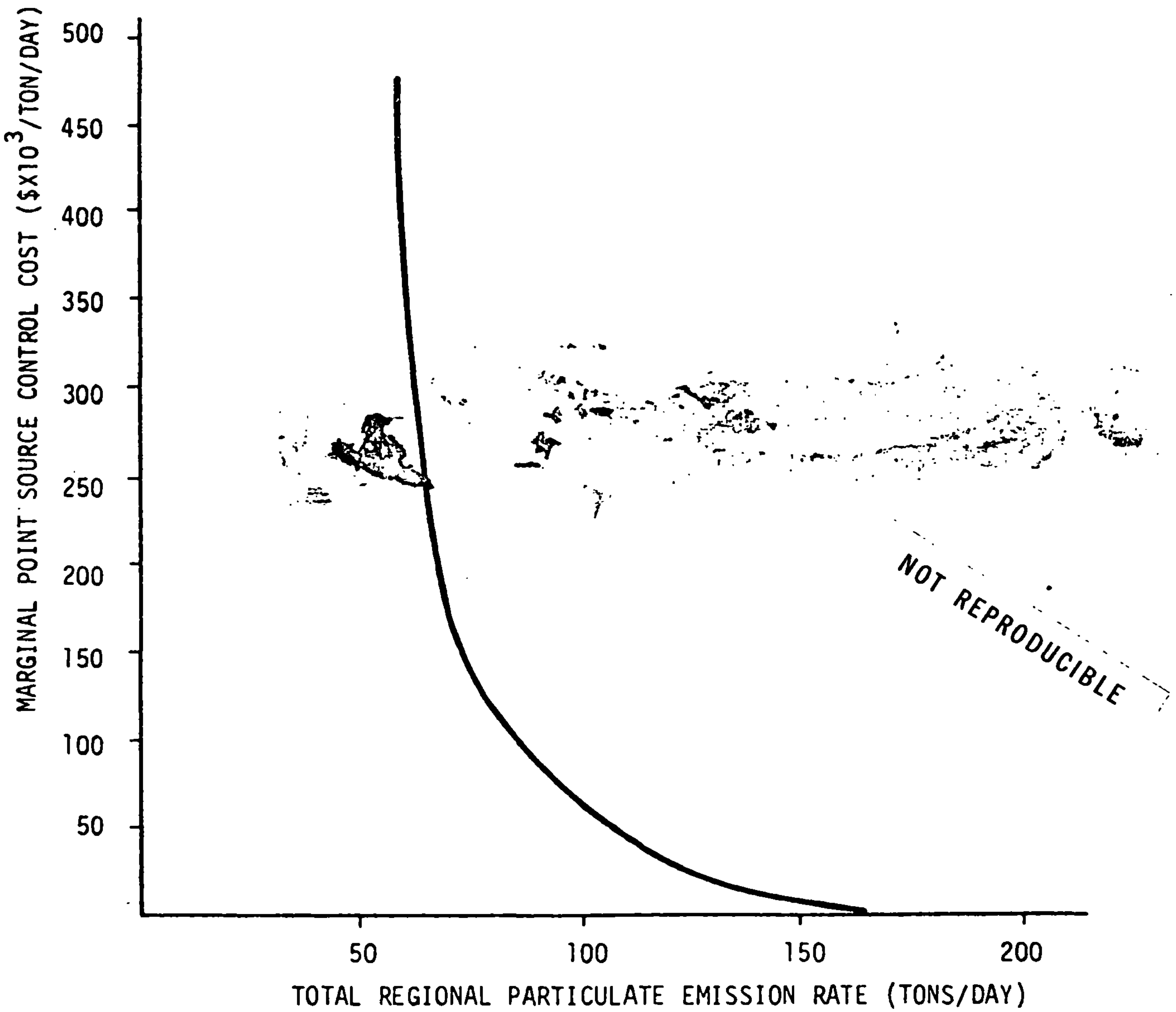
