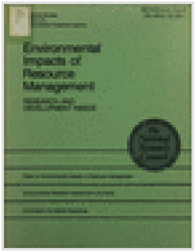

# Environmental Impacts of Resource Management: Research and Development Needs (1977)

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for the U.S.
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# Environmental Impacts of Resource Management

## RESEARCH AND DEVELOPMENT NEEDS

**A Report of the Panel on Environmental Impacts of Resource Management to the Environmental Research Assessment Committee**

**Commission on Natural Resources**
**National Research Council**

**NATIONAL ACADEMY OF SCIENCES**
**Washington, D.C. 1977**

# NOTICE

This report is one of several commissioned by the Environmental Research Assessment Committee for use in its study of the role of research and development in regulatory decision making in EPA. The views expressed herein are those of the Panel on Environmental Impacts of Resource Management and do not necessarily represent those of the Committee.

The project of which this report is a part was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Panel responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by the Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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# PREFACE

The Panel on Environmental Impacts of Resource Management was one of four panels commissioned by the Environmental Research Assessment Committee (ERAC) to identify scientific and technical information needed for effective regulatory decision making. The reports of the panels are part of the assessment by ERAC of the role of research and development in the U.S. Environmental Protection Agency (EPA), an analytical assessment that is, itself, one part of a more extensive study by the National Research Council of the acquisition and use of scientific and technical information by EPA in its regulatory decision making.

The prime objective of the ERAC study was to examine the processes by which information is acquired by EPA through research and development. Because these processes have both managerial and scientific aspects, the Committee divided its work into two parts. One part, concerned with the organization, coordination, and management of research and development to support the agency's mission, is the subject of a separate report by the ERAC itself. The other, which deals with the identification of technical opportunities for research and with strategies for guiding research planning, was divided among the four panels. The report of the Panel on Sources and Control Techniques deals with research needed on the generation of residuals and strategies for their control. The report of the Panel on Fates of Pollutants deals with research needed on the transport, transformation, and accumulation of pollutants in the environment. The report of the Panel on Effects of Ambient Environmental Quality deals with research needed on the effects of environmental pollution on living and nonliving things.

This report, prepared by the Panel on Environmental Impacts of Resource Management, deals with the identification of fundamental and important needs for information on the environmental consequences of the management and use of natural resources. Knowledge of the effects of resource management activities is an important component of the information EPA needs for many of its regulatory decisions, as well as a vital consideration in the decisions of other agencies whose missions are to manage resources.

In its charge to this panel, the ERAC asked the panel to recommend strategies and priorities for research and development that would produce information of significant value for environmental decision making. The objective of this panel's study was, therefore, to identify questions that EPA needs answered and to suggest effective ways to apply the nation's diverse research capabilities to the task of finding those answers.

The Environmental Research Assessment Committee wishes to express its appreciation of the contributions made by the members of the Panel on Environmental Impacts of Resource Management in the preparation of this report, for the cooperation of the members of various agencies and institutions, and for the assistance and support of Dr. James J. Zucchetto of the Department of Environmental Engineering Sciences of the University of Florida in Gainesville, who served as a consultant. It also wishes to acknowledge the contributions made by the staff, particularly the dedicated work of Dr. Edward Groth III who, as Staff Officer for this panel, provided invaluable direction, support, and editorial assistance.

John M. Neuhold

Chairman

Environmental Research Assessment Committee

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# SUMMARY

Many activities undertaken in the development and management of natural resources occur on very large geographic scales, and the effects of such activities may be felt over extended periods of time. Decision makers responsible for the management of resources must identify and compare the likely long-term and short-term consequences of alternative management choices. Those consequences include both benefits of resource use and adverse effects, such as undesirable environmental impacts. In order to be most useful for decision making, research on the environmental impacts of resource management activities should be part of a comprehensive analysis of the ecological and social systems in which the resources occur and are managed. An analysis is needed that integrates the many physical, biological and social considerations that affect policy choices.

Chapter 1 of this report discusses the size and complexity of resource management problems, and examines the apparent inability of existing institutions for decision making and research to deal with such issues in an appropriately comprehensive manner.

Chapter 2 describes a generalized approach to the analysis of resource management problems, based on simulation modeling of resource systems. The physical and social elements of a generalized system and the ways those elements interact as the system changes with time are discussed in terms of components that a useful model should include.

The chapter next briefly reviews several analytical tools for the study of complex systems, and finds each valuable, but none entirely satisfactory. Ecological models, although some are very large and sophisticated, cannot yet be said to represent the actual complexity of real ecosystems; nevertheless, simplified ecosystem models have useful practical applications in the management of specific resource systems. Similarly, available methods for social and economic analysis of systems need not include all the elegance of current economic theory in order to be useful for management decision making; simple, practical

techniques can be developed for applying such tools to specific resource problems. Some existing models attempt to integrate the ecological and socioeconomic elements of systems; for example, EPA developed the Strategic Environmental Assessment System (SEAS) model. Although such efforts still face substantial methodological problems, some significant progress has been made toward the needed comprehensive analysis of resource systems. Energy analysis, a still-developing technique for measuring and comparing the transfers of energy that occur in natural and technological systems, is a somewhat different analytical approach that can provide valuable descriptive information. However, the theoretical and methodological foundations of energy analysis are currently too imperfectly developed to make this approach a primary analytical tool.

The principal conclusion of Chapter 2 is that no existing approach is satisfactorily comprehensive or flexible to meet the need for analysis of complex resource systems. The most urgent research need, therefore, is to develop, test, and bring into general use an improved capability for comprehensive, integrated analysis of such ecological and social systems.

Chapter 3 identifies information needs and recommends research programs to support decision making in the management of natural resources. The research recommendations are structured around the framework of the generalized resource system described in Chapter 2. In the panel's judgment, the most important and fundamental general research needs are in the following areas:

- Better information on resource flows that a system can produce, and particularly flows of extra-market resource products;

- Quantitative estimates of interactions among resource flows;

- Improved techniques for measuring and projecting the social and economic impacts of resource management activities;

- Post-project assessments of the total costs and benefits of selected major resource management actions;

- Studies to assess the validity of methods for projecting social demands for resource products;

- Studies of the ways in which legal and institutional structures constrain and influence resource management activities and their environmental and social impacts.

In addition, for many resource systems, specific needs exist for the following kinds of information:

- Improved resource inventories;

- Improved understanding of interactions among resource systems;

- Data on physical impacts of management activities;

- Data on impacts of management activities on the functions of ecosystems;

- Improved techniques for the mitigation of physical impacts;

- Improved methods for measuring and comparing the values of resource products, including extra-market products.

Each of these major research topics is illustrated with examples of information needs on specific management activities in particular resource systems, drawn from the special knowledge and expertise of panel members.

Finally, Chapter 4 examines the critical issue of institutions for research, and some institutional mechanisms that might lead to the comprehensive, integrated analysis that is needed. Examples are presented of research programs, within and outside the federal government, that have taken a comprehensive approach to analysis of resource management alternatives and their environmental impacts. While numerous programs contain elements of the desired approach, none of the programs meets the criteria set down in Chapter 2 for the research needed to support decision making. Furthermore, there has been little effective coordination among programs; each agency has used somewhat different methods and models to achieve different research goals. As a result, it has not been possible to achieve a synthesis in the study of interrelated resource management problems. There has also been considerable wasteful duplication of effort, when several agencies had to gather complementary data, but in incompatible forms.

We conclude that there are substantial obstacles to the conduct of comprehensive, integrated research, which are inherent in the institutional structures through which resources are managed, the related research is conducted, and researchers and decision makers are trained. These obstacles include the specialization of researchers into reductionist disciplines; the focus of agencies (and of most research funding) on narrow missions, either in the production and use of resources or in the protection of environmental quality; and the failure of even "successful" coordinating mechanisms to transcend the mission orientation of the participants. These institutional factors make it unlikely, in our judgment, that a capability for comprehensive analysis of resource systems, flexible enough to be applied to the diverse management problems, could be developed within existing research programs, even by building upon the best existing efforts and coordinating mechanisms. While several excellent programs are described in the chapter, and we believe these efforts should continue, we also believe that there is a need for a research institution with a truly comprehensive mission.

We recommend, therefore, that a new national research center be established for the purpose of developing and testing a generalized systems approach for the integrated analysis of resource systems, management activities, and environmental impacts. As we envision it, the new institute would work closely with EPA, resource-managing agencies, and other users of research on resource systems, but the primary responsibility for data gathering and for the conduct of modeling and other studies would remain with those user agencies. The chief functions of the new center would be to assist agencies in the application of emerging methodologies for comprehensive analysis to their own more mission-specific problems, and in the process to increase the correspondence among approaches and to broaden the exchange of data and experience among the different researchers. In addition, we believe it is essential for the new institute to establish close ties with decision makers in resource-managing agencies, so that throughout the design and conduct of the research effort the work of the center will be as valuable as possible for resource management policy making.

As a corollary to our recommendation for a new national research center, we recommend that an interagency task force be established immediately, to assemble information on current comprehensive research programs, identify the most critical research needs, and suggest operating procedures for the proposed institute.

# CHAPTER 1

## RESOURCE MANAGEMENT ACTIVITIES AND THEIR ENVIRONMENTAL IMPACTS: AN OVERVIEW

Many of the most significant environmental problems facing modern societies result from activities undertaken in the use and management of natural resources such as agricultural lands, forests, minerals, and fossil fuels. This class of environmental problems is particularly important because most resource management activities take place over large geographic areas and long time periods, and the impacts they have on the environment, although often diffuse and subtle, are likely to occur on similarly large spatial and temporal scales. Furthermore, the size and complexity of the ecological and social systems in which resources occur and are managed frequently make it an exceptionally difficult challenge to develop resources without damaging the environment.

The environmental impacts of resource management activities may be desired objectives of management, as in the case of altered nutrient flows or regulated densities of pest populations in agriculture and forestry, or may be generally unsought, detrimental consequences, such as acid mine drainage, nutrient and sediment loss from crop lands, the scarring of desert lands by tracks of recreational vehicles, or the inundation of farmlands behind dams. Some impacts, such as the cultivation of preferred crop varieties or the selective harvesting of fish populations, are changes in the structure of biological communities, rather than changes in the physical or chemical character of the environment. Other impacts, such as changes in patterns of growth and community structure in rural areas that are subject to rapid development of mining or recreational facilities, are primarily social in nature. Each kind of change may have secondary and higher-order environmental effects.

The same ecosystems that produce food, fiber, and timber also provide recreational opportunities and wildlife habitat, and perform ecological functions that are critical to human society, such as the regeneration of clean air and water and the cycling of nutrients. When management activities are undertaken to optimize production of one or a few of the many possible outputs of the resource system, the consequences of such activities may include the inadvertent foreclosure of the potential production of other resources, or the reduction of the capacity of the system to perform important ecological "public services."

The large geographic extent and long time spans of many potential impacts of resource management and the cost to society of long-term environmental damage and potential losses of vital resource products make the careful evaluation of such impacts an extremely important element in the sound management of the nation's natural resources. Resource management issues, in turn, are clearly among the most prominent, critical, and urgent social and political concerns facing society. Growing and competing demands for land, water, energy, materials, food, recreation, and other resources or resource products will be central national and international issues for the foreseeable future. Major societal decisions that determine how crucial resources will be managed will of necessity be made during the next few decades. The resource and environmental consequences of those decisions will, in all likelihood, have substantial impacts on the quality of life that future generations will experience, and could influence the structure and stability of future societies.

The importance of managing resources is more than matched by the complexity and difficulty of the task of choosing strategies that ensure adequate protection of environmental values. We share the often-stated view that environmental considerations cannot usefully be extracted and examined in isolation from resource management processes as integrated entities. (For detailed discussion of this point, see Ford Foundation 1974; National Research Council 1972a, 1973, 1975a; Moll 1976.) Environmental impacts of resource management activities are best dealt with in a context that permits simultaneous consideration of the ecological, technical, economic, and social dimensions of the entire system. Furthermore, many different resource cycles (e.g., food, water, minerals, energy) are interconnected and interdependent, a fact that adds still greater complexity to the analytical task.

