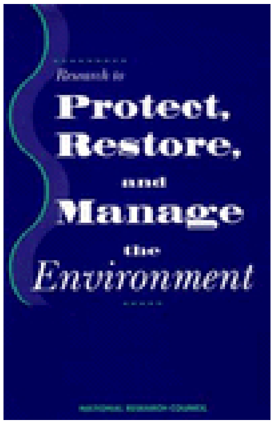

Research to Protect, Restore, and Manage the Environment

Committee on Environmental Research, National Research Council

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Committee on Environmental Research
Commission on Life Sciences
National Research Council

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The report has been reviewed by a group other than the authors according to procedures approved by a 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 national and global environmental problems we face are acute. They include the familiar subjects of chlorofluorocarbons and the ozone hole in the stratosphere, global warming, and toxic-waste disposal (experts quote numbers as high as $50 billion to clean up the Hanford nuclear-energy site alone). We are beginning to understand the implications of the loss of biological diversity and extinction of species.

These and other environmental problems derive from a combination of population growth and the increasing rate of natural-resource consumption stimulated by the rising standard-of-living aspirations of peoples everywhere. Some of the problems affect the very future of life on our planet.

Environmental problems are international in character, and some international cooperation and coordination exist, but not nearly to the extent we think essential. The problem is eloquently stated in the Carnegie Commission report *International Environmental Research and Assessment:* "The free passage of winds and currents, without passports, makes environmental matters peculiarly and quintessentially international. Sustained, effective international action requires that the poor develop into the rich and that the rich improve their behavior with respect to the environment and resources." Because international considerations are beyond our charge, we do not deal with them in this report. However, the Carnegie Commission's report has called attention to these critical issues.

The federal government spends a large amount, $5 billion a year in round numbers, on research and development that addresses environmental problems, much of it of high quality. Some of the research is coordinated, the global-climate change program, for example. Other programs appear uncoordinated.

In spite of the large expenditures, our country has no adequate way to set national goals and a national environmental research agenda agreed to and participated in by federal agencies and national laboratories, by industry, and by academic institutions, a program understood and supported by an informed citizenry.

Environmental policy, both legislative and regulatory, is often produced without benefit of the best science available. Scientists often pursue research programs without adequate consideration for the policy-makers who must make policy in the face of inadequate information and understanding.

Environmental science and technology is such a broad and encompassing field that attempts to analyze and organize it adequately exceed the capacity of this or any other single body. We narrowed the discussion from the beginning to an examination of environmental-research vigor and adequacy, with identification of strengths and weaknesses together with suggestions for closing the gaps and providing for more responsive organizational relationships. We have chosen to concentrate on the general nature of the research program as organized and supported by the federal government rather than on a detailed examination of specific research efforts.

We excluded detailed examination of human-health research, even when related to environmental problems. We recognize the degree to which environmental factors jeopardize health and we recognize that environmental-policy decisions cannot be made without consideration of data and information concerning human health. However, the research and organizational arrangements for producing those data exists and there is a public commitment to maintain the institutional arrangements.

To assess the status of the research pursued by the federal agencies, we talked to federal officials in their offices, we were briefed by officials in formal sessions, we consulted them in their offices again, and finally we submitted to them our written understanding of their programs. We sought input from the public interested in environmental research in a one-day hearing where we received both oral and written testimony.

We also consulted, with excellent cooperation, other bodies that were conducting studies of environmental research problems: the Carnegie Commission study of environmental research organization, the Carnegie Commission study of international environmental research issues and the study by the National Commission on the Environment performed in cooperation with the World Wildlife Fund. The American Association for the Advancement of Science (AAAS) report on the organization and funding of environmental research in the various federal agencies supplied us with an excellent oversight of agency programs. We also had good cooperation by the Committee for the National Institute for the Environment (CNIE).

These several studies, the two Carnegie Commission reports, that of the National Commission, the AAAS report, our own and the CNIE proposal–all appearing within a few months, covering all aspects of environmental affairs, from the broadest policy, to governmental organization, to specific research fields–constitute a fortunate circumstance. These reports largely agree in their diagnosis of the problems and the reasons for their proposed solutions, even though their recommendations differ in details. The new federal administration has a set of carefully thought-out recommendations available as it seeks to define its environmental agenda.

Because environmental problems result from both slow and fast processes, we have analyzed federal research programs from both short- and long-range perspectives. Maximal assistance cannot be provided to policy-makers from either perspective alone. We use both time frames to identify research areas that are inadequately covered today, to identify gaps, and to suggest changes in administrative structures and resource allocation designed to respond more effectively to current and future environmental challenges.

Based on our analysis of existing programs and their inadequacies, we set forth different organizational frameworks for closing the gaps. These organizational options range from maintaining the federal-agency mission and program status quo, adding only what is minimally required to close the gaps, to an outline of a rational structure for a Department of the Environment.

Our judgments and conclusions are limited by the collective experience of our committee. Recognizing these limitations, we suggest a continuing process that will ensure inclusion of important environmental research in the national agenda, along with an organizational framework to ensure vigorous pursuit of the problems.

Finally, turning again to the seriousness of our environmental issues, if we knew the time to irreversible change in any of the myriad problem areas, we could better assess the degree of urgency that should drive our responses. We do not know those times, however. Too much fundamental understanding is missing–hence the importance of research in critical areas. However, faced with a combination of potentially very serious consequences but great uncertainty about when or where the troubles will arise, an ounce of prevention is likely to be worth a pound of attempted cures. A healthy degree of risk awareness combined with serious efforts to understand the problems better will provide us with insurance we badly need.

There are now about five billion people in the world, approximately one billion in the developed world and the others in the developing world. During the twelve days of the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in June 1992, world population increased by three million people, all but 150,000 of them in developing countries (these numbers were called to our attention by Thomas F. Malone of North Carolina State University). At projected population and economic growth rates, the developing-world population will likely double in the next 50 years while the developed world will grow much more slowly, so that the population ratio of developing to developed world will be more like eight or ten to one.

Our own vigorous economy has depended on exploitation of our natural resources. Our people have been industrious and innovative, and the developing countries want to emulate our success. Yet we know that if they do, the impact on the world environment will equal our own but multiplied ten times over. This is a formula for environmental catastrophe. Nonetheless, how can we deny those billions of people in other parts of the world the same opportunities we have had? How can we help them avoid our mistakes?

Research must help identify development pathways that are environmentally sustainable.

The health of our own economy, as it operates today, depends on growth, and past growth paths have meant even heavier demands on natural resources and heavier demands have meant greater environmental problems. The demands on the world's fossil fuels, particularly oil, whose supply is measured in decades, not centuries, continues to grow. How can we adjust our economy so that it remains healthy but at the same time minimizes the burden on our natural resources and on the environment?

We do not know how to deal with these problems, but we must learn and we must learn quickly.

We have the potential to make our own future and that of the developing world more secure and more benign than will be the case if we do not use science, technology, and wise policy to avoid the pitfalls likely to face us if we simply replicate our past history.

We must mobilize all our great talent and all our great institutions to cope with current and future environmental problems–a challenge that if not met jeopardizes our national security in its most fundamental aspect. We must learn how to bring our federal agencies with their national laboratories together with the best minds and the best laboratories in industry and the academic world, and we must tap the strengths of nongovernment organizations, all in the cause of finding our way ahead as our natural resources decline, toward extinction in some cases, and our environmental quality and functioning continue to be imperiled. Learning how to marshal all this national capital is one of the biggest challenges of all.

I am grateful for the excellent work by Alvin Lazen, who became our study director after the committee began its work with Barry Gold's assistance. I want to thank Gordon Orians, Kai Lee, and Paul Risser for extraordinary effort in preparing drafts for much of the report and the reviewers for their thoughtful comments. We have been served in excellent fashion by our Staff Assistant Sharon Holzmann and Project Assistants Adriénne Staggs and Juliette Walker. We have had valuable help from James Reisa, David Policansky, Raymond Wassel, and Eric Fischer of the NRC staff, and from study directors of earlier NRC environmental study committees. Norman Grossblatt, of the Commission on Life Sciences staff, edited the report.

Dale R. Corson
Chairman

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Executive Summary

We stand at a time when science and engineering have the tools to address environmental problems of enormous consequence to our social and economic well-being. But we are not using those tools most effectively. Rather, federal environmental research and policy are trying to cope with today's problems by using a system that was constructed when the problems perceived to be important were different. The purpose of this report, by the Committee on Environmental Research in the National Research Council's Commission on Life Sciences, is to suggest how the nation can organize its science and engineering resources and organize itself to address environmental problems of local, regional, national, and global scope.

The activities of people in large numbers have been the major force in making our planet less able to meet the needs of people of coming generations. The daily activities of people have so affected the chemistry of the atmosphere that various trace gases–such as carbon dioxide, methane, and chlorine compounds–are present in increasing concentrations. People have injected an enormous variety and quantity of chemicals not only into the air, but also into water and soil. Some of those chemicals might endanger us or our children, and we must learn how to deal with them. People have altered the landscape of much of the earth. Lakes have been made, and the Aral Sea is drying up. Vast land areas have been devoted to agriculture, and vast new areas of desert have appeared. Those changes have made many areas more hospitable and have allowed greater numbers of people to be clothed and fed; but they have also disrupted ecological systems that benefit humans, and many thousands of species have become extinct.

The nation's "system" to address those and other environmental challenges consists of hundreds of programs distributed in more than 20 federal agencies that invest about $5 billion a year in research and development related to the environment. The committee's assessment of the federal environmental programs and the system for organizing and managing them shows substantial strengths and weaknesses. Among the strengths, the United States is blessed with an impressive array of scientific, managerial, and political talent. It also has a citizenry that is as informed and concerned as that of any nation, even though its knowledge and involvement are much less than would be desirable. Federal agencies spend large sums of money on environmental research, which has produced much useful information in support of their missions. Cooperative programs addressing important environmental problems have been organized, such as the Office of Science and Technology Policy's successful coordination of the global-change program. These strengths need to be maintained and improved.

The committee also finds the following weaknesses that need to be addressed:

- The research establishment is poorly structured to deal with complex, interdisciplinary research on large spatial scales and long-term temporal scales. These traits characterize the primary needs of an effective environmental research program.
- There is no comprehensive national environmental research plan to coordinate the efforts of the more than 20 agencies involved in environmental programs. Moreover, no agency has the mission to develop such a plan, nor is any existing agency able to coordinate and oversee a national environmental research plan if one were developed.
- The lack of an integrated national research plan weakens the ability of the United States to work creatively with governments of other nations to solve regional and global problems.
- The nation's environmental efforts have no clear leadership. As suggested by the lack of a cabinet-level environmental agency, the United States has lacked strong commitment to environmental research at the highest levels of government. Environmental matters have been regarded as less important than defense, health, transportation, and other government functions.
- Although individual agencies and associations of agencies analyze data to provide a base for decisions on strategies and actions to address specific environmental problems, no comprehensive "think-tank" exists for assessing data to support understanding of the environment as a whole and the modeling of trends whose understanding might help to set priorities for research and action.
- Bridges between policy, management, and science are weak. There is no organized system whereby assessments of environmental problems can be communicated to decision-makers and policy-setters.
- Long-term monitoring and assessment of environmental trends and of the consequences of environmental rules and regulations are seriously inadequate. The United States has a poor understanding of its biological

resources and how they are being affected by human activities. Although biological surveys have a long history at the state and federal level in the United States, only very recently are we approaching a consensus on the need for a comprehensive, national biological survey.

- There is insufficient attention to the collection and management of the vast amount of data being developed by the 20 agencies involved in environmental research. Collection and management of environmental life-science data are less well organized than those of environmental physical-science data.
- Education and training in the nation's universities are still strongly disciplinary, whereas solution of environmental problems requires broadly trained people and multidisciplinary approaches. Opportunities for broadly based interdisciplinary graduate degrees are few, and faculty are not rewarded as strongly for interdisciplinary activities as they are for disciplinary activities. Thus, there is a risk that environmental scientists appropriately trained to address pressing needs will be lacking.
- Biological-science and social-science components of environmental research are poorly supported, compared with the (still inadequate) support given to the physical sciences.
- Research on engineering solutions to environmental problems is seriously underfunded. That reduces our ability to protect and restore damaged ecosystems to productivity and jeopardizes the nation's ability to achieve major economic benefits that are certain to derive from increasing worldwide employment of technologies for these purposes.
- With respect to environmental affairs, government operates in a strongly adversarial relationship with both industry and the general public, to the detriment of integrated planning and maintenance of an atmosphere of mutual trust that is essential for effective government functioning.
- With important exceptions in the National Science Foundation, the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Geological Survey (USGS), most federal environmental R&D is narrow, supporting either a regulatory or a management function. That appears to be particularly true in the environmental life sciences.

This committee recommends *cultural changes* and *organizational changes* to correct those weaknesses. Some of the cultural changes require new offices or programs and are thus both cultural and organizational changes. The organizational changes are ways to incorporate all the cultural changes into a comprehensive system for effective environmental research and communication of the results to decision-makers.

CULTURAL CHANGES

The committee uses the term *culture* to refer to the institutionalized beliefs, values, policies, and practices that characterize the administration of an agency's environmental research program and the nation's overall effort. For example, it refers to an agency's use of intramural research versus extramural research and to an agency's focus on mission-oriented research, rather than on research with potentially broader applications. With respect to a national environmental research program, it refers to the development of agency research programs with minimal reference to the cognate work in other agencies and with minimal consideration of the fit of the research in a coordinated national effort to address environmental problems.

We believe that our recommendations for changes can improve the effectiveness of our environmental research effort, no matter what new organizational arrangements might be made. Implementation of the cultural changes should be systemic, that is, they should be used throughout the government environmental research system.

RESEARCH DIRECTED TO PROTECTION, RESTORATION, AND MANAGEMENT

> The committee recommends that environmental research advance the social goals of *protecting* the environment for present and future generations, *restoring* damaged environmental functions so that they are once more ecologically productive, and *managing* our natural, economic, cultural, and human resources in ways that encourage the sustainable use of the environment.
>
> In advancing those three goals, environmental research should, first, collect and analyze information needed in and outside government to pursue the goals; second, improve our knowledge of the fundamental processes that shape the natural world and the human behavior that affects that world; and, third, apply the knowledge to solving environmental problems with a comprehensive management strategy in the context of economic and social needs.

The terms *protection, restoration*, and *management* set out directions in which environmental action should proceed; the terms should not be taken to imply absolute goals.

NATIONAL-LEVEL LEADERSHIP AND COORDINATION

The directions for environmental research must be set and responsibilities among various federal agencies must be coordinated at the executive level because environmental research is of the highest national importance. The setting of national directions requires both leadership by an official at the highest level of the administration, because it is a national priority, and the participation of those who are responsible for the agencies that will be conducting the federal program. The federal program will operate within the context of the entire national environmental research program, that must include the efforts of scientists, state and local governments, the public, and the private sector. It must ultimately be accountable to and responsive to the public. Therefore, there should be linkages to these communities, perhaps through a system of advisory committees.

> The committee recommends the establishment of a *National Environmental Council* in the executive office of the president to be chaired by the vice president. It should be composed of the heads of the federal environmental agencies. Advisory committees for the council should be established to represent the scientific community, the public, state government and the private sector. The council should provide national leadership and coordination among the federal agencies for environmental research and oversee implementation of the National Environmental Plan.

NATIONAL ENVIRONMENTAL PLAN FOR RESEARCH

There are many demands on the nation's overall resources and many competing ideas about relative priorities for a program of environmental research. A number of constituencies have a right and deserve to play a role in setting these priorities. Duplication of effort or omissions in a research program can occur in a field as important and complex as environmental research. A comprehensive national plan for environmental research is required.

> The committee recommends the development of a *National Environmental Plan* that will form the basis for coordinating environmental research responsibilities of federal agencies. The plan, which identifies the nation's environmental research agenda and the

> responsibilities of the individual agencies, should be updated every 2 years and comprehensively reconsidered every 5 years in the expectation that it will evolve. The National Environmental Council should take primary responsibility for ensuring that the plan is developed. In doing so, it should reach out, through the use of appropriate advisory committees, to the states, the private sector, nongovernment organizations, and the academic research community to ensure their participation in developing the plan and thereby to encourage them to participate in implementing it.

Our National Environmental Plan differs from the "National Environmental Strategy" recommended by the National Commission on the Environment in that the latter focuses on policy issues, such as economic incentives to improve the environment, whereas ours concentrates on research. The two ideas are complementary.

LINKAGE OF ENVIRONMENTAL RESEARCH AND POLICY

Among the most important roles of environmental research is creation of a foundation of sound information on which to base the policies that are necessary to protect, restore, and manage the nation's environmental resources. However, the link between environmental data and information and their use in decision-making is now weak within agencies and almost absent when larger issues that cross agency boundaries are in question. The committee believes that linkages between science and decisions need to be strengthened at all levels. It would be highly advantageous to ensure that the best scientific information is translated into strong and defensible policies for protection, restoration, and management. The two-part effort we recommend would supplement the present situation, in which each federal agency assesses environmental data to develop policy applicable to its own mission needs.

> We recommend the establishment of an *Environmental Assessment Center* in which large environmental issues that cross agency mission boundaries can be assessed and policy options developed.
>
> We recommend that an official (and staff) of this center serve as an environmental "intelligence officer" whose task will be to convey the

policy options to decision-makers in the National Environmental Council, to Congress, and to other involved parties. It would be advantageous if the center were represented also on the president's National Security Council and Economic Council, in recognition that decisions on environmental issues strongly influence national security and the national economy.

PERFORMANCE OF ENVIRONMENTAL RESEARCH

Fundamental changes must be made in how environmental research is conducted and used within the federal research enterprise.

We recommend the following essential changes to strengthen the nation's environmental research:

- Fundamental advances in understanding and in factual knowledge are needed if we are to grasp and to solve urgent environmental problems. Research should enlarge our comprehension of and ability to observe the components of the environment, deepen our understanding of how transfers of energy and materials occur among those components, and improve our knowledge of the interactions among components.
- The current strength of disciplinary research must be maintained, but more research must be multiscale and multidisciplinary to match the characteristics of the phenomena that we seek to understand. Research must cross the boundaries of mission agencies for the same reason. It must be international in scope, foster collaboration between public and private sectors, and include the valuable contributions of state environmental organizations and nongovernment organizations.
- Research must be economical. It must be of high quality. It must have stable funding bases. It should be pluralistic in approach and be supported by multiple funding strategies with proper regard for balance between intramural and peer-reviewed extramural support. It must provide for the support and training of the next generation of

scientists while providing for appropriate development of instrumentation and facilities for research. Only in that way can the nation's environmental research be efficient in solving problems and effective in contributing to international competitiveness and economic strength.

BALANCE

As environmental research has evolved, substantial imbalance in emphasis has developed. Imbalance exists in the funding of disciplinary fields of research, in the distribution between intramural and extramural performance of research, and in the type of research–disciplinary versus multidisciplinary or interdisciplinary research–that is supported. The physical sciences have been emphasized to a greater degree than biology, and both the physical sciences and biology have fared better than the social sciences and engineering. We believe that a more balanced program will be important in the future. Although imbalance in the funding patterns is evident, we are concerned primarily about asymmetry in program emphasis and in intellectual leadership.

The committee recommends that all relevant environmental disciplines be supported and that additional emphasis be placed on the biological and social sciences and on engineering.

The committee recommends continued emphasis on disciplinary research supporting the protection, restoration, and management of environmental systems, and increased emphasis on interdisciplinary and multidisciplinary research with the same goals.

The committee recommends that mission and sector agencies substantially expand their extramurally funded research programs, creating such programs where appropriate. These should provide maximal opportunity for the nation's academic and other nonfederal researchers to avail themselves of national environmental research opportunities. The principles of competitively awarded, peer-reviewed, investigator-initiated awards should be applied.

CONTINUOUS MONITORING OF THE NATION'S ENVIRONMENTAL STATUS

The United States has a wealth of natural resources. Although these resources must be used to support the quality of human life, their use must be managed in such a way that they are sustained for future generations. We must therefore know the status of and changes in the resources if we are protect, restore, and manage them. Many agencies have legal responsibility for different components of these resources, so a coordinated program among the agencies for measuring the status and trends of the resources is necessary.

> We recommend the initiation of the *National Environmental Status and Trends Program* to be coordinated by the National Environmental Council to function as an integrated cooperative program among the federal agencies to inventory and monitor the status and trends of the nation's natural resources. A national biological survey of appropriate scope would be a valuable addition to the existing programs and an important component of the status and trends program.

The National Biological Survey initiated by the Department of the Interior, if of appropriate scope, will assist in meeting this recommendation.

ORGANIZING ENVIRONMENTAL INFORMATION AND MAKING IT AVAILABLE

Information is the currency of a strong environmental research program that will inform the best policies and practices for protecting, restoring, and managing the nation's resources. New technological developments have increased our ability to collect and manage information. Many agencies contribute to the ever-increasing amount of information, and other individuals and institutions contribute to archiving data. There must be a system to organize and handle this information and make it available for the integrated use of the biological, physical, social, and engineering sciences.

> We recommend the establishment of a *National Environmental Data and Information System* to be coordinated by the National Environmental Council and conducted by the federal agencies with the best available technology to collect and make available and easily accessible a wide range of environmental data from the biological, physical, social, and engineering sciences.

ENVIRONMENTAL EDUCATION AND INFORMATION

The importance of developing sustainable environmental systems for future generations and thus for making the best decisions for protecting, restoring, and managing these resources is so great that both this generation and the coming ones must be informed. Educational opportunities must be provided at every level from kindergarten to graduate school. Citizens who know more about the environment can play an important role in solving environmental problems. Moreover, the nation's environmental research effort will require a supply of sophisticated scientists trained in disciplinary and interdisciplinary science.

> We recommend that programs be established, and present ones expanded, for educating the next generation of environmental scientists and engineers and increasing understanding of environmental issues in the general population and that information on environmental matters be built into educational programs.

ORGANIZATIONAL CHANGES

Implementation of the cultural changes is of paramount importance but will require organizational changes and innovations in how the nation's environmental program is managed. The committee has considered four frameworks ranging from relatively minor to major change for enhancing the organization of environmental research and for ensuring that the best science is used in forming decisions and policies. Framework A (current agency structure with enhancements) preserves in large part the identity and functions of existing agencies but adds a few new offices that are essential to put the critical cultural changes into effect. Framework B is the proposal of the independent Committee for the National Institute for the Environment to create such an institute. Framework C is a different institute as visualized by our committee–a National Institute for Environmental Research. Framework D is a Department of the Environment.

> The committee recommends that, at a minimum, Framework A (current agency structure with enhancements) be implemented. If the nation is to make major improvements in the quality and strength of its environmental research programs, we urge that the Department of the Environment described in Framework D be established.

FRAMEWORK A

Framework A conserves the identity and functions of existing agencies. Added, when essential, are new offices to perform functions absent in the current organization but required to implement the cultural changes that the committee has recommended. With refinements and strengthening in the individual federal agencies' programs and with additional efforts devoted to interagency coordination, improvements can be made in the nation's environmental research program to help it to meet the needs of the future.

Although Framework A calls for a minimum of *organizational* change, it is imperative that the *cultural* changes recommended above be instituted if the nation is to improve its ability to address pressing environmental problems. The cultural changes provide for a National Environmental Plan as a road map for the organization of environmental programs and coordination of the use of the road map through leadership at the highest levels of government by the National Environmental Council. The research directions of protection, restoration, and management are specified, and an approach calling for fundamental research is endorsed. Essential programs for information collection (the National Environmental Data and Information System) and a National Environmental Status and Trends Program are identified. Means to assess data to develop policy options and to convey these options to decision-markers are described among the cultural changes.

Mission-oriented agencies and other entities that support and perform research have special roles to play. They are called on to cooperate in focusing on the research directions specified above, to perform research that contributes to the understanding of the environment while continuing to fulfill their own missions, to establish educational programs to train scientists and to increase public understanding of environmental matters, and to increase support of environmental science and engineering programs. The unique contribution of the National Science Foundation to basic research in a wide variety of environmental sciences is recognized, and its important role should be recognized by the provision of substantial additional funding for its programs in support of environmental research.

FRAMEWORK D

Framework D is a Department of the Environment. It is important to note that the department we recommend includes the Environmental Protection Agency (EPA) but would *not* be created by elevation of EPA to cabinet level. Rather, the recommended department would have a character derived from the research orientation of NOAA and the strong and varied research and data-management programs of all the agencies to be included in the department–NOAA, EPA, USGS, and parts of the National Aeronautics and Space Administration (NASA). Furthermore, although our suggested department would have a regulatory function, this activity would be clearly separated from the research and operational functions.

As this report is being completed, Congress is considering legislation to elevate EPA to cabinet rank. We believe that the creation of a Department of the Environment is an appropriate and long-overdue move but that, from the standpoint of environmental research, more should be done than simply elevating EPA to cabinet level. We believe that the research-oriented department we recommend is closer to what is required to improve environmental research. If EPA (as a department) is to play a more central role, it must be successful in implementing changes suggested in its own report, *Safeguarding the Future: Credible Science, Credible Decisions*, and the cultural changes recommended in this report. Implementation of these recommendations would substantially improve the science base at the agency and increase its credibility. The committee believes that the many laws enforced and regulations promulgated by EPA dominate the attention and budgetary decisions of the agency's personnel and make difficult the development of high-quality research programs. Steps should be taken to separate the research and regulatory functions within EPA so that the research program can grow to provide the necessary science base on which to justify rules and regulations.

The department described in Framework D would have research, regulatory, and operational arms and would have wide-ranging responsibilities in protection and restoration and in innovation for management of natural resources.

With coordination overseen by the National Environmental Council as a major implementer of the National Environmental Plan, the department would take the lead in and be the natural home for support of training and facilities for environmental research, cooperation with the Department of the Interior for the development and management of a National Biological Survey, public information and education, management of the status and trends program, information collection and management, cooperative efforts with state and local environmental organizations, and cooperation with international environmental research organizations and development of U.S. positions for international agreements. It would be responsible for implementing all the cultural changes recommended in this report.

As head of a cabinet-level department, the secretary would have entree to national policy discussions and would serve as a senior member in National Environmental Council coordinating activities.

NOAA, USGS, EPA, and parts of NASA would become parts of the Department of the Environment. Coordination with research in other agencies–such as the Department of Agriculture, Department of Defense, Department of Energy, and Department of the Interior–would be effected through the National Environmental Council and ensure broad coverage of all environmental disciplines. The operational functions of agencies combined in the new department would continue under the new auspices, for example, the weather- and climate-forecasting function of NOAA and the mapping function of USGS.

The regulatory functions of EPA and NOAA would become parts of the department. Those responsible for regulatory decisions would be able to use the knowledge derived from the department's research, monitoring, and assessment activities to inform their decisions. Conversely, the regulatory branch of the department would advise the secretary about research required to perform and improve the department's regulatory function. The regulatory function would be administratively separate from the research functions of the department.

Each of the agencies involved in land management engages in protection and restoration activities, including research. These include the Bureau of Land Management, the Forest Service, the Fish and Wildlife Service, the National Park Service, the Department of Defense, and other agencies. The programs of these agencies would need to be coordinated with the work of the Department of the Environment.

The Environmental Assessment Center described earlier would not be part of the department. Rather, it would be free-standing and draw on the information resources of the department and other agencies, such as those involved with human-health aspects of the environmental sciences, so that assessments and policy formation could take into account all information from the various centers of environmental science, regulation, and management. Assessment and policy formation can be effective only if they consider human health, economic, and behavioral aspects of the issue to be dealt with, as well as the natural-science and engineering aspects.

The elevation of EPA to cabinet level and the efforts of the Department of the Interior to play a greater role in research on the environment (as evidenced by Secretary of the Interior Babbitt's initiative for a National Biological Survey) can be steps forward. If the cultural changes that we suggest in this report are integrated into the plans and actions of the Department of the Environment (created by elevation of EPA) and the Department of the Interior, we believe that the nation's environmental research program will be enhanced vastly.

FRAMEWORKS B AND C

Framework B, the National Institute for the Environment (NIE) as proposed by the Committee for the NIE, is based on ideas that converge with our own, and we are favorably impressed with many aspects of the proposal.

The plan is a credible and effective view of a means to organize environmental research. It would enhance the nation's ability to perform environmental research and increase knowledge that will contribute to the solution of environmental problems.

We believe that NIE, because it would be a new agency that complemented but not encompass existing agency programs, could, if not carefully monitored, duplicate the roles and missions of existing agencies and engender "turf battles" as it competed for funds and programs with the existing agencies. We believe that the creation of NIE would improve the nation's environmental research effort but does not go far enough to solve all the problems in environmental research that we have identified.

Framework C is this committee's concept of a National Institute for Environmental Research that encompasses research programs of EPA, NOAA, USGS, and other agencies, rather than creating new and potentially duplicate programs. Again, after due consideration, the committee believes that the institute described in Framework C does not go far enough to solve all the problems in environmental research that we have described.

COSTS AND OTHER FACTORS

The costs of implementing the cultural and organizational changes that we recommend are not limited to the expenditure of dollars. Political costs and the costs of organizational disruption also come into play. Congressional jurisdiction over agencies is already cumbersome and could be further complicated by organizational changes. Reorganization of government agencies to bring similar activities into closer relationship does not always ensure good coordination. When EPA was created in 1970, the air office was moved from the Public Health Service, the water office from the Department of the Interior, and the pesticides office from the Department of Agriculture. The 1970 executive order that created EPA emphasized the need to integrate environmental actions and to consider the environment as a system. Yet, after more than two decades, the various offices within EPA continue to be fragmented. Separate statutes, separate Congressional oversight subcommittees, and separate cultures among EPA's various programs have persisted. The problems that might result from even more massive transfers of activities from other agencies to create a new structure must be considered carefully.

Regarding dollar costs, implementation of Framework D would obviously be more expensive than implementation of Framework A in the short term but could be less expensive in the long term—especially if redundancies in agency work can be identified and eliminated. Although the committee has not addressed budgetary matters specifically, it believes that expenditures for environmental research should be increased for all agency programs.

The cost-benefit relationships of making the changes that we recommend can be suggested but not quantified with precision. It has been estimated that many billions of dollars will be expended on environmental cleanup. The time and monetary costs of litigation, often engendered by the lack of adequate information to substantiate regulatory decisions, are large. The potential is great for economic gains from a research focus on innovation in environmental technology. The products of such research could be a major contributor to U.S. international trade while helping to remedy environmental problems.

If the changes that we recommend lead to better environmental research and better decisions about the environment, the return on the investment will be large.

1

INTRODUCTION

ORIGIN, SCOPE, AND ORGANIZATION OF THE REPORT

The Committee on Environmental Research was formed in response to Congressional resolutions calling on the National Research Council of the National Academy of Sciences to examine the performance and organization of federal environmental research. The resolutions were prompted by the work of the independent group organized as the Committee for the National Institute (originally Institutes) for the Environment. Before the study began, the National Research Council and the sponsors arranged to broaden the charge so that the committee would consider appropriate ways to organize environmental research that would *include* consideration of the National Institute for the Environment, but not be limited to that option.

The charge to our committee follows the legislative resolution that led to our creation:

> The study committee will review existing federal programs for the support of environmental research and training, and examine ways to improve these programs, including proposals to establish a National Institutes for the Environment. It may, if appropriate, recommend actions by the federal government that would improve the science base in environmental protection and resource management.
>
> In carrying out this charge, the study Committee will:

(a) assess the status of environmental research in the U.S., including current research and training activities, needs, funding and trends;
(b) examine ways to improve, if needed, federal intramural programs and extramural funding for environmental research and

training, including proposals to establish a National Institutes for the Environment (NIE);

(c) address the development and funding of institutional mechanisms to support the full range of research, training and education needed to increase the science base in the environmental regulatory process; and

(d) examine how the results of environmental research are used to inform environmental policy decisions made by EPA (Environmental Protection Agency) and other federal agencies with missions that affect environmental quality and natural resources.

If, in the course of the study, other critical issues arise the committee will consider them in an appropriate manner.

In this report, Chapter 2 provides a perspective on environmental problems in the nation and world. Chapter 3 assesses the strengths and weaknesses of current environmental research programs. Chapter 4 describes the desirable characteristics of an environmental research program that would lead to effective organization of research, training, and education. Chapters 3 and 4 contain commentary on issues mentioned in the charge, such as the balance of intramural and extramural funding of environmental research and the means for using the scientific findings of environmental research to inform environmental policy decisions. Chapter 5 uses the needs identified in Chapter 3 and the desirable characteristics described in Chapter 4 to construct a series of recommendations for changing the culture for the performance of environmental research and for organizing it within the federal government.

Appendixes contain essential information that guided the deliberations of the committee. Appendix A describes current environmental research programs in the federal agencies and provides data on trends in financial support of the research. Appendix B deals with biodiversity and its loss and expands on a briefer discussion in Chapter 2. Appendix C reproduces the proposal by the Committee for the National Institute for the Environment.

OTHER REPORTS

Concern for the environment and for environmental research has been reflected in several nearly coincident studies of different aspects of the field. A 1992 report of the American Association for the Advancement of Science, *Federal Funding for Environmental R&D* (Gramp et al. 1992), analyzes the federal budget for environmental research support by categories and by agency. It also describes and discusses each agency's programs. The report gives an excellent view of what the federal government is doing in environmental research, and we have relied on it for our own examination of federal programs and for financial information concerning the federal environmental programs described in Appendix A.

NATIONAL COMMISSION ON THE ENVIRONMENT: CHOOSING A SUSTAINABLE FUTURE

This report (Train, 1992) deals primarily with larger issues of environmental policy, prevention of pollution, and sustainable economic development and to only a small extent with organizing the federal government for environmental research. Many far-reaching recommendations focus on tax incentives and disincentives to reduce pollution, on management of subsidies to reduce water consumption, and on equity-citizen issues.

Regarding government organization that bears on environmental research, the commission proposes:

- That Congress enact legislation providing for a National Environmental Strategy.
- That a Department of the Environment be established and that it formulate and oversee the National Environmental Strategy. This recommendation goes beyond elevation of EPA to departmental status. The proposed department would include offices devoted to the environmental problems of agriculture, transportation, energy, and other major sectors. The department would take responsibility for expansion of environmental research and for improvements in monitoring. Research would be protected from regulatory functions in the department.
- That the Council on Environmental Quality (CEQ) be strengthened and play a major role in formulating the national strategy. It should set 5- and 10-year environmental-quality goals.
- That the department include a Center of Environmental Statistics.

CARNEGIE COMMISSION ON SCIENCE, TECHNOLOGY, AND GOVERNMENT: ENVIRONMENTALRESEARCH AND DEVELOPMENT: STRENGTHENING THE FEDERAL INFRASTRUCTURE

This report seeks to strengthen environmental research by building on and coordinating existing organizational structure. Major recommendations include (Carnegie, 1992a):

- That the Office of Environmental Quality (OEQ), working with the Office of Science and Technology Policy (OSTP), have the primary role in coordination of environmental research.
- That an Institute of Environmental Assessment, reporting to CEQ, be established to assess natural-science data and evaluate them in the context of economic, social, and political considerations to aid in developing environmental and risk-related policies.
- That a long-term program of environmental monitoring be undertaken with an eye to bringing all federal monitoring R&D efforts into a common policy framework.
- That EPA have a major research role and that its laboratory system be consolidated into a smaller number of laboratories. EPA should establish six environmental research institutes associated with academic institutions with research support (each with a $10-15 million annual research budget) greater than that provided for current EPA environmental research centers.
- That the U.S. Geological Survey and the National Oceanic and Atmospheric Administration be joined to form a U.S. Environmental Monitoring Agency.
- That a National Center for Environmental Information be established.
- That an interagency Environmental Technologies Program be initiated.
- That mission agencies and the national laboratories be expanded and their research coordinated.
- That international cooperation and ties between federal agencies and nongovernment organizations be strengthened.
- That the environmental intellectual base be strengthened by substantial expansion of National Science Foundation programs in policy and in both interdisciplinary and disciplinary research.
- That education in all relevant fields be improved.

COMMITTEE FOR THE NATIONAL INSTITUTE FOR THE ENVIRONMENT

Part of the charge to our committee was to consider the establishment of a National Institute for the Environment as a means to improve environmental research. We present the proposal from the Committee for the National Institute for the Environment (CNIE) in the detail with which it was made available to this National Research Council committee at our last meeting in January 1993. The CNIE proposal continues to evolve, and its latest form should be consulted. We have included the CNIE proposal among the frameworks we have considered for the organization of environmental research in Chapter 5, as called for in our charge.

At the end of Chapter 5, we compare the recommendations of our report with those of the above reports and comment also on the pending legislation to elevate the EPA to cabinet status.

RECENT NATIONAL EVENTS

As this committee concluded its work, a new federal administration was actively proposing and implementing far-reaching changes in the organization of environmental research and policy. President Clinton moved almost immediately after he took office to abolish the CEQ and to establish in its place the White House Office of Environmental Policy to integrate environmental considerations into all aspects of decision-making by the Administration. Bills to elevate the EPA to cabinet level were introduced into the House of Representatives and Senate, and they moved ahead rapidly into the legislative process. Secretary of the Interior Bruce Babbitt has taken steps to reorganize environmental research, including creation of a National Biological Survey, in his department; another committee of the Research Council has been formed to advise the Department of the Interior in this regard. As these developments proceed in the months ahead, we hope that our report will inform decisions and illuminate implementation of actions already taken.

2

PERSPECTIVE

OUR ENVIRONMENTAL PROBLEMS ARE SERIOUS

Our planet has always changed, continuously by geological and evolutionary processes and sometimes suddenly by astronomical cataclysm. Now, there is change from another cause, and it appears to be accelerating and creating severe problems for us. That cause is a single biological species: *Homo sapiens*. Several examples will illustrate the severity and complexity of the problems.

- *Population Growth Is a Driving Force*. Today's human population is more than 5 billion. It will probably reach 8.5 billion by 2025 and level off at 13 billion or more, probably not until the middle of the next century. Population growth has been accompanied by a more rapid increase in the use of natural resources and the production of environmental pollutants. We have converted about 11% of the earth's land area and more than 90% of the most productive habitats, such as prairies and river valleys, to agricultural use. We exploit much of the remaining land, as well as coastal waters and lakes, to harvest natural resources. We are using about one-third of the solar energy fixed by plants, and the fraction is growing (Vitousek et al., 1986).

Humans depend on various organisms in the environment for their survival. Those organisms provide oxygen, food, fuel, and fiber; mediate floods; affect climate; contribute to soil formation; fertilize flowers that produce fruits; increase soil fertility; and break down pollutants. These "environmental services" do more than ensure survival; they improve the quality of human life. Many environmental services (and threats to them) respect no political boundaries, can operate at very large scales, and are often affected by human activities in unintended ways.