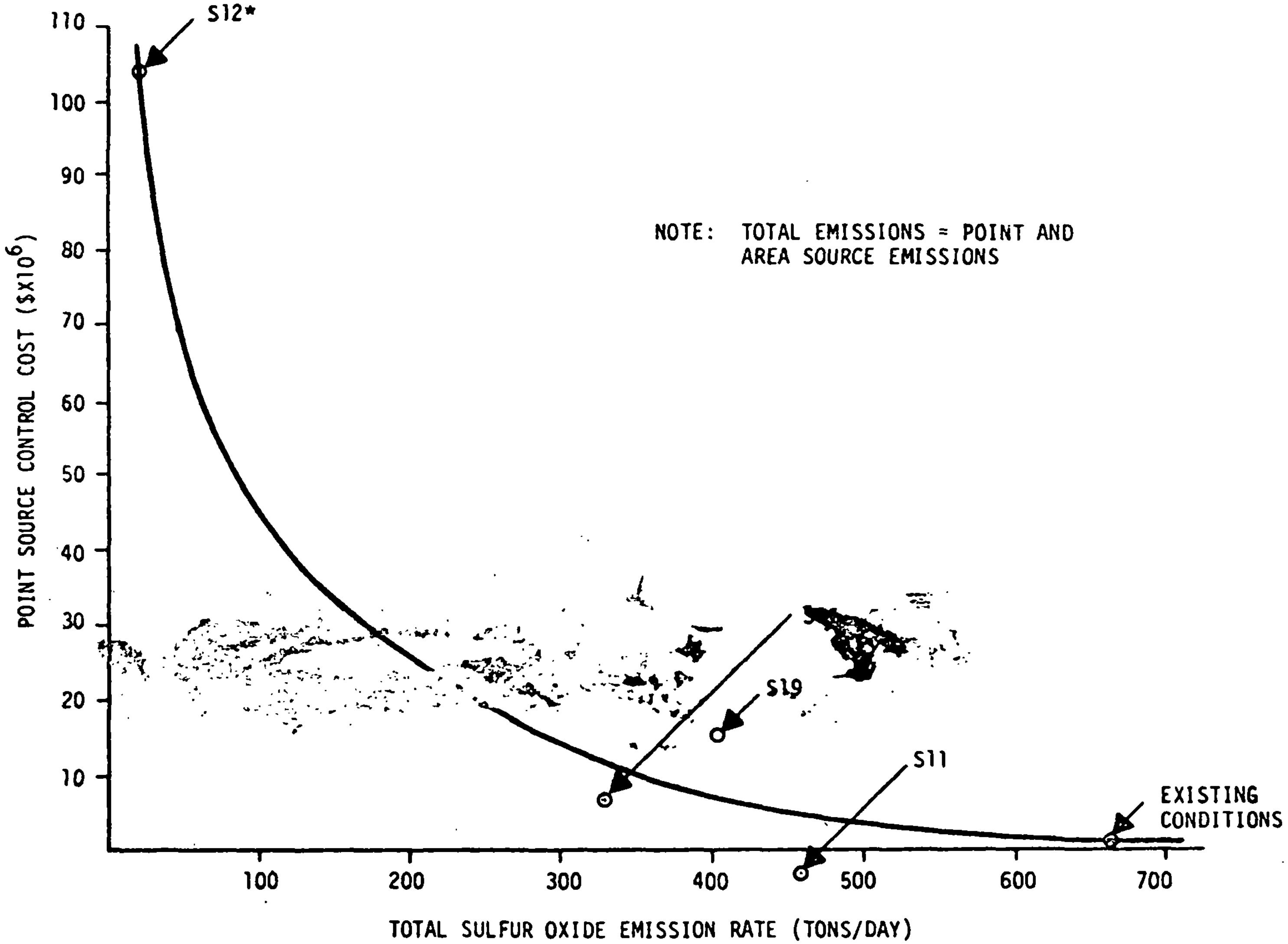