## INFORMATION NEEDS FOR DECISION MAKING IN RESOURCE MANAGEMENT

Decisions about management of the nation's natural resources and about environmental protection in resource management ultimately reflect social policy, but they require a sound scientific and technical information base. Some environmental hazards may be trivial in comparison to the social benefits to be gained through proper use of resources; for example, a well-managed forest resource system can yield many products and amenities with minimal lasting impacts on the environment. In a few other cases, the environmental impacts of a resource management action would be so overwhelming and severe that the action is clearly unacceptable; a dam that would inundate Yosemite Valley is one hypothetical example. For the great majority of resource management decisions, however, the choices are not so obvious; many complex and subtle trade-offs are involved. It is in such cases that decision making is most difficult, and the need is greatest for thorough, credible scientific and technical assessments of policy alternatives.

The information needed for resource management decision making includes (1) knowledge of the fundamental social goals and narrower specific goals that are the objectives of the management process; (2) descriptions of alternative combinations of management activities that might be carried out in a given resource system; (3) projections of the expected consequences (resource production and environmental impacts) of the various possible management strategies; (4) estimates of the positive and negative value to society of the various possible combinations of outcomes. Given such information, policy decisions can then be made in light of social and political values and pressures, as well as of the available scientific and economic assessments. Throughout the process, the institutions through which problems are identified, strategies are designed, and decisions are made can constrain and guide management choices toward particular goals at the expense of others.

The principal function of research in resource management decision making is to acquire and display information in a manner that will permit decision makers to compare the likely consequences of alternative policy options. The questions posed by research, however, should be broad enough to encompass all the elements of decision making listed above. That is, we believe it is important to compare the implications not only of alternative strategies for achieving resource management goals, but also of alternative sets of goals, and of alternative institutional mechanisms for selecting goals and strategies.

Ideally, information would be available to resource managers before decisions were made, describing or estimating all of the ramifications of each plausible management option in terms of production of resources, environmental impacts, and social impacts, over the entire geographic and temporal extent of those consequences. In practice, this ideal is unattainable. In the first place, knowledge can almost never be so exact or so complete as to eliminate uncertainties, and decisions will probably always have to be made in the face of some possibly significant unknown consequences.

More importantly, however, we believe that resource management decisions up to now have seldom been founded upon an adequately broad base of that information which is already available or readily obtainable. In many cases, resource managers do not appear to have considered a full range of alternative strategies; and the task of examining in an integrated manner all the important aspects of resource management problems seems frequently to have been beyond the capabilities of both researchers and resource managers. As a result, we believe that some important aspects, and particularly the long-term environmental and social impacts of resource management choices, have received less attention than they merit.

For example, the National Environmental Policy Act (NEPA) makes such a comprehensive, long-term assessment an explicit goal of national policy in the development of resources, and the U.S. Environmental Protection Agency (EPA) has been given the responsibility for review of environmental impact statements (EIS's), prepared by those federal agencies engaged in managing resources. However, the informational and conceptual base upon which such EIS's are prepared and reviewed has seldom been adequate, and can be improved. The chief concern of this report is to define an approach to research that would lead to such improvements. Although techniques for projecting the behavior of complex, dynamic ecological and social systems over long time spans have acknowledged limitations, we are confident that significant progress toward more complete and accurate evaluation of the consequences of resource management choices is possible.

## THE RESOURCE MANAGERS

Throughout this report, it is assumed that some individuals or collective entities have the responsibility for making decisions that determine how resource systems shall be managed. A large and diverse number of constituencies and interests usually participate in both making decisions and implementing strategies. Individual property owners, large and small corporations, executive agencies of local, state, and federal governments, and in some cases, legislative bodies acting as representatives of society as a whole, may have management responsibility for a given resource. Responsibility for identifying, mitigating, or preventing environmental impacts of management activities rests with many of the same managers, as well as with those governmental agencies, such as EPA, that are charged with protecting the environment. In some cases, the accomplishment of mandated measures for environmental protection may require that environmental decision makers act as resource managers. For example, EPA participates in the development of land-use plans for river basins under Section 208 of the Federal Water Pollution Control Act (86 Stat. 839, PL 92-500).

Responsibilities for management of resource systems can best be described as diverse and fragmented. The goals and preferred management strategies of the many different sets of managers and institutions involved are often dissimilar, and sometimes incompatible. This fragmentation has had important consequences for resource management; for example, several different management entities have authority to withdraw lands (such as forests, areas of unique geological character, or rangeland) from mineral development in order to preserve other values. Very extensive areas have been withdrawn from exploration and mining by several agencies, apparently without much coordination. The impact on the nation's supply of minerals and other resource products of this piecemeal approach to management has not been evaluated in a comprehensive manner. None of the management agencies appears capable of balancing the multiple considerations involved to the satisfaction of the many interests with a stake in the outcome (Bennethum and Lee 1975).

When several management entities with divergent missions have overlapping responsibilities for management of a given resource system, the political process of reaching a decision can be extremely complex, divisive, and time-consuming, and need not always produce balanced decisions. In particular, we feel that institutions and interest groups that tend to manage resources to maximize economic or environmental benefits on a relatively short-term basis have been dominant over those that operate to serve long-term objectives, with results that have sometimes been detrimental to the best interests of society as a whole, and of future generations. Among the abundant examples of such short-sighted management are the overgrazing and subsequent erosion of extensive range lands in the western U.S. and the systematic and continuing overexploitation of many of the world's whale populations.

We believe that it is vital to shift the balance in resource management decisions significantly toward long-term stewardship, and to incorporate the concepts associated with the ecological limits of resource systems more prominently into the management process. As a nation, we have not yet resolved the ponderous political question of whether such objectives could best be accomplished through the assumption of increasingly broad control over and planning of the management of resources by the federal government, or through a diverse, disaggregated decision-making process more typical of the situation today. (As we note in Chapter 3, however, research can be conducted to examine the advantages and disadvantages of such alternative institutional arrangements; and the optimum choice may be different for different resource systems.)

No matter what approach society ultimately employs for managing natural resources, resource managers will benefit, and the process should be improved, by having available more complete and precise information about the consequences and implications of alternative decisions. In order to generate information to support decisions that will protect and preserve the ecological integrity of resource systems, it is essential to begin with a broad, integrative perspective, one that examines long-term environmental impacts in the context of the dynamic behavior of the system as a whole.

# CHAPTER 2

## THE NEED FOR COMPREHENSIVE ANALYSIS OF RESOURCE AND ENVIRONMENTAL SYSTEMS

In order to minimize the adverse environmental consequences of the use of resources, managers should be able to examine those impacts in the context of comprehensive information on the physical and biological nature of the resource base and on the social and economic consequences of, and constraints on, management of that system. Decision makers need projections of the behavior over time of complex, dynamic ecological and social systems so that they can compare the projected consequences of alternative management strategies. Some of the kinds of questions that resource managers might try to answer before making decisions are represented by these examples:

- What inputs of land, water, materials, energy, and other factors would be associated with each of a variety of possible management scenarios for a given agricultural region or crop? What are the production, environmental impacts, and regional, national and international economic and social consequences of each alternative?

- What are the technical, economic, and social costs and benefits of a nonstructural water management program, such as management of a flood plain, compared to the costs and benefits of a more traditional, but probably more environmentally damaging, solution to the same problem, such as a dam or a levee?

- What is the optimal combination of timber production, grazing, recreational development, preservation of natural areas, and other uses for a given national forest area over a period of several decades?

- How does the design of a city--the location and density of housing, industry, transportation, services, recreation areas--influence per capita resource consumption, environmental quality, and the social desirability of the city as a place to live?

The predominant characteristic of each of these examples is the complexity of the underlying management problems. Inability or failure to deal adequately with such complexity is, in our judgment, the most significant deficiency of past and present research to support decision making in the management of natural resources. The most critical need in such research, therefore, is to improve the capability to carry out comprehensive, integrated analysis of extremely complex ecological/social systems.

To be most useful for decision making, information on the consequences of management alternatives should have the following features:

The information must be comprehensive. It should recognize and account for all of the relevant components of the system being managed, including the physical, ecological, social, economic, and institutional elements and processes and the ways in which these are interconnected. It is practically axiomatic that, for almost any problem, the gathering and analysis of such a broad spectrum of information requires a close-knit, multidisciplinary research program.

The analysis must deal with the dynamic nature of resource systems. Descriptive models of systems that display the interactions of multiple components under relatively static conditions are inadequate for examining the behavior of systems over the time dimensions that are relevant for management of natural resources. Many of the critical variables that influence the system can change substantially over periods of decades, and some may shift in a matter of a few years. Some of these factors are population size; reserves of nonrenewable resources; rates of economic growth and technological advances; social and political values, goals, and institutions; and the natural states of ecosystems and climate. Furthermore, changes in several of these parameters are likely to be interdependent. Projections of alternative scenarios for resource management need to be responsive to the effects of such changing conditions.

The analytical capability must be practical to obtain and useable by resource managers. It is critical to have an analytical capability suited to the objectives of the resource managers: that is, one that permits the comparison of multiple management alternatives; produces needed information quickly; is not so costly as to be beyond the means of most management agencies; and is flexible enough to be used for the variety of problems managers face. For decision-making purposes, analytical procedures need to display enough information to permit intelligent choices to be made; they do not necessarily have to be extremely detailed in their representation of the "real world." Simplifying assumptions, uncertainties, and margins of error in projections need to be explicitly identified, but realistically cannot be eliminated. Attempts to build bigger and more accurate predictive models can generate nearly insatiable demands for data (which often are not obtainable); the use of such models may be very costly, time-consuming, and even ultimately self-defeating. To support decision making, it is far more important to determine the extent to which models can be simplified and still be adequately comprehensive and responsive to changes in critical variables.

Analyses of different systems should be compatible. A large number of attempts have been made to describe and analyze a variety of different resource systems (e.g., agriculture, minerals, marine fisheries), and some single systems have been analyzed on different geographic scales. Differences in the objectives, assumptions, structure, and data requirements of the models that have been employed are widespread. Although no single analytical approach is likely to be perfectly suited to all systems and all levels of aggregation, a compatible treatment of the general features of most resource systems can probably be developed. Increased consistency among models would be likely to broaden the applicability of data gathered for study of a single system or subsystem. More importantly, the development of a general systems approach should facilitate the examination of linkages between or among different resource systems, important aspects that are not adequately considered by most current analytical techniques.

## MODELING RESOURCE SYSTEMS

We believe that simulation modeling is essential to improve capabilities for the analysis of complex systems. As an aid to decision making, simulation modeling techniques have both some important advantages and some clear limitations.

The premier advantage of modeling and systems analysis is the disciplined structure the modeling effort imposes on the organization of information. A model requires that assumptions and logic be formally stated, with the result that data are displayed in ways that permit identification of gaps in knowledge. In addition, the formal statement of the concepts, assumptions, and prejudices of the modelers permits them to be tested scientifically, and modified if found faulty. The result is that models can evolve toward greater reliability through use.

Second, simulation models probably are the best tools available for the coherent study of problems that are as large and complex as those that confront resource managers. Computer models give the resource manager the substantial advantages of flexibility (the opportunity to examine a great number of alternatives or to test many different assumptions) and speed.

The limitations of simulation modeling, on the other hand, must be realistically appreciated when models are used in management decision making. Models project, rather than predict, possible scenarios for the future. The accuracy and validity of those projections are no better than the assumptions and data upon which they are based. Particularly as the size and complexity of the system modeled increase, attempts to describe real-world interactions in mathematical terms inevitably must be oversimplified, reducing the "realism" of the output. Accumulation of inherent errors of this sort can lead to major inaccuracies, especially in very long-term projections. In addition, good quantitative data seldom are available for many of the variables contained in a model. The time and cost involved in developing and validating a model are substantial; and subsequent efforts to gather data and use the model to project alternative futures can also be expensive. Modelers frequently are inclined to try to build bigger, more detailed models than are necessary or feasible for decision-making purposes--a tendency that accentuates the problems of cost and excessive data demands, but does not necessarily improve the usefulness of the output of the model for resource managers. In this regard, sensitivity analysis offers a powerful tool for determining the importance of what is not known and ranking data needs in order of priority.