Dwindling world food stockpiles in the early 1970s helped stimulate the application of new agricultural technologies to increase food production; this response has been called the "Green Revolution." Within a decade, the improved crops, irrigation, fertilizer, pest-control chemicals, and other tools of the Green Revolution had provided some answers to the global struggle for food. World population exceeded 4.5 billion in the early 1980s, but the worldwide per capita harvest of grain peaked in 1984. Now, in the early 1990s, the decline of global food stockpiles is causing concern again. There are many questions about how successful we will be in ensuring that the food supply will be adequate for the growing world population.

The continued rapid growth of cities raises questions about the loss of arable farmland to urban spread, about the effects of municipal wastes and industrial pollutants on land and water resources, and about competing demands on and overuse of water supplies. Irrigation can create arable land and increase food production in the short term, but it entails potential long-term damaging effects related to salt buildup and water-logged soils. Similarly, increased use of fertilizer can lead to runoff of mineral nutrients that can overload and alter the ecosystems that receive them. The continuing evolution of resistance to pesticides raises questions about the future effectiveness of current methods to prevent crop losses.

As developing and more densely populated countries improve their economy and standard of living, they seek more animal products in their diet, and that increases demands on the world's grain supplies for animal feeds. More widespread and intensive cultivation with more specialized and productive genetic strains is displacing traditional varieties of crops that had evolved and adapted to the challenges of particular ecosystems around the world. We do not know whether the more productive genetic strains will prove more vulnerable to environmental shifts and pressures or whether the biological and genetic diversity present in native varieties can be captured and preserved. Many potential environmental consequences must be understood and managed or blindly suffered as land, natural resources, and ecosystems are manipulated to meet the increasing need for feed and food to support continued population growth.

- *We Are Producing Global Change*. For more than 99% of the time humans have inhabited the earth, their numbers and activities have been too small to affect more than their immediate, local environment. In the last few decades, however, humans have become a global force in modifying the atmosphere, oceans, land surfaces, and biota-a force that many believe is out of control. Human activities are measurably changing the composition of the atmosphere, adding gases (such as carbon dioxide and methane) that alter the radiative balance of the planet and adding other gases (which contain chlorine) that destroy the life-protecting ozone layer in the stratosphere. Human activities have destroyed vast tracts of tropical forests and agriculturally productive land. They have caused serious degradation of some of the largest sources of fresh water.

Collectively, human-induced changes in the environment are referred to as global change. It resembles an uncontrolled experiment on a global scale, whose outcome is unpredictable and might be life-threatening to many species, including humans. To observe, understand, predict, and—where appropriate—reverse the potentially dangerous aspects of global change requires an unprecedented international effort involving scientists in many disciplines, leaders of public and private sectors, and all the peoples of the world.

- *We Have Enormous Waste Problems*. A good example of our toxic-waste problem is that of the halogenated hydrocarbons (e.g., dioxin and polychlorinated biphenyls, PCBs). Between about 1947 and 1975, over 500,000 lb of PCBs was discharged into the Hudson River near Ft. Edward, New York. PCBs had been developed as nonconductive coolants for use in electrical transformers and condensers. Ironically, at the time of their development, PCBs were considered an important environmental advance over earlier materials, because they were much more fire-resistant. In 1968, accidental consumption of PCB-contaminated fish oil in Japan led to the observation of a strong connection between exposure to PCBs and chloracne, a serious skin malady. Tests in the United States indicated that PCB caused cancer in laboratory animals. Natural biodegradation of PCBs in the environment appeared negligible. Legislation to limit PCBs in foods was passed in 1970; manufacture of the chemicals later stopped, and the nationwide removal and destruction of PCBs were initiated.

About 1970, it was discovered that PCBs had contaminated fish in the Hudson River after breaching of the dam at Ft. Edward. Immediate dredging of the PCB-contaminated sediment in the upper Hudson River could probably have removed about 90% of the PCBs for perhaps $30 million. However, uncertainty about the environmental consequences of dredging delayed the dredging decision. Natural hydrological characteristics of the watershed caused substantial movement in the sediment deposits, which resulted in higher and higher cleanup costs (up to $250 million) for smaller quantities of PCBs (perhaps 30%). The many state and federal agencies with responsibilities for health, water supply, fishing, environmental protection, river transportation, etc., have each aggressively and persuasively pursued their (sometimes overlapping) legislative obligations but have never agreed on what actions to take. The PCBs are still in the river, although natural dilution, sediment distribution, clean sediment covering contaminated sediment, volatilization, and biodegradation have resulted in reduced PCB concentration in the fish populations (but fishing is still restricted).

The issues related to the PCB problem cross many of the conventional disciplinary boundaries, such as ecology, chemistry, biochemistry, geology, hydrology, sedimentology, and medicine. (As more knowledge of the health impacts of PCBs has become available, some scientists have begun to believe that they are less toxic than suspected.) They cross the three media: land (sediment), water, and air (volatilization of PCBs). They are multijurisdictional among and within federal, state, and municipal agencies. And they involve many aspects of the engineering of dredging, treatment, and disposal; economics; social science; and public policy. There is little established consensus on how clean is clean enough. The PCB problem operates on many physical scales: the molecular scale for sorption and biodegradation; the regional scale, which affects 175 miles of the Hudson River, the New York Bight, and Long Island Sound; and the global scale, over which volatile PCBs are dispersed.

- *Biological Species Are Becoming Extinct*. Human activity threatens to cause the extinction of hundreds of thousands of species during the next century unless strong preventive action is taken. Although we do not know why frog populations are declining and even disappearing all over the world or why migrating bird populations in the eastern United States have declined at rates as high as 5% per year over the last 15 years, enough is known to make human activity a prime suspect. More research will be needed to identify the causes with confidence.

If the human population continues to grow and per capita resource use rises as living standards increase in developing countries, the proportion of terrestrial biological production co-opted for human use will continue to rise. Biological production is co-opted primarily by converting species-rich environments into intensively managed areas in which a few species of commercial value are favored at the expense of most other species. Habitat destruction is believed to be contributing to the endangerment of about three-fourths of the species whose continued existence is threatened.

Another important cause of species extinctions is overexploitation driven by prospects of economic gain (see, e.g., Ludwig et al., 1993). The prospects include lucrative specialty markets (e.g., in sperm oil, alligator skins, and ivory) and harvest for food, fuel, and fiber. Introduced species have been responsible for the extinction of many native species, particularly on oceanic islands.

Extinction of large numbers of species is a concern for economic, aesthetic, and moral reasons. Humanity depends on the diversity of living organisms for food, fiber, construction materials, medicines, and drugs. Genes from wild organisms are incorporated into domesticated species to improve production and to provide disease resistance and pest resistance. In fact, natural biotic resources are the raw materials for the biotechnology industry. The world's ecosystems provide the important services already discussed. All these services depend, in part, on the richness of species.

Not only does the loss of species diminish the benefits we derive from nature; the loss is irreversible. Polluted environments can be cleaned up and degraded systems restored, but extinction of a species is permanent.

- *Large Sums Are Spent on Environmental Regulation and Management* . An enormous amount of money is spent on environmental regulation and management, particularly in the United States. No one knows precisely how much damage to public health and the environment is prevented by these regulatory and management activities, but it must be enormous as well. To what degree is the money being well spent, how much damage is it preventing, and how could the money be spent better? In fiscal year 1991, the federal government spent approximately $18.6 billion for environmental protection and management, and state and local governments spent an estimated $28.4 billion on sewerage and solid-waste management (CEQ, 1991). Environmental regulations cost an estimated $115 billion in 1990, or about 2% of the GNP; compliance with the Clean Air Act alone costs approximately $32 billion a year (Abelson, 1993; CEQ, 1991; EPA, 1990a). Other estimates of similar costs—also measured in billions of dollars—are provided in the 1992 Office of Technology Assessment report *Trade and Environment: Conflicts and Opportunities*. The cleanup of all the major hazardous-waste sites in the United States would cost an estimated $750-1,000 billion over the next 30 years (Russell et al., 1991). Nine Ohio cities estimated the cost of compliance with environmental regulations at $3 billion over the period 1992-2001 (Ohio, 1992).

Although environmental regulation and management have measurably and noticeably improved many aspects of environmental quality, there is not enough money in the U.S. economy to eliminate environmental risks. Yet some risks are clearly serious. Where should the effort and money be spent to be most effective? As an example of the need for such research, a recent National Research Council report demonstrated that the Environmental Protection Agency's multibillion-dollar program to control tropospheric ozone might have been seriously misdirected because of the failure to monitor and verify estimated emissions of ozone precursors and the reductions in those emissions that were predicted to occur as the result of regulatory controls (NRC, 1992a).

WE HAVE LEARNED MANY LESSONS ABOUT ENVIRONMENTAL PROBLEMS

The physical, chemical, and biological systems that determine how the environment functions are individually complex, and they interact with one another in complex ways. The problems of human effects on ecosystems are essentially systems problems that involve interactions among many biological, physical, chemical, and social components. The results of the interactions are themselves complex and unpredictable, and the underlying causes of ecosystem change, although they might be simple to understand, are almost always multiple.

The problems are fundamentally nonlinear in causation (i.e., effect is not proportional to cause) and demonstrate multiple stable states and discontinuous behavior in both time and space. They are increasingly caused by slow changes that reflect decades-long accumulations of human influences on air and the oceans and decades- to centuries-long transformations of landscapes. Those slow changes cause sudden changes in environmental variables that directly affect people's health, productivity of renewable resources, and vitality of societies. Examples of such problems are global climate change and the accelerating loss of biological diversity. The loss of the last 1,000 hectares of tropical forest would cause a greater proportional decline in biological diversity than would the loss of the first 1,000 hectares.

Equilibrium-based concepts and the models and policies based on them are often inadequate. They result in policies that are unlikely to be successful, because they rely exclusively on social and economic adaptations to smoothly changing and reversible conditions. We must understand the interactions between slow and fast phenomena, and monitoring must focus on long-term changes in structural variables. Political pressures are for quick solutions, often in the face of incomplete and inadequate understanding, that can lead to more unforgiving conditions for later decisions, more fragile natural systems, and more dependent and distrustful citizens.

Environmental problems are now fundamentally cross-scale; i.e., they operate in both space and time. The spatial and temporal connections are becoming so important that problems cannot be dealt with as though their causes were operating on only one scale. National environmental problems are more and more likely to have their sources both at home and half a world away—witness global climate change, loss of biodiversity, and the biological, social, and economic effects of the increasing human population. Natural planetary processes mediating these interactions are coupling with the human economic and trade linkages that have evolved among nations since World War II.

WE MUST UNDERSTAND COMPLEX ENVIRONMENTAL SYSTEMS

Understanding the environment—how it works and how and why it changes—is essential for anticipating environmental hazards, for learning to live with long-term changes, for preventing undesirable changes, and for remediating and restoring damaged and degraded environments to ecological productivity. Prudent public policy dictates that we understand environmental systems well enough to assess the impacts of societal development on the resources that we depend on now and our children will depend on in the future.

Environmental research is the means by which we can develop the necessary understanding of complex environmental problems. The task is a daunting one and is fraught with difficulty. The difficulty arises from the inherent complexity of the systems, the diversity of their components, the need for interdisciplinary research, and the fact that many environmental services and the threats to them respect no political boundaries and have very large scales.

Environmental research has produced great societal and economic benefits. Investment in agricultural research has been estimated to yield a return of 15-40% per year in improved human abilities to harvest food and fiber from land under cultivation. The engineering studies that made it possible to build sewage collection and treatment facilities opened the path to drastic decreases in waterborne infectious disease. Without that advance in water-pollution control, it would not be possible for such large populations to live in cities so relatively free of disease. Advances in the understanding of weather patterns—such as the El Niño-Southern Oscillation (ENSO), which affects weather in the Pacific Ocean and, indirectly, throughout the world—have improved the abilities of human societies to predict and to organize responses to seasonal climatic changes that cause failure of food crops and threaten large-scale famine. Fundamental understanding of ENSO yields benefits each time El Niño occurs, which is more than once per decade.

Rachel Carson's description of the accumulation of DDT in predatory birds in her book *Silent Spring* (Carson, 1962) awakened America to the problems associated with the accumulation of chemicals in the environment. Ironically, DDT and other pesticides were introduced to solve environmental problems associated with the loss of agricultural products to pests and the transmission of disease among humans. DDT and its relatives seemed ideal because they eliminated many different pests and their persistence made less-frequent application feasible. However, these very properties were the source of unexpected and eventually serious environmental problems. Research has helped us to understand why resistance to pesticides evolves rapidly and why agriculturally beneficial predators of crop pests might be affected more adversely than the pests we wish to control. This understanding has helped us to develop a new approach known as integrated pest management.

Although not all research brings large economic or societal benefits, it is clear that better understanding of the natural world and its responses to human activities has resulted in enormous gains in human welfare over the last century, and such payoffs are needed more than ever before.

WE HAVE NEW TOOLS

Daunting as the research task is, we have new tools that give us new advantages. Major advances in knowledge and methods make it possible to identify the dimensions of current environmental problems and to develop a new generation of research to deal with them. For example, in the last 20 years we have been able to reconstruct the composition of the earth's atmosphere over the preceding 160,000 years (through analysis of the gases trapped in Antarctic glaciers) and to correlate changes in it with climate changes. As a consequence, we can now say with some assurance that the present concentration of carbon dioxide in our atmosphere is at least as high as it has been at any time in the last 160,000 years.

The revolutionary advances in molecular biology not only have provided ways of improving human health and agricultural productivity, but also are yielding techniques that allow ecologists, systematists, and other biologists to unravel affinities in related groups of species and individuals. These techniques are transforming the evolutionary, ecological, and conservation sciences. Satellite imagery and other remote-sensing technology and geographical information systems are now routinely available to analyze patterns on a variety of scales. Computer advances, toward both portable and powerful large and parallel machines, have yielded ways to visualize complexity in both space and time.

These tools give us a picture of discontinuous behavior, of multiple stable states, and of interactions between slow processes that accumulate natural resources and fast processes that mediate ecological goods and services. Not only can we characterize the problems, but we now have the concepts and methods to begin to deal with them.

WE NEED NEW ORGANIZATIONAL ARRANGEMENTS FOR ENVIRONMENTAL RESEARCH

American environmental agencies and programs were created largely in the 1970s. The nature and scope of environmental problems have since changed dramatically. The human population has increased by half, and many of the issues that dominate today's environmental agenda were not widely perceived as urgent in the 1970s. In the 1970s, the degree of damage that we could do to the earth's ozone shield was not fully recognized. We were aware that a few species in the country were in danger of becoming extinct if protective measures were not taken, but few expected that human activities might cause the extinction of more than a million species during the next half-century (Wilson, 1992). When the first comprehensive environmental protection laws were written, we were not aware that the continuing flow of laws and regulations to protect the environment would commit the nation to capital expenses of hundreds of billions of dollars annually and a backlog of environmental remediation costs measured in hundreds, if not thousands, of billions of dollars.

It is essential that new information be reflected in revisions of environmental policies. Furthermore, if we are to sustain the current environment and improve it where it is unsatisfactory, we must continue to produce new environmental knowledge so that we can better comprehend the consequences of population growth, increases in the use of natural resources, and the production of environmental pollutants.

The way in which environmental policies emerged in the federal government has strongly influenced the organization, character, and effectiveness of the research that is conducted and how it is used to solve environmental problems. The nation's environmental efforts are not organized in any comprehensive way, and fragmented efforts cannot surmount the impediments to achieving the full benefit of research, including reduction of the enormous costs outlined above. Some of the reasons are described below.

- *Most federal environmental research is mission- and medium-oriented* . Government agencies can be conveniently grouped into three broad categories. The primary purpose of research agencies is to do research, that is, to collect information systematically with the aim of creating new knowledge. These agencies include the National Science Foundation (NSF), for basic science; the National Oceanic and Atmospheric Administration (NOAA), for weather and climate forecasting, study of biological marine resources, and oceanography; and the National Aeronautics and Space Administration

(NASA), for collection of information from satellites. These three research agencies account for about half the government's annual spending on environmental research.

Sector-specific agencies, responsible for broad sectors of economic activity, include much of the U.S. Department of Agriculture (USDA), the Department of Defense, the Department of Energy, the Department of Health and Human Services, and the Department of Transportation.

Finally, management agencies are responsible for more specific functions, such as regulation of activities that affect the environment and management of natural resources. These include the Environmental Protection Agency, much of the Department of the Interior, the USDA Forest Service, parts of NOAA, and the U.S. Army Corps of Engineers. Sector-specific and management agencies together account for about half the government's annual spending on environmental research. Their missions are distinctly more targeted than those of the research agencies (NSF, parts of NOAA, and NASA) that support the other half of environmental research.

Mission-oriented research (in contrast with basic research) cannot address the most important problems facing society, unless missions change in response to new knowledge and changing circumstances. Because mission-oriented research must be closely coupled to the priorities of sponsoring agencies, there is a natural tendency to attend more to the operational needs of the agencies than to the changing perception in the technical community about which problems are most important. Nor can mission-oriented research ensure that gaps in the national research agenda will be recognized and closed; indeed, mission-oriented agencies are not likely to promote a balanced research agenda at the national level, because they necessarily articulate their own agendas.

At the same time, one must recognize that mission agencies perform a necessary research function. Agencies focusing on basic research are unlikely to provide relevant information for pressing management problems that mission agencies must address.

- *Laws and organization influence approaches to research*. Existing agencies' environmental research programs are structured by agency mission, the environmental medium to be protected or used, and discipline. All three reflect specific legislative mandates to solve problems of specific concern to specific constituencies.

How laws are written and how agencies are organized make it difficult to deal with the challenge posed by environmental problems, for example, multimedia management of pollution. The policy mandates of the 1970s called for cleanup of polluted water and air and better protection of land.

Initially, improved pollution control could be carried out without concern for how the waste products of the control effort were themselves to be treated. But as air-quality concerns led to higher smokestacks to disperse localized pollutants, acid precipitation and vision-obscuring haze (often far from the source) emerged as problems. Attempts to solve those problems produced waste streams from scrubbers that had to be managed, lest they foul water or landfills. Environmental cleanup in one medium came to threaten environmental quality in other media. But the policy mandates have been slow to change, and research focusing on effective management of cross-media pollution lags.

- *Organizational "culture" can foster or impede research*. The "culture" of government agencies influences the perception of problems and the importance given to them. For example, American national parks were established in an era when simple preservation was believed sufficient to maintain the natural resources for which the parks were established. The possibility that this vision might change over the decades was not foreseen, but research in the national parks has too often had low priority and been highly fragmented (NRC, 1992b). Park managers today lack a good understanding of their resources and the threats to them.
- *There are other confounding issues*. Research findings alone might be insufficient to trigger clearly warranted regulation. For example, although national and international action came relatively soon after the Antarctic ozone hole was discovered in 1986, the scientific concerns expressed a decade earlier (Molina and Rowland, 1974) were largely ignored by governments until the hole appeared.

Many environmental problems result from human activities or are exacerbated by them, and solutions to many of those problems require changes in human behavior. Attempts to change human behavior depend on a solid understanding of why people do what they do and how they respond to various types of incentives. Lack of attention to the determinants of human behavior might be responsible, in part, for many environmental policy failures (e.g., Ludwig et al., 1993). Ecological restoration, an emerging skill in the United States and around the world, is a clear case of tight coupling between natural and human systems. Excellent scientific understanding of how and why a site is degraded is necessary but not sufficient to ensure improvement; a comparable understanding of the human institutional and behavioral contribution to the degradation is also essential.

SCIENCE BY ITSELF IS NOT ENOUGH

No matter how good the science, environmental problems cannot be solved without integrating the science with environmental policy. To accomplish that, integrative study is needed to bridge the multidisciplinary gaps and to deal with the conflicting policy goals held by varied constituencies. Research is necessary but not sufficient to solve problems. As an example, consider environmental problems that are caused by multiple widely dispersed pollution sources. Water-quality problems dominated by emissions from a small number of major point sources have been attacked with relative success, and many badly polluted waters are now fishable and swimmable. But today's leading contributor to surface-water pollution in the United States is nonpoint pollution originating from thousands of households and farms. Determining the actual contributions of these dispersed sources and developing appropriate and effective remediation procedures will be much more difficult. Solutions to such problems promise to be even more difficult to devise and implement and promise to involve large social, economic, and political adjustment. Indeed, engineering solutions are not likely to be feasible, so understanding of how to induce changes in human behavior must supplement engineering in the search for solutions to problems.

Even if scientific methods and information are available, the effort to seek or implement solutions might not be forthcoming, especially if there is residual scientific uncertainty or if the solutions are potentially costly. Organizational, political, economic, behavioral, and legal issues often need to be resolved to achieve a solution.

SUMMARY

The environmental problems we face are serious, and they are becoming more serious every year. We have poor understanding of many of the basic physical and biological interactions that cause them. Our government environmental agencies were created mostly two decades ago or earlier, and in the meantime the problems they were created to address have become more numerous and more complex. Understanding these problems is a daunting research task, but we have new tools to help us. The ways in which environmental research is organized are important, and new circumstances demand new ways. Research is essential but, by itself, is not sufficient. To solve problems, the best science must be combined with the legal, behavioral, economic, and political considerations required to provide people with opportunities to lead more secure lives, with assured futures for themselves and for their children.

3

STRENGTHS AND WEAKNESSES OF CURRENT FEDERAL ENVIRONMENTAL RESEARCH PROGRAMS

This chapter assesses the strengths and weaknesses of the current federally supported environmental research effort and evaluates its success in responding to some of the needs identified in Chapter 2. This assessment is illustrative but not comprehensive, given the large number of fields of science and engineering–such as chemistry, mathematics, water resources, and marine biology–that are important to the understanding and solution of environmental problems but that cannot be encompassed in this brief report. Appendix A describes the environmental research programs of federal agencies.

On the basis of the assessment presented here, Chapter 4 describes the desirable characteristics of a federal environmental program. Chapter 5 then proposes cultural and organizational changes to deal with the deficiencies identified here.

CREATING THE KNOWLEDGE NECESSARY TO CHARACTERIZE ENVIRONMENTAL PROBLEMSAND CHALLENGES

A body of knowledge about environmental issues must be generated to enable us to interact with the environment so that it continues to provide resources and amenities for humans and retains its functional characteristics for the benefit of future generations. This is a difficult task because the sun, atmosphere, oceans, earth, and ecological systems are all individually complex, and their interactions are even more complex.

GLOBAL ATMOSPHERIC, OCEANIC, AND EARTH SYSTEM

The atmospheric, oceanic, and terrestrial systems interact with one another and with organisms in complex ways to produce the richly varied environment that supports all life, including our own. Until recently, scientific studies have concentrated primarily on processes in each of these sectors separately because of the need to understand simpler pieces before tackling the larger system.

How Well Are We Doing?

Much is known about the earth and its space environment as a result of investigations extending over centuries. We know about the general magnitude and quality of changes in the physical environment that have occurred over the history of the planet, and we can make some projections about what might happen in the future. But our knowledge is still sparse. Although we are beginning to have some success in predicting large-scale phenomena, such as El Niño, many months in advance, we can predict local weather patterns with useful accuracy only a few days in advance. We still know little about how the oceans work–how their chemical, biological, and physical processes interact. Vast areas of the oceans remain unmeasured in any systematic way, and we have little idea of the long-term variability of marine systems. We have good observations of the surface geology of the earth, but we have only a few samples from below the surface, most of them from shallow depths. Our knowledge of the interior of the earth comes almost exclusively from indirect measurements.

New insights from research and new technology, such as accurate chemical techniques and satellite imagery, supported by powerful computers, have given us the ability to view the earth with greater comprehension. During the last two decades, the atmospheric, oceanic, and geophysical communities have developed coordinated global research programs that use the new insights and technology that are now available. Examples of such programs are the International Geophysical Year (1957-1958), the International Ocean Drilling Program (begun in 1968), the Global Atmospheric Research Program (begun in 1979), and the World Climate Research Program and International Geosphere-Biosphere Program (begun in the 1980s) (Fleagle, 1992).

The federal government has provided considerable support for research on the physical and chemical components of the global system, but good ideas for productive research outstrip the available support. Shortfalls in funding have already affected the global nature of some programs and could impair our ability to develop global data sets critical for sensing long-term trends and for testing hypotheses. Moreover, the present structure for funding science in the United States is not well organized to support U.S. contributions to international programs.

Why Are We Not Doing Better?

Global environmental research programs are costly, because they require expensive technology–such as satellites, weather stations, ships, and supercomputers–and dedicated personnel. In addition, to enable trends to be distinguished from normal environmental variability, long-term data sets are required. Such requirements make it difficult for this type of research to compete effectively for funding. Long-term monitoring inevitably appears less exciting than research designed to test new hypotheses. Only recently has the value of long-term research been recognized by the scientific community, Congress, or the funding agencies. And no federal agency has been given a mandate, accompanied by appropriate resources, to support long-term, large-scale research on the global environment.

ECOLOGY

Ecological research has the potential to make major contributions to our understanding of the ability of the environment to sustain human activities and populations of other species in the long term. Among the many themes of ecological research, five were identified as especially important by the Ecological Society of America (ESA) Sustainable Biosphere Initiative (ESA, 1991):

- Ecological causes and consequences of changes in climate, soil, water chemistry, and land-use patterns.
- Ecological determinants and consequences of biodiversity and the effects of global and regional change on biological diversity.
- Definition and detection of stress in natural and managed ecosystems.
- Restoration of damaged systems.
- Management of pests, pathogens, and disease on a sustainable basis.

How Well Are We Doing?

Ecological science is unable to provide answers to the key questions posed by ESA. Not only are the underlying processes complex, but they must be studied at different spatial and temporal scales. For example, we must be able to understand how changes in the physical environment affect individual leaves and then extrapolate what we learn to effects on whole plants, interactions among plants, and vegetation dynamics. In addition, we need to consider different species, many of which are as yet undescribed and each of which has unique responses and its own relevant scales of space and time. We need to understand how important are species differences for the behavior of larger-scale systems.

Because dominant organisms in many ecosystems, such as trees, in forests are long-lived, many important ecosystem changes are too slow for us to sense directly. Our abilities to interpret slowly-occurring cause-effect relationships are even less developed. Therefore, processes acting over decades are hidden and reside in what has been called the invisible present (Magnuson, 1990). In the invisible present, one finds the time scales of acid precipitation, the invasion of nonnative plants and animals, the introduction of synthetic chemicals, and carbon dioxide-induced climate warming. Only long-term, sustained research can reveal the slow but important changes of the invisible present, but such studies are rare. The Long-Term Ecological Research (LTER) program of the National Science Foundation (NSF) is an unusual example of a program designed to investigate long-term processes (Callahan, 1984). It is still a relatively young program, but it has already made important contributions to our understanding of responses of watersheds to disturbance, lake acidification, wood decomposition, and modeling of ecosystem processes (Franklin et al., 1990).

Why Are We Not Doing Better?

The unsatisfactory state of current ecological science reflects both the complexity of the processes it studies and the relatively low level of funding that has been allocated to ecology. Shortage of funds has resulted in intense competition between the still-needed small-scale, investigator-initiated research and large-scale, and often multi-investigator, long-term research. Until recently, computational power was insufficient to handle the complex data sets being generated by ecologists.

Ecologists traditionally have concentrated their attention on small-scale processes and have seldom continued experiments or observations for long periods. A review of ecological experiments conducted from January 1980 to January 1987 found that 50% of all studies were done on plots less than 1 m in diameter and 25% on plots less than 25 cm in diameter (Kareiva and Anderson, 1988). In addition, 40% of ecological experiments lasted less than 1 year and only 7% 5 years or more (Tilman, 1989). Large-scale and long-term experiments were often deemed too expensive relative to the resources available to support ecological research. Consequently, the field was unprepared intellectually to respond to challenges of global research. This problem is fortunately diminishing rapidly. Nonetheless, support for long-term research is still meager, and ecologists still have only modest ties with the physical scientists with whom they must interact if they are to deal effectively with regional and global problems.

BIODIVERSITY

Research on biodiversity provides basic information on the earth's biota–its taxonomy, distribution, uses for human society, management, and contribution to ecosystem services. Biodiversity has genetic, taxonomic, and ecological components (Appendix B). The study of biodiversity should do for biology what the U.S. Geological Survey (USGS) does for geology, that is, the study can provide better knowledge about biological resources and thus increase society's ability to realize economic benefits from those resources (e.g., natural-products development and tourism), improve conservation practices, and promote better appreciation of the full range of benefits that can be derived from the biological resources of the country.

Research priorities in biodiversity need to be set and continually influenced by four groups of people: users of biotic resources, those concerned with protecting it, scientists, and those responsible for setting policy (for land use, water resources, etc.). Biodiversity research requires a long-term perspective and sustained funding because the tasks of description and inventory are complex and because monitoring of trends must continue for many years to reveal useful patterns. The infrastructure elements required by research on biodiversity include museums, specimen-based databases, and data synthesis. Also critical are systematists and taxonomists qualified to identify and classify specimens, especially of the more difficult and special taxa.

The components of a successful program of biodiversity research include

- Intellectual and financial input from the users of biodiversity.
- Flow of data from generators of the data (taxonomists, conservation biologists, ecologists, ethnobiologists, and natural-products chemists) to users (agriculturalists and bioengineers).
- Inclusion of local people in research and development opportunities.
- Long-term funding of field research and monitoring.
- Financial support of maintenance of collections.

How Well Are We Doing?

The United States has only a few scattered centers of research on biodiversity. As recognized by several reports, including an Office of Technology Assessment (OTA) report commissioned by Congress (OTA, 1987) and the report of the National Commission on the Environment (NCE, 1993), there is a need for centralized research planning, for assembling and synthesizing existing information, and for making information more accessible to policy-makers. The Smithsonian Institution performs some research in biodiversity, but its programs are not centrally planned. For most biodiversity programs, there is no connection between research and policy needs and little integration between fields of study (even between ecology and systematics, both of which are performed within the same institution but largely in different laboratories). University research in biodiversity is difficult because funding cycles are too short.

There is no national data center or network for biodiversity, as there is for medicine and several physical environmental disciplines. USGS and the National Aeronautics and Space Administration conceptually include biological data in some of their plans, but they do not have the staffing or the resources to place a high priority on biodiversity data-collecting or even on building a database of databases. Several conservation organizations, state agencies, and the Fish and Wildlife Service have databases on endangered taxa and environments, but they are necessarily narrowly focused and often developed from secondary sources. One of the greatest needs for biodiversity research is to provide quality data to state agencies continuously. Research institutions are becoming overwhelmed by requests for biodiversity data and lack the resources to support their activities.

The U.S. Department of Agriculture (USDA) has a germplasm program that concentrates on wild relatives of crop plants. Collection of germplasm of plants that are not agriculturally important has little support and depends primarily on volunteer centers, such as the Center for Plant Conservation, and botanical gardens. Zoos, a few museums, and such institutions as the American Type Culture Collection (a private, not-for-profit research and culture-distribution center) hold animal and microbial germplasm. However, all have resources inadequate to cover demands made on them for research and conservation purposes.

There is potential industrial support of research on biodiversity, but the sums involved are small. Some pharmaceutical companies are engaged in prospecting for natural products. Most tropical countries receive no payment from prospecting within their boundaries, but Merck Pharmaceutical Company recently signed an agreement with Costa Rica's National Institute of Biodiversity to share in the costs of exploration for and benefits of the marketing of useful natural products; the agreement has attracted much international attention, but it is too early to evaluate the long-term potential of such arrangements.

Why Are We Not Doing Better?

The serious underfunding of biodiversity research is due, in part, to a lack of public appreciation of the importance of knowledge about biodiversity. Within the biological sciences, taxonomy and systematics have been overshadowed by the spectacular successes of molecular biology and have been crowded out of biology departments at many leading research universities. Many universities have found it difficult to continue supporting museums and herbariums during times of fiscal stringency. Therefore, although there is now increasing recognition of the importance of biodiversity research, the United States lacks a sufficient cadre of trained taxonomists, has inadequate and insufficiently curated collections, and is confronted with huge backlogs of specimens waiting to be identified or described as new species.

ENVIRONMENTAL ENGINEERING

Engineering research is needed to develop new environmental-control and pollution-prevention technologies, advances in process-engineering concepts and techniques that are pollution-free, recycling technologies, resource-conservation methods, and energy-efficient technologies. The need for research and related technological advances is important because of global population growth and the related drive to increase the developing world's standard of living. Because the costs of pollution control are projected to be high–approaching $200 million annually in the year 2000 in the United States alone–it is important to find low-cost methods of preventing or minimizing pollution (Carlin, 1990). The currently known methods are inadequate and expensive, and additional investments in research and development will return substantial economic benefits. Engineering solutions coupled with better approaches to public participation and communication might lead to increased public acceptance of environmentally benign technologies.

How Well Are We Doing?

Some critical technologies are being developed by the private sector. For example, decreasing the emission of pollutants by a process is often possible through process changes and material substitutions. Secondary pollution effects can be reduced in some industries by creating more efficient manufacturing or pollution-control technologies, which might, for example, require much less energy. If industry can capture the economic benefits of those technologies, no government incentives are needed to encourage them. However, development of new technologies is usually possible only for large companies. The aggregate of small entrepreneurs (e.g., metal platers, dry-cleaners, and farmers) generates substantial environmental pollution, but such firms individually do not have the means to undertake cost-effective research. They need a government-organized effort to create new effective, efficient, and economical pollution-prevention and pollution-control technologies. Government programs have so far been inadequate to the task. Indeed, creating incentives to develop better pollution-control technologies has received a low priority in the federal government for many years.

Dealing with hazardous materials, solid wastes, waste-treatment residues, and radioactive wastes already released into the environment will require substantial local, regional, state, and national programs. Superfund and its parallels in state governments, Department of Energy (DOE) cleanups, underground storage tanks, Resource Conservation and Recovery Act actions, and radioactive-waste disposal programs are estimated to cost thousands of billions of dollars. Not one of these problems has adequate technology to meet the needs of our nation, let alone of a growing world population. Breakthrough research is essential, if the collective costs of these programs are ultimately to be affordable.

Municipalities face serious environmental problems in dealing with human wastes, especially because higher population densities require higher levels of treatment to keep discharges within the capacities of the receiving environments. Municipalities also need better methods of detecting and treating toxic substances and nutrients. Every 2 years, the Environmental Protection Agency (EPA) publishes a list of needs for publicly owned treatment plants in the United States. The cost of those needs for the coming decade is estimated at about $100 billion. Timely research in those issues alone could save hundreds of billions of dollars' worth of pollution-control facilities over the next several decades and potentially enable local and state governments to improve environmental quality and public health at substantially lower cost.

Most of the engineering research needed to develop technologies to solve pollution problems is not being conducted. Much of the mission-oriented engineering research of federal agencies appears to be overlapping; good interagency communication is lacking, there is little peer review by outside scientists and engineers, and results are not adequately diffused to the governments, firms, and citizens most likely to use them.

Why Are We Not Doing Better?

No federal agency has a central mandate to foster pollution-control research and development of suitable control technologies. Because the United States has relied almost exclusively on a regulatory command and control approach to environmental pollution, the private sector perceives little incentive to invest in development of cleanup technologies from which a direct economic benefit appears unlikely. Therefore, the task of carrying out most pollution-prevention research has been thrust on federal agencies whose primary responsibilities are to promulgate and enforce regulations. Resources have been insufficient to address even the regulatory component of their responsibilities, and there is little money to devote to pollution prevention. In addition, in contrast with the governments of Japan and Germany, the U.S. government has little appreciation of the global market for pollution-prevention technologies.

SOCIAL SCIENCES

Although many environmental problems are the result of natural disasters, most are created by human activities. Attempts to solve the latter kind are at bottom experiments in political science, economics, psychology, and sociology. Many proposed solutions to environmental problems require changes in human behavior, and they suggest methods by which behavior can or should be changed (persuasion, economic incentives, or prohibitions). The natural environment and the activities of humans that modify it have been studied to different degrees by the social-science disciplines. We briefly summarize below their contributions to knowledge as related to environmental policy and environmental studies.

- *Geography*. Geography is in many respects the oldest environmental science, and its practitioners combine both natural-science and social-science expertise in how human activities and the natural world are organized spatially. Geographers have pioneered in studies of deforestation and other changes in land use. Geographers have invented the mapping techniques that underlie the collection of spatially organized information, and they are playing a central role in the development of spatial databases, known as Geographic Information Systems (GISs). Scholars in geography have pioneered humanistic studies of "sense of place," an interdisciplinary focus on the philosophical, historical, and psychological elements of human attachment to particular landscapes. Because geography as a discipline naturally crosses the intellectual boundaries of both the natural and the social sciences, many contributions to environmental research that have geographic components, such as regional economic models, also appear within other disciplines. The interdisciplinary character of the field might also contribute to the tendency of geography to be underrepresented in higher education–indeed, many institutions have no department of geography.
- *Economics*. The economic study of environmental and natural-resource problems is a well-established discipline with a clear framework of assumptions and methods. Research in environmental economics has made important and widespread contributions to public policy, particularly the application of cost-benefit analyses of government decision-making. These contributions have included cost-benefit analyses in support of government rule-making and decision-making and in analyses of other governments' taxation policies as they apply to taxes on atmospheric emissions. Economic studies of the role of technology in shifting the value and use of resources provide important insights into the origin and development of human uses and abuses of natural resources.
- *Decision sciences*. Two decision sciences, operations research and risk analysis, are particularly pertinent for the environmental sciences. Operations research is a formal approach for analyzing information. It has been used effectively in selecting chemicals that require further research and in selecting environmental projects to fund with a diminished overall budget.

Risk analysis is a hybrid discipline that combines the individualist framework of economics with a set of statistical tools to analyze rational choices in the face of uncertainty. Risk analysis provides a rubric within which EPA proposes to set priorities for all its regulatory and research activities. Risk analysis has been applied to human-health issues. It involves the combined use of data from many sources–such as atmospheric emission, resident population, costs of preferred control technologies, and statistical analyses–to estimate the potential impact of an exposure on human populations and to develop alternative management approaches. Ecological risk assessment, an evolving interest of several agencies, is not yet as well developed as risk assessment for human health (NRC, 1993a).