Figure B-2. Point Source Marginal Control Cost vs. Total Regional Particulate Emission Rate for NCIAQCR --- for Selected Strategies



*SEE TABLE B-1 FOR DESCRIPTION OF PARTICULATE AND SULFUR DIOXIDE CONTROL STRATEGY.

Figure B-3. Point Source Control Costs Vs. Total Regional Sulfur Oxide Emission Rate for NCIAQCR --- for Selected Strategies

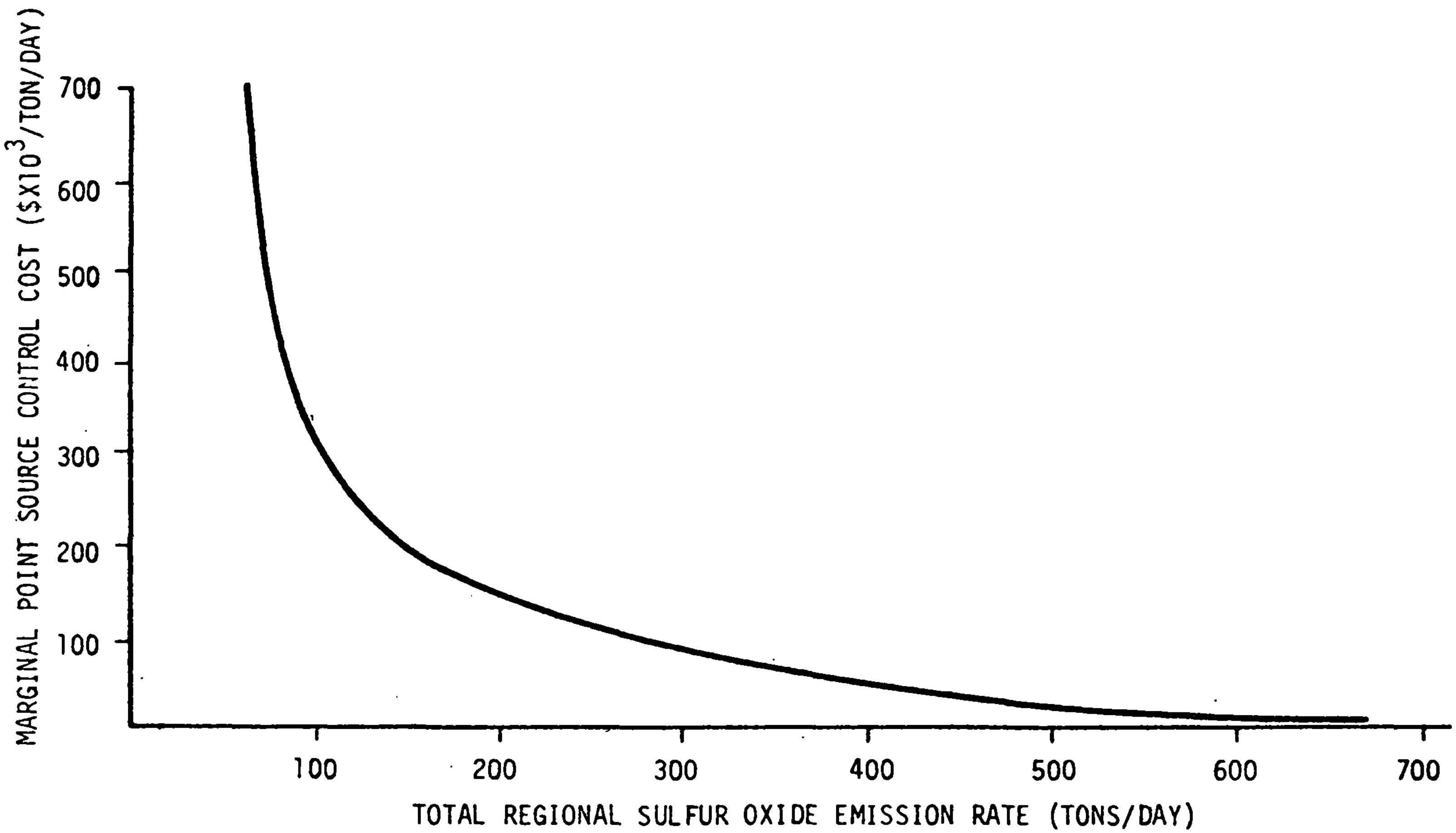


Figure B-4. Point Source Marginal Control Cost vs. Total Regional Sulfur Dioxide Emission Rate for NCIAQCR --- for Selected Strategies

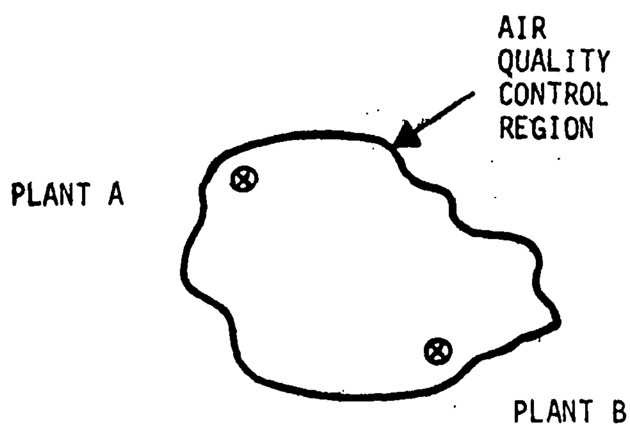
APPENDIX C

EFFICIENCY EVALUATIONS OF COSTS AND BENEFITS

To illustrate the type of analysis which will be employed in economic efficiency evaluations, some sample calculations and plots were prepared. This exercise is presented here as an aid to understanding the relationships that will be encountered and as a stimulus to further analysis. A model region is used to illustrate efficiency evaluation procedures for control costs and benefits.

EFFICIENCY EVALUATION EXERCISE

Given:

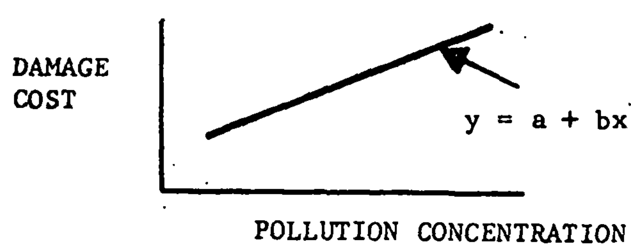


(1) An air quality control region with two point sources, Plant "A" and Plant "B"

(2) Control cost functions for a pollutant for each source

(3) Benefits for a pollutant for each source. It is assumed that benefits have been determined by the use of a damage function, where:

- the function is linear (i.e., constant elasticity) for all concentrations of the pollutant, i.e.,



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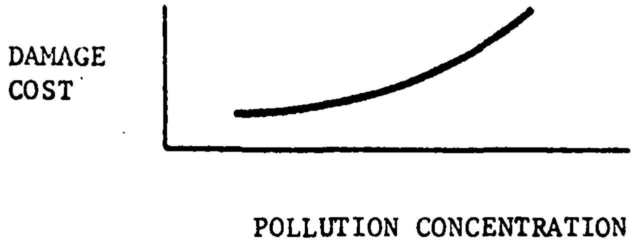
- the function is curvilinear, i.e.,



and specific air quality conditions for the pollutant are given.

(4) Specific control strategies defined as follows:

- Equi-Control Costs - all sources spend the same absolute amount to control.
- Equi-Marginal Control Costs - all sources spend the same absolute cost per ton removed to control.
- Equi-Tons Removed - all sources control the same absolute quantity of pollutant.
- Equi-Benefit - all sources control to a level where the benefits (on receptors) per source are identical.
- Equi-Marginal Benefit - all sources control to a level where the benefits (on receptors) per ton removed are identical for each source.