These acknowledged limitations do not, in our judgment, offset the value of simulation modeling as a tool to assist in the management of complex resource systems, if the objectives for which modeling is used are realistic. Models should not be expected to produce precise predictions of the real behavior of a system, although the iterative process of fine-tuning will improve the accuracy of a model as experience in using it is accumulated. Instead, models should be used to provide a uniform format for comparing "best guesses" about the possible consequences of alternative management choices, and to examine the ways those projected consequences are influenced by different assumptions about changes in other elements of the system.

## DESCRIPTION OF A GENERALIZED RESOURCE SYSTEM

A brief description is presented below of the way information might be organized into a general model of a resource system. The heart of such a model would be a series of mathematical expressions of the relationships among different variables; many of these interactions might be non-linear.

The starting point is a description of the goals of the management process. Both broad goals, such as productive use of resources and maintenance of environmental quality, and more specific, quantified objectives of management should be stated explicitly. Such a statement provides a baseline against which the projected outcomes of management scenarios can be measured. Since social preferences and the objectives of resource management may change with time, models might also be used to examine the effectiveness of particular management strategies in achieving different sets of goals.

A description of the physical resource system is the next major component of the model. For most resource systems, this module would be a model of the ecological system in which the resources occurred, with modifications suited to the needs of resource managers. The model would include the spatial units of the managed system (which might be an area of land, fresh water, or ocean, and the sub-surface space in each case); the stocks of resources that exist within the system (such as air, water, soil, minerals, plants, animals, aesthetic qualities); and the ecological structure and functions of the system (biotic communities, material and energy flows) which interconnect the many living and nonliving elements of the system.

To characterize the system for management purposes, the model must include expressions of the flows of resource products and services that the system can yield in response to different management activities. Some typical resource flows might be expressed in terms like board-feet of timber, tons of ore, recreation-days, or tons of nutrients assimilated, for a given spatial unit and a given span of time. The relationships that determine resource flows are ultimately bound by the physical and ecological limits of the system, such as the extent of mineral deposits or the maximum potential for production of biomass per unit time in the system.

Descriptions of the interactions among resource flows are additional important features of the physical system that the model should include. Many complementary or competitive relationships exist among the effects of management activities on flows of different resource products. For example, management of an area as a wildlife refuge increases the output of wildlife and some kinds of recreational opportunities and reduces or limits use of the same area for crop or livestock production, residential space, other recreation, or waste disposal.

Environmental impacts are an important subset of the relationships between management activities and the physical system. Some impacts, such as tailings from mining operations or pesticide residues from crop or forest lands, are physical outputs of the system that can be related to the flows of other (resource) products. Other impacts may appear as changes in the structure of the biological community (such as a decreased diversity of plant or insect species) or in the pathways of movement of nutrients or energy through, or from, the system. Many ecological impacts affect the flows of other resource products from the system.

The next major component of the model is a description of the social elements of the system. One important need is to assign positive or negative values (or prices) to the resource flows and environmental impacts that the system produces, including some that are not now ordinarily measured in market terms, so that the costs and benefits of the results of management activities can be projected. Both the magnitude of those costs and benefits and the way in which they are distributed among social groups and over time need to be described. The relationships between various economic, social, and institutional conditions and constraints and the management of the resource system also need to be included in the model. Some of these factors are the structure of industries; the availability of capital and labor; market conditions that influence the effects of management on prices and incomes; rates of economic growth; and social and political influences on demand and supply. Descriptions of institutional determinants of the behavior of the system are an important element of the model. The laws and institutions that influence the ownership of resource systems and define responsibilities for, and objectives of, management are critical determinants on the outputs of the system; they are also subject to change. The most useful models will be those that permit managers to examine the results of management activities under a reasonable range of alternative institutional arrangements.

Depending on the specific system being studied and the length of time over which projections are needed, the model should include assumptions about the influence on the system of variables such as population growth, the evolution of national and international social and political conditions, and the development of technological innovations. Many managers will also need to examine interactions among systems. For example, it would be difficult to project scenarios for development of agriculture in the western United States without considering the impacts of mineral development and coal mining on the availability of water and other essential resources. Such interactions highlight the need for compatible models of interconnected systems.

If models of resource systems such as the one described in general terms above were available, resource managers could use them to examine the short-term and long-term consequences of alternative choices. We do not believe, however, that the capability exists today to model effectively a system as complex as the one depicted in general terms here.

## A BRIEF REVIEW OF AVAILABLE AND EMERGING TOOLS FOR THE ANALYSIS OF COMPLEX SYSTEMS

Research to develop an improved capability for the analysis of complex resource and environmental systems will need to build upon the best currently available techniques for analysis of such systems, or of parts of them. The emphasis here is on the usefulness of various analytical techniques for providing information to support decision making by examining environmental impacts of resource management activities. More detailed discussions of the current state of environmental modeling and analysis of resource systems can be found in several of the publications in the bibliography appended to this report (for instance, see Mar and Newell 1973, Holling 1974, Reichle 1975, Russell 1975, Biswas 1976, Holcomb Research Institute 1976, U.S. EPA 1976, Craven et al. 1977, Hall and Day 1977).

### Ecological Models

Some existing biological and ecological models can be valuable tools in resource management (See Russell 1975). Fairly sophisticated models exist for the population dynamics of some critical species in fisheries, wildlife, forestry, range, and pest management (for example, see Royce et al. 1963; Watt 1964; Stark 1973a, 1973b; Harris 1973; Holling et al. 1976). Models for many other populations that are important to resource management, however, are generally less advanced (Harstock and Hollingsworth 1974, Ruesink 1976).

On a larger scale, some significant progress in analysis of ecosystems has come from the International Biological Program (IBP) and related research efforts (Monsi 1968, Reichle 1975). Useful models exist for some major subsystems such as phytoplankton populations or nutrient cycles (Lehman et al. 1975, Nixon and Kremer 1977), and some approach models of complete systems (e.g., Cole 1976), but no model has yet been devised that accurately represents all important variables. Both descriptive data for a number of components of different systems and adequate theoretical understanding of the complexities of ecosystems are lacking in almost all cases. This deficiency in fundamental knowledge has stymied efforts to develop a generalized model for all ecosystems, and the problem is not likely to be resolved soon.

For instance, in one of the recent biome studies of the IBP, some 3,000 state variables were included in a detailed computer model of a relatively simple ecosystem. Several years of field research produced adequate measurements of the values over time of about 1,000 of these, partial data for another 1,000, and almost no data for the remaining 1,000. Regardless of the time and money available, it may not be possible to model all, or even all of the important, components of an ecosystem. It is vital, therefore, to determine the extent to which simplified models can be reliable representations of systems, or at least of the components most important to the management questions at hand. No general theory relating a model's complexity to its accuracy yet exists. One approach to this problem would be to eliminate sequentially components of the most detailed current models, observe the results, and compare these with the behavior of both the real ecosystem and the most comprehensive model (see, for example, Weigert 1977).

A decade ago, there was optimism that important new general theories of ecology could be developed that could both guide research and support management of ecosystems. Today, so many exceptions have been found for most major new generalizations (such as the "diversity-stability" hypothesis) that both practical and theoretical uses of the concepts have been quite limited. Research to refine the theoretical basis for models of ecosystems may ultimately prove very valuable, both as an academic exercise and for practical applications; but the immediate utility of such research to resource management problems is likely to be quite limited. For the moment, the most promising approach to developing models of ecosystems that will be useful for resource managers is probably an inductive one, based on the accumulation of consistent observations of the responses of systems to management activities and other perturbations. For instance, it has been found that, in general, perturbed or experimentally manipulated ecosystems tend to lose nutrients, while relatively undisturbed systems do not (Bormann et al. 1974, Neuhold and Ruggiero 1977). Observations of this sort, combined with field investigations designed to look at specific responses of ecosystems to management activities, are likely to be among the strongest ecological research tools in the near future.

The application of present ecological modeling capabilities to actual management problems in the field has been limited to date by a lack of contact between modelers and resource managers and by limited opportunities for graduate training in the practical application of theoretical ecological research. It is important at this point to accumulate additional practical experience in the use of models to assist in the management of specific systems. The most promising approach would be to have small, multidisciplinary teams of modelers work closely with experienced field investigators and managers familiar with the systems being modeled and the information needs for management of them. Some such efforts have proven successful in the recent past. One example is the work on integrated pest management conducted by the University of California in cooperation with the State Agricultural Extension Service and a number of farm and forest management agencies (Huffaker and Smith 1973a, 1973b). Another example is a study being conducted for the National Park Service in which predictions of the magnitude and ecological consequences of forest fires, produced by a simulation model of the ecosystem, are among the information available to Park Service managers when they decide whether to let a fire burn, or how much effort to exert to control it (Kessell 1977).

## Social and Economic Analysis of Systems

Models of the social and economic components of systems related to the management of particular resources are widely available and are employed in at least some simplified forms in most resource-related decision making. Two kinds of analytical techniques are commonly used: models that project the states of social or economic variables, such as demand or price, into the future; and analytical techniques for projecting and comparing the costs and benefits of particular projects or management activities.

A number of techniques have been developed for projecting economic and social trends (see, for example, Evans et al. 1969, Naylor 1970, Haitovsky et al. 1974, Fromm and Klein 1976). However, neither the theoretical understanding of the ways in which complex social systems function nor the data base of objective and quantitative measurements of important variables is adequate to support credible models of whole social systems, and it is probably safe to say that this will never be possible. Resource managers instead need to rely on the best available techniques to project critical parameters such as GNP growth, income distribution, or population size and structure. As in the case of ecosystem models, emphasis is needed on the development of models and techniques that are simple enough to be useful for practical management of resource systems, even if some of the elegance of advanced economic theory cannot be incorporated into them.

Cost-benefit analysis, like other techniques discussed, provides a very useful framework for considering all aspects of a problem and is a prime tool for resource management decision making. One prominent limitation of this kind of analysis, however, is the difficulty encountered in assigning precise market values or substitute prices to many of the consequences of management choices, such as changes in the aesthetic quality of a natural area. It is also difficult to determine appropriate weighting factors, or discount rates, for effects that may occur in the very distant future or that are distributed in a skewed manner among different social groups or nations. (For additional discussion, see NRC 1975b; Freeman 1975; Dohan 1977.)

As is true for ecological models, the greatest need for resource management decision making is not the further refinement of the theoretical basis for economic analysis, but rather the application of the best available existing tools to the practical problems of resource managers. Careful analyses of relevant social and economic trends and constraints, related specifically to the geographic area of the resource system in question, would provide the kind of information that would be most useful for decision making. A number of research projects of this sort have been conducted by multidisciplinary teams of natural and social scientists, working closely with resource managing agencies (see for example Brown et al. 1976, Logsdon et al. 1977, Warnick 1969). Analysis of this sort would be desirable as part of the information needed for most resource management decisions.

## Integrated Analysis of Systems

As we have emphasized throughout this chapter, an improved capability to conduct integrated analysis of the dynamic interactions of ecological and social components of resource systems is the most important development needed to support resource management decision making. This is not to say that no such models exist; some are currently used in research to support decision making.

Several federal agencies use various modeling procedures to project demand and supply scenarios for resources under their jurisdiction and to evaluate possible strategies for the development and management of resources. For example, the U.S. Forest Service has conducted a far-reaching assessment of future demands for renewable resources, and of alternative plans for meeting the demands (U.S. Forest Service 1976, 1977; Giltmeir et al. 1976). A second notable attempt to develop a comprehensive model that integrates environmental and social components is the Strategic Environmental Assessment System (SEAS) program of the

Environmental Protection Agency (Lakshmanan 1975, Ember 1976). Other research using similar integrated analytical approaches has been done in universities and other non-governmental research institutions (see for example Dvoskin and Heady 1976, Nagadevara et al. 1975, Boynton et al. 1977, Holling et al. 1976).