- *Political science*. Investigations of government, politics, and law are a central component of environmental research. Environmental law has emerged as a distinct specialty in law schools and in legal practice. Its research tradition has been eclectic, following both legal and substantive changes in policy as the environmental roles of government have taken shape in case law, statute, and regulation. Political science has contributed analyses of the environmental, economic, and institutional conditions under which the users of "common pool" natural resources–including water, air, land, and marine resources–are able to develop durable practices and rules for managing and sustaining those resources.
- *Sociology*. Studies of community structure and social responses to rapid change have been widely used in environmental-impact analyses, for example, to illuminate human responses to the construction of large facilities in rural areas. Sociologists have also probed the processes by which fears of environmental degradation arise. Sociological studies have emphasized the complexities of risk analysis and the ideologically loaded assumptions that underlie its theory and often its application as well. Rural sociology as a discipline forms an influential link between environmental studies and the applied social sciences related to agriculture.
- *Anthropology*. The study of humans from an ecological perspective provides an important conceptual link between social and natural sciences by dealing with how humans take part in the cycles and changes of the natural world. Although anthropological theory has not yet had a large direct influence on environmental policy, anthropological and historical analyses of societies that declined because their economies were not sustainable over the long term have shaped contemporary thinking about the purpose of having environmental policies. Anthropologists are also beginning to work with botanists and others to understand historically and prehistorically stable agricultural systems in fragile ecosystems, such as tropical forests and dry habitats.

- *Psychology*. The study of what motivates human behavior and how it can be changed–a basic concern of psychology–is central to much of environmental policy. Explicitly or implicitly, environmental laws assume the efficacy of particular methods of altering human behavior. The analysis of risk also involves applied psychology–the examination of how concerns are valued when an expensive outcome is not certain to occur. Cognitive psychologists have discovered over the last 20 years, for example, that there are systematic biases in how humans perceive probabilistic occurrences. These biases, which are likely to be a side effect of how humans manage their lives in a complex world, suggest that policies that rely on busy, underinformed people to make fine discriminations are likely to fail or even to be counterproductive.

How Well Are We Doing?

The effects of social-science research on human behavior and policy are largely indirect for two reasons: the way in which values and value conflicts enter studies of human activities and the reluctance of policy analysts and policy-makers to engage directly with the human causes of environmental problems. The physical and biological sciences spawn technological applications whose utility can be foreseen, at least in part, in the laboratory. The social sciences have shaped the conceptual ground on which human action is played out but have not necessarily provided tools and tactics to rechannel those actions. Nevertheless, the social sciences are essential as an intellectual foundation. One cannot imagine the human community without using notions like self, power, and collective interest that have been studied by social scientists. However, the fundamental concepts of the social sciences are characteristically intertwined with value premises. As a result, the basic propositions of any social science are bound to express value commitments, either implicitly or explicitly. Given the variety of human circumstances and histories, value commitments are inherently controversial. Scientific consensus lags, not because there is no applicable scientific method, but because truth in the scientific sense is not the only aspect of most social studies. Therefore, the instances in which social science has produced effective social engineering remain few, and that situation is likely to persist.

Even in the absence of social engineering, however, social science provides essential substantive information on the magnitudes and historical dynamics of population growth and migration, economic development, political behavior, and technological change–forces that shape the human imprint on the natural world in fundamental, large-scale ways. Each of these forces has been studied in different academic disciplines: population in sociology, development in economics and political science, and technological change in history and economics. Because universities and professional associations have been organized principally along departmental lines, there has usually not been a single organizational focus for assembling such information into a body of knowledge clearly identifiable as environmental social science.

Moreover, in a society that puts high value on both individual freedom and technological capability, the idea of altering human behavior to solve the collective problems of environmental quality has often seemed less acceptable than finding technological substitutes or palliatives. For that reason, the fragmentation of the universities has not been countered by environmental research in the social sciences sponsored by either government or the private sector. More recently, as such issues as changes in the constitution of the atmosphere or loss of biodiversity in tropical nations have arisen, it has become clear that global environmental problems, like the "nonpoint" problems that have defied technological cures in the United States, raise unavoidable questions about how changes in human behavior can be attained in ways that are fair and efficient. The contributions to understanding that can be realized by simply bringing together what we already know–and those who already know it–have begun to gain attention in government.

As concluded by the Committee on Human Dimensions of Global Change, there is "an almost complete mismatch between the roster of federal agencies that support research on global change and the roster of agencies with strong capabilities in social science" (NRC, 1993b, p. 232). There is a similar mismatch between the roster of federal agencies with environmental responsibilities and the roster of agencies with strong capabilities in social science. The failure to support or organize environmental social science is deeply structural.

Environmental social-science research is scattered across many agencies under many labels. There is consistent effort in agricultural economics and extension, energy-consumption surveys, use of national parks and rangelands, and social-impact assessments of government projects. But in no mission agency is such research integrated well into high-level research planning. Although it is difficult to obtain reliable numbers, because social-science research has many labels, it is doubtful that any federal mission agency devotes as much as 1% of its research budget to environmental social science. It is usually no one's job to ask such broad questions as "How can we improve methods for assessing the social, economic, and environmental consequences of environmental policies?" or "What knowledge base do we need to predict the response of industry X to new environmental incentives or regulations or to price changes for energy or other natural resources?" When good environmental social-science research is carried out, it is usually despite incentives for short-time goals and the bolstering of political agendas.

Why Are We Not Doing Better?

Many factors have resulted in chronic underinvestment in environmental social science. The inherently value-laden component of social-science research and its attendant controversies are clearly part of the problem. The agencies that most need social-science research tend to have cultures that are unreceptive to social science; social-science research has never been a central part of the mission of these agencies. Moreover, the utility of social-science research depends on informed communication between physical scientists and social scientists–an interchange that is all too rare on university campuses, let alone in federal agencies. Many aspects of environmental social-science research pertain broadly to the missions of various agencies. Thus, no agency perceives such research to be central to its particular mission. That is a good formula for activities to fall into the cracks between agencies. Because many of the topics not only cut across agency missions but also require a cumulative base of knowledge, it is perhaps not surprising that mission-oriented agencies have not been a supportive home for environmental social-science research.

ENVIRONMENTAL MONITORING

Research programs constitute only one way to understand the global environment. Also needed is a monitoring system that can provide early warnings of changes of regional and global importance. The general goal of monitoring is to provide quantitative or qualitative data to document the state of systems over time. A number of objectives are served by different types of monitoring:

- *Trend monitoring*. Measurements made at regular intervals to determine long-term trends in particular characteristics.
- *Baseline monitoring*. Measurements to determine existing conditions and to establish a database for planning and for comparison with future states of the system.
- *Implementation monitoring*. Measurements to assess whether management activities were carried out as planned or mandated.

- *Effectiveness monitoring*. Measurements designed to evaluate whether a specific management activity had or is having the desired effect.

For a monitoring program to be successful, there must be a clear definition of its purposes, what is being measured, why, and for how long. The questions to be answered or the hypotheses to be tested must be clearly stated. Oversight of the monitoring program–including planning, implementation, and evaluation phases–by scientists who are interested in the goals of the program is essential. Because trends can be detected only with long-term measurements, a monitoring program requires reliable funding, institutional stability, and continuing quality control and evaluation.

An effective and cost-effective environmental monitoring program is important, because billions of dollars are spent each year in the United States alone on environmental research and on setting and implementing environmental policies and regulations. Compliance with the Clean Air Act, the Clean Water Act, the Marine Mammal Protection Act, the Endangered Species Act, the Outer Continental Shelf Lands Act, the Coastal Zone Management Act, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and the Superfund Amendments and Reauthorization of CERCLA Act–to name only a few–has forced many businesses and consumers to spend further large amounts. Whereas it is clear that some of those expenditures represent the internalization of environmental costs (i.e., the operator, instead of society at large, pays for the cost of environmental damage), it is also clear that some of the money is being misspent or wasted. For example, a recent National Research Council (NRC) report, *Rethinking the Ozone Problem in Urban and Regional Air Pollution* (NRC, 1992a), suggests that, whereas some regulations designed to control ozone should be strengthened, others are ineffective and should be relaxed or abandoned. Many other NRC reports (e.g., *Ecological Knowledge and Environmental Problem-Solving*, 1986; *Adequacy of Environmental Information for OCS Oil and Gas Decisions: Florida and California* , 1989a; and *Managing Troubled Waters: The Role of Marine Environmental Monitoring*, 1990a) emphasize the importance of monitoring to assess the effects of projects, the effectiveness of policies and regulations, and the high costs of failing to monitor adequately.

How Well Are We Doing?

Monitoring and the institutional structures needed to support it cannot be evaluated with a single assessment, because monitoring serves a variety of purposes and the types of monitoring differ in the quality and quantity of their applications. Implementation monitoring raises no conceptual problems, but funds typically are not available to do it properly. Only a few long-term measurements of environmental processes have been established. Global measurements of sea level were begun in the nineteenth century, measurements of atmospheric concentrations of carbon dioxide in the late 1950s, and measurements of ozone concentrations in the 1980s. Those few long-term data sets have already played key roles in alerting humanity to impending serious problems.

The National Environmental Policy Act requires that environmental-impact statements (EISs) be developed for any proposed major federal action. New developments are, in effect, large-scale experiments being performed on the nation's environment. The EIS process does not take full cognizance of that fact and so does not take advantage of an opportunity to learn from the "experiment." The EIS is designed as a disclosure statement that is part of the legal process for commencing action on a project. It has become a document that provides a snapshot of current environmental conditions and projects the potential for impacts on the environment if a particular course of action is pursued. Unlike other environmental regulations that require continuous monitoring, the EIS has no required followup. As a result, no coherent body of information is being generated that can lead to a comparison of predicted environmental effects of construction and operation with actual effects. We seldom learn what effects the projects cause, and we enter the next, similar project no better informed as to the likely consequences of developments than we were previously. Fundamental changes in EIS procedures, requirements, and goals are needed to increase the rate at which we learn from these experiments, which are repeatedly performed on the environment.

Trend monitoring and baseline monitoring are chronically underfunded in the United States, and existing institutions are poorly designed to support and strengthen them. Mission-oriented agencies are repeatedly deflected by the "crisis-of-the-month" syndrome, which siphons resources away from long-term programs. Basic funding agencies, such as NSF, while paying lip service to the value of long-term monitoring, usually find imaginative, new, "pioneering" projects more exciting to support than long-term monitoring programs. The scientific panels that evaluate proposals are strongly attracted to innovative proposals.

Existing institutions have tapped to only a small extent the rich resource provided by the many concerned and talented amateurs who could usefully be incorporated into a monitoring effort. Amateur climatologists have made long-term observations of weather (temperature and precipitation) for scores of years, and these records are very valuable. Amateur bird-watchers have provided long-term data on breeding and wintering bird populations; these data are used extensively to monitor range expansions and population increases and declines. The advantages of using amateurs include great reductions in the cost of gathering data and the political capital flowing from their increased awareness of and sense of involvement in a clearly identified national program. The costs include establishment and maintenance of a complex network and the need to provide regular reports to participants to sustain their involvement.

Why Are We Not Doing Better?

Monitoring is often viewed as a pedestrian activity with little intellectual challenge. Consequently, little attention has been paid to design of monitoring programs and statistical analyses of the data they generate. Programs of baseline and trend monitoring are difficult to sustain, because they require insulation from political concerns and influences of the moment, long-term stability of funding, capacity to store and synthesize data, and an ability to communicate synthesized information regularly to users.

Several barriers to success in current monitoring programs are evident. First, the institutions with responsibilities for baseline and trend monitoring lack sufficient scientific credentials and are not well buffered against environmental and political crises. Some of them have the conflicting missions to assess environmental changes and to establish and enforce environmental regulations.

Second, current institutions carrying out monitoring activity find it difficult to attract and maintain sufficient internal expertise and to take advantage of the expertise of the broad scientific community. Wise use of intramural and extramural scientific expertise is essential, because the environmental processes and products that could be monitored are virtually infinite. Careful thought must be given to determining which information would best inform society of important environmental changes to which more detailed attention should be directed. Indeed, long-term monitoring programs should be initiated only after extensive review and evaluation to determine the feasibility, reliability, and utility of various measurements that might be made.

Third, there is a general failure to recognize the importance of monitoring, the wide variety of purposes it serves, and the necessary conditions for its functioning. Such lack of understanding of monitoring accounts for its underfunding and for the failure to establish appropriate institutions to perform it. Because this barrier is primarily an informational one, its solution requires education of appropriate decision-makers.

In addition to assembling data already collected, the monitoring of important social indicators, such as the extent and condition of land under cultivation in countries susceptible to famine, appears likely to yield useful results for both policy and basic research in the near term. As discussed above, it is important to define monitoring carefully and skeptically, because information-collection costs can mount swiftly without timely administrative review of the utility of what is being collected.

CREATING AND MANAGING INFORMATION SYSTEMS

A system must be provided for storing information, coordinating databases, analyzing information, monitoring data quality, and identifying potentially useful databases that are not yet being assembled. Such capability is necessary to avoid unnecessary duplication of efforts, ensure comparability and quality of data, assist in the massive job of synthesizing large data sets, and make information readily available to all appropriate users. All too often, data sets are collected at great expense and then not used at all or not used to their full potential. As a consequence, environmental decisions are made without the benefit of valuable existing information that could and should inform them.

The ingredients of a good information system are the following:

- Involvement of information producers and users in the development of all aspects of the system, including design of experiments, quality control, interpretation and archiving of data, and design of systems to permit easy access to the data.
- Either a central facility connected to a network of users who can gain access to the data remotely or a distributed network.
- Definition of "community" and "individual" data sets. Those who collected the data should have some period of preferred status to analyze and publish their results, but after a reasonable time (1-2 years) the data sets should be available to the full user community.
- Standardization of formats or use of "self-describing" data sets through user-friendly software.
- A steering committee composed of knowledgeable scientists to oversee production, archiving, and use of the data.

- Quality control for the accuracy of the data.
- Availability of funds to analyze archived data and to collect new data.

How Well Are We Doing?

No coordinated system exists to store, synthesize, and distribute data in many important fields of environmental science, such as biodiversity and environmental biology (OTA, 1987). Data from many reports and environmental-impact assessments go unused. The 1987 Office of Technology Assessment report on biodiversity listed only federal sources of data and not data from other sources. Environmental biological data are housed by individual university and institute researchers. Data-sharing is often based on personal research ties. Museums and related natural-history institutions also house large data banks on identity, relationships, and distributions of organisms, but much of the information stored in collections is yet to be captured electronically. Federal-agency databases are scattered and are adapted for narrow, mission-oriented purposes. Their quality is variable and often hard to assess, and they are not readily available to extra-agency users. The Association of Ecosystem Research Centers has called for establishment of a new center for analysis of ecological data.

Why Are We Not Doing Better?

Until recently, computers were not powerful enough for scientists or teams of scientists to handle massive data sets. The capacity to do so developed much more rapidly than the institutional arrangements to facilitate collection, storage, analysis, and communication of large amounts of data in a format accessible to a broad range of users. In addition, funding agencies have given higher priority to collection of new data than to analysis and synthesis of existing data. Indeed, the task of funding synthetic work in environmental science has fallen primarily to private foundations that have moved in to fill this serious gap. Graduate students rarely can get a degree based on synthetic research. To remedy those problems, both changes in priorities and creation of centralized or coordinated facilities will be required.

SUPPORTING THE RESEARCH INFRASTRUCTURE

An infrastructure to meet continuing research needs must be developed and maintained. The complex, multidisciplinary, long-term research needed to deal effectively with current and future environmental problems and challenges requires sophisticated support structures. Many environmental research programs depend on multiple investigators who use sophisticated measuring equipment and complex mathematical models to generate massive amounts of information. If appropriate support infrastructure is not available, much of that effort will fall short of its objectives, and data collected will be poorly used.

Vital components of the support infrastructure for modern environmental science are research facilities and hardware, including laboratories, instrumentation, satellites, ships, pilot facilities, field stations, collections, computers, and computer networks; computer models; databases, information systems, and readily accessible expert systems; and training and education facilities.

How Well Are We Doing?

The nation's infrastructure and support services for environmental research are provided through many agencies and programs. For example, NSF has several programs that provide support for research equipment in response to specific proposals. DOE, the National Aeronautics and Space Administration, NOAA, and EPA all provide support in various ways, usually in connection with specific research projects. USDA, both through its experiment stations and through its experimental forests, provides infrastructure support. Thus, each agency has developed support services consistent with its mission and resources.

Why Are We Not Doing Better?

Until recently, support for environmental research has been adequate to meet demands. However, the system described above, which has served agencies reasonably well, is not keeping pace with the dramatic growth in the need for research infrastructure and support services. The current response is both quantitatively and structurally inadequate–quantitatively because the current system is not able to provide the direct support that is needed and structurally because current efforts are too fragmented. The key problem is the high rate at which environmental research has grown in response to pressing local, regional, national, and international needs. As a result, the building of infrastructure has lagged behind needs. Unlike other elements of environmental research programs we have analyzed, the importance of supporting adequate research infrastructure is widely recognized. But resources have not been committed to support development of the necessary infrastructure.

SETTING AND COORDINATING A NATIONAL ENVIRONMENTAL RESEARCH PLAN

There must be a mechanism for establishing, monitoring, and, when appropriate, modifying a national environmental research plan. Such a mechanism is necessary to establish long-term feasible goals to avoid fragmentation of effort. Today, researchers often investigate isolated components of key problems and waste scarce financial and intellectual resources by needless duplication of efforts.

Although it is easy to identify the major benefits of setting a national environmental research plan, some potentially serious pitfalls must be avoided in establishing such an agenda and the mechanisms for implementing it. First, the plan might be seen as unchanging when, in fact, it should be an evolving document subject to change as needed and open to new ideas. Second, because many environmental problems are international in scope and must be solved by cooperative efforts among nations, a U.S. national environmental research agenda must be coordinated with the environmental agendas of other nations lest fragmentation and duplication of efforts be transformed from the national to the international arena. Third, setting a national agenda must be accomplished by methods that obtain and objectively evaluate input from broad segments of the natural-science, social-science, regulatory, managerial, and environmental communities. Fourth, carrying out a national plan requires stable funding for the long-term, large-scale research that is certain to form its backbone. Such support must be provided through a deep commitment from political leaders at high levels of government.

How Well Are We Doing?

The United States lacks both a national environmental research plan and a mechanism for generating one. Each federal agency involved with environmental research has its own programs. There is some information transfer among agencies, but it is irregular, unsystematic, and not based on stable arrangements. Coordination between federal agencies and other institutions in the United States is sporadic and often adversarial. Few efforts are under way to coordinate environmental plans with those in other countries.

Why Are We Not Doing Better?

Lack of attention to a national environmental research plan appears to be the result of an absence of clear incentives for individual agencies to engage in such activities and a lack of authority to implement or enforce any plans that might be developed. In addition, the disparate mandates of the various agencies generate different priorities for environmental research goals and the means to support them. Therefore, even if stronger incentives were created, it would probably be difficult for the federal agencies to develop a plan about which they could generally agree, unless additional institutional arrangements were created.

BRINGING KNOWLEDGE AND PERSPECTIVE TO BEAR ON POLICY ISSUES

Decisions that depend on scientific judgment–and some decisions are so heavily laden with economic and political considerations that science plays only a small part–will be questioned if they are made without scientific consensus or qualified scientific judgment. When scientific consensus is missing, policy-making is difficult. Strong voices with articulate and well-structured arguments can come to opposite conclusions. Balanced views from groups of experts, including those qualified to assess policy impacts on humans, are essential.

Legislators and managers, who are constantly called on to make major decisions quickly, must be able to make the fullest possible use of existing information; that is difficult because the information necessary to predict the consequences of their decisions might not be available or complete. There must be mechanisms for conveying the best scientific information to the decision-makers.

How Well Are We Doing?

Many branches of the government have scientific advisory committees whose members represent the best scientific thought the country can provide. These bodies include the President's Council of Advisors on Science and Technology, the EPA Science Advisory Board, DOE advisory committees in particular fields, the Department of Defense's Defense Science Board, and the National Science Board, whose primary mission is to help NSF to formulate its policy. Many federal agencies have policy offices that do or contract for analyses of environmental topics to substantiate agency positions; these analyses tend to be mission-specific and not comprehensive.

Congress also has competent, nonpartisan bodies to help it to shape its legislative policies. These include OTA, the Congressional Research Service in the Library of Congress, the Congressional Budget Office, and the General Accounting Office.

NRC is a long-standing, independent body that serves government and other organizations. Its studies, usually requested by government agencies, are far-reaching investigations and evaluations of problems important for policy-making purposes.

The existing institutions and processes have contributed scientific input to policy formulation successfully. For example, the Montreal protocols regarding chlorofluorocarbons (CFCs), a 1987 international treaty on limitation of CFC release, was a successful blending of scientific research and policy formulation in the environmental field. There was an international network of informed scientists among whom scientific consensus existed, there were monitoring mechanisms for continuing assessment of the problem, scientists worked with policy-makers in formulating policy options, and scientists participated in the negotiations that led to the treaty. In another example, the ban on the use of DDT grew out of careful measurements made with historical bird's-egg collections and comparisons with thin-shelled eggs exposed to DDT. The development of policy based on this research led to the solution of a serious environmental problem.

Why Are We Not Doing Better?

Despite such positive examples, means to bring scientific knowledge to bear on environmental policy issues have lagged behind needs. That is due in large part to the fragmentation of environmental research, the absence of institutionalized processes to determine a consensus on extremely difficult and complex environmental problems, and failure to provide gateways and processes for scientists to help decision-makers to determine a course of action. Also, important policy decisions must be made in environmental fields when the science is incomplete and will be incomplete for decades to come. Inaction can exact a high price, but action is expensive and uncertain. It appears that this nation is not using its best science to determine the course of action that is economical and effective.

Science is sometimes poorly communicated. Scientists often speak a language and use professional vocabularies that are unintelligible to policy-makers. Unless scientists and policy-makers can talk together so that both understand the policy-makers' problems and to ensure that the policy-makers understand what the scientists are saying, the policy might be flawed. In the last analysis, even when there is a strong scientific consensus and good communication, other factors–such as politics, economics, and special interests–often play a greater role than science in determining policy.

ESTABLISHING APPROPRIATE EDUCATION AND TRAINING PROGRAMS

Students must be taught to deal effectively with today's environmental problems and to grapple with future problems whose nature we cannot perceive today.

How Well Are We Doing?

Disciplinary training at the nation's major universities is generally of high quality and sets an example for the rest of the world. However, few graduate or undergraduate programs of science education are educating and training students to deal with and understand today's complex environmental problems. Although a federal Environmental Education Act was passed in 1970, the funds appropriated were never adequate to achieve even a fraction of its ambitious aims. As a result, the growing popularity of environmental topics in elementary- and secondary-school curricula has been confined largely to raising awareness of environmental quality as an important question of social values and public policy. That awareness reflects the wide public support for environmental policy in recent years, even in the face of wariness toward government and higher taxes. Yet the level of understanding of citizens about the scientific concepts behind pollution, global climate change, and other environmental issues remains low. The situation is only slightly better in higher education and the professional schools. Over the last two decades, professional education, particularly in engineering and legal training, has gradually expanded its coverage of environmental topics. With notable exceptions, however, that training has not sought to characterize environmental questions in the complex, interactive fashion that we now understand as indispensable. Instead, the strong disciplinary traditions for organizing the natural and social sciences in universities actively inhibit the kinds of interdisciplinary training and experience that are required. The core of the needed interdisciplinary education includes thorough grounding in one discipline; extensive exposure to environmental physics and chemistry, evolutionary biology, and ecology; training in modes of integrative inquiry from mathematical modeling to historical analysis; and active experience with interdisciplinary projects.

The necessary key additions to traditional programs are experience in methods to integrate knowledge, experience in interdisciplinary research, and exposure to ways of dealing with interrelationships across scales in time and space. This requires training in and use of computer-based techniques of modeling and visualization and exposure to nonlinear mathematics within a program that includes field ecology, evolutionary theory, systematics, environmental restoration, and environmental policy.

Why Are We Not Doing Better?

Until recently, graduate science programs in universities were geared to producing young professors to staff rapidly expanding university departments nationwide. In fields in which graduate students were trained for employment outside academe, such as geology, clearly defined career tracks required and made effective use of disciplinary skills. There was little need for the type of training just described, and professional recognition was accorded to single-discipline scientists. Stability in the presence of rapid and often fickle social change has been one of the most important characteristics of universities; it has enabled them to analyze and interpret society in a somewhat detached manner. Not surprisingly, universities resist pressures to be too "relevant," believing, instead, that solid training in the traditional disciplines is the best preparation for an uncertain future. Providing the type of interdisciplinary training that we advocate without weakening the strong disciplinary bases that must contribute importantly to such programs is not easy. Because the federal government continues to play a major role in the financing of research in universities, the strengthening of interdisciplinary studies can be affected substantially by federal policy. The fragmentation of environmental research among mission agencies tends to dissipate the efforts made by individual agencies to improve interdisciplinary research.

Many people interested in the face of environmental research question the adequacy of human resources to do the job. We examined available data on degrees granted and employment in the environmental sciences and discovered that the available information did not permit the needed comparisons. Employment categories were not parallel with degree fields. Environmental biologists were dispersed among such fields as "biological science," "agricultural science," and so forth, whereas in some data sets all of geology is considered "environmental science."

ESTABLISHING AND NURTURING STRONG LINKS WITH BUSINESS

New partnerships between government and industry must be established and promoted for setting R7D priorities for the development of new environmentally benign technologies, new methods for controlling process byproducts, new environmental control technologies, and training and education for corporate offices on environmental processes and problems. These should be developed not only to improve our country's environment, but, through their export, to enhance the developing world's environment and to create jobs in our country as a result of the export.

How Well Are We Doing?

A historical adversarial relationship between the private sector and the federal state and local governments, particularly regulatory agencies, has occurred at a time when other countries, notably Japan and Germany, have developed relatively stringent environmental regulations, which not only improve the environment, but drive the development of new technologies for pollution control and energy efficiency and are more environmentally benign.

Government and industry increasingly recognize that environmental problems are important and need to be addressed cooperatively by the two sectors and that so addressing them is to the advantage of the nation's economic position in the world and the health of the environment. Steps in that direction are the identification by the Office of Science and Technology Policy of pollution minimization, remediation, and waste management as critical; EPA's Green Lights Program with industry in a search for energy-efficient lighting that could save up to $20 billion a year in electricity bills and reduce air pollution from electricity-generating sources by 5%; EPA's cooperation with the automobile industry in supporting the Health Effects Institute and its studies on pollution reduction and the health effects of automobile emissions; and industry's emphasis on and dedication of larger amounts of R&D funding to "industrial ecology" aimed at manufacturing practices that are environmentally sound and products that are safe and economically recyclable.

Mechanisms for controlling pollution through innovative taxation policies are few; the permit process associated with atmospheric emissions under the 1990 Clean Air Act amendments is an example of such a mechanism. Taxation policy needs to be examined for the feasibility of taxing not products and services, but the pollutants that need to be controlled or prevented. By changing tax policies in ways similar to those of Europe and Japan and by forging new R&D links and common agendas between government and industry, the United States can develop new technologies that are beneficial to our environment and to our economy (WRI, 1992).

Why Are We Not Doing Better?

Government is related to industry mainly as a regulator and enforcer of a multitude of environmental laws. The United States lacks the tradition, common in other developed countries, of extensive cooperation between the two sectors. There is no strong record of cooperation and coordination of effort for the environment like the linkage of government support to industry (R&D funding, procurement, and formation of research consortia) that produced great strides in aerospace technology, computers, defense, and medicine after World War II.

It is clearly desirable that we find the means to form the necessary partnerships that will establish trust and cooperation between government and the private sector.

ESTABLISHING AND NURTURING COMMUNICATION LINKS WITH THE GENERAL PUBLIC

The general population must become environmentally literate. Citizens should be informed of key findings of environmental science and be involved in decision-making and policy-setting. Informed citizens are better able to understand and accept policy decisions, some of which might demand sacrifices of them, and to assume responsibility for putting environmental values into practice. Abundant experience has shown that if people feel that they are not involved in a decision or do not trust the decision-makers, they are unlikely to accept the decision. However, modern government is based on the premise that people do not have time to be involved in all public-policy decisions and therefore identify (elect, appoint, or otherwise choose) representatives or delegates to make and execute most decisions for them.

How Well Are We Doing?

Until fairly recently, people were more trusting of their representatives than they now seem to be. Hance et al. (1988) quote the assistant commissioner of the New Jersey Department of Environmental Protection, Doland Deleso: "Since the 1970s, I've watched a change. In the early days … when we came into a public meeting, we were believed. People walked away relieved or alarmed, depending on the message, but they believed us and felt that we were competent and had the best intentions. Now the presumption is that we're incompetent, that we have a hidden agenda, that they've got to ferret out the truth for themselves, and that the agency is an obstacle to getting the truth."

We have seen spirals of decreasing trust in public institutions and of increasing bureaucracy, legislation, and regulations to prevent abuses-all accompanied by a further decrease in trust. Now, various organizations and individuals are spending much time trying to figure out how to involve the public in decision-making so that trust in government can be restored. The whole system, which fundamentally depends on trust, is in such a poor state that voters in 1992 elected an unusually large number of newcomers to federal office.

Why Are We Not Doing Better?

Agencies have often failed to recognize that their perceptions of events, risks, and benefits are a function of their culture and psychology as much as are the perceptions of the people who might be distrusting or opposing them (NRC, 1992c). As a result, government officers have often treated citizens as though they were uninformed or misinformed and have aimed communication at correcting misguided perceptions. In addition, genuine involvement of citizens with decision-making is time-consuming and expensive. To an agency under pressure to act, such involvement often appears to be an unfortunate diversion of resources that would be better directed to accomplishing the agency's mission. Whether or not the distrust now directed at government is justified, one must recognize that the crisis in confidence demands substantial investment of resources in an effort to restore trust and to earn it.

Restoration of trust is hampered by a lack of information on how to generate and maintain it. Little effort has been devoted to research on how to develop an informed and involved citizenry in a modern, complex, industrial society. The report of the Committee on Risk Perception and Communication (NRC, 1989b) outlines a number of subjects that warrant research, such as

- How are risks compared and evaluated? Across which dimensions should risks not be compared? How do people assess magnitudes of risk?
- What is the role of message intermediaries?
- What determines pertinence and sufficiency of risk information?
- Which risks produce strong psychological stress and why?

Because of a lack of attention to those issues, we cannot provide reasonable answers to such basic questions.

SYNTHESIS OF HOW WELL WE ARE DOING AND WHY WE ARE NOT DOING BETTER

The preceding analysis demonstrates the existence of substantial strengths and weaknesses in the current structure and functioning of environmental research in the United States. Among the strengths, the United States is blessed with an impressive array of scientific, managerial, and political talent. It also has citizens who are as informed and concerned as those of any nation, even though their knowledge and involvement are much less than would be desirable. Federal agencies spend large sums of money on environmental research, and much useful information has been gathered in support of their missions. These strengths need to be maintained and improved on, with other, more fundamental changes that need to be instituted.

The committee also finds the following weaknesses that need to be addressed:

- The research establishment is poorly structured to deal with complex, interdisciplinary research on large spatial scales and long-term temporal scales. These traits characterize the primary needs of an effective environmental research program.
- There is no comprehensive national environmental research plan to coordinate the efforts of the more than 20 agencies involved in environmental programs. Moreover, no agency has the mission to develop such a plan, nor is any existing agency able to coordinate and oversee a national environmental research plan if one were developed.
- The lack of an integrated national research plan weakens the ability of the United States to work creatively with governments of other nations to solve regional and global problems.
- The nation's environmental efforts have no clear leadership. As suggested by the lack of a cabinet-level environmental agency, the United States has lacked strong commitment to environmental research at the highest levels of government. Environmental matters have been regarded as less important than defense, health, transportation, and other government functions.
- Although individual agencies and associations of agencies analyze data to provide a base for decisions on strategies and actions to address specific environmental problems, no comprehensive "think-tank" exists for assessing data to support understanding of the environment as a whole and the modeling of trends whose understanding might help to set priorities for research and action.
- Bridges between policy, management, and science are weak. There is no organized system whereby assessments of environmental problems can be communicated to decision-makers and policy-setters.
- Long-term monitoring and assessment of environmental trends and of the consequences of environmental rules and regulations are seriously inadequate. The United States has a poor understanding of its biological resources and how they are being affected by human activities. Although biological surveys have a long history at the state and federal level in the United States, it is only very recently that we appear to be approaching a consensus on the need for a comprehensive, national biological survey.
- There is insufficient attention to the collection and management of the vast amount of data being developed by the 20 agencies involved in environmental research. Collection and management of environmental life-science data are less well organized than those of environmental physical-science data.
- Education and training in the nation's universities are still strongly disciplinary, whereas solution of environmental problems requires broadly trained people and multidisciplinary approaches. Opportunities for broadly based interdisciplinary

graduate degrees are few, and faculty are not rewarded as strongly for interdisciplinary activities as they are for disciplinary activities. Thus, there is a risk that environmental scientists appropriately trained to address pressing needs will be lacking.

- Biological-science and social-science components of environmental research are poorly supported, compared with the (still inadequate) support given to the physical sciences.
- Research on engineering solutions to environmental problems is seriously underfunded. That reduces our ability to protect ecosystems and restore damaged ones to productivity and jeopardizes the nation's ability to achieve major economic benefits that are certain to derive from increasing worldwide use of technologies for these purposes.
- With respect to environmental affairs, government operates in a strongly adversarial relationship with both industry and the general public, to the detriment of integrated planning and maintenance of an atmosphere of mutual trust that is essential for effective government functioning.
- With important exceptions in the National Science Foundation, the National Oceanic and Atmospheric Administration, and the U.S. Geological Survey, most environmental R&D is narrow, supporting either a regulatory or a management function. That appears to be particularly true in the environmental life sciences.

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DESIRABLE CHARACTERISTICS OF FEDERALLY SUPPORTED ENVIRONMENTALRESEARCH PROGRAMS

A FOCUS OF ENVIRONMENTAL RESEARCH ON PROTECTION, RESTORATION, AND MANAGEMENT

The committee believes that environmental research should advance the social goals of *protecting* the environment for present and future generations, *restoring* damaged environments so that they are productive once more, and *managing* our natural, economic, cultural, and human resources in ways that encourage the sustainable use of the environment.

We include management as a social goal because we believe that finding ways to manage our resources is one of the great challenges of our time. Environmental systems consist not only of natural resources, but also of linkages with interrelated economic, social, political, and cultural processes. We must find ways to help the developing world to raise its standard of living and at the same time maintain environmental quality and function. Some of those ways lie within the province of environmental research–ways to prevent the inevitable waste stream from devastating the air, the water, and the land, for example. Environmental research must focus on understanding natural and human-mediated effects on our natural resources but must also study the relationships between natural resources and economic, human, and cultural resources. If we fail in this task, the entire world, including the United States, will suffer the consequences. Research on how to manage our resources will lead to opportunities for both economic and environmental well-being.

The terms *protection, restoration*, and *management* set out directions in which environmental research and action should proceed; these terms should not be taken to imply absolute goals, because in a changing world absolute goals might be elusive, infeasible, or impractical, given other human objectives. Protecting the environment is not necessarily the same as preserving it; the natural world changes on its own, and the human place in the landscape varies over space and time. What is important is to protect the capacity of nature to provide the ecological services essential to human well-being–such services as assimilation of wastes, production of food, and provision of an aesthetically satisfying context for human interaction. Similarly, restoration of damaged ecosystems does not imply re-creation of pristine conditions that prevailed at some arbitrary time in the past; nor does it mean complete removal of the signs of human intervention into a natural system. It does imply the rebuilding of damaged ecological functions and depleted natural settings so that they regain the ability to deliver ecosystem amenities to human and nonhuman populations. Finally, it will be impossible to reconcile growing populations and expanding demand for natural resources and ecosystem services unless innovative solutions to myriad environmentally related problems can be found. Human aspirations for prosperity can be met, in the long run, only through sustainable use of the natural world. It is essential to find ways to manage our resources to achieve economic prosperity that are in harmony with the environment.

Research along those lines has long been conducted in various government, university, and private-sector laboratories. But the action flowing from the research typically has been fragmented in its application to environmental systems because there has been little recognition that humans were intervening in complex ecosystem processes whose response to human activity would often be surprising, indirect, and delayed and sometimes counterproductive. As that recognition has grown with environmental awareness and a deepening understanding of ecosystem behavior, it has become appropriate to revise how the federal government invests in research. The starting point of such a rethinking is to identify the social purposes that environmental research should enable us to pursue more effectively. Protection, restoration, and management of resources are goals that will be important to the United States for some time. The challenge of creating a relationship between people and the natural world that can be economically and ecologically sustainable demands re-examining the fundamental structures of industrialization–a deep, complex set of issues that can be addressed successfully only on a time scale of decades. The environmental and natural-resource problems that face the world and this nation clearly warrant an investment in research to find practical solutions to such needs as protecting, restoring, and managing our natural resources and to lend coherence to the investment while preserving the variety and creativity that have been essential to American leadership in science and technology.

The committee believes that environmental research that can produce essential data and can inform and support policy must have the characteristics discussed below. These characteristics are necessary, although not sufficient, if research is to lead to improved environmental outcomes. Implementation of the research direction and approach requires a change in the culture of federal support of the research.

RESEARCH DIRECTIONS

The desirable environmental research program proceeds in two directions–first, addressing issues of protection and restoration, and second, addressing issues of innovation in management of resources. Building a base of knowledge for protection and restoration has been the objective of most existing environmental research. As the scale and scope of the interactions involved in effective management of environmental resources have become clearer, the need to emphasize deliberate learning about how to manage resources in a sustainable way has become apparent as well.

RESEARCH FOR ENVIRONMENTAL PROTECTION AND RESTORATION

Basic and applied research on ways to protect the environment and to ensure the continued flow of essential goods and services from the environment must provide a focal point for the nation's environmental R&D program. Examples are general modeling research–research on modeling of processes by which chemicals are transported through, and their ultimate fate determined in, the environment–research to determine patterns and processes of atmospheric and oceanic circulation, studies of the responses of ecosystems to stresses, and investigation of natural processes and patterns of ecological succession and soil erosion.

Concern about global change–including the loss of biological diversity, carbon dioxide accumulation, and stratospheric ozone depletion–fits within the rubric of protection and restoration and can be a unifying theme for the nation's environmental research program.

RESEARCH FOR INNOVATION IN MANAGEMENT OF NATURAL RESOURCES

The committee believes that although environmental protection and restoration are essential foci for environmental research, they are not sufficient to address the long-term environmental needs of the nation and the world. They deal with present and past human activities but do not look to a future for which we must seek to ensure sustainable use of our resources that will protect and even enhance environmental quality while improving standards of living and quality of life.