<u>OBJECTIVES</u>

(a) To examine the following relationships for each source:

- Control costs per ton removed
- Benefits per ton removed
- Marginal control costs per ton removed
- Marginal benefits per ton removed
- Benefit cost per ton removed
- (Marginal benefit/marginal cost) per ton removed

(b) To examine these same relationships for the air quality control region for each control strategy specified.

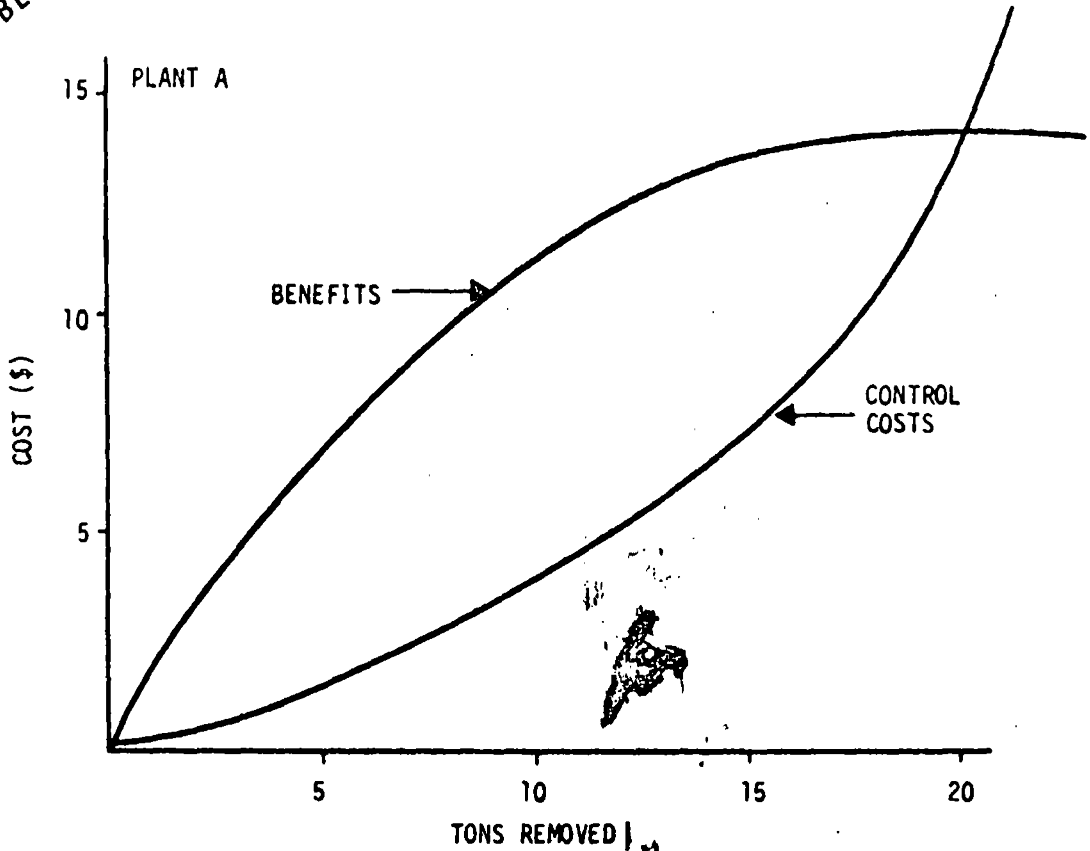
DISCUSSION

Figure C-1 illustrates control cost functions and benefit functions for the two autonomous plants (A and B). These functions have been plotted against a "tons-removed" variable; an "efficiency" variable could be used instead without changing the significance of the analysis. It may be noted that the elasticity of the control cost function increases as a higher level of control is attained. This observation is consistent with actual practice, where more money must be spent for each additional increment of emission control. The elasticity of the benefit function on the other hand decreases as emission control increases, a fact which indicates that as ambient concentrations are reduced benefits increase at a declining rate.

Figure C-2 relates marginal control costs and marginal benefits as a function of the quantity of pollutants removed. These functions illustrate the rate of change in cost for each incremental change of pollution control. A point of Pareto-optimality has been reached when one additional dollar spent in improving someone's welfare detracts proportionately from the welfare of another. At this point marginal costs equal marginal benefits. In Figure C-2, the welfare optimum for each source is reached at the intersection of the marginal control cost curve and the marginal benefit curve. This optimal position corresponds to a level of just under 11 tons removed per day for Plant A and 5.5 tons for Plant B.

The upper-graph in Figure C-3 shows the benefit/cost relationships as plotted against tons removed while the lower-graph portrays marginal benefits versus marginal costs as a function of tons removed. As in Figure C-2, the point of Pareto-optimality is located at approximately 11 tons removed for Plant A and 5.5 tons removed for Plant B. It should be noted the lesser the slope of the marginal benefit versus marginal cost function, the less significant it is for the source to be at the exact point of Pareto-optimality. As the slope of the function approaches the horizontal, the source will deviate less from the optimum as the controls slightly more or slightly less. As the slope of the function approaches the vertical, deviation from the optimum welfare position will be more significant as more or less pollution is controlled.