Some of these efforts to develop and use integrated models of physical and social systems represent significant progress in promising directions. Nevertheless, some serious methodological problems remain. (See, for example, Vaux 1976 for a critique of the USFS Assessment and Leontief et al. 1975 for a review of the SEAS model.) One particularly important area in which such models are limited is their ability to define the linkages between biological and social components of systems, such as the influence of institutions on processes that produce adverse changes in the environment.

None of the models now available meets the criteria listed above for use in resource management decision making; except for the SEAS effort, most of them contain little in terms of projected environmental consequences. None are as comprehensive as seems desirable, although some are extremely detailed in their descriptions of those components they do include. (SEAS, for example, may well be the largest and most detailed model of the U.S. economy ever developed. See Leontief et al. 1975.)

An integrated analytical approach of quite a different kind is represented by the work of Forrester (1971), Meadows et al. (1971), and Mesarovic and Pestel (1974), in which attempts have been made to model the resource, environmental, and social-political systems of the entire world into the twenty-first century and beyond. The degree of simplification of descriptions of components in such a highly aggregated model makes its projections relatively meaningless for the management of specific resource systems. Nevertheless, models of the global system may be useful for the insights they provide about underlying relationships that are fundamental to all resource systems, and may suggest critical linkages or limits that can then be examined in more detailed models of subsystems.

The most useful developments in the use of integrated models as tools for resource management and environmental decision making seem likely to come from attempts to apply models to the analysis of specific practical management problems. Both relatively small systems (such as a single national forest) and larger systems (such as the water resources of regions of the country or the national agricultural system), can be modeled; efforts to use models in management of problems on all geographic scales should provide valuable experience.

## Energy Analysis

Within the last several years, a method for the analysis of environmental problems based on an accounting of energy transfers through resource and ecological systems has been developed (Gilliland 1975, Bayley et al. 1976, Odum 1977). Two separate concepts are interwoven in energy analysis. The first is that the amounts and forms of energy generated, consumed, and transferred among compartments of systems are important physical and ecological measures of the functions of complex systems. The second concept, which is more controversial, is that the values to society of many different resource products, ecological functions, and environmental impacts can be measured and compared in terms of energy units, in addition to or instead of in monetary units.

Detailed energy budgets can be prepared for resource systems under different management scenarios (for instance, see Hirst 1973, 1974; Berry and Fels 1973; Gilliland 1975; Lavine and Meyburg 1976; Kemp et al. 1977). Proponents of energy analysis argue that it is more comprehensive in that it includes important flows of natural energy that are not included in standard economic analysis. The use of energy measures of value may also eventually prove to be an important supplement to standard economic estimates of costs and benefits of management alternatives. (For a detailed discussion of this point, see the report of the Workshop on Energy Analysis and Economics, International Federation of Institutes for Advanced Study 1976.)

Some substantial theoretical and methodological advances will be required, however, before energy analysis attains the widespread utility of its economic counterpart (See Huettner 1976). For example, there is not now a robust, generally accepted theoretical basis for the conversion of some important economic measures to energy terms. Such conversion is required if all consequences are to be evaluated in terms of their energy impacts. The energy values of some important processes of systems have not been measured, and many of the energy flows that can be measured cannot be described in comparable terms. For example, a kilocalorie of sunlight and a kilocalorie of electricity cannot do equivalent amounts of work; although Cdum (1977) has suggested a method for conversion of such units to a common scale, the methodology is still at a primitive stage.

We believe that it is useful to measure the energy expended or produced as part of the evaluation of environmental impacts of alternative resource management activities (see Chapter 3). In practical terms, neither energy analysis nor economic analysis is comprehensive enough to evaluate all the important outcomes of resource management in a meaningful way. Attention should focus on improving methods for using the two approaches in complementary fashion to evaluate management choices.

## CONCLUSIONS

None of the analytical techniques available today is comprehensive enough to meet the need for analysis of management alternatives for complex ecological and social resource systems. Some fairly advanced models are being developed and used in research on specific systems, but these are not often applicable to different resource systems and are frequently too elaborate and costly to be practical for most resource management decision making.

The most pressing need we have identified is to develop, test, and bring into general use an improved capability to do comprehensive, integrated analysis of specific resource and environmental systems. Standard methods for modeling different systems are desirable, in that they would expand the applicability of data gathered in studies of narrower subsystems and would enhance the capability to examine interactions between and among different coupled resource systems.

Research to develop improved modeling capabilities for use in resource management and environmental protection will require coordinated, multidisciplinary programs that seek to build upon and increase the complementarity of the best existing tools from ecological modeling, economic modeling, and systems analysis. It is vital, we feel, that modelers coordinate very closely with resource managers throughout the course of the research in order to keep the focus on the practical problems and information needs of decision makers.

If work to develop modeling techniques generally applicable to resource management is the first need, the structure that such efforts impose on the organization of information will lead quite directly to additional topics for research. We have used the framework of the general systems model described earlier in this chapter as an outline for some recommendations for research to build a data base for modeling studies, described in Chapter 3.

## CHAPTER 3

## THE COMPREHENSIVE APPROACH TO RESEARCH FOR DECISION MAKING IN RESOURCE MANAGEMENT

It is no small task to describe research programs to produce the information decision makers need about environmental impacts of resource management activities. The task is truly enormous if information on environmental impacts is viewed as but one of the many interrelated considerations on which resource managers must be informed. Nevertheless, we believe it is vital to study environmental impacts from such a perspective.

Such breadth of vision did, however, create a dilemma for this panel in carrying out its study. It would have required a massive effort to conduct a complete survey of research on all the important aspects of the great number of resource management activities, to evaluate the many existing research programs, and to identify critical information needs. Such an effort would have been far in excess of what was possible, given the time, resources, and expertise available for this study. Furthermore, the output of such a survey would, in all likelihood, have been an almost endless list of topics for study, which would have had little value for research planning unless the topics were ranked in order of priority. We found through some tentative efforts to do so that such ranking is extremely complex and difficult when the subject matter is as all-encompassing as the environmental impacts of resource management.

The alternative, which we elected, is to expand upon the general, comprehensive approach sketched out in Chapter 2, and to develop from it a set of generic research needs that might apply to the management of any resource system. Within that general framework, examples are presented to illustrate research needs in terms of specific resource management activities, or to describe particular existing research programs that typify the kinds of studies we feel are needed. Although the illustrations chosen cannot cover all the important categories of resource management activities or related research programs, they have been selected from subject areas in which panel members have expert knowledge to provide a balanced series of examples of research needs and programs within the very broad study topic.

## SETTING PRIORITIES FCR RESEARCH

The problem of setting priorities for the commitment of limited research funds and manpower is difficult to resolve. The panel was unable to reach a general consensus on the relative importance of study of environmental impacts of different resource management activities. For instance, a judgment of the relative priority of research on the social consequences of urban land use patterns versus study of the ecological impacts of strip mining of western coal transcends the expertise of this group. Not only do perceptions of the value of different kinds of information vary widely according to the perspectives of individuals, but these perceptions also can change rapidly in the face of new developments. Predictions of what information may be most urgently needed in five, ten, or twenty-five years inevitably risk being inaccurate. Nevertheless, this inability to establish firm priorities among specific research projects ought not to be taken as justification for attaching low priority to the research area as a whole. Rather, it accentuates the importance of establishing a broadly applicable research program on environmental impacts of resource management, which can be flexibly and quickly brought to bear on specific problems as they emerge.

In addition, some general principles to guide research on these topics can be set down, as follows:

(1) The most conspicuous and important research need is to develop the capability to study resource systems in a comprehensive, integrated manner that includes physical, biological, and social components and examines the behavior of systems over long spans of time (i.e., decades to centuries or more). Such broad overviews of resource/environment problems are the critical first steps to guide the acquisition of more detailed information on specific management activities in specific systems.

(2) Priorities among research projects on <u>different</u> resource systems and management activities should be set in some proportion to (a) the value or potential value of the resource products to society; (b) the magnitude and significance of potential adverse environmental impacts; and (c) the extent to which potential adverse consequences may be irreversible. The spatial and temporal extent of possible impacts of the activities in question should be weighed; short-term or local effects may be quite significant, but great importance should be assigned to

study of potentially very large-scale or long-lasting problems. Both the immediacy of the potential impacts and the immediacy of a need for action to avert long-term adverse consequences should be considered.

(3) The priority assigned to research needs within a given resource system or management activity should be in proportion to the importance of the information for decision making. Sensitivity analysis can show the extent to which having certain information can influence the outcome of a decision. Some information may be vital, and the decision process may be seriously hindered without it. Other information, although it may be of academic interest, might have little impact on the choices decision makers must make. In the context of research to support decision making, the latter information needs should have lower priority.

(4) The amenability of the problem to study must also be considered in setting priorities. Some information is critical for decision making, but neither the basic knowledge upon which to build meaningful studies nor the methodologies required to deal with complex analytical problems may exist. In other cases, the availability of experts and research facilities may be a constraint. If a research program offers little promise of producing timely results, the research should be assigned low priority. (Under such circumstances, decision making must either be postponed until the information is available, or must proceed without this knowledge, with some social value assigned to the uncertainty thus introduced into the outcome.)

(5) Additional factors that may be considered in setting research priorities include the breadth of applicability of results and popular demand or political pressures to study a particular topic that has attracted great public attention. Public opinion and its political expression play legitimate roles in directing research. However, we believe that many environmental problems associated with resource management demand long-term study; steps should be taken to minimize the impacts of shifting public attitudes insofar as they might threaten to disrupt the continuity of important research programs.

# INFORMATION NEEDS FOR MANAGING RESCURCE SYSTEMS

In Chapter 2, we described a model of a generalized resource system as a structure for organizing information for decision making in resource management. That same framework is used here to describe generic research needs; that is, to suggest the kinds of studies that might need to be performed in support of management of any given resource system. Examples based on specific resource management problems are included both to illustrate the categories of research needed and to indicate where some recent or current research programs fit into the general framework.

## Physical and Biological Components

Effective resource management requires detailed understanding of the physical and biological characteristics of the resource system being managed. These characteristics include the capacity of the system to produce desired outputs, given current levels of inputs, management techniques, and technology, as well as the array of sought and unsought outputs that might also result from specific management practices. Beyond lists of possible outputs and input/output ratios, quantitative estimates are needed of the relationships among alternative, complementary, or competing resource outputs and uses.

### Resource Inventories

> Improved methods for measuring and monitoring the inventories of key resources are needed to support evaluations of the consequences of management activities.

Improved resource inventories are needed at both aggregate (national) and site-specific levels to provide baseline data on the nature and amounts of resource stocks present, for later comparison with inventory or monitoring data to determine whether the objectives of management have been attained or to measure environmental impacts.

For example, one important need is for expanded inventory data on groundwater, in order to increase knowledge of the characteristics of aquifers between recharge areas and discharge areas. Until such information is available, use will concentrate primarily on aquifers whose properties are already well known, and as a result these may be depleted. Another example is the need to review the effectiveness of current procedures for inventorying and monitoring of marine fish populations, particularly to determine whether trawling data now gathered provide an adequate basis for population estimates from which the year-by-year availability of commercial fish species can be reliably assessed. Such a review might also seek to improve the scientific use of commercial catch data to determine whether fish populations are changing, and if so, why.

The substantial efforts now being expended on the development of resource inventories should be better focused. Instead of the massive assemblages of sometimes-irrelevant data that make up most existing inventories, decision makers need information on selected parameters that can serve as indicators of the response of the system to management activities.

A top priority for research on physical characteristics of resource systems should be to develop criteria for selecting such critical resource parameters, both for establishing baseline inventories and for subsequent monitoring of systems. Such criteria should be founded on understanding of the ecological structure of resource systems, on the character of the principal technologies in current or prospective use, and on expectations of the general kinds of impacts management activities might have. Improved criteria, once developed, could be used both to conduct and to evaluate site-specific resource inventories.

## Resource Flows

> Information is needed on the rates and limits of resource flows, including extra-market flows, that a system can produce in response to various management activities.

Resource managers need measurements or quantitative estimates of the responses of a system to a given management activity. Responses are generally measured in terms of the rates of production (flows) of specific resources. The upper boundary to estimates of flows is the limit of the system to produce outputs over time. For a renewable resource, the limit might be a maximum sustainable yield; for a non-renewable resource, the limit might be expressed as the time until the resource would be exhausted under given patterns of use, given technology of recovery, and given economic conditions.