The committee found that substantial conceptual and philosophical barriers complicate the reconciliation of the need for long-term environmental protection with the need for economic development. The most fundamental barrier is the view that there is a difference between sustaining the environment for its own sake and sustaining the environment as a resource for people. Current attempts to find common ground between environmental protection and economic development have generally focused on the concept of sustainability, embodied in such terms as *sustainable development* and *sustainable biosphere* . We view these terms to have the same purpose, which we express in the concept of *management* of our natural resources. Realization of the goal requires new tools and new industries created through research and development that produce the following outcomes:

- The creation of wealth and enhancement of standards of living and quality of life in the short term.
- Enhancement of, or at least no diminution, in the capability of future generations to continue to improve their quality of life.
- Provision of continued availability of nonrenewable resources for future generations. (In addition to extractable and minable materials, nonrenewable resources include species that are nonrenewable in that they cannot be recreated if they become extinct. Nonrenewable resources also include at least some ecosystems that would be extremely difficult to recreate if destroyed or highly degraded.)
- Reversibility of negative environmental impacts, if any, of resource use, preferably in the span of one generation.

The current rate of consumption of renewable and nonrenewable resources is not sustainable in the long term. Petroleum reserves will give out, probably in the next century. Serious risks are associated with current and projected magnitudes of waste production globally, including the risk of global warming and various threats to public health. Species are becoming extinct at an unprecedented rate, which will probably increase as habitats continue to degrade. These problems will be exacerbated by the combination of projected population growth and worldwide expectations of increased standards of living, especially in the developing countries. Failure to develop management tools will increase the risk of reduction in quality of life for the next generation and decrease the capacity of future generations to recover from that reduction.

We are not in a position to implement fully the sustainable management of natural resources. We have the beginnings, but considerable research and development are needed. Emerging disciplines, such as industrial ecology and ecological economics, that contain key elements of this approach. Among these elements are the creation of an industrial cycle that mimics biospheric processes via a materially closed system, in which waste materials produced by one segment become inputs for another; internalizing the parameters of our economic models that are now considered externalities, so that production costs will include true environmental costs; and maximizing energy efficiency.

The creation of the new tools needed for sustainable management of natural resources will not be easy, but it will create new opportunities, in that whole new industries will be needed, such as major recycling and remanufacturing industries. And it will reinforce the current drive to continuous improvement and to high-quality products because these are likely to reduce waste in most cases.

RESEARCH APPROACH

Human survival depends on various biological features of the environment. Organisms provide oxygen, food, fuel, and fiber; mediate floods; affect climate; contribute to soil formation; fertilize plants that produce fruits; increase soil fertility; and break down pollutants. These so-called environmental services include more than merely the means for survival; they also improve the quality of human life. The biggest and most difficult environmental problems include alterations of ecosystems (including extermination of species) and alterations of habitats, sometimes on a global scale. As a result of such alterations, environmental services can be interfered with or interrupted–also sometimes on a global scale. As human population and activity increase, environmental services will be increasingly altered. Scientific understanding is increasing, but much more environmental research is needed.

To understand the nature of environmental services and their susceptibility to human activities, we must describe, count, and measure components of the environment that can be inventoried; understand the transfer of materials and energy from one component to another; and learn the rules by which components interact–in other words, how the systems work. That research approach presents major challenges. The systems are inherently complex, their components are diverse, and the threats to them exist across political boundaries and can operate at large scales. The understanding needed to ensure a sustained flow of environmental services requires coordination of environmental research at all levels, especially in the federal government.

RESEARCH-PROGRAM CHARACTERISTICS

The R&D programs to be implemented will make the most effective contribution to a coordinated program if they are planned and implemented with the following characteristics in mind.

CROSSING DISCIPLINES AND SCALES

It is important to maintain strength in disciplinary studies, but many environmental issues cross the boundaries of traditional scientific disciplines, including biological, physical, and social sciences. In addition, most environmental processes operate over a wide range of spatial and temporal scales. Solutions to most environmental problems depend on bringing together several traditional disciplines and evaluating the problems on several space and time scales.

CROSSING MISSIONS

Government agencies carry out specifically mandated missions that direct their environmental research to mission-oriented goals. It is important that environmental research programs be designed and coordinated in ways that will permit crossing mission boundaries and make the products of the research useful for increasing knowledge about environmental problems in general.

UTILITY FOR DECISION-MAKING AND POLICY FORMATION

Knowledge gained from research can improve public understanding of environmental issues, inform decision-making, and assist in making policy decisions. There must be an organized system that sets priorities for research in a consultative process and that provides for communication of new information to the decision-makers and policy-setters.

PLURALISM

There is no simple way to anticipate the most effective research approach to many environmental problems, so the nation's environmental research program must facilitate creative and diverse scientific approaches to environmental protection and restoration problems.

MULTIDISCIPLINARY RESEARCH

All relevant disciplines must be brought to bear in a coordinated approach to actual environmental problems. The nation must explore alternative funding mechanisms for environmental research, including novel ways of funding existing organizations and initiating new centers and other structures to address environmental issues in a multidisciplinary manner.

CONSISTENCY OF FUNDING FOR ENVIRONMENTAL RESEARCH

Many topics in environmental protection, restoration, and innovation require research over long periods. Funding patterns must be designed to provide stable funding for long-term studies on specific problems and for measuring the status and trends of natural resources.

ADEQUACY OF FUNDING FOR ENVIRONMENTAL RESEARCH

Agencies must have the wherewithal to support the full range of components of a coordinated environmental research program, including research, training, and infrastructure.

A BALANCE BETWEEN INTRAMURAL AND EXTRAMURAL RESEARCH

One of the strengths of science in our nation is that each sponsor of research can choose to support research in the way that appears most advantageous. That ensures that research will be done in diverse settings by the full range of human talent and temperament and that in most cases the diverse interests will be represented in the choice of research to be done.

Historically, much of the talent in environmental research has resided outside the formal structure of the federal agencies; this is especially true in basic research in the biological and social sciences and in engineering research and applications. However, the American Association for the Advancement of Science report on funding for environmental research reveals that, compared to other areas of federally supported research, environmental research funding overall is directed more toward inhouse federal-agency funding than to universities and not-for-profit research institutions. "Much of the government's environmental expertise is either in-house or in non-academic institutions. Extrapolations from data on R&D performers suggest that about one third of federally-funded environmental R&D is conducted in-house in government laboratories. This compares to about one fourth for other nondefense R&D programs" (Gramp et al., 1992, p. 5). The AAAS report explains that many of the federal agencies that fund environmental research emphasize inhouse research for management purposes (e.g., the National Oceanic and Atmospheric Administration, NOAA; the Department of the Interior, DOI; the Agricultural Research Service, and the Forest Service) or regulation and monitoring (e.g., the Environmental Protection Agency, EPA). The share of federally funded environmental research performed in academic institutions is small compared with other types of research performed in academic institutions.

If we are to invigorate federally sponsored environmental research, we must become more creative and long-sighted and must direct research to the understanding of basic environmental processes and to restoration and maintenance of environmental functions. This focus requires the open, interactive research environments characteristic of universities and research institutions, and it requires the quality controls inherent in merit review.

The opportunity to do environmental research must be made available to the best minds. This is not always the case today. Environmental research in the United States will improve only marginally if we simply reshuffle pieces of inhouse research programs or agencies without strengthening the extramural programs that bring flexibility to the use of human talents for particular research needs. It should also be evident that extramural academic research is pivotal in training new researchers.

The importance of extramural research is illustrated by the presence of myriad environmental databases in industry and academe. Not only must extramural research programs be strengthened; the information generated by them must be integrated into the federal consciousness via federal support for information networks throughout environmental science, as is now the case with research data collected by such federally controlled devices as satellites.

In agencies where both intramural and extramural research are performed, the natural tendency toward competition between the two types of funding should be reduced by providing structural impediments to budget erosion on one side or the other. The rationales and roles of the two types of research funding must be delineated.

INVESTIGATOR-INITIATED, PEER-REVIEWED RESEARCH

Investigator-initiated, peer-reviewed research is already the hallmark of the National Science Foundation (NSF). To stimulate new ideas and to increase the vitality of environmental research throughout the federal government, this approach must be encouraged in appropriate parts of environmental research programs in all agencies.

INTERNATIONAL SCOPE

Many environmental problems are international in nature and scope. The federal environmental research program must lead and collaborate in selected international research activities.

EFFICIENCY AND ECONOMY

Both human and financial resources are limited, so the federal environmental research program must set priorities and be organized and operated economically and efficiently. That requires the use of oversight, coordination, and evaluation techniques that seek to eliminate redundancy, avoid waste, and use personnel, facilities, and systems to the best advantage.

COMBINATION OF GOVERNMENT AND PRIVATE-SECTOR ACTIVITIES

The total needs of a national environmental research program are too large for the federal agencies alone, so the issues must be addressed by a combination of government and nongovernment organizations. Nongovernment organizations should be involved as partners and advise in setting priorities and in providing constructive criticism for government programs, as well as being active performers of research themselves as appropriate.

The committee recognizes the constraints that might make it difficult to institute the research process described above. Solutions to environmental problems are needed now, and working toward solutions will require investment of funds at a time when the nation faces severe economic problems. Furthermore, the steps described above require changes in a federal organizational structure that is already in place and might be politically difficult to alter.

The research and policy-informing system that we believe essential will require national-level leadership and coordination, a national environmental research plan, provision for environmental data collection and distribution, and means of assessing the state of the environment and monitoring trends. Such characteristics, fundamental for environmental research, are necessarily secondary considerations in federal departments, such as the Department of Energy (DOE), DOI, and the U.S. Department of Agriculture (USDA).

NATIONAL-LEVEL LEADERSHIP AND COORDINATION

The essential foundation of a successful environmental research program is leadership at the highest level of government to ensure attention to important environmental issues at all levels of government. The committee believes that it would be highly desirable to establish a National Environmental Council (NEC) for this purpose. The primary responsibility of the NEC would be to ensure that a national environmental research plan is developed and adhered to and that the federal agencies consistently follow a coordinated approach to implementing the plan.

Such a council would be effective if it included

- A focus on environmental matters, which are singled out for high-level attention, in a way parallel to that of the Space Council or the National Security Council.
- Participation by cabinet officers, so that agreements to coordinate carry the authority of the senior official of each agency.
- Continuing visibility of environmental questions across agencies. The authority of cabinet officers can initiate coordination, but maintaining coordination requires continuous monitoring to ensure that momentum is maintained. The influence conferred by a cabinet-level council provides the necessary platform for keeping implementation on track.

Coordination of efforts among agencies already occurs routinely in the government, and it is important to understand how the existing modes need to be changed. Environmental research faces large challenges: much environmental research is inherently of a large scale, and that forces its practitioners to attend to the complexities of building and maintaining substantial organizations to collect and analyze large quantities of data; environmental research crosses functional boundaries, as when economic data are used to estimate and project the volume of hazardous waste generated in an area, and this strains disciplinary and organizational loyalties; and the turbulence of budgets when there are large fiscal strains in the federal government can force cuts in some budgets in a coordinated program while others continue and so disrupt the collection and analysis of data obtained from diverse programs. If those challenges are not explicitly addressed by leadership at the top, they will undermine collaborative efforts among agencies.

About 20 federal agencies have major responsibilities related to the environment. In all instances (except for EPA), concern for the environment is not the primary role of the agency conducting the environmental research and influencing policy. For example, DOE supports much environmental research, but the department's primary responsibility is energy, rather than environment. The roles and responsibilities of the involved agencies should be explicitly described in the national environmental plan described below and managed and implemented by the NEC.

The Office of Science and Technology Policy is a highly placed office whose specific mission is to coordinate federal research. It performs its function in some cases by organizing committees under the Federal Coordinating Council on Science, Engineering, and Technology and in others by convening agency representatives to discuss coordination needs. Presidential directives can call for the formation of high-level coordinating bodies, such as the Space Council, or assign responsibilities among agencies; for example, a directive established USDA as the federal lead agency for nutrition and agricultural research. The Office of Management and Budget (OMB) can issue circulars that direct cooperation among agencies to avoid duplication of effort and overlap in functions; for example, OMB Circular 16 directs a number of agencies to work with the U.S. Geological Survey (USGS) to collect and manage spatial data. In many instances, no special intervention is required for coordination to occur-agencies recognize a need for coordination and bring it into being. All those mechanisms for coordination might come into play in a plan to rationalize the organization of federal environmental research. The committee believes, nonetheless, that a large-scale national program in environmental research requires high-level leadership to ensure that coordination will be established and will persist long enough to begin to return benefits in the form of more-effective and less-expensive environmental policy.

PLANNING FOR ENVIRONMENTAL RESEARCH

A basic element of our recommendations is the need for a national environmental research plan developed and administered by the NEC. No such plan exists, but one must be formulated if the nation is to marshal its resources to identify and address environmental issues. Without a comprehensive plan, the efforts of individual agencies are typically uncoordinated, except when a specific problem, such as global change, receives enough attention to stimulate an effort to coordinate relevant programs. The result is a federal research effort that is fragmented in perspective and leads to partial solutions that sometimes deepen conflict or fail to solve problems, because they are only partially understood. Reliance on ad hoc arrangements has been successful in some instances but generally is not conducive to the organized, long-term studies that are often required to attack environmental problems and track the changes brought about by efforts to remedy them. A national strategy would provide a framework within which individual agency programs would create knowledge that would serve immediate mission needs while building a stock of information for the solution of future problems.

Such a plan must become the first priority of the NEC. Given the rapid changes in the environment and our understanding of it, we recommend that the plan be updated every 2 years and revised comprehensively every 5 years.

LINKAGE OF ENVIRONMENTAL RESEARCH AND POLICY

Good environmental policy formation requires, first, accurate, sound, and timely scientific information and analysis; second, pathways for the scientific assessments to reach decision-makers; and third, flexible policies and alert implementing agencies able to respond to new information so that decisions made under uncertainty can be revised in light of experience. A mechanism should exist that can quickly bring to the policy process the best available information on environmental status, up-to-date understanding about environmental processes and human factors, and accurate analyses of the implications of this knowledge for environmental issues and policy decisions. To be effective, the input should be balanced and as free of bias as possible. Misinformation and poor or biased analyses can easily lead to faulty or misguided policies.

No dedicated mechanism exists on a large-enough scale for analyzing and assessing the environmental issues currently facing the nation and the world. It could be created by setting up a new, independent agency expressly to ensure the best scientific input and insulation from the influence of partisan political forces. The advisory process of the National Research Council is one potential model for such an agency. Yet, as shown in Chapter 2, the record of decision-making in scientifically complex fields is mixed. A complete solution to this problem is unlikely to be available through structural rearrangements alone. Being alert to the need for science and bringing science into the policy process is a task that cannot simply be assigned to a person or organization; it must be rooted in a sense of leadership–and thus will depend on the particular persons in positions of leadership.

A new center or enhanced existing institution would provide a neutral arena for bringing together scientists with those who have responsibility for making decisions about environmental policy. It would focus primarily on the most important environmental policies at the national level. Because environmental problems combine scientific uncertainties, substantial economic consequences, and disputes regarding human values, the connection between environmental science and environmental policy is too important to be left to the current ad hoc arrangements. There should be a national center or institution that can contribute to and be evaluated by both the public and private sectors.

An important characteristic of the policy center is that it would have access to and provide recommendations to the political decision-making processes at the federal level and would also make its products available at the state and local levels to businesses, nonprofit institutions, other nongovernment organizations, and citizens. All are involved in fashioning and implementing solutions to environmental problems. In Chapter 5, we recommend a means for ensuring that the products of scientific analysis of environmental issues are made available to decision-makers.

ORGANIZING ENVIRONMENTAL INFORMATION AND MAKING IT AVAILABLE

Environmental databases are large and will continue to expand in number and complexity. The utility of the data, however, is often low, because of the sheer size of a database, because documentation is not sufficient for the data to be interpreted with confidence, and because mechanical accessibility and practical interpretation are not available to potential users. The nation needs an environmental information clearinghouse that will catalog environmental data sets with their requisite documentation. It is important to create a National Environmental Data and Information System (NEDIS). Current electronic systems for managing information might make it sensible to perform these functions by establishing a systematic gateway to data and information without creating a library in the traditional sense of a building that serves as a data repository.

There are already several efforts to coordinate large environmental data sets at the national level, and new efforts could build on existing systems in, for example, the National Aeronautics and Space Administration, NOAA, EPA, and DOI. For example, the Federal Geographic Data Committee, led by USGS, focuses on spatial data. It has proposed a National Geographic Data System that would promulgate uniform data-transfer standards. Other cooperative efforts to manage databases are the nine-agency group led by NOAA; the Interagency Working Group on Data Management for Global Change; the Global Change Information Center, which is designed primarily to transfer data to developing countries; the NSF Long-Term Ecological Research (LTER) program, which is based on a specific research program; and the planned collection and organization of data sets as part of the EPA Environmental Monitoring and Analysis Program. Despite those and other cooperative efforts, many environmental data sets are still dispersed and only unevenly available or useful. A coordinated national program should be undertaken.

An important responsibility of NEDIS will be to develop institutional connections with databases in other disciplines that are relevant to understanding environmental issues in and outside the federal government. In particular, the combination of environmental, social, and economic data is important to the responsibilities of many agencies. Furthermore, results of all environmental research in the federal agencies should be included in this library of information. It is inefficient for each agency to develop information-management systems independently. NEDIS would save money by eliminating unnecessary duplication of effort while facilitating the synthesis and interpretation of data for use by a wide variety of audiences.

We do not underestimate the difficulty of accomplishing what we believe is desirable. There are so many information sources and they exist in so many different forms that collecting them and making them useful is an enormous task. A large-scale study might be necessary to find ways to collect the data in an appropriate form for use in determining environmental status and trends and to assess comprehensively what the data mean and what options for action can be inferred from them. The need is especially great with regard to information on environmental biology. The first steps have already been taken to collect and use data on physical environmental measures, in particular for the global-change program. The problems encountered by the interagency group on global-change data in coping with the vast amount of data underscore the complexity of data collection and management for environmental data and the need for continuing effort to optimize systems (NRC, 1991).

CONTINUING EVALUATION OF THE NATION'S AND WORLD'S ENVIRONMENTAL STATUS

Environmental status and trends data are collected by virtually all federal agencies, but there is no comprehensive plan for deciding which data are most important and what organization should collect them. The data themselves are scattered across the federal bureaucracy, and the data-collection program in each agency is designed to meet the individual needs of that agency without sufficient regard for collaboration with other agencies and the broad national and international scientific community.

Specific programs must be developed to integrate current status and trends measurements made by a wide variety of government and nongovernment organizations at all levels and to make them broadly available. These include the combination of the NSF LTER program and the USDA experimentation data networks, integration of regional and local networks, and other possibilities.

The federal agencies, in concert with the national and international scientific community, need to establish a nationwide and worldwide program to measure and describe quantitatively the current status of environmental conditions, to describe the trends of these conditions, and to assess threats to environmental resources and processes. In addition, U.S. data-collection capabilities, such as those of earth-orbiting satellites, should continue to contribute to global data collection for international organizations. It is important to create a reliable portrait of environmental status and trends so that the complex and often delayed interactions between humans and the rest of the natural world can be perceived in an accurate and timely way. It is essential that the agencies coordinate their efforts to ensure that collection and dissemination of information about conditions and trends are reflected in their operating procedures and that their research programs contribute to improving the understanding of the processes that are driving the trends. The coordination should ensure consistency in the various status and trend databases.

The program would issue an annual report of its activities and a summary of the status of the nation's environmental conditions. That report should build on the models established in the annual reports of the Council on Environmental Quality (which is now to be abolished) and should reflect and take advantage of advances in information management. A comprehensive and appropriate National Biological Survey, housed in the Department of the Interior, is an important component of this effort. The programs of the Smithsonian Institution, a federal-private hybrid organization, would play a role in providing status and trends data.

ROLE OF NATIONAL SCIENCE FOUNDATION

The solutions to many environmental problems will ultimately arise from basic research on the structure and function of environmental systems. NSF provides the primary support for such fundamental research. It manages a wide-ranging program of basic environmental research and has a variety of funding mechanisms ranging from support of individual scientists to support of groups and centers, such as the National Center for Atmospheric Research and the LTER program. It supports training, instrumentation, and specialized facilities. NSF-supported research does not replace the mission-oriented research programs of the various federal agencies. Rather, they complement one another. NSF is invaluable in a comprehensive environmental program, and a substantial increase in funds available to NSF for the support of environmental research and development is highly desirable and should be expedited.

ROLE OF SECTOR AND MISSION AGENCIES

We believe that such agencies as USDA, DOI, and EPA can profitably be more involved in environmental research than they are now, both in basic research through their competitive grants programs and in their mission-related efforts, all of it to be coordinated through the national plan. A larger component of investigator-initiated, peer-reviewed research in each of those agencies is strongly recommended.

ROLE OF FEDERAL LABORATORIES

Large networks of federal environmental research-performing laboratories exist under the management of EPA, DOI, NOAA, USDA, and other agencies. Coordination of effort among them is desirable to increase the effectiveness of their research.

The national laboratories supported by DOE have skilled personnel and data-handling and other capabilities that make them appropriate to play a major role in environmental research. Several bills introduced in Congress have proposed that these laboratories be used to focus on environmental technologies and thereby to develop products that would contribute to the solution of national and international environmental problems and to the U.S. competitive position in this field.

It would be highly desirable to bring the necessary new talent into the federal laboratories and to find appropriate ways to use the capabilities of the laboratories in a complete environmental R&D program. It would also be highly desirable to seek ways to coordinate the various laboratories supported by many departments as part of a cooperative program of environmental research.

PUBLIC-SECTOR AND PRIVATE-SECTOR COLLABORATION

The actions required to sustain environmental systems–protection, restoration, and management–will be conducted to a large extent by the federal government but also by many other organizations and constituencies. For example, efforts to protect natural resources will occur on federal lands and under federal policies and regulations. But they will also occur on private land and under the jurisdiction of states and local governments. Similarly, restoration and management policies will be implemented on global to local scales. Although environmental research in the public and private sectors has some different objectives, there are many common problems and issues. Increased communication and collaboration between the public and private sectors both in the performance of research and in discussions of policy formation are highly desirable.

EDUCATION AND TRAINING

To ensure that the public can understand the most important environmental issues and to ensure that there will be strong future generations of scientists, the federal environmental research program must support broad environmental education and training programs for the public. Programs sponsored by EPA and others have taken a few steps toward this end, but these must be multiplied.

Training opportunities for scientists must be provided by programs supported not only by NSF, but by all the agencies involved in environmental research. Innovative programs are required to address the need for persons able to deal with the environmental issues that require multidisciplinary approaches.

INTERNATIONAL COOPERATION ON RESEARCH AND POLICY

It is essential that the U.S. research program be coordinated and integrated with international programs. Only in this way can overarching environmental problems be solved. The Carnegie Commission report (Carnegie, 1992b) provides a plan for effecting this critical objective.

DESIRABLE OUTCOMES

The program of environmental research and the translation of information into environmental policy need to be evaluated regularly to ensure that the goals of protection, restoration, and management are being realized and that the program itself continues to contribute to and be supported by the public. The committee has identified above the desirable characteristics of a sound program of environmental research. Some of the salient signs of success are discussed here, to make explicit the benefits that we believe are attainable and that evaluation and oversight bodies should look for.

- Among the hallmarks of national leadership three are of particular importance: readiness to champion policy reforms when the scientific consensus has shifted in favor of new understandings; taking a leading role on behalf of the United States in international organizations and on global environmental issues; and most important, early, effective, and persistent use of scientific information in policy arenas characterized by uncertainty and political risk. As long as voters continue to see environmental quality and its protection as important government responsibilities, those virtues should confer benefits on those who lead.
- Research will function effectively across disciplinary lines, probing on different spatial, temporal, and functional scales. As a result, fundamental understanding of environmental processes will increase steadily and enable the development of more effective technologies, practices, and policies for governing people's use of the natural world and its resources.
- Research will be pluralistic: a variety of approaches will be pursued on most important environmental questions, and that will enable progress to come through different routes.
- Support of research will be flexible and creative to take advantage of different ways of funding existing institutions and creating new organizational forms to foster multidisciplinary creativity. In particular, there will be a vigorous segment of research in which work is initiated by individual scientists, whose ideas are judged through peer review.

- An infrastructural support system will provide for research facilities, data-management facilities, and professional training, as now exist for biomedical and other research with high social priority. Research facilities will be designed to allow efficient sharing of equipment. Support of environmental biological databases will have national priority, as do atmospheric databases today.
- The role of universities and free-standing research institutions, such as field stations and museums, in environmental research and policy will be expanded and will be less subject to fluctuations in support. Academicians will be more conversant with industrial and public-policy concerns, and there will be a greater match between training and societal needs. The public will become more aware of the value of basic environmental research and monitoring outside the federal government.
- State-supported environmental research will be integrated into policy-setting through participation in the status and trends network and through the exchange of ideas and personnel with universities and federal agencies.
- At all levels of education, environmental literacy will be encouraged as an interdisciplinary element of courses of study. Such literacy is as important in the education of accountants, who must grasp the financial value of pollution-control expenditures, as in the education of workers in heating and air conditioning, who are responsible for controlling emissions of chlorofluorocarbon gases. Most important, students whose votes will be counted in the elections of the twenty-first century must profit from the knowledge acquired through environmental research, so that they can participate knowledgeably in dealing with the difficult issues ahead. Today environmentalism–often based on a superficial grasp of the underlying science, value premises, or historical background–is fashionable. But industrial societies seeking to find economic pathways that can be sustainable in the long term must develop the capacity to make hard choices while nurturing democratic values; education is of fundamental importance in that respect, as is the research that informs education.
- Environmental research in the universities will be organized to train scientists, engineers, and social scientists for industry and commerce, nongovernment organizations, and the research enterprise itself. A successful program of national research will keep American research universities and professional schools among the world's leaders in environmental science and scholarship.
- Environmental studies by government and by the private sector will be synergistic and complementary, enlarging the store of knowledge in a cost-effective way. In pollution prevention in manufacturing firms, for example, private-sector research naturally complements public policy. As

business does work that it is suited to carry out–protecting proprietary information in the course of learning how to reduce or eliminate pollution in production processes–so government should pursue its comparative advantage, for example, through studies aimed at lowering the burdens of regulatory compliance while continuing present levels of regulatory protection. As government assembles environmental data in forms usable by citizen groups, so environmental organizations should experiment with ways to improve citizens' understanding of the complexities of risk analysis and enrich concerned citizens' grasp of the varied contexts in which risks can be presented.

- Environmental research will contribute to economic prosperity in four ways. First, in accounting terms, technological advances in pollution control, environmental management, and spinoffs from environmental research will increase business opportunities for American industry in domestic and international markets. Second, in qualitative terms, improved policies, management methods, and voluntary changes in behavior will drive down the cost of environmentally sound outcomes and raise the quality of the environment for a given level of expenditure. Third, long-term changes in cultural values, informed and stimulated by environmental research, could shift the definition of prosperity away from material consumption and toward other forms of human fulfillment that might be more sustainable. Fourth, environmental research will save the raw materials and ecosystem services on which humankind depends.

5

RECOMMENDATIONS

The committee reached two fundamental conclusions–that *cultural changes* must be made in the nation's environmental research programs, regardless of how these programs are organized, and that *organizational changes* would facilitate the implementation of the cultural changes. The committee uses the term *culture* to refer to the institutionalized beliefs, values, policies, and practices that characterize the administration of an agency's environmental research program and the nation's overall effort. For example, it refers to an agency's use of intramural research versus extramural research and to an agency's focus on mission-oriented research, rather than on research with potentially broader applications. With respect to a national environmental research program, it refers to the development of agency research programs with minimal reference to the cognate work in other agencies and with minimal consideration of the fit of the research in a coordinated national effort to address environmental problems.

We believe that our recommendations for changes can improve the effectiveness of our environmental research effort, no matter what new organizational arrangements might be made. Implementation of the cultural changes should be systemic, that is, they should used throughout the government environmental research system.

The committee presents its recommended cultural changes and four organizational frameworks to implement them. Framework A, current agency structure with enhancements, preserves in large part the identity and functions of existing agencies, but adds some new offices that are essential if the desirable characteristics stated in Chapter 4 are to be put into effect and the critical cultural changes implemented. Framework B is the proposal of the Committee for the National Institute for the Environment that our committee considered as part of our charge. Framework C is a different institute as visualized by our committee–a National Institute for Environmental Research. Framework D is a Department of the Environment.

In describing the cultural and organizational changes, we have avoided details because the legislative and executive branches that have the responsibility and authority to act on the suggestions for change should decide on the details. We have tried to convey the reasoning process that began with an examination of current federal environmental research, proceeded to a description of the desirable characteristics of a program, and concluded with recommended cultural and organizational changes required to achieve the desirable characteristics. We hope that the reasoning will inform the national discussions about how parts of the federal government could be organized to address the aggregate environmental issues facing the nation today. A concluding section of this chapter describes the advantages and disadvantages of the organizational frameworks.

The following are the committee's two chief recommendations:

> The cultural changes in the nation's environmental program described below must be implemented if today's and tomorrow's environmental problems are to be addressed. The cultural changes are required, regardless of which organizational structure is decided on.
>
> At a minimum, Framework A (current agency structure with enhancements) should be implemented. If the nation is to make marked improvements in the quality and strength of its environmental research and policy, we urge that the Department of the Environment described in Framework D be established.

CULTURAL CHANGES

The cultural changes we recommend will strengthen the nation's environmental research, correct specific weaknesses, and recognize that research should enlarge our comprehension of and ability to observe the components of the environment, deepen our understanding of how transfers of energy and materials occur among components, and improve our knowledge of the interactions among components. Fundamental advances in knowledge and understanding are needed to grasp and solve urgent environmental problems.

Chapter 4 describes the desirable characteristics of an effective national environmental research program. These desirable characteristics were used by the committee as it defined the necessary cultural changes. Among the most important expectations are a focus on protection, restoration, and management of natural resources as the critical directions for environmental research; improvements in how environmental research is approached, for example, through an understanding of fundamental processes and multidisciplinary and multiscale research strategies; high-level commitment to and coordination of federal environmental research; a national agenda or plan for environmental research; a data-collection and data-management system supporting a continuous and integrated program to measure status and trends in the nation's and world's environmental condition; a strong linkage between environmental research and policy; and a mechanism to make environmental information easily and widely available.

RESEARCH DIRECTED TO PROTECTION, RESTORATION, AND MANAGEMENT

Our recommendations for environmental research are predicated on the goal of sustainable environmental and economic systems. We can achieve this goal through *protection* of resources so that they will not be damaged and become unavailable for use, through *restoration* of resources that have been mismanaged and damaged, and by taking responsibility for *management* of resources, including natural, economic, cultural, and human resources. Reliable information must be obtained if we are to make the best decisions about how to protect, restore, and manage resources, and this information can be obtained from an environmental research program that meets the recommendations in this report.

> The committee recommends that environmental research advance the social goals of *protecting* the environment for present and future generations, *restoring* damaged environmental functions so that they are once more ecologically productive, and *managing* our natural, economic, cultural, and human resources in ways that encourage the sustainable use of the environment.
>
> In advancing those three goals, environmental research should, first, collect and analyze information needed in and outside government to pursue the goals; second, improve our knowledge of the fundamental processes that shape the natural world and the human behavior that affects that world; and, third, apply the knowledge to solving environmental problems with a comprehensive management strategy in the context of economic and social needs.

The terms *protection, restoration*, and *management* refer to *directions* in which environmental action should proceed; they should not be taken to imply absolute goals.

NATIONAL-LEVEL LEADERSHIP AND COORDINATION

Setting the directions for environmental research and coordinating responsibilities among various federal agencies must be done at the executive level because it is of national importance. This setting of national directions must include not only the presence of an official at the highest level of the administration, because it is a national priority, but also the participation of those who are responsible for the agencies that will be conducting the federal program. Because the federal program will operate within the context of the entire national environmental research program, which must include the efforts of state governments and the private sector, and because the program must be ultimately accountable to and responsive to the public, there should also be linkages to these communities, perhaps through a system of advisory committees.

> The committee recommends the establishment of a *National Environmental Council* in the executive office of the president to be chaired by the vice president. It should be composed of the heads of the federal environmental agencies. Advisory committees for the council should be established to represent the scientific community, the public, state government and the private sector. The council should provide national leadership and coordination among the federal agencies for environmental research and oversee implementation of the National Environmental Plan.

NATIONAL ENVIRONMENTAL PLAN FOR RESEARCH

There are many potential demands on the nation's resources and many competing ideas about relative priorities for a program of environmental research. Duplication of effort or omissions in a research program can occur in an effort as important and complex as environmental research. A number of constituencies have a right and deserve to play a role in setting the priorities. We believe it is essential to have a comprehensive national plan for environmental research.

> The committee recommends the development of a *National Environmental Research Plan* that will form the basis for coordinating environmental research responsibilities of federal agencies. The plan, which identifies the nation's environmental research agenda and the responsibilities of the individual agencies, should be updated every 2 years and comprehensively reconsidered every 5 years in the expectation that it will evolve. The National Environmental Council should take primary responsibility for ensuring that the plan is developed. In doing so, it should reach out, through the use of appropriate advisory committees, to the states, the private sector, nongovernment organizations, and the academic research community to ensure their participation in developing the plan and thereby to encourage them to participate in implementing it.

Our plan differs from the National Environmental Strategy recommended by the National Commission on the Environment (NCE, 1993) in that the latter focuses on policy issues, such as economic incentives to improve the environment, whereas our plan concentrates solely on research. The two might be used to complement one another.

LINKAGE OF ENVIRONMENTAL RESEARCH AND POLICY

Among the most important roles of environmental research is creation of a foundation of sound information on which to base the policies that are necessary to protect, restore, and manage the nation's environmental resources. However, the link between environmental data and information and their use in decision-making is now weak within agencies and almost absent when larger issues that cross agency boundaries are in question. Linkages between science and decisions need to be strengthened at both levels. It would be highly advantageous to establish a two-part effort to ensure that the best scientific information is translated into strong and defensible policies for protection, restoration, and management. The two-part effort would be in addition to the present case, in which each federal agency assesses environmental data to develop policy applicable to its own mission needs.

> We recommend the establishment of an *Environmental Assessment Center* in which large environmental issues that cross

agency mission boundaries can be assessed and policy options developed.

We recommend that an official (and staff) of this center serve as an environmental "intelligence officer" whose task will be to convey the policy options to decision-makers in the National Environmental Council, to Congress, and to other involved parties. It would be advantageous if the center were represented also on the president's National Security Council and Economic Council, in recognition that decisions on environmental issues strongly influence national security and the national economy.

PERFORMANCE OF ENVIRONMENTAL RESEARCH

Fundamental changes must be made in how environmental research is conducted and used within the federal research enterprise.

We recommend the following essential changes to strengthen the nation's environmental research:

- **Fundamental advances in understanding and in factual knowledge are needed if we are to grasp and to solve urgent environmental problems. Research should enlarge our comprehension of and ability to observe the components of the environment, deepen our understanding of how transfers of energy and materials occur among those components, and improve our knowledge of the interactions among components.**
- **The current strength of disciplinary research must be maintained, but more research must be multiscale and multidisciplinary to match the characteristics of the phenomena that we seek to understand. Research must cross the boundaries of mission agencies for the same reason. It must be international in scope, foster collaboration between public and private sectors, and include the valuable contributions of state environmental organizations and nongovernment organizations.**
- **Research must be economical. It must be of high quality. It must have stable funding bases. It should be pluralistic in approach and be supported by multiple funding strategies with proper regard for balance between intramural and peer-reviewed extramural support. It must provide for the support and training of the next generation of scientists while providing for appropriate**

development of instrumentation and facilities for research. Only in that way can the nation's environmental research be efficient in solving problems and effective in contributing to international competitiveness and economic strength.

DISCIPLINARY BALANCE

As environmental research has evolved, substantial imbalance in emphasis has developed. Physical-science research has been emphasized to a greater degree than biology, and both the physical sciences and biology have fared better than the social sciences and engineering. We believe that a more balanced program will be important in the future. Although imbalance in funding patterns is evident, we are concerned primarily about asymmetry in program emphasis and in intellectual leadership.

The case for more emphasis on biology is clear. We have a modest understanding of the physical environmental world, but we are only beginning to understand the fragile biological world and our interactions with it. The role of biodiversity and the potentially serious consequences of its loss are only beginning to be perceived. Loss of species that we depend on for the flow of environmental goods to feed, clothe, and warm us has the potential to threaten human life itself. We must do more to understand these problems.

The case for the social sciences is also clear. It is humans who damage the environment, and it is humans whose reactions determine the success or failure of laws and regulations designed to protect the environment. Until we understand human actions and interactions sufficiently to guarantee the success of environmental protection and restoration measures, we will not know how to design these measures. Furthermore, the overwhelmingly complex problems of designing sustainable economic-development policies must be solved before the developing world can enjoy our standard of living without destroying the environment the world over.

The case for environmental engineering is evident in the economics of environmental remediation and restoration, if nowhere else. With chemical and radiological hazardous-waste cleanup estimated to cost many billions of dollars, with inadequate technologies available for that cleanup, and with inadequate research seeking better technology, the need for attention to environmental engineering is obvious.

The committee recommends that all relevant environmental disciplines be supported and that additional emphasis be placed on the biological and social sciences and on engineering.

MULTIDISCIPLINARY BALANCE

Research on environmental phenomena has depended heavily on disciplinary research to study individual components of the phenomena with well-established disciplinary methods. The clear value of this approach is well appreciated, and it must certainly be continued. However, biological and physical processes and functions within environmental systems often depend on separate but interacting phenomena that work across disciplinary boundaries and across different spatial scales–from the molecular and cellular to the environmental landscape–and varied time scales from rapid chemical reactions to long-term biotic and abiotic effects. A more complete understanding of environmental processes will depend on examining the interactions of myriad biological, physical, and social events. Often that will require knowledge from different disciplines. For example, the physical phenomena of variations in ion transport and balance in porous media, such as soil, influence the physiological characteristics of a microorganism; understanding of bacterial ecology will depend on understanding of the physical factors that influence the bacteria. In many cases of environmental research, multidisciplinary studies are essential for addressing problems that extend across disciplines and across different spatial and temporal scales.

> The committee recommends continued emphasis on disciplinary research supporting the protection, restoration, and management of ecological systems resources and increased emphasis on interdisciplinary and multidisciplinary research with the same goals.

MISSION-AGENCY BALANCE AND USE OF EXTRAMURAL FUNDING MECHANISMS

Mission and sector agencies that have environmental responsibilities should themselves carry out environmental research of sufficient quality, amount, and kind to support their agency goals, to permit them to collaborate with other agencies that have environmental responsibilities, and to keep the agencies alert to and applying the findings of environmental research from all sources. Some agencies conduct research largely intramurally. Some (for example, the Department of Defense, the Department of Energy, and the Environmental Protection Agency) contract extensively with extramural institutions other than colleges, universities, and research institutions. The committee believes that there would be major advantages of placing additional emphasis on support of extramural research at the nation's academic research institutions. They have shown themselves to be exceptionally productive partners in conducting research. More advantage should be taken of the nation's academic researchers in performing environmental research. The effective and proven procedures used by the National Institutes of Health and the National Science Foundation are models for how awards to these investigators might be decided on.