Table C-1 illustrates the results of cost-benefit calculations at one level of control for alternative control strategies in an AQCR with two



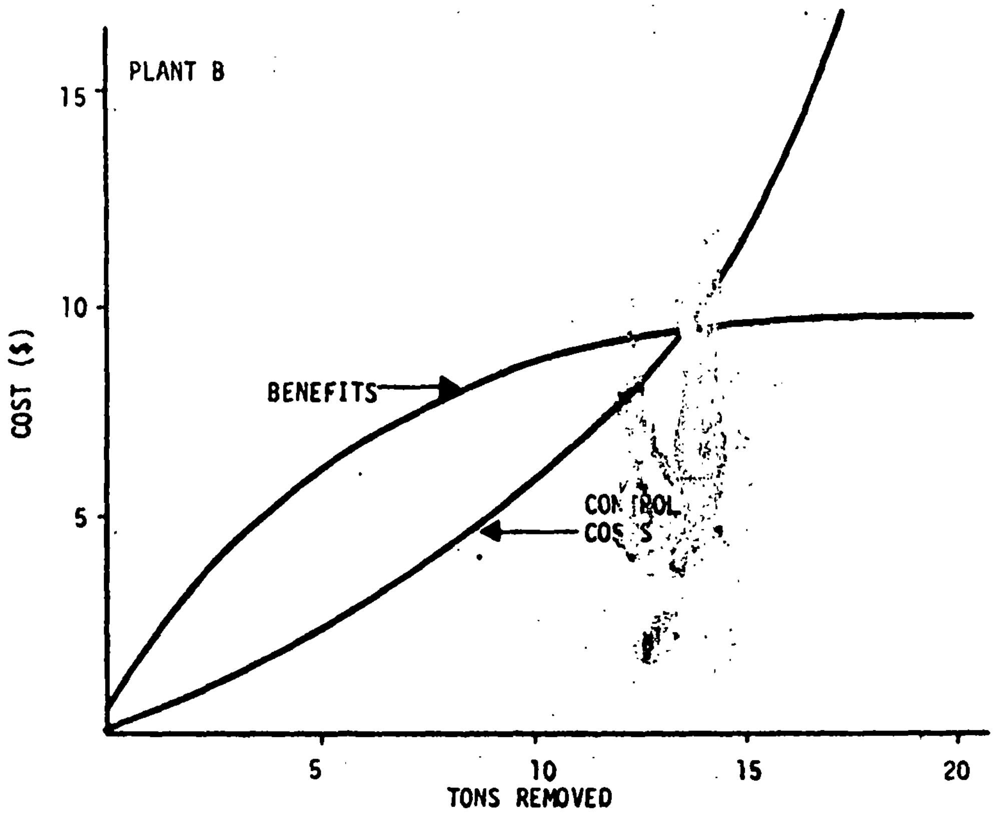


Figure C-1. Control Cost and Benefit Functions for Two Plants

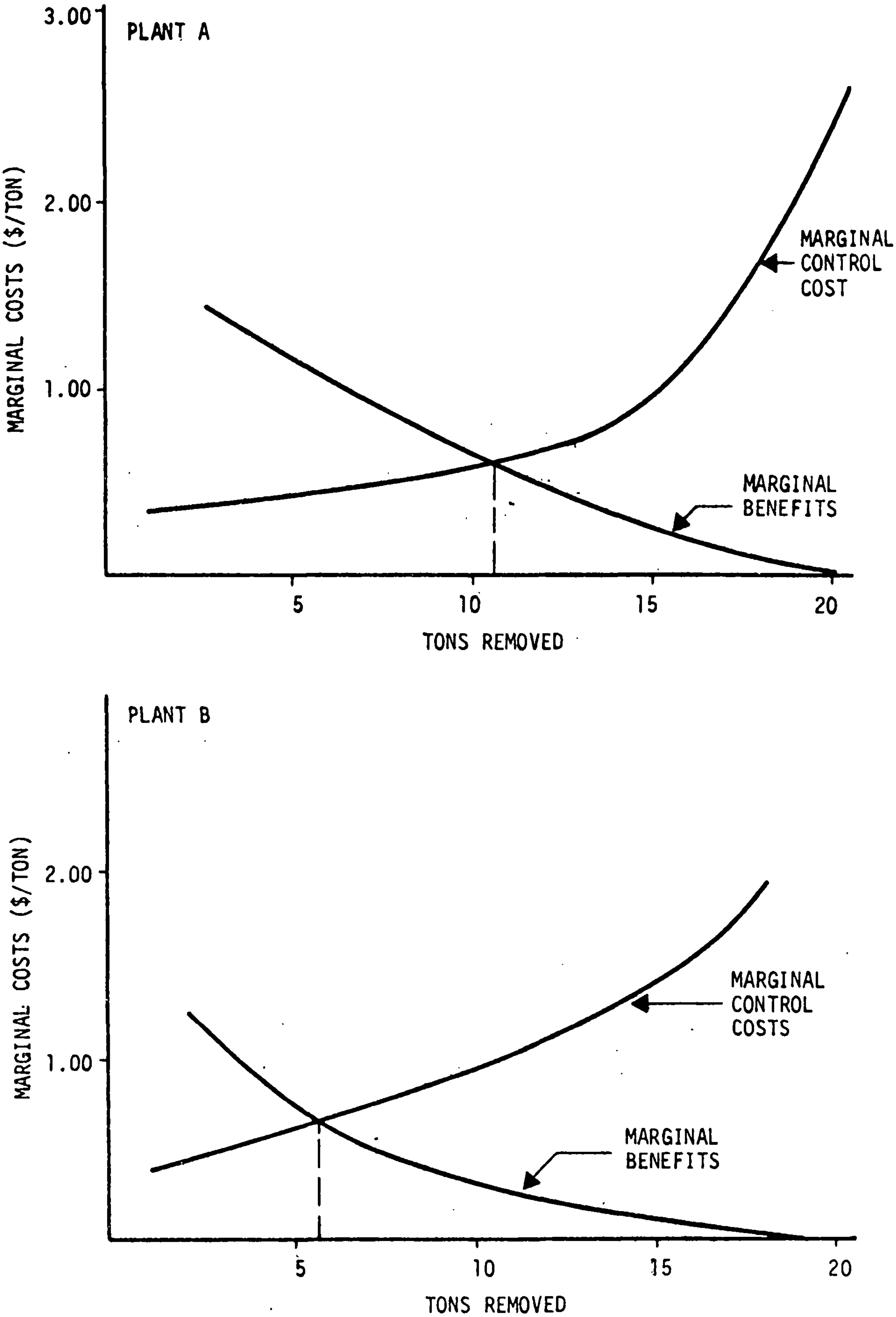


Figure C-2. Marginal Control Cost and Marginal Benefit Functions for Two Plants

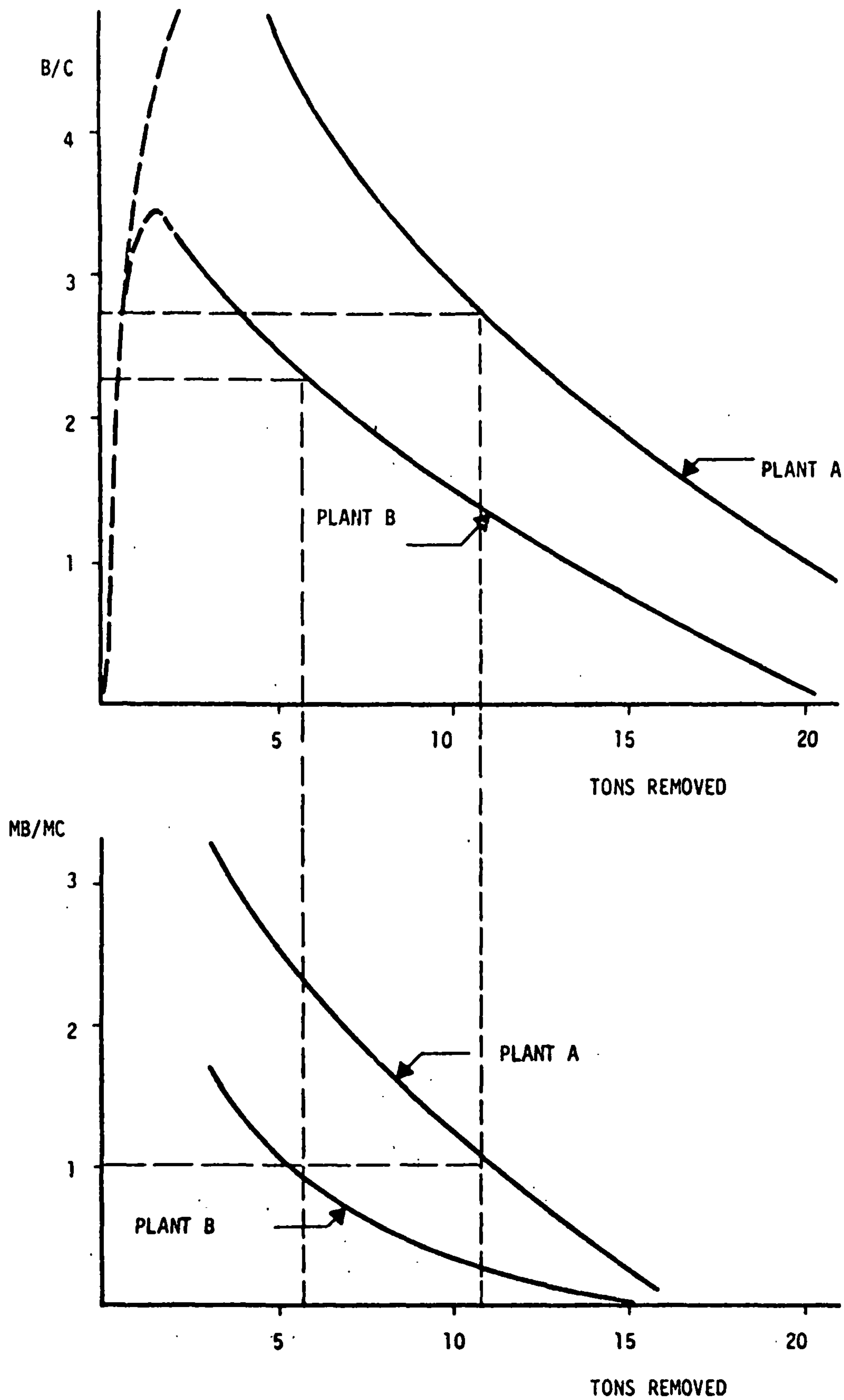


Figure C-3. Benefit/Cost and Marginal Benefit/Cost Plots for Two Plants

Table C-1

COST-BENEFIT STRATEGY EVALUATIONS --- EXAMPLES

STRAT.	PLANT	($) CONTROL COST	($/TON MARGINAL CONTROL COST	(TON) TONS REMOVED	$ BENEFITS	($/TON) MARGINAL BENEFITS	B/C	$\frac{MB}{MC}$
Equi-	A	10.00	1.50	17.5	14.00	0.01	1.40	0.07