In many cases, such as fisheries, forestry, and agriculture, relatively reliable methods and well-tested models or empirical approximations exist for estimating resource flows. In other areas, existing techniques are less accurate, and research is needed to improve their usefulness. For instance, research is needed to determine the upper limits of rangeland capacity for grazing for all classes of animals (domestic and wildlife), individually and in various combinations in time and space, or to develop meaningful quantitative measures of recreational resources, opportunities, and experiences provided by various systems and management activities.

Most resource systems also produce non-marketed goods and services, flows of which are equally dependent on the physical and biological characteristics of the systems. Methods especially need to be developed and improved for recognizing, measuring, and accounting for such extra-market flows in describing the physical components of systems. For instance, research is needed to develop methods for quantitative measurement of the flows of non-marketable resources such as animal habitat, biological diversity, aesthetic attributes, or assimilative capacity for wastes that characterize particular systems and management activities. Resource managers need estimates of these extra-market flows, both to avoid the inadvertent loss of the values derived from them and to support attempts to protect or increase the yield of a given "public service" function. Many of these resource flows are understood in qualitative terms, but with few exceptions techniques do not exist for measuring them quantitatively or for identifying changes in them that may result from management of the system (See Westman 1977 for discussion). New research tools are needed to allow such quantitative estimates. One possibly useful approach is energy analysis (see Chapter 2); others are needed.

## Interactions Among Resource Flows

Information is needed to assess quantitatively the interactions among different resource flows that a given system can produce.

The flows of most goods and services from a given resource system are not independent. Relationships between some outputs may be complementary; for instance, timber harvesting may increase the availability of some kinds of wildlife habitats. Other outputs may compete; for example, recreational use of an area can reduce its availability for grazing. Some resource management activities may create adverse environmental impacts that lead to indirect negative effects on other outputs.

The relationships among various marketable flows, extra-market production functions, and unsought outputs must be identified in relatively precise terms to permit assessment of the net impact of a management choice. For instance, cropland in the corn belt may be used as pasture, forest, or to grow feed grains. Some land can produce more grain than other land at any given time; nevertheless, if crop production is concentrated on the most productive land and less fertile acreage is used as pasture or forest, the total output of grain is less than the maximum possible. Rotational use of land as pasture, however, may enhance its subsequent productivity of grain. Good quantitative statements of these relationships are needed to identify proper combinations and timings of various land uses.

Information on such interrelationships in most systems is either fragmented or is not now generally available; to fill the gap, major investigations of interactions among resource flows in particular systems should be conducted. For example, research is needed to determine more precisely the extent to which waste disposal in the oceans interferes with other resource uses of the seas (such as fishing and recreation), and to determine the relationships between the timing and extent of timber harvesting and the hydrological characteristics of forested watersheds.

Such research will assist in the design of resource inventories and other programs recommended elsewhere in this report; consequently, work in this area should be in the first rank in priority.

## Interactions Among Resource Systems

> Information is needed to assess the interactions among resource systems in terms of both environmental impacts and impacts on resource flows.

Management activities in one resource system often have impacts on other resource systems, and sound management of resources requires more detailed knowledge of the nature and magnitude of such inter-system linkages. Examples of typical research needs on interactions among systems include studies to determine the relationship between biological cycling of nitrogen in coastal marshes and the productivity of estuarine and offshore fisheries, and to quantify the impacts of dredging and filling of marshes on such fish production; or research to identify the relationships between urban recreational opportunities and recreational uses of wildlands, to determine whether provision of additional recreation resources in or near cities could reduce damaging over-use of wildlands.

## Environmental Impacts of Resource Management Activities

A second major category of information needs is concerned with the measurement or prediction of ways in which resource management activities alter the resource systems being managed. Research on such impacts has frequently been treated as less important than studies of the resource production consequences of management; we feel, however, that information on physical and ecological impacts is an equally critical need for sound decision making.

### Physical Impacts

> Quantitative and qualitative information is needed on the generation of residuals, disruption of landscapes, and other physical impacts of resource management activities on resource systems.

Much research is currently being conducted to provide better information on the direct and indirect physical impacts of resource management activities on the environment. Some activities, such as the mining of western coal, have been studied extensively, but information still is needed on the impacts of a great many other forms of resource management. For example, studies are needed to determine with more certainty the impacts of irrigated agriculture on water quality and water supplies, with emphasis on the movement of irrigation waters through soils and into groundwaters, the leaching of salts and nutrients into ground and surface waters, the depletion of stocks of underground water, and the consequences of increased water use in relation to existing and new water development projects. Also, techniques need to be developed to predict secondary impacts of transportation systems and power plants, particularly the linkages between such facilities and subsequent patterns of land use and development. Data are particularly inadequate on the nature and extent of physical impacts on fragile environments such as arid lands, marshes, tundra, and alpine regions.

Many activities in resource systems are by their nature widely dispersed throughout large areas, making measurement of their net impacts difficult. Some distributed impacts, such as nutrient losses from agriculture, have been studied extensively, but few useful general approaches to the study of non-point impacts have been developed, and the environmental effects of many activities such as camping, boating, timber harvesting, or off-road vehicle use have not been determined accurately. Research to improve capabilities to measure, integrate, and monitor environmental changes associated with such activities is in progress (see for example, Vollmer et al. 1976), and will continue to be needed.

## Impacts on Ecosystem Functions

Information is needed on the extent to which resource management activities may alter the basic biotic components and functions of ecosystems.

Physical perturbations of a resource system may lead to changes in its characteristic ecological structure and functions. To assess the extent and significance of any such changes, the structural and functional states of the ecosystem must be determined both before and after perturbations.

Two characteristics frequently used to describe the "health" of ecosystems are productivity (the rate of production or yield of biomass, especially of potentially harvestable plants or animals), and stability (the lack of large or unpredictable variance in the system, including its productivity and major populations, over time). Both stability and productivity are closely related to the continued flow of many goods and services from the system, and knowledge of both characteristics is needed to predict the consequences of management activities.

Some management activities, such as the use of fertilizer in agriculture, improve productivity. Some inadvertent changes in ecosystems also may be beneficial; for instance, forest fires can allow the establishment of younger and more productive stands of trees. While measurement of changes in the productivity and stability of ecosystems can provide a reasonable yardstick to assess the effects of perturbations, further analysis is required to know whether the effects are desirable, adverse, or of no significance to man.

Some excellent work on the responses of ecosystems to perturbations has been done by universities and national laboratories, and a number of large scale experimental field sites have been developed by such institutions with federal support (Likens et al. 1970, Bormann et al. 1974, Woodwell 1967) and by the U.S. Forest Service, for instance in the Coweeta watershed study. Additional studies of the same sort are needed for many other resource systems. For instance, studies are needed to determine the long term impacts on soils, water quality, and biota of land disposal of sewage effluents in natural systems such as marshes, croplands, and forests, or to determine the impacts of such activities as urban expansion and irrigated agriculture on the processes of evapotranspiration and precipitation, and on regional weather and climate.

## Mitigation of Physical Impacts

> **Further research is needed on measures that can mitigate the impacts of resource management activities.**

Some techniques are already in use for lessening or eliminating the adverse physical (including biological) consequences of certain resource management activities; for example, soil conservation practices have long been followed in agriculture and forestry. Similar rehabilitative measures have been developed or are being studied for impacts of other activities, such as surface mining or wilderness camping. To make such measures effective, research is needed to identify the critical ecological functions (such as primary production, decomposition, and the like) filled by organisms that are being replaced; to select suitable replacement organisms; to determine new combinations of uses for damaged areas; and to determine the amounts of other resources needed for rehabilitation, weighing the need against competing demands for the same resource (for instance, see NRC 1974).

In many cases, the timely use of such measures may make the difference between temporary and long-term or permanent damage to the landscape. Thorough examination of the physical and biological aspects of alternative reclamation measures should be a part of research on the impacts of many major resource management proposals, such as mining, construction of highways, pipelines, or electric transmission lines, and construction of large facilities such as dams or power plants. For example, research to mitigate the impacts of mining activities might investigate the feasibility of methods such as underground location of processing plants, return of wastes to the underground, development of open pits as reservoirs, use of below-ground space for storage of commodities, and improved reclamation of strip-mined land and spoils. To reduce agricultural impacts on water quality, research might seek to develop improved methods to increase efficiency of water use in arid and semi-arid lands, such as advances in dry land cultivation techniques, wider dissemination of water conservation measures, and breeding more water-efficient varieties of crop plants.

Environmental impact statements have often mentioned mitigative steps that are theoretically feasible, but that cannot be implemented without on-site research. Many of the kinds of studies needed would involve long-term field investigations.

## Economic and Social Components of Resource Systems

Decision makers need information on the economic and social components of resource systems in order to choose among alternative management strategies. The values society assigns to various outputs of a resource system need to be determined; these should include not only the well-defined market prices of products, but also estimates of the worth of products or services that do not have a known market value, and of the costs of negative outputs such as adverse environmental impacts. The economic and social consequences of management choices include the total costs and benefits of activities and the distribution of those costs and benefits throughout society and time.

Information is also needed on specific economic and social conditions or institutions that may constrain resource management activities, including demands for resource products, market conditions that determine the effects of management activities on prices and income, the structure of industries, government policies or laws, such as export quotas or environmental protection measures, social conditions, such as the mobility of the labor force, and ethical and political considerations.

### Tools for Measuring and Comparing Resource Values

> Available methods for measuring and comparing the values of specific products and services of resource systems should be improved, especially through developing techniques for assigning values to extra-market resources.

The greatest limitation of traditional cost-benefit analysis is the inability of most economic measurement methods to include all the relevant products and services over appropriately long time spans (NRC 1975b, Freeman 1975). Efforts to overcome those limitations have included attempts to extend economic theory (Dorfman and Dorfman 1977), or to develop new analytical approaches such as energy analysis (Gilliland 1975). (See discussion in Chapter 2.)

In the absence of specific measures of value, resource managers often cannot assign appropriate weights to many activities that would either augment or reduce the amounts of individual satisfaction and social benefits produced by some outputs. In such cases some desirable and undesirable results of management activities are implicitly given zero or very low values in cost-benefit analyses. Decision making is thus likely to be biased in favor of production of outputs of well-established, measurable worth. Examples of research to fill such information gaps include studies to develop aggregate regional and national estimates of the capacities of ecosystems to absorb nutrients and wastes, and of the benefits or costs of such assimilation in terms of changed biotic productivity; and research to estimate the direct and indirect production and consumption of different forms of energy for many different resource management activities. (See Westman 1977.)

One reason that quantitative values have not been assigned to many extra-market products and services of resource systems is that the qualities they possess that contribute to individual satisfaction or social benefits have not been identified. Efforts to define these attributes are based largely on sociological and psychological research on consumer attitudes and motivation, to learn how people perceive their lives to be affected by hunting, wilderness camping, or other currently poorly-defined resource uses. (See, for instance, Brown et al. 1977.)

It is unlikely that research will ever provide acceptable comparable measures of value for all of the qualities of a resource system. Research can, however, greatly increase the range and the focus of the display of information available to decision makers and isolate the subjective elements on which choices may depend.

## Social and Economic Impacts

Research is needed to improve techniques for measuring and projecting the social and economic impacts of resource management activities.

Most resource management activities have the potential not only to modify the ecosystem involved and thus indirectly affect social welfare, but also to have direct impacts on human social patterns. For instance, some redistribution of small populations to the vicinity of energy sources has accompanied expanding energy demands, and the Interstate Highway system has dramatically altered rural and suburban land-use patterns (Real Estate Research Corporation 1974).

The social and economic consequences of resource management decisions need to be better understood along with the physical and ecological responses of the system to management. Typical research needs of this sort might include investigation of the short-range and long-range social impacts of development of mining towns; of the effects of reservation of wilderness areas upon the regions in which they are located; or of the environmental and socio-economic consequences of relocating industries and populations from central cities to the suburbs, including both the provision of new facilities and services in the suburbs and the premature abandonment of housing, industrial properties, and other resources in the cities.