> The committee recommends that mission and sector agencies substantially expand their extramurally funded research programs, creating such programs where appropriate. These should provide maximal opportunity for the nation's academic and other nonfederal researchers to avail themselves of national environmental research opportunities. The principles of competitively awarded, peer-reviewed, investigator-initiated awards should be applied.

CONTINUOUS MONITORING OF THE NATION'S ENVIRONMENTAL STATUS

The United States has a wealth of natural resources. Although this wealth must be used to support the quality of human life, the use of the resources must be managed in a way that they are sustained for future generations. It is therefore necessary that we know the status of and changes in the resources if we are to protect, restore, and manage them. Many agencies have legal responsibility for different components of the resources, so it is necessary to have a coordinated program among the agencies for measuring the status and trends of the resources.

> We recommend the initiation of the *National Environmental Status and Trends Program* to be coordinated by the National Environmental Council to function as an integrated cooperative program among the federal agencies to inventory and monitor the status and trends of the nation's natural resources. A national biological survey of appropriate scope would be a valuable addition to the existing programs and an important component of the status and trends program.

ORGANIZING ENVIRONMENTAL INFORMATION AND MAKING IT AVAILABLE

Information is the currency of a strong environmental research program that will inform the best policies and practices for protecting, restoring, and managing the nation's resources. Increasing technological developments have increased our ability both to collect information and to manage it. Many agencies, individuals, and institutions contribute to the ever-increasing amount of information. There must be a system to organize and manage this information and make it available for the integrated use of the biological, physical, social, and engineering sciences. The details of such a system are in Chapter 4.

> We recommend the establishment of a *National Environmental Data and Information System* to be coordinated by the National Environmental Council and conducted by the federal agencies with the best available technology to collect and make available and easily accessible a wide range of environmental data from the biological, physical, social, and engineering sciences.

ENVIRONMENTAL EDUCATION AND INFORMATION

The importance of developing sustainable environmental systems for future generations–and thus for making the best decisions for protecting, restoring, and managing these resources–is so great that both this generation and the coming ones must be informed. Educational opportunities must be provided at every level from kindergarten to graduate school. Citizens who know more about the environment can play a more useful role in solving environmental problems. Moreover, environmental research that will provide the base for the decisions requires sophisticated scientists with expertise in disciplinary and interdisciplinary science.

> We recommend that programs be established, and present ones expanded, for educating the next generation of environmental scientists and engineers and developing increased understanding of environmental issues in the general population and that information about environmental matters be built into educational programs at all levels.

ORGANIZATIONAL CHANGES

Implementation of the cultural-change recommendations listed above is imperative, regardless of which organizational changes are made in the federal structure for the administration of environmental research. The cultural changes will go far toward improving protection, restoration, and management of our resources. Organizational changes can enhance the implementation of the cultural changes. Framework A conserves the current configuration and structure of federal agencies and adds offices to enhance the ability to implement the cultural changes, but it does not meet all the needs for the future. Framework D is a Department of the Environment that does meet those needs. Frameworks B and C are included in this discussion to show the spectrum of alternatives considered by the committee.

FRAMEWORK A: CURRENT AGENCY STRUCTURE WITH ENHANCEMENTS

Description

The object of Framework A is to conserve the identity and placement of federal agencies; that is, no far-reaching *organizational* change in federal-agency organization is called for. Nevertheless, the cultural changes recommended above must be instituted if the nation is to improve its ability to address pressing environmental problems, and several essential new offices are recommended in Framework A to perform functions required to implement the cultural changes. With refinement and strengthening of the individual federal agencies' programs, full implementation of the cultural changes will lead to substantial improvements in the nation's environmental research program.

Agencies Incorporated

By definition, Framework A conserves the current organizational structure of the federal agencies. No major organizational alterations are required.

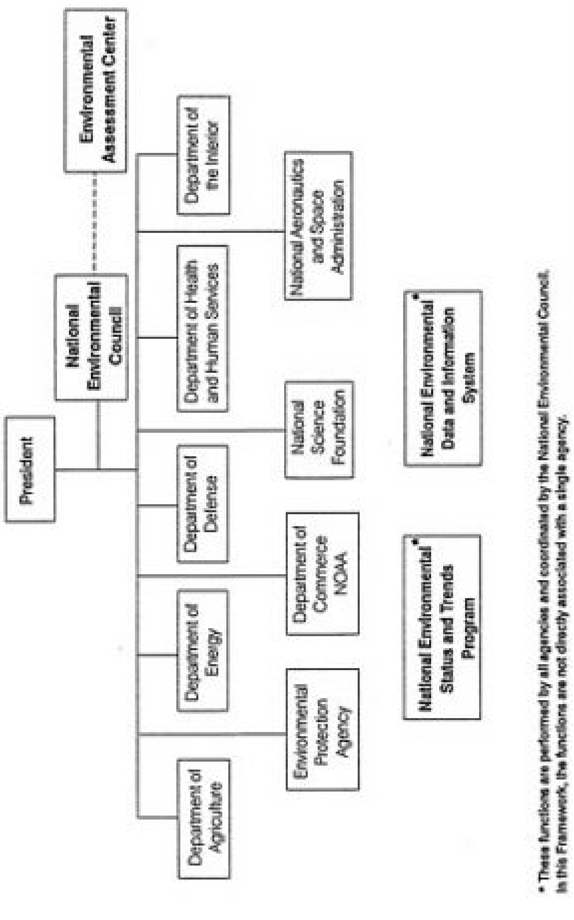


Figure 1 Framework A: Current agency structure with enhancements.

Relationships Among the Agencies

Framework A, to a greater extent than any of the other frameworks, requires the existence of a National Environmental Plan (NEP) and a National Environmental Council (NEC). The success of this framework depends on coordination of effort among agencies; no new agency with a single focus on the environment is created. It would be the responsibility of the NEC to ensure that the agencies cooperate and coordinate their efforts so that they have the following characteristics.

The offices within the U.S. Department of Agriculture (USDA), the National Aeronautics and Space Administration (NASA), the Department of Defense (DOD), the Department of Energy (DOE), the Department of Health and Human Services, and the Department of the Interior (DOI) that are involved in environmental research would be encouraged, under the direction of the NEC, to focus on the environment to a greater degree and to adopt the cultural changes that we have recommended. The National Oceanic and Atmospheric Administration (NOAA) and the Environmental Protection Agency (EPA), whose programs are already focused on the environment, would continue to play a large role in the coordinated program.

Many missions overlap among current agency assignments for environmental research. There are also gaps–subjects not adequately addressed–and cases where agencies are not properly staffed or supported to meet their environmental responsibilities. The NEC should seek to eliminate duplication of effort among the various sector and mission agencies and, where work along similar lines is necessary for the individual missions, to ensure that work is well coordinated. Monitoring activities–such as EPA's Environmental Monitoring and Assessment Program, the National Science Foundation's (NSF's) Long-Term Ecological Research program, and DOI's Gap Analysis Program and U.S. Geological Survey (USGS) programs–could be better coordinated to increase their combined value for understanding environmental status. Environmental-engineering research and remediation and restoration activities are distributed among DOE, DOD, DOI, EPA, and NSF; far greater integration of their efforts should be achieved.

Basic-Research Emphasis

Each agency would be expected to increase funding for investigator-initiated extramural research projects relevant to its mission. Some agencies, such as NSF, would have increased resources for supporting and leading the basic-research effort at the national level and for developing infrastructural elements, such as education, training, and facilities. The NSF effort is critical to basic research, especially in biology, social sciences, and engineering applications.

Monitoring

Each relevant federal agency should recognize that monitoring the status and trends of natural resources is of such a high priority that programs to accomplish that should be planned and supported. Under the guidance of the NEC, the agencies could devise mechanisms for ensuring that the results of their individual research programs were shared to construct a set of national cumulative databases available for use and interpretation by all agencies. The National Environmental Data and Information System and the National Status and Trends Program described in Chapter 4 could serve as foci for individual agency efforts for the collection and standardization of data relevant to monitoring the status and trends of environmental resources.

Education and Training

Each federal agency should take seriously its responsibility to provide environmental education and training programs. In developing these programs, interagency mechanisms would be established for coordination among and between the agencies and the Department of Education and the NSF Education Directorate. Each federal agency involved with environmental research would be expected to assess the support structure and services provided for environmental research within it and for collaborative research programs with the academic, industrial, and international research communities. Useful models of support for training are the graduate-student support, postdoctoral-fellowship, and career-development programs of the National Institutes of Health that have been so successful in producing highly skilled biomedical scientists.

Education programs at the precollege and undergraduate levels are important to educate an informed populace that can understand and participate in making decisions on complex environmental issues. Each agency must initiate or expand current education programs.

Linkages of Agency Programs to Nonfederal Parties

Environmental research today often depends on sophisticated analytical technologies and techniques for managing complex databases. In many instances, these technologies can be shared and the analyses improved with the participation of nonfederal parties, such as state and local governments and industry. Each agency should be expected to develop programs for involving the academic, industrial, and international research communities in cooperative and integrated environmental research programs.

National Science Foundation

NSF would continue to provide the primary support for basic environmental research. Given a substantially increased budget and responsibility to identify gaps in the programs of departments and agencies, it could help to fill the gaps by initiating programs on its own or by reporting the gaps to the NEC and suggesting actions to remedy them.

National Oceanic and Atmospheric Administration

It has been suggested that NOAA could be a more effective performer of environmental research and be in a better position to defend its budget requests before Congress if it were an independent agency. The proposal has merit, but the committee believes that the advantages of making NOAA an independent agency would be only marginal in Framework A because NOAA would still be one of many agencies with relatively small parts of the responsibility for environmental research. Nevertheless, NOAA's contribution to environmental science is substantial, and the agency should be given the resources to continue to be an important partner in the overall environmental research enterprise.

Environmental Protection Agency

EPA must be encouraged and receive the resources to support a strong research program to develop and provide the information necessary for promulgating rational and defensible environmental regulations. If EPA is to play a more central role, it must be successful in implementing changes suggested in the report *Safeguarding the Future: Credible Science, Credible*

Decisions (EPA, 1992a). Implementation of that report's recommendations would substantially improve the science base at the agency and increase its credibility. The committee believes that the many laws enforced and regulations promulgated by EPA dominate the attention and budgetary decisions of the agency's personnel and make the development of high-quality research programs difficult. Steps should be taken to separate the research and regulatory functions within EPA, so that the research program can grow to provide the necessary science base on which to justify rules and regulations. If the legislation to elevate EPA to department status now being considered by Congress is enacted, it will be particularly important that the new department seriously consider how it might change its approach in accord with the above suggestions.

Other Agencies

As an example of the participation of other agencies, the National Park Service, because of its unique environmental resources for research, would participate in the nation's research program while continuing to develop strong research-based management programs for protecting the integrity of the parks. All agencies would work to reduce intra-agency conflicts that result from mixing concerns for environmental use with concern for protection, for example, in timber harvests of the Forest Service and mining and drilling leases by the Bureau of Mining and Mineral Services.

Mission agencies are important to the success of any federal environmental research program because of the research related to their missions and because they support environmental research programs. In practical terms, that means that agencies should organize their research programs to contain a reasonable balance between directly mission-oriented research and research that meets the criteria of research support in keeping with the recommended cultural changes. A major goal of the NEC should be the encouragement of mission-oriented agencies to develop research programs that both serve their mission goals and add to the store of knowledge about the environment in general.

This country has several hundred federal laboratories, including DOE's contractor-operated national laboratories and laboratories with strong relevance to environmental research that are managed by DOI, USDA, and EPA. Coordination efforts should be directed to using the talents and expertise in these laboratories as part of a system to improve environmental research. Several bills have been considered in Congress to create environmental technology centers at the DOE national laboratories. Those and other creative uses should be encouraged under the direction of the NEC as it implements the National Environmental Plan. Use of the DOE national laboratories to create and develop technologies that contribute to innovations for management of natural resources is an especially attractive possibility.

Implementation of the Cultural Changes

Research on Protection, Restoration, and Management

It must be clearly understood that every agency, as it fulfills its mission imperatives, needs to direct its research also to protection, restoration, and management for sustainability. Each agency must approach the research with the aim of gaining understanding through the study of the fundamental components of the environmental systems that it studies, the flows of material and energy between the components, and how components interact. Every agency must try to implement the cultural changes we have recommended.

National Environmental Council

The creation of the NEC is essential. Because of its high-level leadership, its membership of department secretaries, and especially its single focus on the environment, the NEC should be more effective in broadly coordinating federal environmental research than the Federal Coordinating Council on Science, Engineering, and Technology, which has many interests to attend to while the NEC has one–the environment.

One of the NEC's functions would be to coordinate priority-setting for programs and, later, priorities for expenditures among agencies. It would also recommend expenditure levels for environmental research programs. Once high-priority research topics were identified, a process similar to the submission of the current cross-cut budget for the Global Change Research Program to the Office of Management and Budget would be implemented. Advisory mechanisms would need to be used to involve the broader scientific community in developing the details of the environmental research program.

National Environmental Plan

The NEP will provide a map of routes toward goals to which all involved agencies will dedicate some part of their efforts; the NEC will be the driving force to achieve those goals. Without an agency assigned to be the primary focus for environmental research, there is no natural home for programs on environmental status and trends or for data management. Therefore, the NEC must encourage coordination of the work of many individual agencies in these fields to ensure that the cultural changes come into being.

Environmental Status and Trends Program

The NEC will coordinate an Environmental Status and Trends Program, as included in the cultural changes needed in the nation's environmental program.

National Environmental Data and Information System

The NEC would ensure that the National Environmental Data and Information System is created. Programs now conducted by NOAA, NASA, USGS, DOI, EPA, and the Smithsonian Institution might be the beginning points for creation of the system. Success of the system would depend on the ability of agencies to work together under the direction of the NEC. The identification of a lead agency would enhance the chances that the program would be successful.

Environmental Assessment Center

The connection between research results and policy decisions would continue to be a responsibility within each agency in Framework A. Agencies would focus on improving their mechanisms for collecting information relevant to developing policies within their missions, for assessing the consequences of policy frameworks in keeping with the information base, and for providing information and the associated policy analyses to the appropriate decision-makers.

The Environmental Assessment Center (EAC) would play an important role as the assessor of data on large issues that cross agency boundaries. The EAC would be responsible for communicating the results of its assessments to the NEC and Congress.

FRAMEWORK B: THE NATIONAL INSTITUTE FOR THE ENVIRONMENT AS PROPOSEDBY THE COMMITTEE FOR THE NATIONAL INSTITUTE FOR THE ENVIRONMENT

Description

Framework B is a paraphrase of the proposal of the group of independent scientists who formed the Committee for the National Institute for the Environment (CNIE). The following description of the CNIE proposal is abstracted from the latest information available to the present committee at its last meeting and dated December 8, 1992. The full contents of the December 8, 1992, CNIE letter to this committee (with organizational charts) is in Appendix C to this report. The CNIE proposal continues to evolve; a later version received in January 1993, after this committee's last meeting, contains ideas not reflected below. Consideration of the CNIE proposal was a basic element of the charge to our committee.

The CNIE proposal calls for the establishment of a federal science agency, the National Institute for the Environment (NIE), focused exclusively on environmental research, assessment, information management, and higher education and training. The CNIE believes that NIE is needed because existing agencies and organizations are not meeting critical environmental needs and that NIE would complement and strengthen the existing efforts.

The mission of NIE "would be to improve the scientific basis for making decisions on environmental issues." To fulfill this mission, the agency would have the goals of

- Research to increase understanding of environmental issues by supporting credible, problem-focused interdisciplinary research.
- Comprehensive assessment of current environmental knowledge to enhance decision-making.
- Enlarging access to environmental information and improving communication of scientific and technological results.
- Education and training to strengthen the capacity to address environmental challenges by sponsoring higher education and training in environmental sciences.

It would fund research organized in three broad categories: environmental resources, environmental systems, and environmental sustainability. Extramural-research awards would be made by a variety of mechanisms and based on peer review and competition. The CNIE believes that NIE should not duplicate existing agency prerogatives with large, in-house research laboratories.

Agencies Involved

NIE would be a new and independent agency and would not incorporate parts or all of any existing federal agency. It is intended to complement, not replace, the research of federal regulatory and resource-management agencies.

Relationship to Other Parties

The CNIE states that NIE's research and training mission would be guided by a governing body that is representative of major stakeholders, including government and nongovernment organizations, academe, and business. NIE would foster cooperation among those sectors in research, education, and training.

NIE would cooperate with international research and training organizations to assist in taking a comprehensive approach to cross-national and global environmental issues.

NIE, as conceived by the CNIE, would have no regulatory or resource-management responsibilities.

Agreement with Cultural Changes Recommended by our Committee

The CNIE's call for better integration of basic and applied science, more extramural research and training, interdisciplinary problem-solving, a comprehensive environmental information program, and an international component to address global changes parallels the recommendations of this committee.

The CNIE plan includes an NIE Office of Assessment and Evaluation to provide continuing assessments of environmental knowledge on particular issues to ensure that decision-makers have access to "user-friendly" alternative interpretations of the implications of results of environmental research.

The CNIE also proposes the establishment of a National Library for the Environment that would cooperate with other groups concerned with environmental information systems and with evaluating the quality of environmental data in databases. The NIE system appears similar in intent to that of the

National Environmental Data and Information System that our committee has described.

No provision is made for the development of a National Environmental Plan to coordinate the efforts of the various parts of the federal government, nor is there a clear indication of a provision for national leadership of the environmental effort.

FRAMEWORK C: A NATIONAL INSTITUTE FOR ENVIRONMENTAL RESEARCH

Description

Framework C is a research institute as defined by this committee. The major organizational innovation in this National Institute for Environmental Research (NIER) is a coherent research program that addresses protection, restoration, and management of resources, as defined in Chapter 4. The institute we suggest is different from the institute proposed by the Committee for the National Institute for the Environment in some fundamental ways. In particular, creation of this committee's NIER would be coupled with the reduction or incorporation of some other federal agencies' functions. As mentioned above (Framework B), the CNIE proposes a new agency that would complement existing agencies, but not encompass them.

Because no agency focuses on environmental research to the exclusion of other missions, such as land management or regulation, there is no institutional home, comparable with the National Institutes of Health for human health research, for the nurturing of environmental science. NIER would provide such a home. It would also attend to such issues as training of graduate students and postdoctoral fellows, development of young investigators, research support for environmental scientists, information management, large-scale programs for monitoring the environment, and formation of relationships among academe, industry, and government for the performance of research.

The institute would be a new, nonregulatory, federal granting agency organized around the mission of understanding the elements of our environment and its processes and fostering research on protection, restoration, and management of resources. It would be the only U.S. agency with a primary objective of sponsoring a coherent program of mission-oriented fundamental and applied environmental research, education, and training directed to protection, restoration, and management of resources. The existing agencies would continue to have major land-management responsibilities,

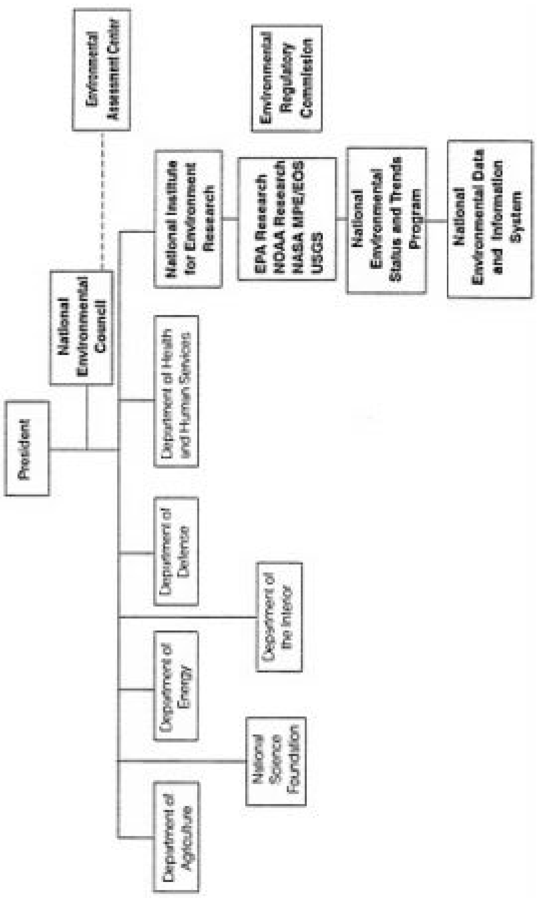


Figure 2 Framework C: A National Institute for Environmental Research.

and they would benefit from the information gained from the environmental research program undertaken through the institute.

Present government agencies, such as the National Science Foundation (NSF), support research that seeks basic knowledge. Subject-specific agencies, such as the U.S. Department of Agriculture (USDA) and the Department of Energy (DOE), support research that applies to problems of the environment, but they are not centered on the environment. In contrast, research sponsored by NIER would seek to understand environmental processes and the interactions of people and the environment so that lasting solutions could be developed.

Agencies Incorporated

The research functions of several existing agencies with missions and responsibilities in protection, restoration, and management of resources would be combined in NIER. At its creation, the institute would encompass almost all the National Oceanic and Atmospheric Administration (NOAA) and U.S. Geological Survey (USGS) research; the part of the National Aeronautics and Space Administration involved in environmental research, in particular the Earth Observing Satellite/Mission to Planet Earth program; and the research component of the Environmental Protection Agency (EPA), but not EPA's regulatory functions. The activities of those individual agencies in monitoring, protecting, and providing the fundamental knowledge about means to restore environmental resources should be enhanced by their association in an integrated research institute. The combination of the agencies allows coverage of atmospheric, oceanographic, terrestrial, engineering, and to a smaller extent social aspects of the environmental sciences. The monitoring and data-handling expertise of NOAA and USGS would eminently qualify the institute to be the focus of efforts to follow status and trends in the environment. EPA's monitoring programs would provide an added dimension. National laboratories could be associated with NIER (especially EPA laboratories involved in environmental engineering and DOE national laboratories) to create strong foci for approaching environmental technology questions.

Relationship to Other Agencies

Because of the uneven distribution of disciplinary environmental research across the various federal agencies and the concentration of biological research in the land-management agencies and USDA–which are not part of the institute described here–the National Environmental Council must coordinate the work of NIER and the excluded agencies to ensure that there are opportunities for interdisciplinary research.

NSF would expand its support of basic research related to the environment. Additional funds provided in the NSF budget for support of all environmental fields–but especially biology, environmental engineering, and social sciences–would lead to the production of data of immediate and long-term use by NIER.

Mission-oriented agencies would continue their traditional work but, under the National Environmental Plan (NEP) and the NEC, would be encouraged to focus to a greater extent on research that would enlarge general knowledge about the environment, as well as satisfying their mission needs.

Land-management agencies must continue to measure environmental status and trends; however, these agencies could provide a broader array of measurements that, with coordination among other agencies, would increase completeness of a database and diminish unnecessary duplication. It would be the responsibility of the NEC to ensure that the land-management agencies participate in the status and trends activities in a coordinated approach.

The large number of regulatory functions of EPA and the few regulatory functions assigned to NOAA might be combined in an Environmental Regulatory Commission that would be independent, not part of NIER. A model for such an entity is the Nuclear Regulatory Commission.

Implementation of the Cultural Changes

Research Focus on Protection, Restoration, and Management of Resources and Research Performance Characteristics

The focus on protection, restoration, and management of resources addresses a set of critically important and broad scientific, social, and economic issues concerning the environment. Such sites as wetlands and coastal borders must be protected or restored to ensure their role in providing life-support systems for economically and ecologically important resources. Remediating toxic-waste sites, nuclear facilities, and military sites might cost as much as $2 thousand billion. Public concern about exposure to toxic substances emphasizes the important role proposed for the institute in risk assessment, communication of results of risk assessment, and education. Addressing those issues requires the involvement of the full range of environmental disciplines, including the physical, biological, social, human health, and engineering sciences. Addressing resource-management issues will require close attention to the integration of the natural, biological, engineering, and social sciences.

Specific Research Fields

Several fields of research warrant special attention. Among them is human-factors research. Because human behavior and institutions are major agents of environmental stress, the study of behavioral factors would be an integral function of the institute and would have to be organized along the general lines set forth in our recommended cultural changes. Also worthy of special note is environmental protection and restoration research, which includes research in waste remediation and other large-scale engineering issues and has received insufficient attention. Such engineering research holds the promise of large economic benefits. Estimates of costs to clean up contaminated environments with currently available technologies run into many billions of dollars. That highlights the value of research designed to reduce further pollution and the need for more efficient and less expensive methods to restore contaminated environments. Furthermore, few methods are available to restore degraded wetlands and grasslands to their former productive states.

National Environmental Council and National Environmental Plan

The NEC and NEP are critical for the successful operation of Framework C. NIER would play a central role in environmental research, but many subjects in the environmental sciences would not be within its domain, and coordination among the institute and other federal agencies would be essential. The NEP would recognize the role of the institute in the overall national and international framework, and the NEC would have a major role in influencing coordination efforts among NIER and other agencies involved in the overall NEP.

National Status and Trends Program and National Environmental Data and Information System

The creation of NIER would facilitate the integration of the National Status and Trends Program and the National Environmental Data and Information System (described in Chapter 4 and included among the essential cultural changes required) as components of a complete program for environmental study and policy-setting. The institute is a natural home for both these entities.

Environmental Assessment Center

The Environmental Assessment Center, performing the functions described previously, would be established as a separate entity.

FRAMEWORK D: A DEPARTMENT OF THE ENVIRONMENT

Description

Framework D is a Department of the Environment. The department we recommend would include the Environmental Protection Agency (EPA) but is *not* created by the elevation of EPA to cabinet status. Rather, the recommended department would have a character that derives from the research orientation of the National Oceanic and Atmospheric Administration (NOAA) and the strong and varied research and data-management programs of the other agencies to be included in the department. Furthermore, although the department would have a regulatory function, this activity would be clearly separated from the research and operational functions. The entity would be a fully functional department with research, regulatory, and operational arms and would have wide-ranging responsibilities in protection, restoration, and innovation for management of resources. It would be the focal point for initiating and performing international research projects and for developing U.S. positions for international agreements.

The department would have a research arm that incorporated the National Institute for Environmental Research (NIER) described in Framework C, a regulatory branch separate from NIER, and an operational part that would manage remediation and restoration activities for the nation and coordinate and facilitate a major program to promote innovation for management of natural resources. It would be responsible for identifying and setting priorities for protection and restoration needs, including waste sites, degraded habitats, and problems of global change ranging from greenhouse gas accumulation to biodiversity.

The research program would consist of a comprehensive approach to issues requiring integrated study of atmospheric, oceanographic, aquatic, and terrestrial processes and the expertise of physical, biological, and social

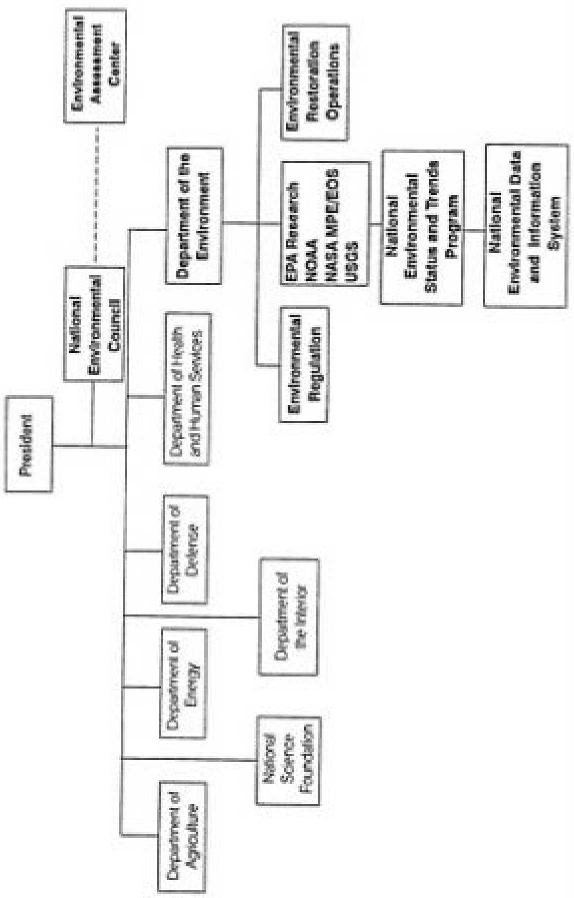


Figure 3 Framework D: A Department of the Environment.

scientists and engineers. Global change and biodiversity are both major concerns of the environmental disciplines in the physical, biological, and social sciences and engineering and could be the initial major interests of the research program of the department in the rubric of protection, restoration, and management of resources.

As in Framework C, special attention to human-factors research, biology, and engineering research is appropriate. The department, perhaps in association with the Department of Energy (DOE) national laboratories, would be responsible for research and development in environmental engineering appropriate to the problems of protection, restoration, and research relevant to management of resources. The department would also be charged with forming linkages with industry.

With coordination overseen by the National Environmental Council (NEC) and as a major implementer of the National Environmental Plan (NEP), the Department of the Environmental would be the leader in such matters as support of training and facilities for environmental research and for public information and education.

As head of a cabinet-level department, the secretary would be in a position to influence national policy and to serve as a senior member of NEC coordinating activities.

Agencies Incorporated

Because the department would manage the research programs described for the National Institute for Environmental Research (NIER) in Framework C, it would include all the research of the agencies specified for inclusion in NIER: NOAA; the U.S. Geological Survey, (USGS); and environmental research parts of EPA and the National Aeronautics and Space Administration). Service functions of such agencies as the weather service of NOAA and research and mapping services of USGS would be included in the department.

All nonresearch activities of EPA would be incorporated into the department. The regulatory functions of EPA and NOAA would be a part of the department, and those responsible for regulatory decisions would be able to draw on the knowledge derived from the research, monitoring, and assessment activities of the department to inform their decisions. The regulatory branch, the Environmental Regulatory Commission (ERC), would advise the department about necessary research and improve its regulatory role, but the ERC would be administratively separated from the research functions of the department.

Relationship to Other Agencies

Although the department would have a large and important role in environmental matters, its focus on protection, restoration, and management of resources would not encompass all environmental issues. In particular, the full range of resources management as administered by the Department of the Interior (DOI) would not be part of the department's mission. It would be essential for the department to coordinate its activities with those of other agencies to ensure that the nation's environmental programs is complete. For example, the National Science Foundation (NSF) must expand its support of basic environmental science, and the mission-oriented agencies must perform research that serves their missions and increases general knowledge about the environment.

The department would need to maintain close liaison with many other departments and agencies, including DOE, the Department of Defense (DOD), DOI, and the U.S. Department of Agriculture (USDA). The linkages and coordination could be effected through the NEC, but could also benefit from a focus on protection and restoration in the Office of Science and Technology Policy's Federal Coordinating Council on Science, Engineering, and Technology. Protection and restoration responsibilities are now spread among a number of agencies, many of which are not proposed for inclusion in this department. EPA is responsible for a broad array of activities, especially in preventing and cleaning up pollution, and these functions would be integrated into the department.

Each of the resource-management agencies not proposed for incorporation into the department engages in protection and restoration activities, including research. These include the Bureau of Land Management, the Forest Service, the Fish and Wildlife Service, the National Park Service, and DOD. The programs of those agencies need to be coordinated with the work of the Department of the Environment. Agencies with responsibility for resource management would maintain intramural programs of research and operations in protection and restoration for specific needs on the resources they managed. For example, DOD would continue to be responsible for cleanup of defense installations. Agencies with functions related to management of resources would continue to perform these functions but would coordinate their work with that of the Department of the Environment.

Agencies that engage in research on environmental engineering–such as DOE, NSF, and DOD–can increase the impact of their work by closer coordination of their efforts with those of this department, which already encompasses the engineering research of EPA.

Other agencies already have programs that contribute to our knowledge of how to enhance our ability to manage our natural resources. USDA has produced substantial improvements in agricultural productivity throughout its history and recently has been moving toward emphasis on long-term sustainable agricultural practice. DOI has focused on the management of public lands for economic production, e.g., grazing; the Tennessee Valley Authority, on regional economic development; the Bonneville Power Administration, on energy conservation and salmon rehabilitation; and the Department of Housing and Urban Development, on urban infrastructure, mass transportation, and other major public investments that represent environmentally responsible economic development. It is essential that those programs be coordinated with the work of the department.

Mechanisms must be put in place for the methods and technologies developed by federal programs (in association with the private sector) to be made available to industry; federal, state, and local agencies; and the general public. For example, techniques for habitat restoration will need to be made available to land-management agencies, such as the Forest Service and the National Park Service. Close cooperation must exist between research programs for the development of innovative approaches to managing natural resources and the industries that have common interests in this goal. Potential models exist in biomedicine (the National Institutes of Health technology-transfer program), agriculture (the USDA extension service), and technology (Sematech and the National Institute of Standards and Technology). Ideally, the model adopted would involve communication in both directions, providing information from users on issues in need of research and development.

Implementation of the Cultural Changes

Research Focus on Protection, Restoration, and Management of Resources and Research Performance Characteristics

The department would include the mission and functions described in Framework C for the National Institute for Environmental Research. Accordingly, it would have the same focus on protection, restoration, and management of resources and the same research performance characteristics as detailed in Chapter 4 and in the section of this chapter on cultural changes. We emphasize the need for a properly balanced program of support of intramural and extramural research that will guarantee a close association of the department with universities and other research performers.

National Environmental Council

The NEC would ensure coordination of research programs between the Department of the Environment and other agencies.

National Environmental Plan

The department, as a focal point for environmental programs, could serve as the developer of the NEP.

National Environmental Status and Trends Program and National Environmental Data and Information System

The National Environmental Data and Information System and the National Environmental Status and Trends Program described in Chapter 4 would be housed in the department. Most of the agencies now involved in gathering and managing environmental information would be incorporated into the department, and their location in one department might facilitate the missions of preparing status and trends reports and providing for an information and data network that enhances research, regulation, resource management, and policy formation. A national biological survey could be a major interest for the department and might be a cooperative effort between the department and the agencies, proposed for inclusion, such as USGS, and agencies not proposed for inclusion, such as DOI.

Environmental Assessment Center

The Environmental Assessment Center described earlier would not be part of the department. Rather, it would be so situated as to be able to draw on the information resources of the department and other agencies, such as those involved with human-health aspects of the environmental sciences, so that assessments and policy formation could take into account all information from the various centers of environmental science, regulation, and management. Effective assessments and policy formation can be performed only when they consider human-health, economic, and behavioral aspects of the focal issue with the natural-science and engineering aspects.

DISCUSSION OF THE FRAMEWORKS FOR ORGANIZATIONAL CHANGE

Because all the frameworks described above call for the implementation of the cultural changes recommended by the committee, we believe that any of them would improve environmental research and decision-making in the federal government. All frameworks would improve the use of existing research capabilities and would provide a focus for a national research effort on protection, restoration, and management of resources. The more ambitious and comprehensive alternatives entail substantial institutional and budgetary costs and are likely to encounter fiscal limitations, desires by interest groups and Congress to maintain jurisdictional authority and patterns of influence, and other barriers to adoption. The committee is also mindful of the hazards and transitional costs of government reorganizations–confusion, costs of changeover that will undercut government-agency effectiveness for some time, risks that long-term monitoring and other unfinished business will be lost, and strife within organizations as responsibilities are reapportioned and established organizational cultures are disrupted. If the more thorough rearrangements are judged to be worthy of investment–as the committee believes–Congress and the executive branch must provide clear mandates, adequate budgets, and political leadership, not only at the outset but for at least a decade.

CURRENT AGENCY STRUCTURE WITH ENHANCEMENTS (FRAMEWORK A)

Continuation of the current structure for managing the nation's environmental research program, with enhancements (creation of new offices and functions) that provide for the implementation of the cultural changes recommended by the committee, addresses some of the needs for a strong program in environmental protection, restoration, and management of resources. This framework is the least expensive to implement, would minimize disruption of existing agencies, and would create minimal political tension. It would also maintain the current diverse and pluralistic base of support for environmental research. For those practical reasons, the committee considers Framework A to be one of its primary recommendations for implementation.

The national environmental research program would be coordinated by the National Environmental Council (NEC), which would oversee the development of the National Environmental Plan and coordinate the research program of the agencies and a program shared by the federal agencies for assessing our natural resources through the status and trends program.

Environmental data and information would be managed more efficiently in the National Environmental Data and Information System (NEDIS). Connections between environmental research and policy would be made by enhanced mechanisms within each agency and by the establishment of the Environmental Assessment Center.

The success of this approach would depend completely on good-faith participation by the agencies and the effectiveness of the NEC in coordinating the activities of a large number of individual agencies. The council could create cross-cut budgets, following the model used by the Office of Science and Technology Policy in the Global Change Research Program. This process could be effective for selected, high-profile programs but might not suffice as a general mechanism for obtaining coordinated support for a wide variety of large and small research projects.

Expanded linkages with the business sector and enhanced education and training programs would remain the responsibility of individual agencies. The only provision for developing a comprehensive program of environmental protection, restoration, and management of resources would be the coordinating effort of the NEC, which could make recommendations to the agencies to focus their efforts on these research directions.

Among the existing agencies, the National Oceanic and Atmospheric Administration (NOAA), the Environmental Protection Agency (EPA), and the U.S. Geological Survey (USGS) are the most likely candidates under Framework A to serve as the home of the new Environmental Status and Trends Program and the NEDIS–two parts of the cultural changes recommended by the committee. Again, it would be the responsibility of the NEC to determine whether the lead for these two programs would be assigned to an individual agency or be a distributed responsibility among the agencies that is coordinated by the NEC. The figure representing the organizational arrangements for Framework A shows the two programs as free-standing to imply that they would not be assigned to a single agency, but would be operated by all the agencies under the coordination of the NEC.

Unless the NEC guides the program with a firm hand, it would be difficult under Framework A to implement the cultural changes related to improvements in how environmental research is performed and supported by the agencies, for example, encouraging each agency to support graduate training or to increase the amount of money awarded in extramural grants.