Control	B	10.00	1.25	13.7	9.40	0.12	0.94	0.10
Costs	TOTAL	20.00	2.75	31.2	23.40	0.22	1.17	0.08
Equi-	A	7.6	1.00	15.5	13.8	0.20	1.82	0.20
Marginal	B	6.8	1.00	11.0	9.0	0.37	1.32	0.27
Control Costs	TOTAL	14.4	2.00	26.5	22.8	0.47	1.58	0.24
Equi-	A	5.1	0.66	12.00	12.7	0.48	2.49	0.73
Tons	B	7.6	1.09	12.00	9.2	0.20	1.21	0.18
Removed	TOTAL	12.7	1.75	24.00	21.9	0.68	1.72	0.30
Equi-	A	1.5	0.42	5.0	7.00	1.10	4.65	2.62
Benefits	B	3.5	0.71	6.5	7.00	0.55	2.00	0.72
	TOTAL	5.0	1.13	11.5	14.00	1.65	2.80	1.46
Equi-	A	1.8	0.45	6.0	8.0	1.00	4.45	0.45
Marginal	B	1.4	0.50	3.3	4.6	1.00	3.28	0.50
Benefits	TOTAL	3.2	0.95	9.3	12.6	2.00	3.94	0.48

*
$$\frac{(MB)_A + (MB)_B}{(MC)_A + (MC)_B} = \frac{(MB)_T}{(MC)_T}$$

sources. The cost curves in Figure C-1 have been used in calculating these results. As may be seen, these control efficiencies vary from one strategy to another, and the relative efficiencies of the strategies cannot be compared on the basis of these examples.

The optimum level of control is illustrated in Figure C-4 for one of the six strategies evaluated (the "equi-tons removed" strategy). The optimum reduction in emissions for the AQCR under this strategy is 13 tons (each plant must thus remove 6-1/2 tons of emissions). It should be noted that the optimum situation occurs where:

- marginal costs equal marginal benefits, or, expressed in another way,
- marginal benefits/marginal costs equal unity.