## Post-Project Analysis

> The accuracy of pre-project cost-benefit analyses of major resource management actions should be evaluated by thorough post-project assessments of the actual costs and benefits produced by selected actions.

Despite the substantial amount of time and resources devoted to cost-benefit analyses to determine the feasibility of proposed projects, efforts are seldom made, once a project has been completed, to determine what the actual costs and benefits are, and how they compare with the predictions used in the decision-making process. Although they are often costly, retrospective analyses of major resource management actions (such as surface mines, large dams or water diversion projects, or development of areas as recreational sites) can be extremely valuable for subsequent decision making and policy development. Examples are the analysis of fisheries management in Chesapeake Bay (McHugh 1972), and an assessment of several major water management projects (Haveman 1972). Similar retrospective studies of the Alaska oil pipeline are now in progress.

Such analyses, drawn from actual experience, form useful bases for evaluations of similar new proposals and illustrate the uncertainties and limitations in the analysis of some management projects. For instance, a review of previous attempts to quantify and forecast impacts of power plants and mining developments and comparisons with actual impacts in selected case studies could indicate what kinds of impact assessments have provided the most useful and accurate projections of effects on the physical, biological, social, and economic aspects of the region. Such research might reveal that important considerations had not been taken into account in earlier cost-benefit studies; if so, this might also lead to requirements for more complete analyses of future actions. For obvious reasons, such studies have limited appeal for the decision makers who manage resources and support research. Although post-project assessment is not a new idea, it is nevertheless one that we feel still deserves priority attention.

## Demands for Resource Products and Services

Increased attention should be devoted to the analysis of social demands for various products and services of resource systems.

Most of the attention of resource managers is devoted to the adjustment of production functions to meet the perceived demands of consumers; except in cases where the flow of a resource is clearly limited, adjustment of rates of demand has received far less attention (Ford Foundation 1974; NRC 1975a, 1975c). Nevertheless, efforts to reduce the need for activities with large environmental impacts or to increase reliance on less environmentally damaging activities must be important elements in national strategies for resource management. The most obvious way to change the demand for a product is to change its price. In the resource field, however, many products and services are "sold" at zero or a token price, and the prices of other outputs do not always reflect their full values. If the price mechanism is to be used to adjust demand, considerable research (much of it described earlier in this chapter) will be needed.

Forecasting demands for resources is a major element of long-term management, and is an area of important information needs. Research is needed, for example, on questions such as how valid are the methods used to make historical projections of demand for fossil fuels or irrigation water, or whether demands for some recreational opportunities (e.g., camping in parks near urban areas) may be effective substitutes for others (e.g., camping in remote wilderness areas) (see NRC 1975c).

The origins of demands for resources are complex. Demand is influenced by such variables as advertising, the amounts of time and money at people's disposal, changes in technology, rates of population growth and economic growth, and laws and government policies. Many of these factors may not be subject to control, but better understanding of the way they interact is an important need in the management of resources. Research to define the nature of demands for resources, to improve techniques for forecasting demand, and to explore methods of adjusting future demand to potential resource constraints should be given higher priority than it has received to date.

## Legal Constraints and Institutions

**A major research effort should be established to examine the influence of legal constraints and institutions on resource management activities and their environmental impacts.**

Environmental problems caused by resource management activities can be perceived, analyzed, and solved only through social and institutional means. Some existing institutions, however, tend to force management decisions in particular directions despite substantial indications of undesirable environmental or social consequences. To align resource management strategies more closely with social goals, changes in laws and institutions may be required. The evolution of institutional structures tends to lag behind the events they are designed to control, and research on the roles of specific management institutions is important for stimulating more rapid institutional adaptation to the accelerating pace of social change. Such research can attempt to identify the goals and objectives of resource managers, the relationships between those goals and the environmental impacts of various management activities, the influences of specific institutional constraints upon the goals and actions of resource managers, the effectiveness of institutions in attaining social goals, and the possible effects of specific changes in institutions on the goals and actions of managers and the eventual outputs.

For example, an important question is whether some laws or institutions designed to protect the environment may in fact merely exchange one set of impacts for another. Research might examine the effects of recently imposed constraints on the development of supertankers on fleet characteristics, port requirements, and other characteristics of ocean transportation. Research might also examine the relationships between the patterns of private ownership, or of government authority over publicly owned resources, and the management of those resources. For example, responsibility for wildlife populations is vested primarily in state organizations, while responsibility for the habitat on which those populations depend is vested largely in either federal agencies or private owners. Thus, a single resource manager rarely has power to deal with the whole system. Similarly, surface rights to particular lands may be held by private interests or government agencies concerned with agricultural or forest production, while other private interests and government agencies may have rights to and management authority over sub-surface mineral or fossil fuel deposits.

The small amount of research that has been done on institutional components of resource systems has not yet provided an adequate basis for designing improved resource management institutions. A major effort in this area is needed and should be among the highest priorities for funding. The most fruitful approach would likely be historical analyses and case studies of important resource management processes that have been carried out by government agencies and corporate and non-corporate private owners.

## HOW MUCH RESEARCH IS NEEDED?

The emphasis we have given throughout this report to comprehensive, integrated research and modeling of resource systems could lead to a massive, overburdening effort to collect data, if steps were not taken to guard against it. We believe that the models developed must not become so large and unwieldy as to be impractical for use in decision making or as a guide to research needs. In particular, the pitfall of collecting data strictly to satisfy the demands of the model or the biases of the modelers must be avoided. In addition, in order to facilitate study of interactions among resource systems and to broaden the applicability of data and interpretations, it is important that models of different systems be similarly structured. This need, too, argues for models of relative simplicity and manageable size. Models that are designed as aids in problem solving for resource managers do not necessarily require extensive amounts of data or minutely detailed data. The data needs in each case will depend on the kinds of alternatives the decision makers need to examine, and on the time available before the decision must be made. Where appropriate, models can be developed within a hierarchical structure that permits more detailed modeling of a particular subsection of a system, as the need may arise (Overton 1977). Funding available for data collection may also limit the research possibilities.

In general, there are two major categories of information needs on the impacts of resource management: information to support immediate decisions or determine the short-term consequences of a management activity; and an information base for the long-term management of resources, including projection of the consequences of actions over decades or longer periods. Short-term, problem-oriented research usually can meet needs of the former type sufficiently to permit decisions. On the other hand, long-term resource management requires that projections of environmental and other consequences be part of an integrated, comprehensive assessment. Such research need not be finely detailed or intensive, but rather should permit present and future resource managers to compare "best guess" estimates of the consequences of policy options.

For some resource management problems, research needs may be rather modest, because adequate baseline data are available from a variety of sources. The chief need in such cases would be to provide a comprehensive, coordinated framework for the use of existing information. In the majority of cases, however, information gaps will exist in at least some of the categories described above in this chapter. If existing information is sufficient to permit data needs to be identified readily, the amount of research needed to support a decision would not necessarily be large. In this regard, it is important to recognize the great value of sensitivity analysis as a tool for determining which missing pieces of information have the greatest influence on the outcome of the model's projections. Such analysis can be a key to ranking research needs and reducing the extent of data gathering efforts (see, for instance, North and Merkhofer 1975).

# CHAPTER 4

# RESEARCH INSTITUTIONS AND COMPREHENSIVE STUDIES ON ENVIRONMENTAL IMPACTS OF RESOURCE MANAGEMENT

In earlier chapters, we have noted that the most conspicuous failure of research on environmental impacts of resource management has been the inability of both research and decision making to deal effectively with the complexity of resource systems and resource management problems. The greatest need for research, therefore, is to develop the capacity for integrated, comprehensive investigations, including simluation modeling of resource systems, that can encompass the full range of physical, biological, economic, and social factors that determine the resource outputs and the environmental impacts that follow from a given set of inputs to a system. Although an enormous amount of research is being done in government agencies, universities, and private institutions, very few research programs have the broad, multidisciplinary approach we feel is needed. We believe that, to a large extent, the existing traditions and institutions for research on resource management contain roadblocks to the effective implementation of the needed comprehensive approach. This chapter examines the institutions for research, some of those obstacles, and possible methods for overcoming them.

## RESEARCH PROGRAMS ON ENVIRONMENTAL IMPACTS OF RESOURCE MANAGEMENT

The number of resource management activities with impacts on the environment is vast, and the number of agencies and other institutions that conduct research related to such activities and their impacts is correspondingly large and diverse. It was impossible, under the terms of this study, for us to examine in any detail the research programs that touch on these issues. Instead, we will present a brief, general overview of some research programs of different organizations with different orientations, emphasizing the relationships between those existing programs and the need we have identified for comprehensive studies. This review is intended to illustrate some general trends and institutional approaches in research on environmental impacts of resource management; it is neither a complete survey of all the programs that might be included, nor a detailed appraisal of any programs that are cited. (Indeed, entire reports have been devoted to assessment of the research programs of single agencies; see for instance NRC 1972b, Mar and Newell 1973, Leontief et al. 1975, U.S. Congress, Office of Technology Assessment 1976, U.S. Forest Service 1976, NRC 1977.)

## Federal Agencies

The federal agencies that play a significant role in research on resource management and its environmental impacts vary in missions from regulatory (e.g., the U.S. Environmental Protection Agency [EPA]), to land and resource management (e.g., the U.S. Forest Service [USFS], the National Park Service, the Bureau of Mines), to research and development with specific goals (e.g., the Agricultural Research Service [ARS] or the Energy Research and Development Administration [ERDA]). The directions taken by research and development within each agency tend to reflect the missions of the agencies. For example, the research programs of EPA are designed primarily to support immediate decision making by providing information on specific pollutants--their sources, processes of environmental transport and transformation, effects on living and nonliving receptors, control techniques, and costs and benefits of control (U.S. EPA 1977, NRC 1977). Although there are some exceptions (see the section on status of comprehensive research, below), this orientation generally does not produce research to assess long-term degradation of ecosystems by large-scale resource management activities.

In contrast, the research programs of most agencies with major resource management responsibilities have generally been designed to understand and improve production of resources. Some of this research is integrated, in the sense that it combines studies of the physical resource base with studies of socioeconomic variables such as demand. However, (again with some exceptions, noted below), such research is rarely truly comprehensive, and usually is not designed to assess long-term environmental consequences of resource management decisions. For instance, most research on agricultural activities is conducted either at ARS research centers, or by agricultural experiment stations that are supported by the Department of Agriculture and operated in cooperation with the land grant universities. The research produced by this system has tended to concentrate on narrow, locally important problems, such as range management or production of a particular crop (NRC 1972b). While this approach has produced some excellent research within its objectives, it has not been adaptable to the sort of integrated study of interconnected problems that is necessary to support management of multiple resources in a single natural system. Similarly, most research carried out by agencies such as the Bureau of Land Management, the

National Park Service, the Bureau of Outdoor Recreation, the Bureau of Mines, and other resource-managing agencies has been focused on specific local resource production questions.

## Comprehensive, Integrated Research in Federal Agencies

Many studies within the diverse research programs of the federal government that deal with resource management and its environmental impacts have involved modeling of environmental systems, and some have included successful applications of models in resource management planning and policy making. (For a synoptic review of this research and its applications, see Environmental Modeling and Decision Making: The United States Experience, a report by the Holcomb Research Institute, 1976.) The most successful efforts, however, have almost always involved narrowly focused questions and small, relatively problem-specific models. Comprehensive, multidisciplinary studies to make long-term projections of large, complex systems for policy-making purposes have been uncommon, for both technical and pragmatic reasons. The models required for such studies still have substantial problems of theory, data availability, and validation; and, as the size and scope of the system modeled increase, the number of resource managers and other interests concerned with the policy issues under study, and the complexity of interactions among those potential users, also increase considerably. Nevertheless, a number of significant steps have been taken toward the kind of comprehensive research on resource systems we feel is most needed, though few if any of the efforts to date could be rated as wholly successful.