NATIONAL INSTITUTE FOR THE ENVIRONMENT (FRAMEWORK B)

The committee accepted that its central charge required a thorough analysis of federal environmental research from first principles. We began with that task, and only when we had a firm grasp on the current status of environmental research and the necessary elements of an environmental research program and had developed a series of hypothetical frameworks of our own did we include the National Institute for the Environment in the context of our broad review. Because the Committee for the National Institute for the Environment (CNIE) was going through a similar learning experience, testing its initial proposal against new ideas in an evolving political climate, the NIE proposal has changed greatly from the one that was presented to use at the beginning of our work. It is interesting to see the extent to which our Committee and the CNIE have converged on common themes.

We are favorably impressed with many aspects of the NIE proposal as it appeared at the end of 1992. The plan is a credible and effective view of a means to organize environmental research. It would enhance the nation's capability to perform environmental research and increase knowledge that will contribute to the solution of environmental problems. In particular, the NIE's recasting of its original five research institutes, which seemed arbitrary and overlapping to many, into three broadly functional questions–"What do we have? How does it work? How can we maintain it?"–is straightforward and focused. The NIE research components fit our proposed research directions: comprehension of the components of the environment, deepening of our understanding of transfers of energy and materials, and advancement of social goals of protecting and restoring the environment.

We agree with the CNIE that it is often wise to isolate the research process, especially the long-term exploratory research phase, from regulatory and management decisions, but we believe that specific research to solve immediate regulatory and management problems also has a place. NIE could focus needed attention on research that bridges the gap between the National Science Foundation's (NSF's) style of investigator-initiated fundamental research and other federal agency research directed at specific regulatory and management problems.

The NIE proposal attempts to structure environmental research in a way that will incorporate the skills of all pertinent disciplines and sectors: business, academe, nongovernment organizations, the states, and the federal government. Its emphasis on quality through the merit-review process is to be commended. Perhaps NIE's greatest service would be its focusing of the nation's environmental effort to capture the talents of nonfederal researchers by providing incentives for them to perform policy-relevant environmental research. That would be done through a significant extramural, multidisciplinary funding program for research on subjects selected by an advisory committee consisting of persons of diverse interests drawn from a variety of communities.

The NIE proposal is predicated on the view that the niche to be filled in federal programs for environmental research is extramural research. The CNIE believes that it would be less difficult to have a new NIE that focused on merit-reviewed extramural research, policy assessment, and information management than to rearrange the existing mission-oriented agencies and change their cultures for these tasks, especially because their own tasks must continue to be addressed.

NIE is proposed as a new agency that does not encompass or replace existing ones. The committee believes that NIE, if not carefully monitored, could duplicate the roles and missions of existing agencies and engender "turf battles" as it competed for funds and programs with existing agencies. For example, NIE's first aim, basic understanding of the components of the environment, might overlap with the Department of the Interior's planned National Biological Survey and EPA's Environmental Monitoring and Assessment Program, unless the roles of extramural and intramural research were understood. The differences between exploratory research versus management research, regulatory research, and monitoring would have to be explored and carefully delineated. To be successful, NIE would have to be seen as a resource for EPA, DOI, and others.

Although a strength of the NIE research-management plan is its attempt to bring many constituencies into research-planning and priority-setting through its advisory process, how this will work in practice within a federal agency is not clear. The various constituencies will have very different agendas. However, the NSF model of the National Science Board for priority-setting suggests that success could be achieved.

The committee believes that the proposed NIE would improve the nation's environmental research effort but does not go far enough to solve all the problems in environmental research that we have identified.

NATIONAL INSTITUTE FOR ENVIRONMENTAL RESEARCH (FRAMEWORK C)

The National Institute for Environmental Research (NIER) that we have described establishes an identifiable central focus for the organization of the nation's environmental research. Its mission would be to conduct a comprehensive environmental research program on protection, restoration, and management of resources, thus addressing critical national needs. Such a program would encompass most aspects of global change (stratospheric ozone depletion, loss of biological diversity, and atmospheric carbon dioxide accumulation), toxic-site cleanup, risk assessment, wetland preservation, and other problems at the forefront of public concern.

NIER would administer the Environmental Status and Trends Program and the National Environmental Data and Information System. As an organization directed specifically toward environmental research, the institute would have the identity and coherence to strengthen links with the private sector, universities, and research institutes. Peer-reviewed science programs would infuse environmental research with creativity and lead to a better science product. The institute would also develop education and training programs to increase the human resources necessary for addressing environmental problems. The research mission of the institute and the products of the research program are directly related to many important policy decisions. Thus, the institute would provide valuable information for setting national environmental policies.

To accomplish its mission, NIER would be composed of EPA (except its regulatory parts), the research components of NOAA, the parts of the National Aeronautics and Space Administration (NASA) that are directed toward environmental research (Earth Observing Satellite/Mission to Planet Earth), and USGS. By providing a single organization, the institute would bring coherence and coordination to a substantial portion of the nation's environmental research program. However, forming the institute would require changes in the current structure of four federal agencies and would separate parts of NOAA and NASA. These changes would create political tension and administrative and implementation costs. As an independent agency, NIER would have the flexibility to set its own priorities within its Congressional mandate. Nevertheless, the institute would be headed by a director, who would have to negotiate with department secretaries in establishing the National Environmental Plan (NEP) and in arguing for funding and assigned responsibilities. The mission of the institute omits important environmental interests, such as land management and environmental regulation. The institute would not include important elements of environmental research related to biological diversity, land management, and global change. Most notable is the absence of programs and offices drawn from DOI, including the Fish and Wildlife Service. The success of the institute in improving federal research and policy would rest to a large extent on the effectiveness of the NEC and its ability to coordinate the activities of the institute with those of other agencies.

Because the institute suggested in this framework is focused on research, it would be necessary to separate the research and service functions of agencies from which a research part is moved. For example, NOAA research might be separated from NOAA weather and climate prediction or NASA's Mission to Planet Earth research from other NASA environmental research. The committee believes that such separations are inadvisable and counterproductive.

The committee believes that NIER would improve the nation's environmental research effort but does not go far enough to solve all the problems in environmental research that we have identified.

DEPARTMENT OF THE ENVIRONMENT (FRAMEWORK D)

The Department of the Environment would include the mission and responsibilities of the National Institute for Environmental Research but also include explicit regulatory functions organized in the Environmental Regulatory Commission. As an administrative unit with research and regulatory responsibilities, the department would provide leadership in the nation's programs for protection, restoration, and management of resources. With its extensive responsibilities, the department would operate at the cabinet level and be headed by a secretary. Environmental issues would thus be elevated to the same level as other national issues.

Forming the Department of the Environment would involve transferring the research and regulatory responsibilities of EPA and NOAA and their research programs. Although the department would have responsibilities for research and regulation, there would be clear administrative separation of regulation and research. Nevertheless, this combined arrangement in one agency is designed to ensure that the nation has a strong environmental research program to support its regulatory decisions and policies.

The Department of the Environment would easily accommodate most of the cultural changes recommended in this report. With the NEC, the department could lead in the setting and implementation of a national research agenda through the NEP. Because most environmental research would be the responsibility of the department, there would be better coordination among many pieces that are now distributed among different agencies. The mission agencies would continue to support their own environmental research programs, such as natural-resource management. These programs would be coordinated with the Department of the Environment through the NEC. The department's coherent environmental research program would assist in ensuring that there are no inadvertent omissions in the nation's research program and would serve as a focal point for expanded linkages with the private sector, academic institutions, and other research performers and clients. The department, with its comprehensive program in research and regulation, would provide a strong infrastructure for environmental research and serve as a catalyst for education and training and for communication with the public about environmental issues and the federal programs related to those issues.

Having departmental status, the Department of the Environment would play a strong role in formulating national policy on all relevant topics. The department would not include land-management research programs, but, given its cabinet status, its research programs would contribute to the effectiveness of other departments as they participate in a program coordinated by the NEC. Moreover, the department would coordinate the nation's activities in international programs.

Although there would be political tension because of the changes in the organization of federal environmental research, the tension might be mitigated because departmental status would elevate the current administrative level of these programs. Similarly, although costs would be associated with the reorganization, these would be repaid by the increase in efficiency, by the reduction in unnecessary duplication of environmental research programs, and potentially by the savings that could result from solving environmental problems. These problems would require enormous amounts to remedy if research were not successful in ameliorating the cost.

The committee cautions, however, that simply elevating EPA to cabinet status without redefining its research responsibilities could be counterproductive. Regulatory agencies have often encountered difficulty in carrying out long-term research (NRC, 1985; EPA, 1992a). If environmental research is to meet the requirements identified in this report, it is crucial that any new cabinet-level agency be designed to take the cultural changes called for into account so that the necessary reorganization improves the quality of research.

ELEVATING THE ENVIRONMENTAL PROTECTION AGENCY TO CABINET STATUS

As this report is being completed, Congress is considering legislation to elevate the Environmental Protection Agency (EPA) to cabinet rank. We believe that the creation of a Department of the Environment is an appropriate and long-overdue move, but we believe that, at least from the standpoint of environmental research, more should be done than simply elevating EPA to cabinet level. If EPA is elevated, its research mission and organization must be redefined.

The difficulties with EPA's research program administered by its Office of Research and Development are well analyzed in EPA's own report *Safeguarding the Future: Credible Science, Credible Decisions* (EPA, 1992a). We concur with the general thrust of the report, and we applaud the agency's moves to implement its recommendations. But serious structural and programmatic difficulties remain.

EPA's mission is regulation, largely to protect human health. This is a large and important mission, and EPA's research, for the most part, is necessarily directed to support of the regulatory function. As a result, there is never adequate time or money to undertake the long-range, multidisciplinary research on fundamental environmental problems and processes that we think is essential to secure our future.

EPA's regulations are often, or usually, responses to perceived emergencies, such as the Love Canal toxic-waste problem in New York state or the Times Beach, Missouri, dioxin problem. In such emergencies, there is usually an inadequate research base for reliable policy-setting and all the agency's resources are consumed to provide even a minimal level of scientific understanding. Even when further research illuminates a problem, legislation and regulations are often so narrowly drawn that it is difficult to modify the law or the rule, and that undermines the usefulness of research and scientific information. Finally, given the seriousness of environmental hazards, policy-setters must act in "better safe than sorry" ways, producing policy so rigidly established that it is difficult to sponsor further research that might change the scientific base.

For all those reasons, we believe it essential to separate the fundamental research on environmental processes and problems from the short-term, regulation-focused research that EPA necessarily pursues. We doubt that that is possible within the existing EPA structure. Without such separation, we believe it unlikely that EPA can recruit adequate numbers of the best-qualified scientists to pursue the high-quality, peer-reviewed, science that must have high priority at EPA.

In the Department of the Environment we have described in Framework D, we have provided for a fundamental research organization dedicated to performance, and support, of basic research and other features of a successful environmental research program we believe must be added. We have laid these out in what we have called "cultural" changes. They include creation of a high-level leadership body (we suggest at the vice presidential level), including the heads of the federal agencies charged with environmental responsibility, to set the agenda for the environmental research program. They also include development of a National Environmental Plan, whose research component is our concern here. Most important, the cultural changes include different ways of thinking about environmental research– ways that have not been part of EPA's culture and that we believe EPA cannot incorporate if it is simply elevated to departmental status. In our Framework D, we incorporate the National Oceanic and Atmospheric Administration, the U.S. Geological Survey, and parts of other agencies with research cultures that would be different from those of EPA.

We see establishment of a broadly based, continuing monitoring program as essential. Although EPA has undertaken this task in its Environmental Monitoring and Assessment Program, we believe a more comprehensive effort is needed.

We think it unlikely that these cultural changes in our environmental research effort can be accomplished by simply raising EPA to cabinet level unless the implementation of the essential cultural changes can be ensured. A broader, more comprehensive organization that included other parts of the federal environmental research enterprise, such as that suggested in our Framework D, would be more likely to get the job done. The EPA functions would be included, but other important functions should also be included, both within the department and as separate bodies.

The elevation of EPA to cabinet level and the efforts of the Department of the Interior to play a greater role in research on the environment (as evidenced by Secretary Babbitt's initiative for a National Biological Survey) can be steps forward. If the cultural changes that we suggest in this report are integrated into the plans and actions of the Department of the Environment (created by elevation of EPA) and the Department of the Interior, we believe the nation's environmental research program will be enhanced vastly.

COST

Our recommendations can be fully evaluated only if one considers what the costs of the different features and the different frameworks might be. The basic importance of our report, however, is not about money, much as we believe that more money is desirable. It is about raising environmental research to new levels of organizational structure and providing it with goals intended to address some large problems of national security more effectively. We believe that if these objectives are achieved, the money issues, in the long run, will sort themselves out.

There is no way to obtain a reliable estimate of the cost of adopting all our recommendations, but we can draw some general conclusions.

Obviously, a move as large as the creation of the new department of Framework D would be expensive, but it is impossible to make even a precise estimate of how expensive. The department would embrace a number of existing agencies, such as the Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration and the U.S. Geological Survey (USGS), and their present budgets can be incorporated in the budget of the new operation. Furthermore, there is duplication in the present decentralized mission-agency organization, and elimination of that duplication could save money. But new functions would add costs.

How much the new department would cost in the beginning would depend on how ambitious it would be. When the National Science Foundation (NSF) began its life in 1950, its budget was hardly noticeable. It grew slowly as NSF's mission was defined and its opportunities developed. Even the most important operations can begin gradually. Starting a new Department of the Environment slowly and with care seems to be in order–restructuring existing functions, making the recommended cultural changes, and eliminating as much duplication as possible.

To get an idea of necessary added costs, we can examine Framework A, which keeps existing mission agencies and adds several functions, including the National Environmental Council (NEC), the Environmental Assessment Center, the National Environmental Status and Trends Program, and the National Environmental Data and Information System. The NEC is an important innovation, and could be created at little dollar cost–only that for a relatively small staff. Large pieces of the National Environmental Data and Information System already exist, and a skeletal coordinated operation could be put into place at relatively small cost. As means were developed not only to collect data and information in a coherent and consistent way, but also to make them readily available with the latest and most effective technology, the cost would become larger.

The National Environmental Status and Trends Program, in the beginning, could be put together with monitoring programs already in place in EPA, USGS, and other agencies. As the gaps were identified and filled, the costs would begin to accumulate.

The Environmental Assessment Center would add a function not available for incorporation from existing agencies to any great degree. It would build from the ground up for the most part but would start relatively small and feel its way.

One can get a rough idea of what a specified amount of money might buy by comparison with existing programs. If one were to add 10% of the budgets for existing federal environmental research programs, one would be adding about $500 million a year–about what EPA's annual research costs are. That is a great deal of new research.

If reorganization of the federal environmental research programs were undertaken with the aim of achieving as many of the desirable goals as possible, through either Framework A or Framework D recommendations, and eliminating as much duplication as possible, and if there were a commitment to begin by adding 10% of the present research budget, it could be achieved. If the objectives were more ambitious, through expansion of the NSF budget to cover fields of research not now covered (for example, through rapid expansion of the monitoring program or through markedly expanded international cooperation), the increased budgets would be much larger.

We believe that there are compelling reasons for spending more money on environmental research than is now being spent. Almost any amount of money–from the 10% increase suggested above to the tripling of the federal investment in environmental research suggested by the National Commission on the Environment–could be wisely invested, provided that the recommended cultural and organizational changes were adopted.

In thinking about costs, one must keep in mind the costs of doing nothing. Many environmental matters have been driven into the courts when scientific uncertainty has made it difficult to establish agreed-on standards of environmental quality and methods of attaining them. Use of the courts will always be part of the problem-solving machinery, but the costs of litigation are large.

Estimates of the cost of present and future efforts to protect and restore the environment are staggering. We have heard $50 billion quoted as the cost of cleaning up the Hanford nuclear site alone. We have a total backlog of toxic-waste remediation that might cost as much as $2 thousand billion (William Reilly, EPA, Congressional testimony, March 1992). We have no adequate technology for that waste cleanup, and we will not have it until we invest in much more research to learn how to do it effectively. Who can estimate the cost to the nation occasioned by loss of biological diversity and extinction of species, if that threat proves as great as biologists predict?

Our national security is at issue. Ensuring that security by spending money to understand the problems that we now see only dimly must have a very high priority.

Appendix A

ENVIRONMENTAL PROGRAMS OF FEDERAL RESEARCH AGENCIES

INTRODUCTION

The descriptions of agency environmental research programs in this appendix were prepared by committee members and staff on the basis of information obtained in presentations by agency representatives, interviews with agency personnel, agency publications, and other published material. Unless specified otherwise, the financial data presented in this appendix were obtained from the American Association for the Advancement of Science report *Federal Funding for Environmental R&D* (Gramp et al., 1992).

The existence of a large number of environmental research programs spread among many parts of the federal government makes it difficult to describe these activities comprehensively or with the same emphasis and detail that some agencies might see as appropriate. The descriptions in this appendix illustrate the breadth of environmental research activity in the federal government, but should not be assumed to be inclusive; nor should the lengths of descriptions be taken to indicate greater or less importance of some programs or sets of programs than of others.

Agency descriptions were sent for review to persons in the agencies described. Not all agencies responded. In some instances, agencies requested inclusion of additional information that was too detailed for use in a brief report. We thank the agency reviewers for their help in correcting and revising the descriptions. However, the committee takes responsibility for the information presented.

DISTRIBUTION OF FUNDS[1]

The committee has used the figures published by the American Association for the Advancement of Science (Gramp et al., 1992) to gain perspective on the distribution of federal funds for environmental research. The AAAS report shows expenditures of about $4.5 billion for environmental research in four categories: environmental sciences (life and physical sciences), $3.1 billion; engineering and other sciences related to the impacts of natural and anthropogenic activities in the environment, $1.2 billion; social sciences related to the environment, such as environmental economics, and adaptation to global change, less than $50 million; and information and data related to the environment, $200 million. The AAAS report states that about $0.7 billion is expended for studies of human health related to the environment in addition to the $4.5 billion of the above-described expenditures. The analysis excludes funding for operational activities related to the environment, such as environmental-policy studies, training, technical assistance, and waste cleanup and $0.3 billion for extraterrestrial environmental sciences. Figure 4 shows the distribution of funds by disciplinary category.

Over 20 agencies provide funds for environmental research and development through hundreds of programs. Six agencies–DOD, DHHS, NASA, DOE, NSF, and USDA–provide 70% of the total. About one-third of the federal funds for environmental R&D is for inhouse government laboratories. The DOI, NOAA, and Agricultural Research Service (ARS) and Forest Service of USDA do most of their work intramurally, and NOAA and NASA also conduct inhouse research extensively. About 45% of the federal support to extramural performers is expended in industry, contractor-operated national laboratories and other nonprofit R&D centers.

The AAAS estimates that the environmental *research* agencies (NASA, NSF, United States Geological Survey (USGS), NOAA, and the Smithsonian Institution) spend about $2 billion of federal funds for environmental R&D. *Sector-specific* agencies (including USDA, DOE, DOD, and the Agency for

[1] Almost all of the information in this section is abstracted from the report titled *Federal Funding for Environmental R&D: A Special Report* prepared by Gramp et al. for the American Association for the Advancement of Science with partial support from the Committee on Environmental Research and with the advice of the committee and others. The AAAS report provides additional detail and information on the methodology and caveats concerning their analysis.

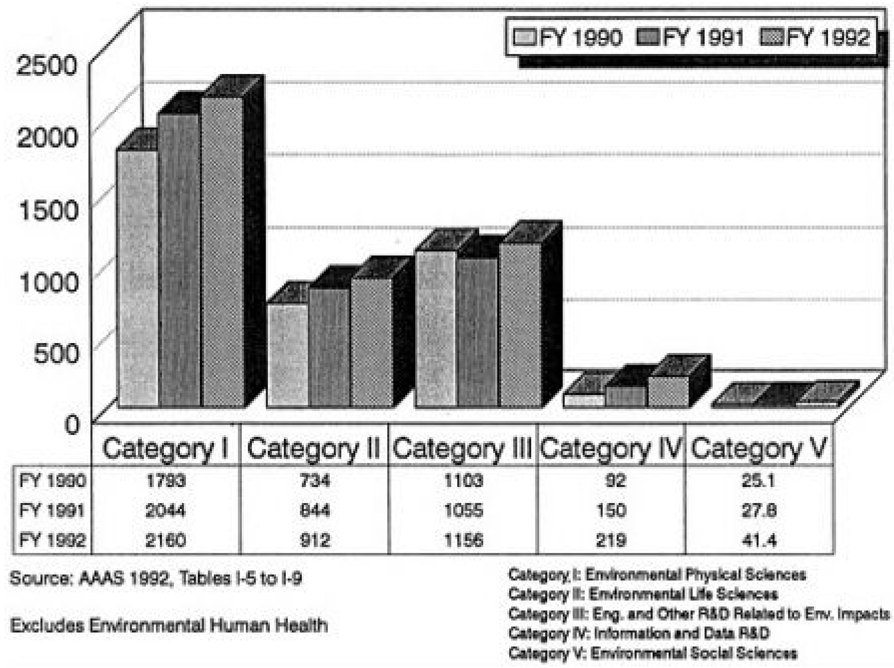
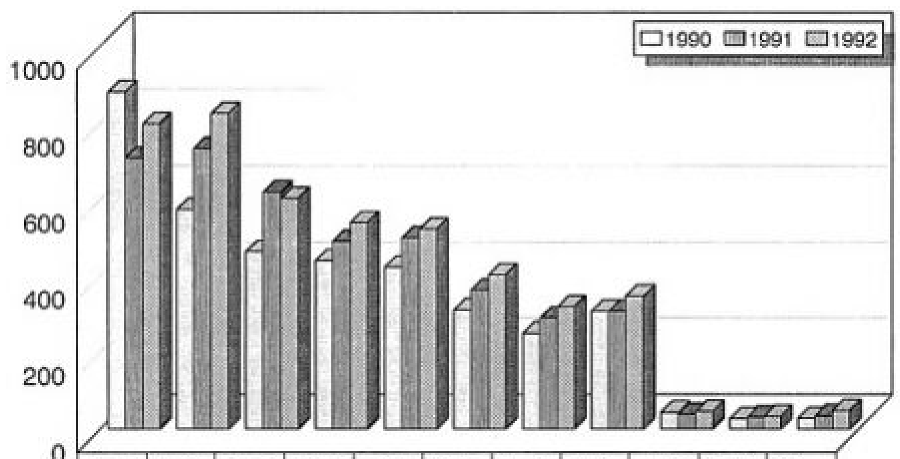


Figure 4 Federal funding for environmental research by category and fiscal year, millions of dollars.

International Development (AID) expend an estimated $1.8 billion. *Management* agencies that implement most of the nation's environmental and resource laws (EPA; NOAA's National Marine Fisheries Service (NMFS) and National Ocean Service (NOS); DOI's Fish and Wildlife Service (FWS), Bureau of Land Management (BLM) and National Park Service (NPS); the Forest Service; and the Corps of Engineers) account for an estimated $0.8 billion. About 75% of the money spent by research agencies is for R&D in physical environmental sciences. The sector-specific agencies invest over half their environmental R&D money in engineering and other R&D related to environmental impacts. The management agencies devote nearly 60% of their Environmental R&D funds to the life sciences. Figure 5 shows the distribution by agency.

Although the AAAS report warns of confounding factors when estimating spending trends by scientific disciplines and alerts the reader to its use of subjective judgments when working with such figures, the report contains informative estimates of funding by scientific focus, as summarized below.

- The bulk of the $3.1 billion estimated for environmental-sciences supports R&D is oriented toward understanding physical environmental procedures and interactions. Roughly $2.2 billion of the above amount involves such fields as oceanography, geology, chemistry, and atmospheric sciences. Two-thirds of the money derives from programs at research agencies, such as geosciences research at NSF; USGS programs; NASA's earth-sciences R&D; all of NOAA's weather, climate, and atmospheric R&D; and a portion of the latter's marine research. Another quarter of the total comes from programs at sector-specific agencies, notably DOE's carbon dioxide and environmental-sciences research, and DODs R&D on weapons-system environmental research involving oceanography and atmospheric sciences. EPA also funds R&D in atmospheric sciences, chemistry, geology, and marine sciences especially for projects on air quality, Superfund and hazardous wastes, groundwater, and cross-media issues. Funding for R&D on physical environmental processes grew at an average annual rate of 10% from FY 1990 to FY 1992, with two-thirds of the added money going to programs associated with the global change initiative.
- The profile of environmental life-sciences funding is quite different. A smaller sum, estimated at $0.9 billion, was available in FY 1992 for processes and interactions of living resources, such as environmental biology, including ecology, forestry, biology, and marine biology. Furthermore, sponsorship differs. Environmental management account for 47% of the funding, notably the DOI, primarily via FWS, NOAA through NMFS and NOS, Forest Service, and EPA (mostly for programs on multimedia issues,



	DoE	NASA	DoD	NSF	DoI	USDA	DoC	EPA	AID	Smith.	Other
1990	882	575	464	440	423	311	250	307	43	27	28
1991	709	735	621	492	501	363	290	307	38	31	35
1992	799	826	604	541	524	403	319	347	45	33	48

Source: AAAS, 1992 Table I-1

Excludes Environmental Human Health

Figure 5 Federal funding for environmental research by agency and fiscal year, millions of dollars.

pesticides, toxic substances, water quality, global change, and acid rain). Research agencies provide 26% of the money, including NSF's environmental-biology programs, various Smithsonian Institution projects, NOAA's sea grants, and about $86 million for NASA's ecological systems and dynamics and related R&D in the global change programs. Sector-specific agencies provide about another 25%, primarily USDA's ARS and Cooperative State Research Service. Programs pertaining to global change account for about one-third of the 12% average annual growth for environmental life sciences from FY 1990 to FY 1992.

- Engineering and other R&D related to environmental impacts of anthropogenic and natural activities lost ground to inflation from FY 1990 to FY 1992. Over 80% of the $1.2 billion allocated to this type of R&D is provided by sector-specific agencies. The largest programs are at DOE where $0.5 billion was spent in FY 1992 on coal-related technologies and $0.2 billion on cleaning up atomic-defense facility sites. Management agencies–mainly EPA–account for most of the remaining mitigation R&D, addressing such priorities as pollution prevention, waste cleanup, oil-spill mitigation, and wetlands. NSF's share in this category is $26 million for R&D on natural and man-made hazards.
- On the basis of budgetary and related R&D reports, the AAAS analysis identified about $41 million for social-science R&D in FY 1992, representing yearly increases of 28% from FY 1990 to FY 1992. NSF provided $12 million mainly for studies of the economic and human dimensions of global change. USDA agencies sponsor another $16 million, mostly for economic research related to resource management, including forests. AID's $9 million supports research on economic and social factors affecting the environment in developing nations.
- R&D on information and data systems related to the environment received an estimated $0.2 billion in FY 1992. The AAAS report notes that these figures are based on judgments because it is often difficult to distinguish between funds devoted to the science and to the data-management component of programs. Included in the AAAS figures are such programs as NASA's information and data systems for the earth-observing satellite system, NOAA's R&D on satellite information systems, DOE's computer hardware and advanced mathematics and modeling physics program, and USGS's mapping, cartographic, and data-analysis R&D. Information and data systems have been one of the fastest growing areas of environmental R&D, increasing at an average annual rate of 54% from FY 1990 to FY 1992.

With respect to the character of environmental work supported by federal agencies, the AAAS report notes that:

- Management agencies use two-thirds of their funds for applied research to obtain information in support of decisions and actions regarding specific habitats, species, or state and regional environmental strategies.
- Half the money at sector-specific agencies supports development activities focusing primarily on solutions to environmental programs.
- Research agencies devote half their funding to basic research but also develop satellites and other technologies needed to support that research.
- Of the $2.2 billion estimated for R&D in the physical environmental sciences, nearly $1.7 billion (77%) is classified as for research ($1 billion for basic research supported by NSF, DOD, USGS, NASA, and DOE), $0.4 billion as for development, and $0.1 billion as for equipment and facilities. Most of the development costs are associated with NASA's upcoming missions and DODs environmental studies for the Strategic Defense Initiative.
- Of the $0.9 billion estimated for R&D in the environmental life sciences, $0.8 billion (over 90%) is for research. About $0.5 billion is for applied research. Management-oriented agencies account for two-thirds of the applied research, notably NMFS, EPA, the Forest Service, FWS, NOS, and NPS. USDA is the largest sponsor of basic research in the environmental life sciences, providing over 40% of the $0.3 billion in this category, and NSF provides another 30%. The development work is associated with NASA's Earth Observing System and other programs.
- Of the $1.2 billion estimated for R&D in engineering related to environmental impacts, 60% is classified as for development and only 7% as for basic research. Sector-specific agencies–primarily DOE and DOD–fund over 90% of the development activities. Those two agencies plus EPA and DOI support most of the applied research and NSF, EPA, and USDA fund most of the basic research in this area.

U.S. DEPARTMENT OF AGRICULTURE

The U.S. Department of Agriculture (USDA) supports and manages environmental research programs through the offices of the Assistant Secretary for Science and Education and the Assistant Secretary for Natural Resources and Environment. Because agriculture, forestry, and grazing are so intimately involved with the use and quality of land and water resources, wildlife habitat, potential toxicity of farm chemicals, and other environmental issues, much USDA research can be considered "environmental." USDA is involved with the U.S. Global Change Research Program and the U.S. National Acid Precipitation Assessment Program (NAPAP). It is the leading funder of environmental life-science research ($296 million in FY 1992) and the sixth largest source of basic-research and applied-research funds in the federal government.

USDA, one of the oldest federal agencies, has a long history of research performance and support, beginning with the Morrill Land-Grant College Act of 1862. In 1887, the Hatch Act created the State Agricultural Experiment Stations and assigned administrative responsibility for them to the land-grant institutions. USDA Forest Service research traces its roots to 1876, when Congress required that a Forest Commissioner be appointed to head the USDA Division of Forestry "to study the present and future demand for timber and other forest products, the probable supply for future wants, [and] the means best adapted for preservation and renewal."

In the late 1960s, environmental problems were recognized as critical to USDA's mission as concern increased about the use of chemicals and pesticides, about combatting animal and plant diseases, and about increasing the productivity of American farms.

USDA research, including environmental research, is performed primarily by the Agricultural Research Service (ARS), the Cooperative State Research Service (CSRS), in cooperation with the State Agricultural Experiment Stations, and the Forest Service.

Although USDA has conducted intramural research since before 1900, ARS was established in 1953. The national program staff in ARS headquarters plans and coordinates research programs, sets priorities, allocates resources, and reviews and evaluates research programs and progress. ARS and the Forest Service have intramural research programs in agriculture and forestry, respectively, with some joint research efforts, such as windbreak forestry and range research. USDA intramural research is performed at federal research centers and by ARS and Forest Service scientists at land grant universities. ARS expenditures for environmental research ($162 million in FY 1992) include programs in soil, plant, water, and nutrient relationships; watershed protection and management; improvement of range resources; adaptation to weather and weather modification; conservation and efficient use of water; remote sensing; alleviation of soil, water, and air pollution; multiple-use potential of forest land; saline and sodic soils and salinity management; wildlife and fish ecology; alternative uses of land; and for environmental sciences supporting other goals. ARS reports $9.5 million in expenditures for the U.S. Global Change Research Program (B.R. Stillings, personal communication, USDA, February 18, 1993). ARS programs in the category of engineering, science, and technology related to pollution issues accounted for $38 million in expenditures in FY 1992 and included programs in alleviation of pollution, watershed protection and management, conservation and efficient use of water, improvement of drainage and irrigation systems, and protection from pollution.

CSRS supports research scientists primarily associated with land-grant colleges, State Agricultural Experimental Stations (SAESs) other public institutions, and private research organizations. The principal funding sources for CSRS are formula funding to SAESs associated with land-grant colleges and universities, special research grants that are either congressionally earmarked to specific research programs or awarded competitively, and competitive research grants that are open to all qualified research investigators. For example, the CSRS special research grants in water quality are peer-reviewed and competitively awarded. The water quality program is directly relevant to environmental research, and the priorities are set locally by SAES directors on the basis of local needs. The CSRS competitive research grants program under the National Research Initiative (NRI) supports peer-reviewed, investigator-initiated grants in six major categories, two of which-plant systems and natural resources and the environment-are directly relevant to environmental issues. CSRS planned to spend $119 million in FY 1992 for environmental research; funds were distributed to SAESs and other college programs, competitive grants, special grants, and cooperative forestry. CSRS expenditures support environmental programs, including soil and water conservation; soil nutrient management; forest biology and management; water quality; alternative and sustainable agricultural systems; biological control of plant and animal pests and diseases; management of agricultural chemicals, nutrients, and wastes to protect environmental quality; management of soil, water, forests, and air resources; fish and wildlife ecology and management; and social, economic, and policy implications of environmental programs. Expenditures for engineering, science, and technology related to environmental mitigation were for SAESs and other college programs, special grants, animal health, cooperative forestry, and competitive research grants. These CSRS programs support research, such as research in prevention of pollution from agricultural systems; water management, including drainage and irrigation; soil erosion control; land use; geographical information systems and remote sensing for environmental planning; landscape and watershed protection; and alternative energy sources. CSRS's plan for FY 1992 expenditures for the U.S. Global Change Research Program was $11.4 million (B.R. Stillings, personal communication, USDA, February 18, 1993).

The mission of Forest Service research (FSR) is to develop and communicate the scientific information and technology needed to protect, manage, and use the natural resources of forest and rangelands. FSR works closely with science agencies, universities, and private and public organizations.

It also works for and with users–policy makers, natural-resource managers, educators, and industries and other producers.

In response to public input and user needs, FSR has developed an environmental research program consisting of a foundation program and efforts to address national problems. The foundation program is the core of basic and applied research that provides essential support for work on each of the national problems. Addressing each national problem involves basic and applied research focused on a specific problem of critical importance. In addition, research focused on one national problem area is often relevant to other national problems. The number and focus of national problems vary from year to year as research provides answers and new topics arise.

In FY 1993, FSR is addressing eight national problems concerning the following topics: wetlands; tropical forestry; forest health monitoring; recycling; ecosystem management research; global change; enhancing forest-based economies in rural America; and threatened, endangered, and sensitive plant and animal species.

Other objectives of FSR include the following:

- Improve methods to prevent, predict, control, and reduce damaging effects of wildfire, insects, and disease.
- Provide a comprehensive, continuing inventory of U.S. forest-land resources.
- Provide the scientific and technical information on forest ecosystems needed to improve the growth and quality of trees and associated vegetation.
- Provide the knowledge, techniques, and strategies needed to manage, protect, and enhance forest, rangeland, and associated aquatic ecosystems emphasizing sustained ecological processes, biodiversity, water quality and quantity, wildlife, and fisheries resources.
- Provide scientific information and technologies to harvest, produce, and use wood products in efficient, safe, and environmentally beneficial ways.

A small staff in Washington, D.C., provides policy direction and coordination for FSR, which is managed through eight experiment stations across the nation; a forest products laboratory in Madison, Wisconsin (the world's largest center for forest-products research); and the International Institute of Tropical Forestry in Puerto Rico. Research laboratories are generally on or near major university and college campuses.

FSR scientists have access to 191 million acres of national forest land, 84 experimental forests, and more than 70 research natural areas. Research is also international in scope–FSR scientists are working with colleagues in more than 20 countries.

FSR employs more than 700 scientists, nearly 500 of whom hold Ph.D.s in a broad array of disciplines from aesthetics to zoology. Their span of expertise includes temperate, boreal, and tropical forests; social systems; and environmental technology.

FSR coordinates its research efforts with a broad array of partners interested in environmental science and technology, including:

- The Utah Division of Wildlife Resources, the Idaho Fish and Game Department, and the Bureau of Land Management to help restore biological diversity and improve range condition in the interior West.
- Citizen groups, environmental organizations, industry, and universities in the Blue Mountains of northeast Oregon and southeast Washington to restore stressed ecological communities.
- The U.S. Global Change Research Program under the auspices of the Committee on Earth and Environmental Sciences (CEES) of the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET).
- The Forest Health Monitoring (FHM) Program, developed by the Forest Service in coordination with EPA's Environmental Monitoring and Assessment Program (EMAP).

The Forest Service is unique in USDA in that its Congressional appropriation is not considered by agricultural committees but by committees related to the Department of the Interior. Most of the FSR program can be considered environmental research. The FSR environmental research budget for FY 1992 was approximately $152 million; $56 million was spent on priority research programs, and $96 million was spent on basic environmental research programs (J.A. Sesco, personal communication, U.S. Forest Service, February 8, 1993).

DEPARTMENT OF DEFENSE[2]

Environmental R&D is a fundamental component of national defense programs, providing knowledge essential to the operation of weapons systems

[2] This description of Department of Defense environmental programs consists of excerpts from a report by the American Association for the Advancement of Science (Gramp et al., 1992), which appear by permission.

and the management of the environmental impacts of defense activities. The Department of Defense (DOD) spent about $577 million on R&D related to the environment in FY 1992, of which an estimated $432 million involves environmental sciences and $146 million mitigation-related engineering, science and technology. Approximately $130 million of this R&D was expected to have been done at universities and colleges, making DOD the second largest sponsor of academic research in environmental fields.

DOD has a long history of supporting research on the Earth's oceans, atmosphere, and terrain as part of its weapons systems development efforts. Environmental R&D has become even more crucial in recent years, because of the emergence of smart weapons, anti-submarine technologies, and diverse battlefield environments. Roughly $265 million of the funding estimated for environmental sciences supports R&D done by the military services to enhance weapon-related capabilities. Most of this activity is either basic or applied research ($160 million and $105 million, respectively) in oceanography, and atmospheric, terrestrial, and solar-terrestrial sciences. The FY 1992 budget for the Strategic Defense Initiative Organization (SDIO) includes $112 million for environmental sciences, all of which is classified as development. Although environmental R&D was identified as a "critical technology" by DOD in 1991, funding for these activities increased by less than 4% from FY 1990-1992, resulting in a decline after adjusting for inflation.

DOD's environmental sciences R&D is oriented toward developing baseline data, remote sensing technologies, and predictive models of the ocean, local area conditions, and target environment characteristics. For example, DOD supports the development of data and models on ocean circulation and structure, the marine boundary layer, feedback between the ocean and atmosphere, and related underwater acoustics. Technologies for improving the accuracy of oceanic measurements have focused on space, air, surface, and underwater-based sensors. Concern about regional conflicts has spurred R&D on surface and space-based remote sensing technologies that could improve specifications of local atmospheric and terrain variables (e.g. clouds, temperature, humidity, winds, etc.) as well as models for predicting conditions and integrating local battlefield data with regional or global data. Accurate environmental data must also be integrated into the design of smart weapons and automatic target recognition systems in order for them to function effectively. Thus, the SDIO and other DOD entities are developing technologies that can measure and simulate the atmospheric boundary layer, the seismic/acoustic and electromagnetic characteristics of terrains, maritime aerosols, "background clutter," and related strategic and tactical concerns.