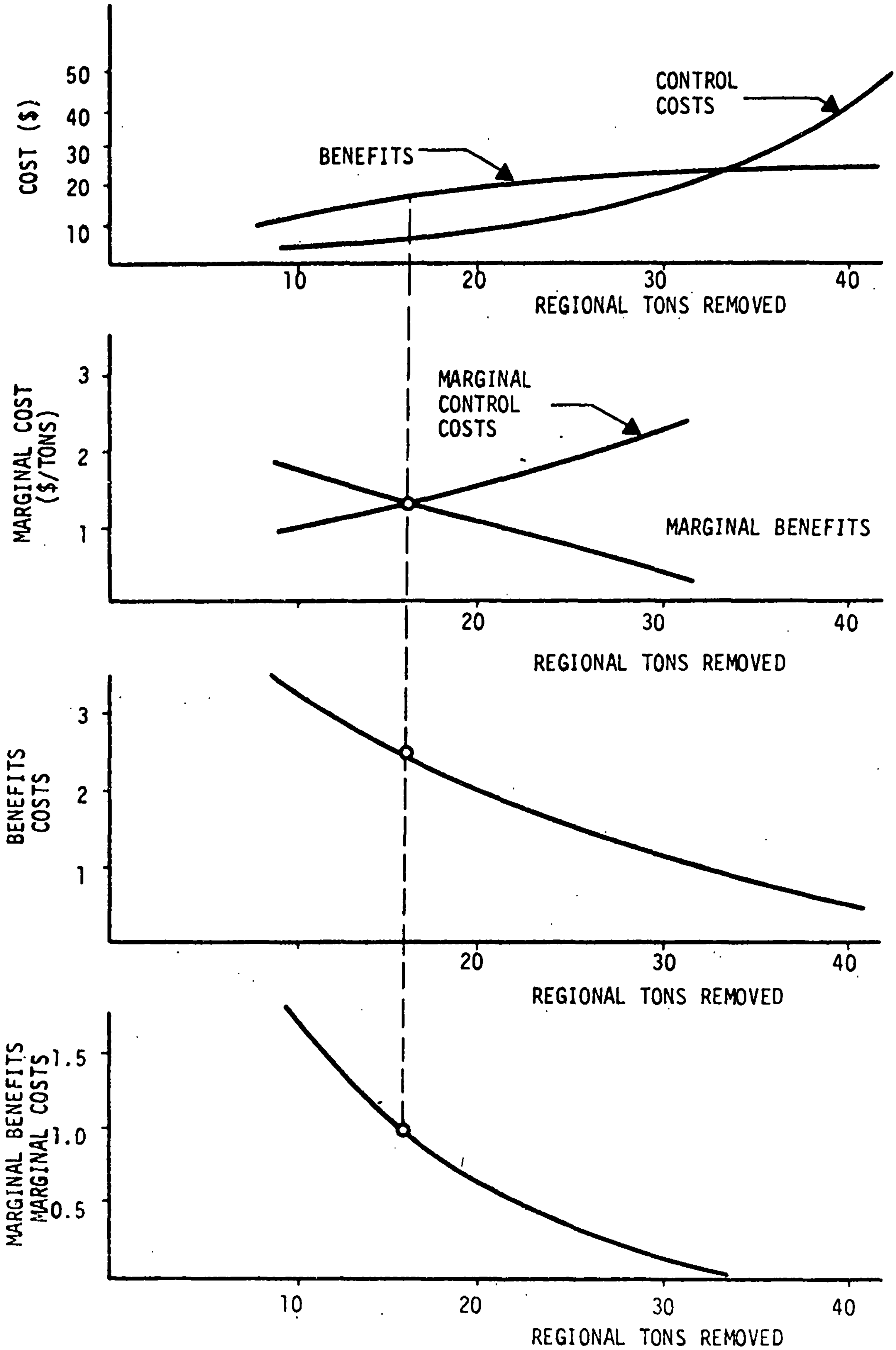


Figure C-4. Graphic Analysis of "Equi-tons Removed" Strategy for Two Plants

APPENDIX D

CONTROL SUPPLIER FUNCTIONS

Regional Air Pollution Analysis should include a provision for examination of the additional economic activity experienced by suppliers of equipment, services, and utilities to firms which are required to control pollutant emissions. The need for a control supplier function became apparent in connection with the use of regional econometric models to evaluate the impact of air pollution control measures on the regional economy. Economic impact is over-predicted for a region when the activity needed to provide control devices and services is not taken into consideration.

Some of the investment in control systems will come from suppliers in the region. Services obtained from within a region may include engineering services for system design and installation, labor for construction of foundations, metal work, etc. On the other hand, much of the hardware (pumps, drives, etc.) will be imported from other locations, in which case the firms that inventory and distribute the equipment within the region will benefit.

Most of the annual cost of controlling emissions will be spent on services from the regional economy. These will include water, electricity, labor, hauling, and other services required to operate emission control systems and dispose of the collected materials.

Economic research is needed to determine the sectors which will benefit from the demand for emission control equipment and services in and outside the region. The following procedure might be used in identifying the value added for a region:

Step 1. Identify the categories of material and labor inputs to emission control systems according to:

- Pollutant
- Control system type
- Process type

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Step 2. Identifv the categories of emission control systems within a region, which will include:

- Turn-key
- Self-made
- Locally contracted, etc.

Estimate the categories for the systems described in Step 1 on the basis of current installations. Also, project future installations.

Step 3. Categorize the elements of emission control systems. such as:

- Process takeoff
- Gas preconditioner
- Emission removal
- Gas postconditioner
- Gas moving
- Stack
- Emission disposal, etc.

Step 4. Identify for each system elements identified in Step 3 the investment categories, such as:

- Direct labor for installation
- Hardware
- Sheet metal
- Concrete, etc.

Step 5. Identify for each system element listed in Step 3 the annual cost categories such as:

- Water
- Electricity
- Disposal charge
- Maintenance labor
- Repair labor
- Parts, etc.

Step 6. Determine whether the value added for control system investment and annual costs is based inside or outside the AQCR.

Step 7. Prepare a matrix such as that shown in Figure D-1, which is similar to the control device matrix in the IPP program,[1]

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[1] Air Quality Implementation Planning Programming, Vol. I, Operations Manual, TRW Systems Group, McLean, Virginia, pp. 5-14 through 5-16, 1971.

REGION: ______________________										
		"VALUE ADDED" MIX								
SOURCE CATEGORY	CONTROL DEVICE NO.	01		,,, ,,		,, ,,,		45		
	LOCATION	IN***	OUT	IN	OUT	IN	OUT	IN	OUT	
SIC. 2040	I**									
	A**									
SIC 2819 nnn 1	I									
	A			72*	28*					
,	I									
	A									
, , , , , , , , , , ,										
SIC 2800	I									
	A									

*REPORTED IN PERCENT

**I = INVESTMENT
A = ANNUAL COST

***IN = "VALUE ADDED" CONTRIBUTION FROM INSIDE THE AQCR
OUT = "VALUE ADDED" CONTRIBUTION OUTSIDE THE AQCR

Figure D-1. Control Supplier Input to Cost/Benefit Model

Control supply functions for source categories and control system types may be input to the C/B Model, so that every time a point source is assigned a specific control device, the value added mix for the AQCR (a ratio of internal to external value added for investment and annual costs) can be computed and applied in a econometric modeling.