For example, several sub-programs of EPA's research have elements of a comprehensive, integrated approach. In the 1977 fiscal year, EPA allocated $6.1 million (of an R&D budget of $234 million) to research on management techniques to meet environmental objectives in the production of renewable resources (U.S. EPA 1977). EPA also spent a small part of its energy-related research funds on integrated assessment of new energy technologies, to examine both environmental and socioeconomic aspects of entire fuel cycles, especially for certain coal-using technologies. Finally, EPA maintains a modest effort ($1.6 million, or 0.7 percent of the 1977 budget of The Office of Research and Development) in Environmental Systems Analysis, under the Environmental Management Sub-program, which is designed to assist state, regional, and local agencies in the analysis of environmental impacts of and policy alternatives for regional development, land use, and transportation patterns. (In this regard, see the discussion of the SEAS model, in Chapter 2).

The Energy Research and Development Administration (ERDA) also has some comprehensive research programs, especially in the assessment of new energy technologies. ERDA's research plan includes a program in general systems analysis that will examine energy development policy options, emphasizing the complex interactions among energy use, technology, the environment, and the national economy (U.S. ERDA 1976). ERDA also supports the environmental research programs of several national laboratories, particularly those at Oak Ridge and Brookhaven, which have made major contributions to the advancement of environmental modeling. The Regional Environmental Systems Analysis Program at Oak Ridge (supported in part by NSF) is similar in objectives to the Environmental Systems Analysis Program in EPA, noted above (Craven et al. 1977). The ERDA program for developing systems research represents a major attempt at integrated, comprehensive assessment of long-range resource management choices; unfortunately, difficulties in integrating economic and technological models and problems in establishing formal channels of communication, cooperation, and coordination among the many agencies and organizations involved in the data-gathering and analytical phases of the program have hampered the early progress of the effort (U.S. ERDA 1976).

The research program of the U.S. Forest Service provides a third important example of a major ongoing effort to provide better integrated analysis and supporting research dealing explicitly with environmental impacts of resource management decisions. Under the Renewable Resources Planning Act of 1974 (RPA) (PI 93-378), the USFS is required to prepare comprehensive analyses of forest and range resources of the country at ten-year intervals. This assessment is intended to provide the basis for choosing programs for the use of forest and range resources that will optimize the mixture of resource benefits--timber production, livestock grazing, wildlife habitat, water yield and quality, recreational services, and the like--while fulfilling the mandate of the National Environmental Policy Act of 1969 to maintain environmental quality. The RPA thus appears to impose on Forest Service decision makers a framework like that advocated in Chapter 2, a least within the constituted authority of the agency. Furthermore, one of the objectives of the assessment program is to design future USFS research on interdisciplinary, interinstitutional lines (see USFS 1976, 1977; Giltmeir et al. 1976).

As estimable as this highly ambitious effort is, brief experience with it to date has already revealed some deficiencies. The RPA Assessment (USFS 1977) has been criticized for its lack of comprehensive treatment of the important interactions of resource systems both with one another (e.g., effect of timber output level on water quality) and with related environmental characteristics (Vaux 1976, Clawson 1977). The Forest Service itself first noted the deficiency, including it in its summary of scientific information and data needs published in its Assessment report. Research specifically designed to fill such gaps might be readily at hand, and a major project to update national and regional forestry research programs is currently under way within the USFS (Anonymous 1977). However, scrutiny of the details of forestry research planning makes it seem less certain that such needs will be met. The program structure through which research priorities are assessed is founded on a product-oriented or discipline-oriented approach that weighs against identification of broader problems or adoption of comprehensive research approaches (see Anonymous 1977, Appendix C). While the current redirection of forestry research programs will certainly result in strengthened research efforts, particularly in terms of emphasis on resource inventories and soil and water components of forest systems, the approaches and problems essential to an adequately comprehensive view of the resources appear to be overlooked. We believe this oversight is the result of institutional factors, described later in this chapter.

These examples indicate that the need for comprehensive, integrated studies of resource/environmental problems is recognized, at least in concept, in research programs of some federal agencies; examples from other agencies might have been cited as well. Nevertheless, none of these programs has provided the practical, accessible analytical capability that we feel is needed for long-term resource management (see Chapter 2). Different agencies have mounted programs with comparable objectives, but divergent approaches; and not even the best of the approaches tested to date has successfully integrated all of the aspects we feel are important.

## Nongovernment Crganizations

A great deal of research on resource management activities and their environmental impacts is conducted outside federal agencies, in universities, private industry, or independent research institutes. As is true within government, however, the number of programs that have produced comprehensive, multidisciplinary studies of resource systems is extremely small.

In general, most of the theoretical research, data-gathering, and validation studies done in academic settings have been concerned primarily with using models as research tools for understanding the systems studied, with less emphasis on the potential applications of modeling techniques in resource management decision making. For instance, much of the research to develop ecosystem models has been done through universities, in part as the U.S. contribution to the International Biological Program (see Chapter 2). Some of the studies done in this context have been used to assess impacts of resource management activities, e.g., studies on the consequences of deforestation in the Hubbard Brook watershed (Bormann et al. 1974). Such applications have been limited by a number of technical and institutional problems (Holcomb Research Institute 1976); nevertheless, recent projects have attempted to integrate ecosystem modeling with resource management. For instance, the program on Regional Analysis of Environmental Systems at Colorado State University has tried to incorporate the IBP Grassland Biome model, existing management procedures, and analysis of economic and social factors into a comprehensive management program for rangeland systems (Holcomb Research Institute 1976:63-64).

Quite a different kind of systems approach has been developed by the Center for Agricultural and Rural Development (CARD) at Iowa State University, where models have been used in agricultural planning and policy studies for more than 20 years. CARD has applied a large, sophisticated modeling capability to studies of U.S. and world food production, with major attention to land, water, and energy requirements and constraints, and to environmental impacts of alternative food production scenarios (e.g., Dvoskin and Heady 1976).

Similar research on different resource systems has been conducted at a number of other universities, and many studies in support of environmental impact assessments have been carried out by academic researchers. However, most such studies have generally been focused on specific regions or management issues, and their transferability has been quite limited (Holcomb Research Institute 1976).

Many private industries that own or manage resources on private or public lands also have extensive research programs, both on the production of resources and on related environmental problems and mitigative measures. Individual companies (e.g., Weyerhauser, Georgia Pacific) and industry consortia (e.g., the American Petroleum Institute, or the electric power producing industries, through the Electric Power Research Institute) have conducted or sponsored some studies that are quite closely tied to management decision making. Nevertheless, such research is usually focused on the production of a specific resource or mixture of resource products, and lacks the broad, long-term perspective.

A number of private research institutions have made important contributions in research on resource management and the environment; two leading examples are Resources for the Future (RFF) and the International Institute for Applied Systems Analysis (IIASA). Research at RFF has employed models of varying degrees of sophistication to study resource management problems in numerous areas, particularly water, mineral, and recreation resource issues (see, for example, Ridker 1972, Kelly and Spofford 1977). Much of the work at RFF has focused on methodological problems in the integration of environmental models with economic and management models (see Spofford et al. 1975, Russell 1975). IIASA, located near Vienna, Austria, was established in 1972 to conduct internationally sponsored, multidisciplinary systems research on global problems, particularly resource and environmental issues. The institute has developed a comprehensive, integrative approach to research, and conducts studies designed both to aid in solving complex social problems and to advance methodologies for their analysis (see IIASA 1976, Holling 1974). Although the approach IIASA has taken to the analysis of resource systems is, in concept, as close to what we believe is needed as any that we know of, the institute's research, with a few exceptions, has in practice been rather fragmented (A. Kneese, University of New Mexico, personal communication, 1977). Thus, while the concepts upon which IIASA is founded deserve to be emulated by research on resource management issues on other than the global, universal scale, the experience to date is further indication of the difficulty of achieving truly integrated research.

## INSTITUTIONAL OBSTACLES TO COMPREHENSIVE RESEARCH

As the brief review of selected research programs just presented indicates, a number of significant attempts at broad, multidisciplinary studies of resource systems have been made. The success of such efforts in guiding resource management, however, has been relatively limited. For the most part, the research, both in government agencies and in private institutions, has not been comprehensive enough, in our judgment, to include all the important components of the systems studied. Furthermore, there has been no uniform approach to problems, even among agencies with similar missions; as a result, neither the products of research (data, insights, and so on) nor the analytical methodologies have been readily transferable from one system to another. In part, these problems simply reflect the relatively early stage of development of research techniques for the study of large, very complex systems. We believe, however, that the inherent difficulty of the task is greatly compounded by several substantial institutional factors, woven into the structures of agencies and the patterns of research organization. Without questioning the validity of the existing institutions or their usefulness in relation to the problems they were designed to solve, it seems clear that they weigh against the kinds of comprehensive analysis of resource and environmental problems called for in Chapter 2.

## Specialization of Research Personnel

The education of most research scientists, the reward systems characteristic of most research institutions, and the value structures that permit the scientist to identify himself all are geared closely to the concept of "discipline." As a result, scientific manpower has become highly specialized in clearly identifiable ways. Most scientific disciplines have emerged through successful application of a reductionist approach, rather than from a synthetic approach characteristic of any systematic view of natural resources and the environment. The emergence of ecology, a clear exception to the reductionist rule, still demonstrates the point, since ecology has not yet integrated biological and social variables adequately to deal comprehensively with natural resource systems. Even the discipline of systems analysis does not contradict this generalization, since such analysts usually must rely on others for the formulation and collection of the vast quantity of data required.

These deep-rooted, powerful directive forces affecting the education, rewards, and identity of research workers obviously have not entirely precluded the development of a more comprehensive and synthetic approach to natural resources research, but the paucity of examples of such research suggests that these have been accomplished because of the ability of some scientists to transcend the directives of the established educational, reward, and identification systems. A significant challenge is to develop improved institutional means to encourage more resource scientists to grapple with the problems of synthesis and system building, despite the existence of strong incentives to focus their efforts in the opposite direction.

## Specialization of Research Missions

The current structure of institutions for the management of natural resources, and for research on such management and its environmental impacts, evolved in concert with general perceptions of resource problems and their solutions. For instance, agriculture and forestry research programs were first developed in response to perceived needs for more effective methods of protecting the basic resources, and producing and distributing the commodities derivable from them (Knoblauch et al. 1962, Baker et al. 1963). The institutions created in response to such needs have been adaptable, as the scale of resource management efforts has grown. Nevertheless, most of the existing research on natural resources has been executed through government agencies, state experiment stations, or public or private research institutes that have specific, identifiable missions. For the most part, such missions were defined at a time when the need to preserve the quality of the environment, if perceived at all, was much less important than it is today. The subsequent growth of environmental concerns has frequently been recognized by tacit or explicit revision of stated missions to include environmental constraints, but the central thrust of the original mission orientation remains, in most institutions.

The influence of agency missions on the scope and content of research programs can be illustrated by an example, drawn from forestry research. During the embryonic years of forestry research in the U.S. (1875-1910), two central lines of scientific inquiry were in silviculture, i.e., the treatment of forests to produce goods and services, such as timber or watershed protection; and in forest influences, i.e., the study of the effects of various sorts of cover on the physical characteristics of the micro-environment (for instance see Fernow 1902, Marsh 1907, and Kittredge 1948). With the advent of mission-oriented forestry research in the early 20th Century, this binocular view of the forest began to disappear. Research tended to emphasize improving man's ability to manipulate the forest more effectively to meet human needs for commodities and services, i.e., silvicultural studies, while research on forest influences experienced little or no commensurate growth. The recent increased emphasis on environmental constraints in silvicultural research has not in any fundamental way shifted the focus of the research approach from the forest viewed as a producing organism to the forest viewed as major determinant of soil, water, air and other environmental characteristics. Yet a comprehensive model of the forest, adapted to solving today's complex problems of forest management, would require equal emphasis on and integration of both approaches.

Given the focused nature of the missions of existing resource research institutions, a significant fraction of the research needed for comprehensive analysis of resource/environmental systems may be "falling between the stools." No major research institution has the focal mission of generating information and analysis on the relationships between particular states of a natural resource and broadly significant environmental parameters influenced by that resource. We have identified, above, a number of programs with such a focus that are in fact supported, at least in part, by mission-oriented agencies; but such situations appear to be exceptional.