Research sponsored by defense agencies other than SDIO accounts for another $54 million of the environmental sciences total. The Defense

Advanced Research Projects Agency (DARPA) and Defense Nuclear Agency (DNA) together expect to fund about $34 million in geological research, mostly for nuclear weapons testing and treaty verification purposes. DNA also plans to spend $2 million for applied research in environmental biology and $5 million in atmospheric sciences related to weapons testing. The budget of the Office of the Secretary of Defense includes $8 million for oceanographic and $4 million for atmospheric studies pertaining to other defense priorities.

A small portion of DOD's mission-oriented R&D pertains to the U.S. Global Change Research Program. Studies and models being developed by the Office of Naval Research account for $5.8 million of DOD's $6.3 million[3] contribution for FY 1992. This includes $1.0 million for research on ocean ecological dynamics.

Congressional interest in linkages between defense and non-defense environmental research was a factor in the creation of the Strategic Environmental Research and Development Program (SERDP) in 1990. The types of expenditures for SERDP include: costs associated with de-archiving and "sanitizing" environmental data previously collected by DOD researchers; the marginal cost of excess computer time on federal supercomputers made available to environmental researchers; the incremental costs of certain environmental data collection activities, including remote sensing; and funding for R&D on pollution prevention, nuclear, toxic, and hazardous waste management, and advanced energy generation and conservation technologies. SERDP activities are overseen by a joint council that includes officials from DOD, Department of Energy (DOE), and Environmental Protection Agency (EPA), and by a scientific advisory board. In the absence of funding details on SERDP's diverse portfolio of projects, the program has been included here under engineering, science, and technology R&D.

The threefold increase in funding for DOD's mitigation-related R&D over the last two years is the result of recent initiatives like SERDP and an added emphasis on environmental management by the services. Among the new starts since FY 1990 are rocket motor demilitarization under the START Treaty ($27 million in FY 1992), a Navy environmental quality project ($26 million), and a special environmental project under defense agencies ($20 million). Despite the scope of SERDP's activities, its FY 1992 budget has been shaved to $10 million, because of the $90 million rescinded from prior appropriations as part of Congress's May 1992 deficit reduction package (Congress originally provided $150 million for FY 1991 and $50 million for FY

[3] These funds are included in the $265 million estimated for the services' weapons environment R&D.

1992). In making this cut, lawmakers cited the slow pace of program implementation, and precluded the use of the remaining funds for remote sensing projects.

The $62 million estimated for service-related mitigation engineering, science and technology is nearly double the level of activity in FY 1990. The Army and Air Force each account for roughly half of the funding for R&D on installation environmental restoration, pollution prevention, and atmospheric compliance. The Army funds all of the R&D on terrestrial and aquatic assessment and base support operations, while the Air Force does most of the work on noise abatement. In addition to the special project noted above, the Navy's mitigation R&D also involves a small global marine compliance program.

In 1990, the Corps of Engineers adopted what it termed "new environmental approaches" to its investment and regulatory programs. Under that policy, the Corps accorded priority to restoring fish, wildlife, and vegetative habitats affected by its projects, implementing its regulatory programs to achieve "no net loss" of wetlands, and pursuing nonstructural solutions to water resource problems. From FY 1990-1992, funding for environmental R&D at the Corps increased 44% to $27 million, primarily because of increases for wetlands research (up sevenfold to $7 million). Most of the Corps' environmental R&D total focuses on the impacts of natural and anthropogenic activities, including coastal engineering ($6 million), aquatic plant control ($4 million), and flood control ($3 million). Other research areas include the ecological effects of dredging ($1 million), the economic impacts of global warming ($0.4 million), water investment risk analysis ($1.0 million), and surveying and remote sensing R&D ($1.6 million).

DEPARTMENT OF ENERGY

The Department of Energy (DOE) was established in 1977 as the successor of the Atomic Energy Commission (AEC) and the Energy Research and Development Administration. It inherited a research base, primarily from AEC, including the national laboratories and a network of university researchers. Research in DOE is distributed among the Office of Energy Research, defense programs, and various research groups under other offices, for example, the Office of Fossil Energy. In the last decade, severe reductions have been made in some research areas such as the Offices of Fossil Energy, Conservation and Renewable Energy, and Nuclear Energy. Defense programs on nuclear weapons conducted mainly at Los Alamos, Livermore, and Sandia weapons laboratories consume almost half of DOE's expenditures for R&D

(OTA, 1991). Over 80% of the $799 million estimated for DOE's environmental R&D in FY 1992 addressed mitigation issues; the balance was allocated to basic research on carbon dioxide, other environmental sciences, and related information-science R&D.

When costs of environmental remediation and technology are included in expressing environmental-program expenditures for the federal government, DOE ranks first in the amount of expenditures. Considering only planned expenditures in FY 1992 for environmental science ($129 million), it ranks eighth, above only the Smithsonian Institutions and the Agency for International Development among agencies involved in environmental research. DOE's planned expenditure for FY 1992 for environmental mitigation, technology programs, and environmental-waste restoration projects was $667 million. The largest expenditures in this category were for clean-coal technologies ($390 million) and for environmental-waste management and restoration at nuclear-weapons production sites ($224 million).

Environmental research at DOE is focused mainly in the Office of Health and Environmental Research (OHER). Some programs are in the Office of Basic Energy Research. The origins of the environmental research are programs of AEC that sought an understanding of the transport of radioisotopes in the environment. The program now includes atmospheric science, terrestrial ecology, environmental research parks, subsurface transport and microbiology, ocean margins, environmental radon, and global change. The global-change program is the largest environmental program in OHER, with planned expenditures in FY 1992 of about $75 million. The program consists of studies of the carbon cycle, climate diagnostics, effects on vegetation, atmospheric radiation measurement, computer-hardware advanced mathematics and model physics, ocean research, and education and the National Institute for Global Environmental Change.

The atmospheric-science program is intended to

- Concentrate on the transport and transformation of energy-related emissions in the atmosphere.
- Improve the understanding of meteorological, chemical, and physical processes that influence the transport, transformation, and fate of gaseous and particulate species emitted to the atmosphere.
- Emphasize such aqueous-phase processes as in-cloud chemical reactions and precipitation scavenging.
- Understand contaminant flows in complex terrain for application in models used in emergency preparedness and emergency response.

The terrestrial-ecology program is intended to

- Demonstrate fundamental processes of ecosystem adjustment in microcosms that simulate plant communities and biotic communities in soil and quantify self-adjustment in selected natural ecosystems.
- Characterize biotic communities in different soil types before and after physical disturbances and releases of energy-related contaminants and develop or adapt techniques to monitor adjustments by the soil biota as above-ground ecological changes occur among photosynthesizing organisms.
- Characterize and quantify effects that biotic communities in the soil have on biomass production and evapotranspiration in different soil types as nutrient and water levels change.
- Detect and quantify photochemical, carbon fixation, and respiratory responses that are the most likely to be disrupted or limited by changes in available nutrients and water and develop technologies to characterize the ecological and biological mechanisms that control responses.
- Detect and quantify physiological and genetic adaptations of plant populations and soil microbial populations to variation in nutrient and water availability.
- Develop the theoretical basis and analytical methods to understand the evolved dynamics and capacities of ecosystem adjustment to environmental change and its role in ecosystem resilience to perturbations and in developing ecosystem sustainability and biodiversity.

The subsurface-science program consists of

- Long-term basic research on physical, chemical, and biological mechanisms that control the mobilization, stability, and transport of chemicals in subsoils and groundwater; hydrogeology, including the hydraulic, microbiological, and geochemical properties of the subsurface that affect chemical mobility and stability; and the microbiology of deep sediments and groundwater.
- Focused efforts to obtain cost-effective solutions to long-term needs in environmental restoration, particularly at DOE sites.

The ocean-margins program is designed to

- Quantify the mechanisms and processes by which carbon dioxide is assimilated, transported, and transformed in the coastal ocean and define ocean-margin sources and sinks in global biogeochemical cycles.

- Determine whether continental shelves are quantitatively important in removing carbon dioxide from the atmosphere and isolating it via burial in sediments or export to the interior ocean.

The Environmental-radon program is designed to

- Characterize the availability and emanation potential of radon within soils.
- Define the environmental variables that control radon transport within soils and its movement into homes.
- Develop predictive models to link environmental transport with indoor radon concentrations.
- Identify areas that might be affected by increased indoor radon concentrations.

The global-change program

- Estimates the future concentrations and rate of increase in atmospheric carbon dioxide and other energy-related emissions and attempts to improve understanding and prediction of effects of emissions on climate and biota.
- Strives to obtain scientific information to support energy policy options aimed at preventing, mitigating, or adapting to increasing greenhouse gas concentrations and global environmental change.

DOE research priority-setting is shared among headquarters and individual national laboratories. Review of proposals for awards is primarily a staff function, with advice in many cases from outside reviewers. Although the research performed and supported by DOE is aimed at solving mission problems concerning energy, fundamental studies constitute a substantial part of its portfolio of research (OTA, 1991).

The national-laboratories complex is a unique feature of DOE's research system. Seventeen laboratories make up the system. Three are devoted to weapons research, and a fourth to domestic use of nuclear energy. Eight single-program laboratories are formed primarily around specialized-use facilities, such as the Fermi National Accelerator Laboratory. The remaining five-Argonne, Brookhaven, Lawrence Berkeley, Oak Ridge, and Pacific Northwest-are energy multipurpose laboratories with a long history of research in chemistry, biology, risk assessment, ecology, and medicine. The laboratories are managed for DOE by university consortia or industry and are an integral part of the department's research, testing, and evaluation mission.

The system of government ownership and private management lends flexibility and independence to the operation of the laboratories, especially in personnel policies and practices (DOE, 1992). OHER awards about 60% of its funds for environmental research to researchers at the national laboratories; the remainder goes to university-based scientists (Galas, 1992).

As national priorities have changed over the decades, the roles of the national laboratories have been diversified, and new ones have been taken on. It has been suggested, among other things, that the laboratories might serve as environmental research centers. One special capability of some of the laboratories lies in the kind of large-scale data handling that characterizes environmental research.

DEPARTMENT OF THE INTERIOR

The Department of the Interior (DOI) administers a large and diverse program of environmental research and land-management programs. Its mission covers natural-resource programs from fish and wildlife to mines and ocean minerals and from grass and timber to water, parks, and recreation. About 30% of the U.S. land surface is owned by the federal government, and 65% of that is under the jurisdiction of DOI. About 1.5 billion acres of the outer continental shelf, included in the approximately 3 billion acres of the President's Exclusive Economic Zone (EEZ), which extends 200 miles beyond the U.S. coast, also comes under its jurisdiction (Deason, 1991).

Resource management is a major responsibility of the department's Bureau of Land Management (BLM), National Park Service (NPS), and Fish and Wildlife Service (FWS) (Grad, 1986). The Office of Environmental Affairs coordinates environmental policy for DOI.

Research is performed and supported mainly through two of DOI's bureaus, the U.S. Geological Survey (USGS) and FWS. DOI's planned spending level for environmental-science research in FY 1992 totaled $524 million. Most research in the department is directed to support internal program-management decisions and is tailored to meet specific needs of individual programs (Deason, 1991).

U.S. GEOLOGICAL SURVEY

USGS was established in 1879 to provide a permanent federal agency to conduct the systematic and scientific classification of the public lands and examination of the geological structure, mineral resources, and products of the national domain (USGS, 1991). It has a vast research program, with planned research expenditures of $367 million in FY 1992 for R&D in environmental sciences. USGS plays a large role in DOI's global change program. USGS is increasingly applying its technical expertise to such national needs as natural-hazard research and response, mineral and energy assessments, water-quality research, geological and other resource mapping, and development of a national spatial-data infrastructure. Its scientific programs are administered through the Geologic, Water Resources, and National Mapping Divisions and supported by the Information Systems and Administrative Divisions. National headquarters is in Reston, Virginia, and investigations are carried out through an extensive organization of regional and field offices throughout the 50 states, Puerto Rico, the Virgin Islands, and the Territory of Guam (USGS, 1991).

Among the large USGS programs related to environmental sciences programs with large planned expenditures for FY 1992 are those in geological hazard surveys, mineral-resource surveys, energy-resource surveys, marine and coastal surveys, national water quality assessment program, volcano hazards, toxic-substances hydrology, global-change and climate history, global-change hydrology, and core hydrological research. Large information R&D programs include those in federal-state water data collection and analysis, national mineral and energy surveys, national geological mapping, national digital cartographic databases, Landsat data archive, marine and coastal surveys, and global-change data systems.

Building on previous cooperative arrangements among federal agencies, the Office of Management and Budget issued Revised Circular A-16 on October 19, 1990 (OMB, 1990). The circular directs the formation of a Federal Geographic Data Committee (FGDC) led by USGS and establishes the breadth of coordination carried out by the committee. Agencies involved and their responsibilities are the U.S. Department of Agriculture (USDA) (vegetation through the Forest Service and soils through the Soil Conservation Service), Department of Commerce (cultural and demographic subjects through the Bureau of the Census and geodetic through the Coast and Geodetic Survey), Department of Defense (DOD), Department of Energy (DOE), Department of Housing and Urban Development, DOI (base cartographic and geological subjects through USGS, cadastral though the BLM, and wetlands through FWS), Department of State (international boundaries), Department of Transportation (DOT) (ground transportation through the Federal Highway Administration), Federal Emergency Management Agency, Environmental Protection Agency (EPA), the National Aeronautics and Space Administration (NASA), and National Archives. The purpose of the FGDC is to promote the coordinated development, use, sharing, and dissemination of surveying, mapping, and related spatial data.

OMB Memorandum 9201 (M-92-01) delegates to USGS the lead responsibility for a Water Information Coordination Program (WICP). This program coordinates the water-data acquisition and information-sharing activities of all federal agencies, including the quality and quantity of streams, lakes, estuaries, and groundwater and water-use and sedimentation data. M-92-01, which replaces Circular A-67, expands coordination activities to include water information, thereby including investigations and interpretative products. Agencies are to ensure that plans to initiate new water-information programs or expand old ones are coordinated with other agencies in advance. Participants in the WICP are required to collaborate with other groups coordinating related categories of information, including meteorology and spatial data. The Secretary of DOI established a steering committee to oversee the WICP, and there are two advisory committees. The Advisory Committee on Water Data for Public Use solicits input from 16 national organizations involved in water issues, and the Interagency Committee on Water Data has representatives of 30 federal organizations that either collect or use water data.

Through formal and informal links, USGS cooperates with other agencies in several environmental research programs. With the National Oceanographic and Atmospheric Administration (NOAA) and NASA, USGS takes responsibility for the land-data part of the global-change activities associated with the Earth Orbiting System. USGS and NOAA have a Joint Office for Mapping and Research to coordinate marine activities. This joint office facilitates sharing of federal agency mapping and research activities in the EEZ. USGS is one of the agencies with NOAA, NASA, and the National Science Foundation, participating in the Interagency Working Group on Data Management for Global Change. USGS also has contacts with EPA's Environmental Monitoring and Assessment Program. (G.A. Thorley, USGS, personal communication, 1992).

Scientists in the Core Hydrologic Research Program work cooperatively with many other federal agencies, including the DOE, DOT, DOD, NASA, EPA, NOAA, NPS, Bureau of Reclamation, BLM, FWS, and Bureau of Indian Affairs. The Toxic Substances Hydrology Program studies are coordinated with USDA and EPA. Each of the study-unit teams in the National Water Quality Assessment Program has a local liaison committee consisting of representatives of federal, state and local agencies, universities, and the private sector. USGS is cooperatively involved in water-resources research at 54 of the nation's land grant universities through its State Water Resources Research Institute Program.

The National Geologic Mapping Act of 1992 (PL 102-285), passed May 18, 1992, directs USGS to be the lead federal agency responsible for planning, developing priorities, and coordinating and managing the established geological mapping program. An advisory committee is being established that will advise the director of USGS on planning and implementation of the geological mapping program. Members of the advisory committee include one representative each from the EPA, the DOE, USDA, and the Office of Science and Technology Policy. Additional members include representatives of State Geological Surveys, academe, and the private sector. The purpose of the act is to expedite the production of a geological-map database for the nation, which can be applied to land-use management and assessment, conservation of natural resources, groundwater management, and environmental protection.

The Land Remote Sensing Policy Act of 1992 (PL 102-555), passed October 28, 1992, repeals the Land Remote Sensing Commercialization Act of 1984 and directly affects programs of USGS. In stressing the importance of Landsat data to national security and global environmental research, the act specifies the following:

- Transfer of responsibility for the data archive from the Department of Commerce to DOI which delegates to the USGS.
- Providing for educators and nonprofit organizations to obtain data at the cost of fulfilling a request.
- Authorizing and encouraging DOI and other federal agencies to carry out R&D programs in applications of these data.

FISH AND WILDLIFE SERVICE

The Fish and Wildlife Service was created in 1885 as the Office of Economic Ornithology, with a charge to discover and document the distribution of the nation's wildlife resources. From its inception, the service has had a charge to conduct research to provide a basis for the intelligent management of those resources, and the subsequent enactment of 17 major laws involving research activities of the service has provided the legal basis for that responsibility. The research arm of today's FWS continues to address the responsibility by providing research results to the seven operational regions and the more than 700 refuges, hatcheries, field offices, and other facilities operated by the service. R&D efforts in the service provide information for the management of fish and wildlife on national wildlife refuge lands; for the management of migratory birds and anadromous, coastal, and transboundary fisheries; for assessment and control of fish and wildlife diseases; for protection and recovery of endangered species; for evaluating effects of environmental contaminants on fish and wildlife; and for propagating fish species to restore stocks depleted by federal water projects and other environmental-management activities.

The service comprises a headquarters office in Washington, D.C., with seven regional offices spread across the nation. Each regional office administers a number of national wildlife refuges, fish hatcheries, and field offices to conduct the operational assignments of the agency. Research, also headquartered in Washington, D.C., is considered an eighth regional office for administrative purposes. FWS has an extensive intramural research program conducted at 13 research centers and 94 field stations dispersed across the United States and its territories. Planned FWS expenditures for environmental research in FY 1992 were $73 million, including $3.6 million for the Global Change Research Program (T. Terrell, personal communication, U.S. Fish and Wildlife Service, December 31, 1992). Other programs of environmental research are fishery research, wildlife research, technical development, contaminant research, and endangered-species research.

One focus of fishery research is on the interactions between fish and their changing environments. Habitat investigations are intended to describe the environmental requirements for maintenance of important species, determine the impact of environmental degradation on system productivity, and recommend to resource-management agencies remedial actions, where necessary. Another focus of fishery research in the service is to evaluate fish population dynamics. This research provides information used in the assessment of fish stocks and setting of harvest limits and provides a basis for predicting the impacts of selective harvest on populations and long-term effects of intensive fishing on naturally reproducing stocks. A third focus of fishery research is on the culture of fish stocks to support federal and state fish stocking and restoration programs. FWS activities include research on the physiological requirements of fish in culture systems, fish reproductive biology, optimal rearing methods for diverse fish species and life-history stages, nutrition and feeding technology, fish disease and health management, registration of chemicals and drugs used in fisheries, and concomitant improvements in hatchery water quality and reduction of effluent pollution to ensure compliance with federal and state environmental legislation. The final focus of fishery research is on the problems related to the unintentional introduction of aquatic nuisance species. The principal species currently of interest is the zebra mussel.

Because the service has the lead responsibility for setting hunting regulations for migratory waterfowl, much of its wildlife research activity has traditionally focused on the population dynamics, ecology, and habitat requirements of migratory waterfowl. In addition, the service conducts research on wildlife health problems, including especially avian botulism and avian cholera, as well as providing support to FWS land managers by investigating the causes of major wildlife dieoffs. This research is designed to develop management methods to reduce the depletion of wildlife populations. Nongame-wildlife research activities deal mainly with neotropical migratory birds, especially in developing census techniques and in elucidating environmental factors related to population changes. Wildlife-ecology studies on service lands and marine-mammal research are small programs related directly to legislation mandating service involvement in management of these resources.

Most of FWS activity in technical development is concentrated on development of impact-assessment techniques to evaluate effectiveness of mitigation actions. These tools are used by service operational staff in providing comments to other federal agencies on the impacts on fish and wildlife of management manipulations, such as federal water projects and dredging and filling of navigable waterways. This involves translating modern scientific information and technologies into operationally useful tools tailored to FWS-mandated responsibilities. A biodiversity-research effort consists mainly of development of gap analysis, a tool designed to identify gaps in the protection of biological diversity and of endangered species. Gap analysis is now being implemented in the mapping and relating of land ownership, land use, vegetation distribution, and animal distribution in 23 states.

The service's contaminant-research efforts focus on fish and wildlife resources of high national interest or concern. Projects address resource issues and information needed to manage fish and wildlife and their habitats effectively. Subjects include monitoring and surveillance of the magnitude of existing and potential contaminant threats and developing techniques to improve these capabilities; acid-precipitation effects on aquatic ecosystems; contaminant effects of land, water, and energy development; impacts of agricultural activities; Great Lakes contaminant problems; and long-term effects of contaminants on communities and ecosystems. In addition, FWS research provides a substantial operational assistance program to regional staff in the analysis of water, sediment, and animal tissue for contaminants. In FY 1991, over 21,000 samples representing over 350,000 individual contaminant determinations were reported to operational staff. Research provides these determinations through contract laboratories or inhouse analysis and manages a major quality-assurance/quality-control program to ensure accuracy. Great accuracy is required, because many of the samples are the basis of law-enforcement actions by the service or can be involved in court actions as a result of natural- resource damage assessments.

The service provides scientific staff support to the Scientific Authority for the Convention of International Trade in Endangered Species of Wild Fauna and Flora. Other endangered-species research activities include development of population-monitoring techniques, captive-propagation methods, and reintroduction techniques. Research is also conducted to determine limiting factors in the environment. Species currently under study include black-footed ferrets, Hawaiian forest birds, Puerto Rican parrots, eastern timber wolves, southern sea otters, West Indian manatees, and whooping cranes.

The Cooperative Fish and Wildlife Research Units are state-federal academic partnerships in research and education that focus on needs for the management of natural resources. One to three FWS employees per unit are stationed at state university campuses and charged to conduct research of interest to the cooperators and to train high-quality resource managers in the process. The university provides administrative support, faculty status, and office and laboratory space. The state fish and wildlife management agency provides operational support and access to equipment. The arrangement provides federal access to state natural-resource management agency expertise and to university faculty expertise in disciplines not represented within FWS. In addition, the research work-order process, established by the Cooperative Units amendment to the 1978 Fish and Wildlife Coordination Act, allows any other federal agency access to this pool of high-quality expertise. Currently, the service operates 41 units at 40 campuses in 38 states.

In carrying out its research and development activities, FWS cooperates closely with other federal and state agencies to ensure that regional and local research needs are addressed through the active exchange of information and sharing of methods. In FY 1992, it used over 1,100 cooperative agreements and memoranda of understanding to facilitate formal cooperation and had at least 10 times that many informal arrangements to ensure cooperation.

MINERALS MANAGEMENT SERVICE

The Minerals Management Service (MMS) has a large program that supports DOI's oil and gas and marine-minerals development program under the Outer Continental Shelf Lands Act. Through the Environmental Studies Program (ESP), MMS provides scientific and technical information on the potential impacts of the development of oil, gas, and marine mineral resources on the U.S outer continental shelf (OCS). These scientific studies assist MMS in managing activity on the OCS. ESP information is used in deciding which OCS areas to lease for oil and natural gas, in managing the review of industry plans for exploration and development activities, in granting permits, and in designing methods to minimize environmental effects of drilling and production.

The environmental studies encompass physical and biological oceanography, ecological monitoring, protected species, socioeconomics, and selected research on fisheries, birds, turtles, marine mammals, air quality, hazardous wastes, spill mitigation, and information management. The geographic areas studied include the coastal and OCS waters off the Atlantic, Pacific, and Gulf Coast states and the Alaskan coast. Scientific committees, regional technical working groups, coastal state agencies, and the public help to guide the program's research agenda.

ESP is managed out of headquarters and has components in the four OCS regions (Alaska, Pacific, Gulf of Mexico, and Atlantic). The majority of the research has been contracted competitively. Recently, MMS has emphasized cooperative agreements with state institutions and interagency agreements with other federal agencies. The program began in 1973, and it is one of the longest, unified, applied marine environmental research programs in the country. Through 1992, the program has funded more than $530 million worth of scientific research directly related to the possible impacts of offshore oil, gas, and marine mineral activities on the natural and human environments. The ESP budget was nearly $20 million per year, with $6 million authorized for oil-spill R&D in FY 1992. (J.W. Workman, MMS, personal communication, February 12, 1993).

NATIONAL PARK SERVICE

The majority of the National Park Service (NPS) environmental research program provides scientific information from field and laboratory studies to support protection, conservation, and restoration of natural and cultural resources in units of the national park system. A portion of this program contributes data to interagency and cooperative programs that improve scientific understanding of regional and global influences on ecosystems and other resources, including air and water pollution, acidic deposition, habitat fragmentation, and climate change. The program includes resource inventories; monitoring of resource conditions and processes; research on and predictive modeling of natural and anthropogenic factors influencing ecosystems, species populations, and other resources; and research to develop effective management practices.

The current organization and approach of NPS treat research as part of resource management. The two subjects were combined to enhance cooperation.

NPS estimates that research funding grew from $18.5 million in FY 1987 to $29 million in FY 1992 (NRC, 1992b).

BUREAU OF LAND MANAGEMENT

The Bureau of Land Management (BLM) is the nation's largest land and mineral records manager and oversees the legal land-survey system that defines all public land boundaries. This continuity of management from legal land boundary to land records to comprehensive resource and environmental management heavily involves BLM in investigating and incorporating scientific applications and technological developments.

BLM supports and encourages research designed to acquire and promote the use of scientific knowledge for maintenance of healthy and sustainable ecosystems capable of producing diverse resources. BLM's niche is in applied, interdisciplinary research. Although BLM conducts some research with assistance from its scientists, most research is accomplished through contracts with university scientists and by using the expertise available in other federal agencies or in the laboratories managed by them.

Most of the research supported by BLM is related to the environment; habitat and ecosystem research is emphasized. However, some species-specific research is also supported, especially to address questions related to endangered-species management or conflicts between species and resource-development demands.

Most of the public lands for which BLM has management responsibility are in the western United States, including Alaska. Therefore, most of the environmental research that BLM conducts is also in the western states. BLM expenditures planned for research in FY 1992 were approximately $11 million.

BUREAU OF RECLAMATION

The Bureau of Reclamation manages or supports such research efforts as ecological studies of dam-altered river systems (e.g., Glen Canyon environmental studies); wetland development (e.g., Eastern Municipal Water District) and restoration (Garrison Diversion Unit); and integrated river-basin management (San Joaquin action plan). The bureau also is involved in a global climate-change-response program.

The bureau manages aquatic resources in 17 western states for the protection of wildlife, fisheries, and water quality. Wetlands research focuses on assessing the value of wetlands in water-resources management and developing the capability to locate, design, construct, and maintain wetlands. Examples include

- Use of constructed wetlands as part of reclaimed-water treatment and reuse systems.
- Evaluation of wetlands as a "best management practice" for the control and treatment of agricultural non-point-source runoff.
- Use of constructed wetlands to treat irrigation return flows in an environmentally acceptable manner.
- Evaluation of the importance of existing and restored wetlands in removing nutrients and improving water quality.

ENVIRONMENTAL PROTECTION AGENCY

The primary goal of the Environmental Protection Agency (EPA) is to mitigate the impacts of pollution on human health and the environment. Thus, EPA management must make decisions regarding the development of policy, guidance, standards, regulations, and the appropriate tools for implementing pollution-abatement strategies.

Environmental research is conducted primarily by the Office of Research and Development (ORD). The research program had a budget of approximately $496 million in FY 1992, employs 1,900 people, and includes 12 environmental laboratories distributed across the country.[4] The activities of ORD offices include basic and applied research, technical assistance, regulatory support, technology transfer, assessment of health and environmental risk, monitoring, and review and interpretation of studies. For example, EPA's assessment of environmental tobacco smoke and the reassessment of dioxin risks were produced by ORD. Similarly, ORD laboratories support technical-assistance programs, such as the Center for Exposure Assessment Modeling in Athens, Georgia, and the Technology Support Center in Ada, Oklahoma. Thus, the approximately $496 million in the ORD budget is not spent purely on "research."

Scientific activities–research, data analysis, assessment of risks, monitoring, and quality assurance–are undertaken in all parts of EPA. The four major program offices (Air and Radiation; Solid Waste and Emergency Response; Water; and Prevention, Pesticides, and Toxic Substances) are

[4] Excluding administrative overhead and R&D related to environmental health, EPA's R&D funding was approximately $340 million in FY 1992.

responsible for developing environmental regulations and policies. Under each of the assistant administrators of these offices, there are several offices with specific program responsibilities. To support their programs, these offices and the Office of Policy, Planning, and Evaluation conduct research and technical studies on policy issues. There are no readily available estimates of expenditures of the program offices and the Office of Policy, Planning, and Evaluation for research or technical activities.

OFFICE OF RESEARCH AND DEVELOPMENT

The mission of ORD is to provide high-quality, timely scientific and technical information in the service of EPA's goals. As one function, ORD focuses on answering key scientific and technical questions related to EPA's decision-making and conducts short-term scientific and technical studies that support immediate regulatory and enforcement decisions. In addition, ORD maintains a longer-term research program intended to extend the knowledge base of environmental science and to anticipate environmental problems. Research programs are conducted through the Washington, D.C., headquarters offices, EPA laboratories and field locations, extramural contracts, and EPA exploratory environmental grants and research centers.

ORD research is carried out within a disciplinary structure as follows:

- Health-effects research–to determine exposure and adverse effects of pollutants on human health.
- Ecological-effects research--to determine exposure and adverse effects of pollutants on ecological resources.
- Environmental-process and -fate research–to understand how pollutants are transported and modified as they move through soils, ground and surface waters, and the atmosphere.
- Environmental-monitoring research–to develop methods of identifying pollutants in the environment and measuring exposure to such substances and to develop indicators by which the status and trends of ecosystems can be identified.
- Risk-assessment research–to develop methods to integrate information on pollutant sources, fate and transport, exposure, and health and ecological effects to assess the overall risk posed by a pollutant or group of pollutants.
- Risk-reduction research–to develop methods and technologies to reduce or eliminate the sources of pollutants or prevent exposure to pollutants and to develop control technologies to treat, destroy, or contain pollutants.

RECENT DIRECTIONS

In 1988, the EPA Science Advisory Board (SAB) issued a report entitled *Future Risk: Research Strategies for the 1990s* (EPA, 1988). This report emphasized that EPA is more than a regulatory agency–it has substantial responsibilities for environmental research, technology transfer, and education. The report suggested that EPA needed to reshape its strategy for addressing environmental problems in the future and to focus on the reduction of pollution before it is generated. To support the new focus, the report made a number of recommendations concerning the R&D program, including developing a more fundamental, long-term research program and instituting a strategic planning approach.

In response to the *Future Risk* report, ORD took the following steps:

- Established a "core," or fundamental, research program in FY 1990 addressing ecological risk assessment, health risk assessment, risk reduction (focusing on pollution prevention), and exploratory grants and research centers. By FY 1992, this program constituted 17% of the total ORD budget.
- Implemented a new strategic planning process to set overall directions, with guidance from an agency-wide senior management group, the Research Strategy Council.
- Started the Environmental Monitoring and Assessment Program to monitor status and trends in the health of the nation's ecosystems, whose budget grew to $33 million by FY 1992. (J. Benforado, personal communication, EPA, January 22, 1993).
- Enhanced the human-exposure research program and began planning a national human-exposure survey for FY 1993.

In 1990, the SAB issued a report entitled *Reducing Risk: Setting Priorities and Strategies for Environmental Protection* (EPA, 1990b). This report reviewed and expanded on the earlier EPA report *Unfinished Business: A Comparative Assessment of Environmental Problems* (EPA, 1987). The SAB acknowledged the successes that had been achieved in handling the most obvious and most easily remedied environmental problems facing the nation. However, it noted that the development of national policy had been driven largely by media-specific concerns and legislation. That approach had resulted in fragmented policies; consequently, the goals and tactics of many environmental laws are inconsistent. Moreover, the efforts of the different EPA offices administrating the laws were regarded as rarely coordinated, and the agency as having become largely reactive and involved primarily in managing the reduction of pollution as defined in the laws that it administers.

The impact of the *Reducing Risk* report has been far-reaching. EPA has undertaken a number of efforts to focus on high-risk problems and important opportunities for risk reduction. In planning and budgeting, it is moving toward an issue-based approach that promotes coordinated, cross-media strategies for environmental protection.

In response to the SAB's reports, ORD developed a strategic plan for research that focuses on broad cross-media environmental problems and issues. The over-arching strategic directions are as follows:

- Ensuring that the research program reflects the highest-risk areas.
- Placing greater emphasis on ecological research and ecological risk assessment.
- Aggressively evaluating innovative approaches to risk reduction, for both pollution prevention and pollution control, that offer order-of-magnitude improvements over current practices.
- Improving methods for assessment of health and ecological risks, with a special focus on the comparative-risk recommendations of the SAB.
- Establishing a strong program of technology transfer.
- Establishing productive working relationships with other federal agencies, industry, academe, and other countries to help leverage EPA's resources and take advantage of outside expertise.

In 1991, Administrator Reilly convened an external advisory panel to advise him on how to ensure that EPA uses the best available scientific information in efforts to reduce environmental risk and how EPA could provide leadership in the nation's environmental science, research and assessment efforts. The panel's report, *Safeguarding the Future: Credible Science, Credible Decisions* (EPA, 1992a), contains many specific recommendations for enhancing the EPA's science base and encouraging the development and use of the highest-quality science. In response, EPA has taken a number of actions to improve the quality of science in EPA. Science advisors have been appointed for the administrator and in all program and regional offices; these advisors constitute a new Council of Science Advisors for EPA. The council has developed an agency-wide peer-review policy and is preparing guidance on implementation of the policy.

ORD has worked to improve the research program by instituting a new issue-based planning process. Another important thrust has been to enhance relationships with other federal research agencies and with industry. ORD's interactions with other agencies span a wide range. In the Environmental

Monitoring and Assessment Program, for example, EPA works closely with a number of agencies and provides funding to support other agencies' participation. The EPA global-climate research program is coordinated with other agencies through the White House Federal Coordinating Council on Science, Engineering, and Technology. EPA also uses less formal mechanisms for coordination, such as working groups to plan and conduct joint research with the Department of Agriculture on Midwest agricultural systems. Finally, at the laboratory level, scientists are encouraged to undertake collaborative efforts with outside scientists.

Another recent trend for ORD research has been increased cooperation with industry. During the last 2 years, 50 cooperative R&D agreements have been developed under the Federal Technology Transfer Act, and many more are being negotiated. These agreements provide opportunities for EPA to work with industry to develop and commercialize promising innovative technologies to prevent and control pollution.

Finally, ORD is working to strengthen the involvement of academic community in solving environmental problems. Increased funding for investigator-initiated grants has been a high priority for several years.

RESEARCH PLANNING

ORD is implementing a new planning process for its environmental research program. In this new "issue planning process," the ORD strategic plan will establish the overall priorities. A dozen broad themes, encompassing some 35 research issues, make up the research program:

- Protecting ecological systems.
- Environmental monitoring and assessment.
- Global change.
- Air pollution.
- Drinking-water contamination.
- Waste management.
- Environmental cleanup.
- Health risk assessment.
- Innovative technology and technology transfer.
- Exploratory research and special environmental problems.
- Infrastructure.
- Cross-cutting issues.

This framework will be oriented primarily around environmental problems, with more emphasis on ecological systems and stressors. Some issues focus on EPA's regulatory priorities in air, water, and waste management, particularly priorities that are relevant to several EPA offices and are multidisciplinary. A few cross-cutting issues are included to provide a comprehensive research program.

LABORATORIES AND RESEARCH CENTERS

ORD administers six environmental research laboratories:

- Ada, Oklahoma (Robert S. Kerr Environmental Research Laboratory): Groundwater research, including the transport and fate of contaminants in the subsurface, and developing methods to protect and restore groundwater quality.
- Athens, Georgia: Predictive environmental fate and exposure and modeling of ecological process in fresh-water, marine and terrestrial ecosystems.
- Corvallis, Oregon: Plant and wildlife ecology, regional- and landscape-scale functions, and response of inland ecosystems.
- Duluth, Minnesota: Aquatic toxicology and fresh-water ecology.
- Gulf Breeze, Florida: Impact of hazardous materials on marine and estuarine environments, especially ecotoxicology, biotechnology, and pathobiology.
- Narragansett, Rhode Island: assessing risks to marine and estuarine ecosystems, including marine and estuarine disposal, water and sediment criteria, and global-change impacts on marine systems.

ORD also administers five engineering research laboratories:

- Cincinnati, Ohio (Risk Reduction Engineering Laboratory): Engineering research to prevent or reduce risks associated with environmental contamination, focusing on waste management, remediation of waste sites, and drinking-water treatment.
- Research Triangle Park, North Carolina (Air and Energy Engineering Research Laboratory): R&D of pollution prevention approaches and control technologies for stationary sources of air pollution.
- Research Triangle Park, North Carolina (Atmospheric Research and Exposure Assessment Laboratory): Monitoring and modeling research to

measure and predict air-pollutant concentrations and assess human and ecological exposures.

- Cincinnati, Ohio (Environmental Monitoring Systems Laboratory): Research on laboratory-method development to determine organic and inorganic chemical pollutants in water and wastes, transport and fate of human pathogenic parasites in the environment, and responses of organisms to environmental stressors.
- Las Vegas, Nevada: Development and application of field monitoring techniques, analytic methods, and remote sensing systems for monitoring environmental pollutants.

EPA also has a Health Effects Research Laboratory in Research Triangle Park, North Carolina, to study human health effects resulting from exposure to environmental pollutants.

RESEARCH GRANTS AND CENTERS

EPA has a modest grants program that provides support to the academic community. EPA is in the process of reshaping the program to give more emphasis to subjects of particular interest to EPA, such as terrestrial and aquatic ecology. FY 1992 funding for the grants program was approximately $21 million. (J. Benforado, EPA, personal communication, January 22, 1993).

There are five Hazardous Substance Research Centers:

- New Jersey Institute of Technology: Incineration.
- University of Michigan: Bioremediation.
- Louisiana State University: Sediments.
- Kansas State University: Soils.
- Stanford University: Surface and subsurface transport.

Four new Exploratory Environmental Research Centers were established in 1992:

- Massachusetts Institute of Technology, including consortium members California Institute of Technology and New Jersey Institute of Technology: Sources, transformation, transport, and control of airborne organic chemicals.
- University of California, Davis: Ecotoxicology.