## Interagency Coordination

Most resource systems yield a diversity of resource products, and management of a given system often involves several agencies. Circumstances also may place different agencies in similar management roles in different systems, as for instance in watershed protection or management of recreation as these occur on forested lands, range lands, or areas of mineral extraction. Effective coordination of research is needed to improve the correspondence of approaches and assumptions used by different agencies, and to reduce costs through sharing data on problems or regions where agencies' concerns overlap. Interagency coordination becomes particularly important when the research involves large, comprehensive modeling studies.

Both formal and informal mechanisms exist for accomplishing some forms of coordination. For example, an impressively comprehensive effort has been made during the last fifteen years to coordinate both agricultural and forestry research. Through dissemination of detailed project information and some degree of financial control, the efforts of several thousand research workers in the Department of Agriculture, the state agricultural experiment stations, and the schools of forestry are linked, at least in part. This mechanism is being used in long-range planning for agricultural and forest research, including studies of environmental impacts (Anonymous 1977, U.S. Department of Agriculture 1977).

A different mechanism was used to coordinate studies under special appropriations for energy-related research in the 1975 fiscal year; special interagency task forces were formed to plan the research and allocate the funds, under the auspices of the Office of Management and Budget (see reports of the two U.S. Interagency Working Groups, 1974a, 1974b). This effort was successful to a large extent because the task forces exercised budgetary control and were not merely advisory bodies (NRC 1977).

Experience suggests that such coordinating devices can accomplish certain functions effectively. These include avoiding unnecessary duplication of research efforts, improving communication among scientists working on similar problems in different places or different agencies, diversifying the background and experience brought to bear on research planning, and facilitating interdisciplinary research efforts, once the need for this has been perceived.

While there are numerous examples of at least partially successful coordination of research on some problems, many cases could also be cited in which improved coordination is needed. For instance, several agencies, including EPA, ERDA, the Bureau of Land Management, and the Bureau of Mines, all are sponsoring studies of the environmental impacts of surface mining of coal in the Rocky Mountain states. Some minimal coordination has been achieved on small projects through a Western Regional Coordinating Committee (WRCC-21) on reclamation of mined lands, but as far as we have been able to determine, no serious attempt has been made to coordinate the work done by several agencies to produce a comprehensive assessment of impacts on the systems affected. Despite the work of an interagency task force that conducted a comprehensive, integrated assessment of environmental research needs for the Rocky Mountain region (Neuhold et al. 1975), effective coordination of research on most resource management issues has been slow to emerge.

Perhaps a more fundamental problem is that existing research coordination mechanisms seem to be ineffective devices for searching out gaps in broad research programs. The mission-specialized structure of the existing research establishment inevitably produces specific lines of thrust and, as inevitably, gaps within the structure. Coordinating devices, whether institutional or informal, are not designed to detect such gaps; such detection can occur only by scanning the area from a different vantage point. Unfortunately, substantial amounts of the data and analysis needed for adequately comprehensive models of resource management/environmental quality relationships are in research categories that fall between existing disciplines or institutional missions. Because no agency has a mandate to pursue comprehensive analysis of multi-resource systems, few incentives or funds exist, even in the interagency context, to extend research into areas that are not suited to the more parochial interests of the participating institutions.

### Gaps Between Research and Decision Making

Resource managers commonly complain of having to make decisions without an adequate information base, while researchers, on the other hand, frequently bemoan the fact that too little of the results of their research is used in decision making. Difficulties in the application of research are particularly marked when the work in question involves large, complex simulation models. Resource managers often may be unfamiliar with or have misconceptions about modeling, or may lack confidence in the results of modeling studies; and modelers frequently have paid more attention to the theoretical refinement of their models than to the usefulness of the tool for answering questions that most concern the decision makers. (See Holcomb Research Institute 1976 for more detailed discussion.) Cooperation and interaction between modelers and decision makers is important, beginning at the early stages of model development, if the results are to be useful for resource management. However, such interaction is frequently hindered by differences between researchers and decision makers in terms of goals, perspectives, approaches to problems, and reward systems. While most researchers are primarily specialists, resource managers are of necessity synthesizers. This difference alone suggests that development of stronger, comprehensive models of resource systems may be one significant way to bridge some of the gaps that exist.

## INSTITUTIONAL MECHANISMS TO ADVANCE COMPREHENSIVE RESEARCH

We believe that it would be advantageous to all resource managers to have at hand a capability for comprehensive research to support the management of resource systems and protection of environmental quality; that is, research that could integrate the concerns of all the different managers involved in activities in a given system, and project the environmental impacts and other consequences of alternative combinations of management activities. Such a capability does not exist today. As we have shown above, several federal agencies have made efforts to carry out broad-based studies; but the attempts have been based on different approaches, models, and objectives, and the results have seldom been widely applicable. If it is assumed that most agencies will eventually wish to develop some capacity to do comprehensive modeling of resource systems, devising institutional arrangements that will meet the needs effectively is a critical challenge.

The least desirable alternative, in our judgment, would be for each of the principal resource managing agencies to develop its own, in-house modeling capability independently. The almost certain result would be a number of greatly different models, each suited to the missions of the sponsoring agency, but none comprehensive enough to integrate analyses of the multiple resource problems that must be managed simultaneously. Without compatible approaches, there would very likely be an enormously wasteful duplication of effort, since many different managers would need to gather similar data on the same or comparable resource systems. Also, as noted earlier, because the missions of individual agencies tend to emphasize the production of resources, it seems improbable that environmental protection would be given appropriate weight in each case.

A second institutional strategy might be to expand and strengthen those research programs that now are comprehensive in scope (such as those of the Forest Service or ERDA, cited above), and to attempt, through multi-agency coordinating mechanisms, to make that research suit the needs of the various agencies with an interest in the results. It seems doubtful, however, that such an arrangement could satisfactorily avoid the pitfalls of attempts to serve several masters; and, without closer control of the modeling capability, many of the resource-managing agencies might judge the results of the research to be of too limited value to be relevant for their own decision making.

We believe that the institutional home of a program to develop a broad, integrative research capability should be an agency with a comprehensive mission. This seems to be the surest way to build a unified approach to the analysis of resource systems, one that can overcome the specialized missions of the different agencies and achieve a synthesis in the study of interrelated resource and environmental management problems.

Since environmental protection is an aspect of resource management that must, of necessity, encompass all activities that are pursued in a given system, a third option might be to assign responsibility for the development of comprehensive modeling to an agency oriented toward understanding and protecting the environment, such as EPA or the Council for Environmental Quality (CEQ). This approach, however, also has important drawbacks. The primary mission of EPA is to protect the environment; its primary tool is regulation. The agency has neither a mandate nor the capability to conduct research on broader problems of resource management. In addition, EPA's experience with comprehensive modeling to date (i.e., the SEAS effort, discussed in Chapter 2), has not been regarded as an unqualified success, and there might well be skepticism inside and outside the agency as to whether another involvement in large-scale systems analysis would be worthwhile. CEQ, on the other hand, has no regulatory responsibilities, but also lacks at present any capability to mount a large-scale research program. Furthermore, housing the needed research in an environmental agency would run the same risks noted above of producing results that were insufficiently comprehensive, in this case perhaps underemphasizing the production and use of resources to meet social needs. Finally, the problem of multi-agency management of a program located within one of the user agencies, also noted earlier, would be substantial.

A fourth option, and one that, in our judgment, has the greatest likelihood of achieving the desired objectives, is to create a new, independent national institute for comprehensive research on resource and environmental systems. Such an institute, with an explicit mandate to study problems that transcend the missions of several agencies, would have the best opportunity to coordinate the various in-house research efforts and to develop a unified approach to the study of common problems.

As we envision it, this new national research institue might be supported by appropriations included in the research budgets of the several resource-managing agencies, EPA, and other potential users of the results. As noted earlier in this chapter, the possibility that effective coordination might be achieved would undoubtedly be greatly enhanced if the new research institute had the administrative responsibility for allocating federal research funds for studies involving comprehensive modeling and analysis of resource systems.

The missions of the new institute would be to develop improved methods for comprehensive analysis of resource/environmental systems, and to work with the individual agencies on a project-by-project basis to apply the emerging methodologies to particular resource management issues. The purpose of the new research center would not be to conduct all comprehensive modeling research or to gather most of the data on resource management activities and their environmental impacts; those responsibilities would remain primarily with the agencies charged with management of the resources, to be carried out through their own in-house research or through contracts with universities and other research organizations. Instead, the chief function of the new institute would be to assist agencies in designing comprehensive, integrated research on resource systems, and to coordinate the exchange of data and methodologies among programs with comparable needs. Such a centralized institution should make a synthesis of the approaches taken by different resource-managing agencies and other institutions more attainable.

At the same time, the new institute would need to carry out a modest program of its own research in order to advance the methodology, maintain the scientific vitality of the center, and attract top caliber staff. We would expect resource management agencies to contract with the new center for selected studies that could both provide a needed analysis of pending policy choices and make new modeling techniques available for the agency's own use on other problems. To conduct a small number of studies, the new center would not need to have a large staff; much of the work might be subcontracted to modelers or other scientists outside the institute.

The success of the proposed new institute would depend heavily on the quality of its interactions with two constituencies: the research community, and the decision makers who would be the chief users of results of comprehensive modeling studies. In the first case, the institute we envision would play a crucial leadership role in the advancement and coordination of research on resource systems, and would need close, effective ties to researchers in resource-managing agencies, academic institutions, and private industry. The new institute might also provide training for scientists working on comprehensive, integrated research. One mechanism that would lead to the needed interactions would be to form research teams, under the aegis of the new center, that would bring together agency scientists, researchers from other institutions, and staff from the center itself, on an ad hoc basis for specific projects. The use of subcontracts would also provide opportunities to maintain ties between the new center and the research community.

The second set of interactions, those between the proposed research center and the resource managers, would be even more critical to the success of the effort. It is very important for decision makers to participate actively in the formation of the new institute and in the design of its research programs. Potential users should take part in planning and reviewing the research, to ensure that it emphasizes problems that the decision makers perceive as most important. Involvement of policy makers throughout a study would increase their familiarity with modeling techniques, with the assumptions that underlie the models, with the advantages and limitations of the research, and with the degree of confidence they should have in the results. Some mechanisms for fostering such interactions have been proposed (Holcomb Research Institute 1976); and the existence of a research center would open the possibility of using visiting fellowships or other vehicles to involve present (or future) decision makers in research projects.

## The Role of EPA

What would be the implications for EPA's research program if a new national center were established to develop techniques for comprehensive, integrated analysis of resource management and related environmental impacts? EPA is responsible for review of the environmental impact statements that other federal agencies must prepare in connection with proposed resource management activities. In order to perform such reviews, EPA has often had to conduct some research of its own, to supplement data gathered by the agency preparing the EIS. We would expect EPA to play a large role in the design of comprehensive models, particularly in the determination of which parameters of the environment should be measured, before and after perturbations, to determine the nature and extent of impacts on the system. To fill this role, EPA will need to continue to do research on both the unperturbed and the perturbed conditions of ecosystems. However, if the central coordinating function of the proposed institute proves effective, EPA's research should guide resource-managing agencies to collect appropriate data, so that many studies that are now redundant would be unnecessary. If EPA chooses to continue its own development of large-scale modeling to support environmental management (i.e., the descendants of SEAS), the new national research center would be available to provide expert assistance and coordination with other agencies whose data or models might be useful to EPA.

## RECOMMENDATIONS

(1) We recommend that a new national research center be established, having as its mission to develop, test, and make available to resource-managing agencies an advanced capability for comprehensive, integrated analysis and modeling of resource systems, management activities, and environmental impacts.

(2) We recommend that an interagency committee be established with the following assignments:

- Assemble information on current federal research programs that involve comprehensive analysis and modeling of resource and environmental systems.

- Identify the most critical research needs in comprehensive, integrated analysis of systems, including both the needed advances in methodology and the important policy questions that could best be approached through modeling studies.

- Suggest mechanisms for operation of the new national research center recommended above, especially methods to foster interactions between the new institute and both researchers and decision makers of the resource-managing agencies.

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