- Michigan Technological University, including consortium members University of Wisconsin and University of Minnesota: Clean manufacturing technologies.
- University of Maryland system, including Horn Point: Multiscale coastal marine ecosystem research, including ways to extrapolate data to whole ecosystems.

OTHER RESEARCH ACTIVITIES

The program offices and regional offices of EPA also undertake a variety of scientific activities, including research, assessment, and reviews of studies. For example, the Office of Water and Office of Prevention, Pesticides, and Toxic Substances Programs recently collaborated on a study of the nation's drinking-water wells for possible pesticide contamination. The two offices designed the study, developed the analytical methods, collected and analyzed the samples, analyzed the data, and published a report.

The Office of Policy, Planning, and Evaluation has a major program to evaluate policy options for responding to global-climate change, which relies heavily on global-climate modeling. In some cases, the research conducted by the program offices or the Office of Policy, Planning, and Evaluation involves ORD. In the drinking-water pesticide study just mentioned, ORD developed the methods, but was not involved in any other aspects of the study. For global-climate research, a substantial portion of the ORD research program is designed to meet the needs of the Office of Policy, Planning, and Evaluation.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

The National Aeronautics and Space Administration (NASA) was created in 1958, 1 year after the launch of Sputnik. It now ranks first among federal agencies as a performer and supporter of environmental research and third in total expenditures for all research. NASA expenditures for environmental R&D in FY 1992 was about $648 million (M. Edwards, NASA, personal communication, April 1993). The agency has no regulatory responsibilities, and the data it collects are for scientific and policy-formation purposes. NASA's major contribution to environmental research is the Mission to Planet Earth (MTPE) program—a long-term research effort that uses space- and ground-based measurement and analysis systems to provide the scientific basis for understanding global change. Phase 1 of Mission to Planet Earth began with the launch of the Upper Atmosphere Research Satellite (UARS) in September 1991. More than 20 spacecraft missions are planned for Phase 1, and a broad variety of in situ studies are under way or planned. Phase 2 will begin in 1998 with the launch of the first Earth Observing System (EOS) spacecraft.

NASA's environmental programs are managed by the Office of Mission to Planet Earth, which was created out of the former Office of Space Science and Application's Earth Science and Applications Division. NASA reorganized its science and applications activities in early FY 1993, placing all earth-related environmental programs in the Office of Mission to Planet Earth. Environmental studies of other planets are carried out in the Office of Space Science's Solar System Exploration Division.

The establishment of environmental research priorities at NASA occurs through input from the research community and from national policy and priorities. In particular, these priorities are guided by the goals of the U.S. Global Change Research Program (USGCRP), an interagency program to understand and predict global environmental change. The central goal of the USGCRP is to help establish the scientific understanding needed for prudent national and international environmental policy-making. The highest-priority near-term scientific and policy-related issue for the USGCRP is whether and to what extent human activities are changing or will change the global-climate system. The USGCRP is coordinated by the Federal Coordinating Council for Science, Engineering and Technology's Committee on Earth and Environmental Sciences (CEES). NASA, with all Federal agencies with environmental research responsibilities, is a member of CEES. The Office of Mission to Planet Earth also has an internal advisory panel consisting of persons in academe, industry, federal laboratories, and other interested organizations. It also relies heavily on the National Research Council's Space Studies Board. About 80% of NASA environmental research is performed extramurally. About 45% of this funding is devoted to basic research.

International participants in the MTPE program include the European Space Agency (ESA), Japan's Science and Technology Agency, and the Canadian Space Agency (CSA). Other U.S. agencies—including the National Oceanic and Atmospheric Administration (NOAA), the Department of Defense, the Department of Energy, and the U.S. Geological Survey (USGS)—are also making significant contributions.

The MTPE program is designed to enable scientists to study the earth as a system. The program emphasizes a multidisciplinary approach to understand and monitor the highly complex interactions among the natural processes and human activities that affect the earth's environment and climate.

Using observations from spacecraft for global studies and ground instruments for in-situ and regional studies, MTPE scientists are studying various earth system processes. These include the following:

- Hydrologic processes, which govern the interaction and transport of water and heat between land, ocean surfaces and the atmosphere.
- Biogeochemical processes, which contribute to the global formation, dissipation, and transport of trace gases and aerosols.
- Climatological processes, which control the formation and dissipation of clouds and their interactions with solar radiation.
- Ecological processes.
- Geophysical processes, which have shaped or continue to modify the surface of the Earth through tectonics, volcanoes, and the melting of glaciers and sea ice.

Through these studies, the MTPE program will help address the seven issues identified by the USGCRP and the United Nations Intergovernmental Panel on Climate Change (IPCC) as critical to understanding global-climate change. These issues include the role of clouds, radiation, water vapor and precipitation; the productivity of the oceans, their circulation, and air-sea exchange; the sources and sinks of greenhouse gases and their atmospheric transformations; the changes in land use, land cover, primary productivity and the water cycle; the role of the polar ice sheets and sea level; the coupling of ozone chemistry with climate and the biosphere; and the role of volcanoes in climate change.

Mission to Planet Earth includes continuing and near-term satellite missions to monitor the earth from space. Beginning in 1998, the EOS and the earth probes missions will begin providing a comprehensive 15 year data set of space-based earth observations. These data will complement data gathered from in situ and aircraft studies. To facilitate use of earth science data, the MTPE program includes management and analysis of both space-and ground-based data and a comprehensive EOS Data and Information System (EOSDIS). It also includes a continuing base research program focused on process studies and modeling, and funding for U.S. Global Change Research Fellowships to train the next generation of earth scientists.

The EOS program has put major emphasis on the Data and Information System (EOSDIS), in consideration of the vast amount of data that will be generated in coming years. The EOSDIS will enable quick and easy access to earth system data by the research community around the world. It will include data not only from EOS spacecraft, but from other MTPE spacecraft and in situ studies as well. EOSDIS will provide command and control of

EOS spacecraft and instruments, and it will process, archive, manage and distribute data. Eight Distributed Active Archive Centers (DAACs), each with a specialized set of data, are being developed at sites throughout the country. EOSDIS will be integrated into the overall plan being developed by the Interagency Working Group on Data Management for Global Change, a subcommittee of the CEES. NASA is working especially closely with NOAA and USGS to integrate data sets of interest to earth scientists.

NASA has one of the largest process-based environmental research programs in the federal government. This program seeks to provide the scientific underpinning and model development necessary to understand processes of global importance, such as the role of clouds in the earth's energy budget and the role of carbon and nitrogen dynamics in deforestation and its consequences for atmospheric carbon dioxide. The research program helps to define the major scientific issues for which global measurements, and therefore satellite missions, are appropriate.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, DEPARTMENT OF COMMERCE

The National Oceanic and Atmospheric Administration (NOAA) in the Department of Commerce administers a large and varied environmental research program with funds of $319 million in FY 1992. Its mission is research- and service-oriented, except for its regulatory responsibility for governing living marine resources under the Marine Mammal Protection Act, the Endangered Species Act, the Fishery Conservation and Management Act, the Marine Protection, Research, and Sanctuaries Act, and other statutes. NOAA's mission statements calls on it to describe and predict changes in the earth's environment, manage the nation's ocean and coastal resources, and promote global stewardship of the world's oceans and atmosphere). It pursues its missions through a program of intramural and extramural research at a network of environmental research laboratories (ERLs), often associated as ERL joint institutes with universities, National Marine Fisheries Service (NMFS) facilities, the Sea Grant College Program Network, and undersea research operations. NOAA spent about $54 million in FY 1992 on university- and college-related research. NOAA is considered the "earth-system agency," because its realm of interest is from the surface of the sun to the bottom of the ocean and its facilities and personnel are deployed globally from Alaska to the South Pole. Terrestrial ecology and geological and solid-earth geophysical processes are not included in its sphere of environmental interests, except for some data-management functions (J. Knauss, NOAA, personal communication January 1992,).

NOAA was established in 1970 by Congressional action after a 1965 reorganization that linked two Department of Commerce activities—the Weather Bureau and the Coast and Geodetic Survey. Other federal units were incorporated into NOAA, including the Bureau of Commercial Fisheries from the Department of the Interior, the Great Lakes Laboratory from the Department of Defense, and the Sea Grant Program from the National Science Foundation (J. Knauss, NOAA, personal communication, January 1992). The amount of money planned for expenditure by NOAA in FY 1992 for all environmental sciences rank it fifth among federal agencies, second after the Department of Agriculture among supporters of environmental life sciences, and fifth among the agencies that support environmental physical sciences. NOAA spent approximately $44 million for the study of long-term climate change.

The Office of Oceanic and Atmospheric Research (OAR) manages programs (funded at about $148 million in FY 1992) in weather research, long-term climate and air quality natural variability; coupled ocean-atmosphere models for greenhouse warming; biogeochemical cycling stratospheric ozone depletion; and atmospheric chemistry, marine prediction, fishery recruitment, coastal ocean interannual and seasonal climate, biotechnology, and Great Lakes ecosystems. The ERLs conduct a variety of research. OAR is also responsible for management of the Sea Grant College Program Network and undersea research operations. The National Network of Sea Grant College Programs involves 26 colleges and three institutional programs. The sea grant program is similar to the well-known relationship between the Department of Agriculture and land-grant colleges and, as in that relationship, research, training, and extension services are included. OAR is involved in numerous arrangements for cooperative research with other federal agencies and university research laboratories (J. Knauss, 1992; N. Ostenso, 1992).

The National Marine Fisheries Service has 28 science centers, laboratories, and field stations attached to five regional centers in coastal areas around the United States. NMFS's principal research concern is the assessment and monitoring of the status of the nation's living marine resources. Living marine resources include marine fish and invertebrates, marine mammals, sea turtles, and the coastal and offshore habitats within the U.S. Exclusive Economic Zone. Numerous research disciplines are involved, including population dynamics, fishery biology, marine ecology, biological oceanography, environmental chemistry, fishery pathology and systematics, organic chemistry, seafood-product safety and quality, habitat assessment, marine forensics, protected- species recovery, and habitat-loss mitigation. NMFS's environmental R & D budget in FY 1992 was $104 million.

The National Ocean Service supports research in national estuarine research reserves and national marine sanctuaries. The National Estuarine Research Reserve System (NERRS) is a national network of areas set aside to serve as field laboratories for long-term research. The primary goal of the NERRS research program is to support environmental studies that contribute to understanding of the existing and evolving functional ecology of ecosystems.

The National Marine Sanctuary (NMS) program consists of 13 marine sanctuaries, which have been set aside because of their important ecological or cultural resources. The NMS program encourages a variety of research within sanctuaries. Recently funded research in NMS includes damage assessments of coral reefs in the Florida Keys and American Samoa, study of the physical ecology of Channel Islands NMS off California, and development of indicator-species assessment techniques to assess the health of coral-reef ecosystems in Hawaii. The NMS program is developing a comprehensive research effort to deal with the conservation of biodiversity in marine environments. Sanctuaries provide excellent areas for long-term analyses of biological, physical, and chemical trends in the marine environment.

NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) maintains, develops, and analyzes research-quality databases applicable to a variety of environmental problems and issues. NESDIS supports a satellite research laboratory (Camp Springs, Maryland) which focuses on the development and analysis of various satellite products. It also operates the world's largest data centers in Asheville, North Carolina (atmospheric data), Washington, DC (oceanic data), and Boulder, Colorado (geophysical data), which provide data, products, and analyses for various environmental research problems.

NOAA expects to improve its infrastructure by modernizing the weather service (proposed expenditure of about $4 billion over 10 years), modernizing its fleet of ships ($1.5 billion over 15 years), and revamping the environmental data system ($500 million over 10 years) (J. Knauss, NOAA, personal communication, 1992).

NATIONAL SCIENCE FOUNDATION

The National Science Foundation (NSF) was founded after World War II in recognition that the contributions of scientific research to the national well-being were too valuable to be limited to periods of armed conflict. Although President Truman and Congressional leaders wanted to create an organization to support basic science, debate over the exact purpose and organization of the incipient NSF resulted in a veto of one bill for its establishment and delayed its inception until 1951. The final bill (the "Organic Act") contained provisions for both a National Science Board and a director and stated that the purpose of NSF was "to promote the progress of science." It has carried out its mission by pursuing two goals–creation of new knowledge through basic research and training of future scientists. The two are coupled in the form of graduate research, and NSF has always used support of graduate research as one of the primary means of carrying out its mission.

In continuance of a philosophy put in place at its inception, it still predominantly issues grants in response to unsolicited proposals. It continues to emphasize "little" science (grants to individual university-based investigators account for over 60% of its expenditures), excellence, and peer review.

NSF support of basic environmental research is diverse, covering physical, biological, social, and engineering aspects of the field. In total NSF spends about $540 million a year on environmental R&D, which places it high among federal agencies for support of environmental research, including environmental science exclusive of development, life sciences, physical sciences, and social sciences.

NSF sees its role in research on the environment to be to develop the fundamental knowledge base, support research facilities and infrastructure, and foster education and training. Its disciplinary coverage includes biology (terrestrial, fresh-water, and marine); earth, atmospheric, and ocean sciences; social and economic sciences; engineering; basic physical sciences; and mathematics and computing related to environmental research. It pursues those interests through a variety of mechanisms, including individual investigator-initiated projects, awards to applicant research groups and centers, such dedicated centers as the National Center for Atmospheric Research (NCAR) and the U.S. Antarctic Program (USAP) and such specialized activities as the Long-Term Ecological Research (LTER) program (M. Clutter, NSF, personal communication, 1991).

The USAP is the major one of several parts of NSF that operate facilities and are therefore required to conduct research applied to understanding, identifying, and assessing environmental effects potentially associated with the operation of the facilities, as well as with the scientific research conducted at the facilities. This type of applied environmental research has received serious attention only with respect to the USAP and its scientific and operational activities.

NSF's environmental research activities are centered mainly in the Directorate for Biological Sciences (BIO) and the Directorate for Geosciences (GEO). Programs are also found in the Directorate for

Engineering (ENG) and the Directorate for Social, Behavioral and Economic Sciences (SBE).

DIRECTORATE FOR BIOLOGICAL SCIENCES

BIO's Division of Environmental Biology (DEB) supports fundamental research on biological diversity at and above the organismal level. Postdoctoral and midcareer fellowships and dissertation-improvement awards are also funded. DEB funds two networks of field-intensive research sites. One network is Long-Term Ecological Research (LTER), composed of 17 sites across the United States (including Alaska and Puerto Rico) and a network office at the University of Washington responsible for coordination and communication. Two sites in Antarctica (funded through NSF's polar programs) also participate in the network activities. LTER research is interdisciplinary and focuses on ecological phenomenon operating on temporal and spatial scales that are longer than those addressed by the usual 2- or 3-year research grant. The other network is Land-Margin Ecosystem Research (LMER), consisting of six sites jointly funded with GEO's Division of Ocean Sciences, at which the focus is on understanding the linkages between terrestrial and marine ecosystems. The LMER sites also interact with the LTER sites. BIO had expected to spend about $79 million on environmental research in FY 1992.

DIRECTORATE FOR GEOSCIENCES

GEO's global-change programs, the primary focus of NSF's contribution to the interagency U.S. Global Change Research Program and a mainstay of the overall effort, seek to gain an understanding of how the earth system functions and to describe the major cause-effect relationships among the system's processes. Major scientific themes include studies of global ocean and atmospheric circulations; the continental hydrological cycle; global tropospheric chemistry; exchanges of biological and chemical materials within the oceans and among the atmosphere, land, and ocean ecosystem; the role of the polar regions in global change; properties of the solid earth and the geological record, especially tectonics and geodynamics; studies of the latitudinal coupling of the middle and upper atmospheric regions; and evidence of these processes operating in the past at various temporal and spatial scales. GEO's role in the overall interagency program is to support basic abiotic research, including model development, and to collect data.

The disciplinary research divisions of GEO–atmospheric sciences, earth sciences, ocean sciences, and polar programs–also support environmental research. Substantial portions of those programs include elements of GEO's global-change programs. The National Center for Atmospheric Research received about $50 million of FY 1992 funds from NSF through GEO, and the directorate spent an additional $69 million for atmospheric-research projects. In total, GEO spent about $426 million on environmental research in FY 1992.

GEO's Division of Polar Programs (DPP) supports a program of applied antarctic environmental research through its Office of the Environment. The program focuses on strengthening environmental protection and management efforts of the USAP and on providing strong scientific foundations to the USAP's environmental decision-making process. DPP has prepared a draft *Program Solicitation for an Environmental Sciences Program in Support of USAP*. The solicitation is designed to accept proposals from basic and applied environmental-research scientists, the private sector, and other federal agencies. Proposals would be peer-reviewed, and reviewers would assess the scientific quality of the proposed research and whether it addressed program-specific criteria applicable to environmental management and decision-making.

DIRECTORATE FOR SOCIAL, BEHAVIORAL, AND ECONOMIC SCIENCES

SBE provided about $7 million for social-science research in FY 1992. Most of it (about $6.8 million) was related to social-science aspects of global change. Other research subjects included geography and decision, risk, and management sciences (Gramp et al., 1992).

DIRECTORATE FOR ENGINEERING

ENG supports research pertaining to the mitigation of environmental impacts of human activities and earthquakes, landslides, floods, and other natural events. FY 1992 funds in the amount of $26 million supported investigations of technologies used to understand contaminant interactions, alleviate environmental degradation in coastal zones, manage industrial and urban waste, improve pollution-abatement processes, design structures resistant to earthquakes and other hazards, and upgrade unsafe structures.

SOME IMPORTANT FEATURES OF NSF

In addition to its broad authority ("to promote the progress of science"), several other characteristics have been essential to NSF's operation in general as it is related to the environmental sciences.

Instead of contracts, NSF uses grants and in some special situations cooperative agreements. NSF uses grants widely because they "imply a freedom on the part of the investigator to pursue work subject to broad conditions." NSF has always recognized the unpredictability of fundamental research.

NSF works through contractors to manage facilities. There are a number of such arrangements, typically university consortia. For example, University Cooperation for Atmospheric Research (UCAR) manages the National Center for Atmospheric Research (NCAR), and Associated Universities, Inc. (AUI), operates radiotelescopes.

Probably as a result of the "rotator" system of visiting staff and the use of mostly former academics as permanent staff, NSF always has tolerated diversity among its divisions with respect to how they operate and the setting of their internal procedures and policies. Different divisions sometimes have quite different procedures and policies. Moreover, although there is strict adherence to excellence and peer review, the actual procedures vary greatly between divisions. Divisions also have considerable latitude in setting funding priorities with regard to support of conferences, instrumentation, travel to meetings, support of undergraduate research, and support of postdoctoral fellowships.

NSF identifies subjects in which it would like to encourage proposals. It typically does that by issuing program announcements, which are of two varieties: one variety is for standing disciplinary programs, such as ecological studies and atmospheric chemistry; the other is for special limited or one-time activities. NSF uses requests for proposals for scientific or operations services. Many of the larger, complex activities are managed through cooperative agreements.

Support for NSF science and technology centers has increased substantially since the first 11 were established in 1989. Fourteen others were funded in FY 1991. Several of the centers are involved in environmental research, including the Center for Microbial Ecology at Michigan State University and the Center for Clouds, Chemistry and Climate at the University of Chicago. Other agencies often contribute to the funding of the centers; state governments sometimes contribute large sums. Graduate and postdoctoral training and outreach programs for local precollege students and teachers are important parts of center operations. The determination of the mix of NSF support of individual investigators and major facilities and centers is usually left to the divisions and their advisory committees.

NSF has always relied on peer review to judge the proposals it receives. Ultimately, staff make the final decision on the basis of criteria established by the National Science Board. The criteria include excellence, qualifications of the principal investigator, available facilities, and contributions to infrastructure (e.g., education). The first three criteria are judged largely through peer review; the staff make judgments about infrastructure issues. To distinguish peer review from the application of the board's selection criteria by NSF staff, NSF now refers to the total process as "merit review."

The details of implementing peer review vary among NSF divisions. In the physical sciences, ad hoc mail review is predominant. A program officer selects reviewers and then decides when enough reviews have been received (a minimum of three substantive reviews is required). The program officer, with the help of the peer reviews, ultimately decides whether to fund or decline the proposal. In other fields, such as the life sciences, a combination of mail and panel review is the predominant mode of review. Mail reviewers are solicited as in the physical sciences, and panels of experts meet once or twice a year to rate proposals, drawing on and weighing the mail review in their deliberations. The program officer's decision is made with the help of all the peer reviews–both mail and panel.

ENVIRONMENTAL RESEARCH AT OTHER AGENCIES[5]

Four other agencies provided $126 million for environmental R&D in FY 1992–for projects addressing issues ranging from environmental management in developing nations to the environmental impact of snowand ice-control methods on U.S. highways.

AGENCY FOR INTERNATIONAL DEVELOPMENT

U.S. aid to developing nations now includes among its goals several environmental objectives, such as promoting sustainable natural-resource and agricultural development, protecting biodiversity, mitigating urban pollution and toxic contamination, and balancing economic and environmental needs. To support those efforts, the Agency for International Development (AID)

[5] Based on descriptions presented in Gramp et al., 1992.

spent approximately $45 million for environmental R&D in FY 1992, primarily in environmental sciences related to agricultural and natural-resource development. The inclusion of $9 million for social and economic research on environmental issues suggests that AID ranks among the leading sponsors of such R&D. AID's mostly applied research is conducted by universities abroad and in the United States and by nonprofit and other research entities.

AID's transnational and country-specific research activities are guided by its environmental objectives. About $28 million of the FY 1992 budget was under the purview of the Bureau for Research and Development, which was created in FY 1991 to administer AID's central research programs. In FY 1992, the bureau budget included $5 million for collaborative studies with Israeli scientists on development problems in target countries (especially those involving arid lands and other subjects of Israeli expertise), $5 million for R&D on agricultural and other environmental priorities of international organizations, $4 million for research on economic and social policies affecting the environment (e.g., land tenure rights and natural-resource accounting), $3 million for competitive grants for innovative scientific research on biodiversity and other subjects, $3 million for other biodiversity studies, and $2.5 million for R&D on pollution prevention.

Although that bureau's programs gained 45% during FY 1990-1992, AID's funding of environmental R&D on country-specific issues declined by 29% to $17 million in that period. The $3 million estimated for environmental R&D under the Development Fund for Africa focused on the sustainable management of the fragile resources underpinning African countries' agricultural economies, including studies on natural pharmaceuticals, biodiversity, and socioeconomic policies. The U.S.-Asia Environmental Partnership signed in 1992 is expected to mobilize private resources to complement AID efforts in environmental training, technology, infrastructure, and biodiversity conservation. AID's FY 1992 budget for Asia included $3 million for the management of lagoons, reefs, and other sensitive ecosystems in the South Pacific; $3 million for natural resource and forestry management in Southeast Asia (Indonesia and Thailand); and $3 million for agricultural and forestry management in central Asia (Afghanistan, Pakistan, India, Bangladesh, and Nepal). Issues emphasized in AID's $3 million research effort in Latin America and the Caribbean include watershed management, sustainable uses of biological resources, and agroforestry.

SMITHSONIAN INSTITUTION

Scientists at the Smithsonian Institution's museums and institutes conduct basic research in the environmental sciences, primarily long-term studies in the life sciences. The Smithsonian's $33 million FY 1992 budget for this research exceeded its FY 1990 budget by 24%, mostly because of increases for global-change projects. Of the total, $19 million funded environmental studies at the Museum of Natural History on the abundance, diversity, and evolutionary relationships of animal and plant species. Priorities included research on biological diversity in Central and South America and studies pertaining to global change, such as paleoecological effects, sea-level change, tropical ecosystems, and human ecological history. The $7 million budget for the Smithsonian Tropical Research Institute headquartered in Panama emphasized behavioral ecology, molecular evolution, tropical marine ecology, tropical forest dynamics, canopy biology, and paleoecology. Scientists at the National Zoological Park had a $3 million budget for continuing research (e.g., on conservation of wildlife and zoo species, molecular genetics, and population biology) and for global-change studies (e.g., on factors affecting species' survival or extinction in the face of major environmental changes). The Smithsonian's Environmental Research Center devoted $2 million to interdisciplinary research on coastal ecological, air, land, and water systems at its location on a tidal subestuary of the Chesapeake Bay. The $0.9 million budgeted for the International Environmental Science Program funded long-term, interdisciplinary monitoring of unique ecosystems, especially in tropical and subtropical regions. Finally, the Smithsonian's Astrophysical Observatory and National Air and Space Museum together spent $0.7 million in FY 1992 on global-change research.

TENNESSEE VALLEY AUTHORITY

As part of its regional and power-development mandates, the Tennessee Valley Authority (TVA) budgeted an estimated $31 million for environmental R&D in FY 1992. TVA began emphasizing environmental R&D at its National Fertilizer and Environmental Research Center in FY 1991. The center's FY 1992 budget included $13 million for R&D related to nutrients and water quality, with such priorities as minimizing groundwater contamination from nitrates, developing environmentally acceptable agricultural chemicals and fertilizers, reducing pollution from fertilizer production, and cleaning up sites contaminated by nutrients, pesticides, and related organic materials. Another $9 million was allocated to reducing agricultural, municipal, and industrial wastes by converting them to alternative fuels or products, including fertilizers. TVA also began participating in the global-change program in FY 1992, budgeting $0.1 million for regional climate assessments. Approximately 85% of the center's funding come from federal appropriations; the remainder was financed by proceeds from the sale of products or services. TVA ratepayers funded the $8 million for R&D on air quality and other environmental issues related to the power program (this excluded any environmental R&D that might have been done by the Electric Power Research Institute using TVA contributions).

DEPARTMENT OF TRANSPORTATION

Funding of environmental research at the Department of Transportation (DOT) has increased, largely because of statutory mandates related to preventing or mitigating environmental impacts. The Coast Guard, which administers the oil-spill liability trust fund created by the 1990 Oil Pollution Act, increased funding in FY 1992 for marine environmental protection by 51% since FY 1990. The $6 million budget for this R&D addresses both the mitigation and prevention of oil and hazardous-material spills, including R&D on countermeasures for damaged vessels, equipment for containing and cleaning up spills, and technologies for improved navigation. Mandates in the 1990 Clean Air Act Amendments explain most of the growth in environmental R&D at the Federal Highway Administration (FHWA). Air-quality programs accounted for $2 million of the $6 million budgeted for environmental R&D in FY 1992, funding research on processes, technologies, and institutional strategies for predicting, preventing, and reducing pollution from vehicles and highway operations. FHWA's remaining R&D focused on reducing the environmental impacts of highway operations, including snow and ice control, corrosion protection, paints and coating, runoff, and noise.

Reducing noise and fuel emissions were among the priorities of the Federal Aviation Administration, which budgeted $4 million for environmental R&D in FY 1992.

COUNCIL ON ENVIRONMENTAL QUALITY[6]

The Council on Environmental Quality (CEQ) was established within the Executive Office of the President by the National Environmental Policy Act (NEPA) of 1969. Its mission is to advise the President regarding environmental policy, federal environmental programs, and environmental conditions and trends. It also coordinates the environmental-impact statement process. During the 1970s under Presidents Nixon, Ford, and Carter, CEQ performed a highly visible role in U.S. environmental policy; it was less active during the Reagan years and re-emerged as a key source of policy advice and coordination during the Bush Administration.

Two of CEQ's activities have been most relevant to environmental research. First, CEQ performs continuing analyses and annually reports on the nation's environmental conditions and trends, and it reviews and coordinates the environmental data and monitoring activities of federal agencies pursuant to Section 201 of NEPA, as well as mandates in the Environmental Quality Improvement Act of 1970 and later executive orders. To assist CEQ in these activities, the it chairs the Interagency Committee on Environmental Trends. Second, CEQ chairs the Interagency Task Force on Acid Precipitation, which coordinates the National Acid Precipitation Assessment Program (NAPAP), a multiagency research and assessment program that was originally authorized by Title VII of the Acid Precipitation Act of 1980 (P.L. 96-294) for 10 years and then reauthorized by Title IX of the 1990 Clean Air Act Amendments.

CEQ participates in a range of other research-related activities. For example, it was responsible for advancing the concept of a national biodiversity center, now being established in cooperation with the Smithsonian Institution. CEQ is a member of several subcommittees of the Federal Coordinating Council for Science, Engineering, and Technology, with particular emphasis on subjects in which CEQ is involved in policy-making, including the Subcommittee on Wetlands Research and the Subcommittee on Water Research of the Committee on Earth and Environmental Sciences and the Subcommittee on Environmental Biology of the Committee on Life Sciences and Health.

[6] The President has proposed the abolition of the Council on Environmental Quality. Congress has not acted on this proposal, so the following description is provided for reference.

INTERAGENCY COMMITTEE ON ENVIRONMENTAL TRENDS

CEQ is required by law to "gather timely and authoritative information concerning the conditions and trends in the quality of the environment [and] to analyze and interpret such information. Determining the conditions and trends in environmental quality by collecting environmental data is essential for formulating, implementing, and evaluating national environmental policy. Reliable information on environmental status and trends also helps to define the long-term health of ecosystems and identify potential causes of environmental degradation.

In a recent summary, CEQ and the Environmental Protection Agency (EPA) identified 83 environmental-data programs in 25 federal agencies. Given the scope and diversity of available data, it is often suggested that decision-makers need an overarching framework to assess linkages among environmental stresses, the state of the environment, and policy responses.

Work on the development of a comprehensive and integrated framework for environmental-trend reporting is being pursued under the Interagency Committee on Environmental Trends (ICET). Convened in 1991 by CEQ, ICET is a federal coordinating body composed of a broad range of agencies involved in environmental-data collection and reporting. The goal of ICET is to work with existing programs to develop a process of data exchange and environmental reporting. An interagency team conducted a similar exercise in 1989 that resulted in the publication of *Environmental Trends* (CEQ, 1989), a comprehensive state-of-the-environment report that included over 350 tables and figures reflecting conditions and variations in environmental quality. ICET will publish comprehensive and integrated state-of-the-environment reports similar to those developed in Canada, Europe, and elsewhere.

NATIONAL ACID PRECIPITATION ASSESSMENT PROGRAM

From 1980 to 1990 under its original mandate, NAPAP was coordinated by an interagency task force that consisted of representatives of 12 federal agencies and four national laboratories, as well as four Presidential appointees. Major program direction was provided by a Joint Chairs Council (JCC) that consisted of high-level officials of CEQ, EPA, the National Oceanic and Atmospheric Administration (NOAA), the Department of Agriculture (USDA), the Department of Energy (DOE), and the Department of the Interior (DOI). Other participating federal agencies were the National Aeronautics and Space Administration (NASA), the Tennessee Valley Authority (TVA), the National Science Foundation, the Department of Health and Human Services, the Department of Commerce, and the Department of State. Two interagency groups, the Interagency Science Committee and the Interagency Policy Committee, were made up of senior representatives of the agencies that composed the JCC. The two committees were responsible for overseeing scientific quality and the policy relevance of NAPAP research and assessment activities. Overall executive management of NAPAP was performed by a director housed in CEQ.

NAPAP developed a research and assessment process to identify the causes and to quantify the extent and magnitude of effects associated with acidic deposition. The process was also designed to evaluate the comparative benefits of different emission-control strategies (NAPAP, 1991). Task-group leaders, who reported to their agencies and to the NAPAP director, were responsible for the coordination of research and assessment activities in seven subjects: emissions and controls, atmospheric processes, atmospheric transport and modeling, atmospheric deposition and air-quality monitoring, terrestrial effects, aquatic effects, and effects on materials and cultural resources. NAPAP also developed assessment working groups on atmospheric visibility, human health effects, and economic evaluation. The assessment working groups were organized in 1988 to develop assessments; they did not conduct research activities under NAPAP, whereas task groups were responsible for the planning and conduct of extensive research programs.

Title IX of the 1990 Clean Air Act Amendments re-established NAPAP and authorized a new task force composed of the administrator of the EPA, the secretary of DOE, the secretary of DOI, the secretary of USDA, the administrator of NOAA, the administrator of NASA, and any other persons that the President might appoint. The President has appointed the chairman of CEQ to the task force as its chairman. The new task force is responsible for activities that include the following:

- Reviewing the status of research conducted pursuant to the Acid Precipitation Act of 1980 and developing a revised plan that identifies important research gaps and establishes a coordinated program to address current and future research priorities.
- Coordinating with participating federal agencies, augmenting the agencies' research and monitoring efforts, and sponsoring additional research in the scientific community as necessary to ensure the availability and quality of data and methods needed to evaluate the status and effectiveness of the acid-deposition control program (established by Title IV of the Clean Air Act Amendments). These efforts will include continuous monitoring of emissions of precursors of acid deposition; modeling that describes the interactions of

emissions with the atmosphere and the responses of ecosystems to acid deposition; and analyzing the costs, benefits, and effectiveness of the program.

- Publishing and maintaining a National Acid Lakes Registry that tracks the condition and change over time of a statistically representative sample of lakes in regions that are known to be sensitive to surface-water acidification.
- Submitting to the President every 2 years a unified budget recommendation for activities of the federal government in connection with this research program.
- Beginning in 1992 and every 2 years thereafter, submitting a report to Congress describing the results of its investigations and analyses. This report is to be in a format that facilitates communication with policy-makers and the public and includes the following information:

- Actual and projected emissions and acid-deposition trends.
- Average ambient concentrations of acid-deposition precursors and their transformation products.
- Status of ecosystems (including forests and surface waters), materials, and visibility.
- The cause and effects of such deposition, including changes in surface-water quality and forest and soil conditions.
- The occurrence and effects of episodic acidification, particularly those on high- elevation watershed.
- The confidence level associated with each conclusion to aid policy-makers in use of the information.

- Beginning in 1996 and every 4 years thereafter, reporting to Congress on the following:

- Reduction in deposition rates that must be achieved to prevent adverse ecologic effects.
- Costs and benefits of the emission-reduction program created by Title IV of the Clean Air Act Amendments.

OFFICE OF SCIENCE AND TECHNOLOGY POLICY

The Office of Science and Technology Policy (OSTP) was established in 1976 and is situated in the Office of the President of the United States. Its mission is to advise the President on matters of science, engineering, and technology. The size of OSTP has varied greatly over the years, depending on the Administration's reliance on the office.

The Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) was established by the National Science and Technology Policy, Organization, and Priorities Act of 1976 (PL 94-282) to consider cross-cutting science, engineering, and technology issues. The OSTP director is chairman of FCCSET, and the membership is composed of the heads of the 18 federal agencies with major R&D programs. Only recently has a full range of committee and subcommittee structures been organized in FCCSET. The specific purposes of FCCSET are to consider problems and developments in science, engineering, technology, and related activities that affect more than one federal agency and to recommend policies and other measures designed to

- Provide more effective planning and administration of federal scientific, engineering, and technological programs.
- Identify research needs, including subjects requiring additional emphasis.
- Achieve more effective use of the scientific, engineering, and technological resources and facilities of federal agencies, including the elimination of unwarranted duplication.
- Further international cooperation in science, engineering, and technology.

Each FCCSET committee has subcommittees and working groups. For example, the Committee on Life Sciences and Health has subcommittees that deal with environmental biology, risk assessment, radiation research and policy, biotechnology research, human-subjects research, HIV-vaccine development, brain and behavioral science, and genome patenting.

The FCCSET Committee on Earth and Environmental Sciences (CEES) is the focus for the U.S. Global Change Research Program (USGCRP). CEES maintains an Interagency Working Group on Data Management for Global Change and an Economics Task Group on Global Change. Although agency interest in a global-change program and substantial interagency activity in that subject predate the formation of CEES, the establishment of the committee in OSTP and effective presentations of a coordinated plan for the program by OSTP to the Office of Management and Budget (OMB) are credited with bringing the program to its present state of visibility and funding success. Priorities and strategies for the USGCRP are described in the CEES publication series *Our Changing Planet*, which is updated each fiscal year (e.g., CEES, 1992); it describes the objectives of the program as

- Establishing an integrated, comprehensive, long-term program of documenting the earth system on a global scale.
- Conducting a program of focused studies to improve understanding of the physical, geological, chemical, biological, and social processes that influence earth-system processes and trends on global and regional scales.
- Developing integrated conceptual and predictive earth-system models.

FCCSET committees are composed of secretaries, directors, and administrators of government agencies. Consensus reached among them can be translated directly into action. FCCSET committees are generally chaired by agency heads, rather than by OSTP personnel, although OSTP personnel may serve as ex officio members.

The activities of FCCSET committees vary, but often begin with a programmatic and fiscal audit of agency activities in a specific field. Committees engaged in this activity, called a budget cross-cut, prepare reports that describe research needs and a plan for interagency cooperation. The programs of the relevant agencies are ranked according to a framework developed by the committee overseeing a budget cross-cut. The agencies' budgets are ranked accordingly, and recommendations are made for allocation of funds. On completion of a cross-cut, OSTP's director meets with OMB officials and holds a series of press conferences to highlight the importance of the subjects in question. The budget cross-cuts generally develop into Presidential initiatives and are given priority attention in the science and technology budget. For FY 1993, five initiatives were originally identified: global-change research, mathematics and science education, high-performance computing and communication, biotechnology research, and advanced materials and processing.

FCCSET developed a category, a national research program (NRP), for continuing Presidential initiatives that have reached maturity. Although global change continues to be a budget cross-cut priority subject and a Presidential initiative for FY 1993, NRP status has been conferred on global-change research for FY 1994.

The OSTP director is also chairman of the President's Council of Advisors on Science and Technology (PCAST). PCAST committees have been formed to provide private-sector viewpoints on science and technology. PCAST committees mirror FCCSET committees overseeing budget cross-cuts; therefore, there is a PCAST committee on each budget cross-cut field.

ORGANIZATION OF FEDERAL ENVIRONMENTAL DATA AND INFORMATIONSYSTEMS

A description of federal environmental data and information systems is essential as a separate part of this appendix because of the importance of data questions in environmental research and because of the complexity of the subject. Almost a dozen departments and agencies of the federal government are important contributors to environmental research. Some of their data resources are enormous, such as those of the National Oceanographic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA) on satellite observations. Many agencies have collected data for decades in fulfillment of their missions, and those data could be extremely valuable if combined with other agency data to understand and solve environmental problems. Numerous inventories, indexes, and catalogs of data on environment-related topics have been gathered; in some cases, offices are analyzing sets of these data.

Several large consortia of agencies are working to coordinate environmental data management. For example, the Interagency Working Group on Data Management for Global Change (IWGDMGC), the Interagency Committee on Spatial Data, and the Interagency Advisory Committee on Water Data. The Environmental Protection Agency (EPA) is enlarging or organizing several data-management programs, and individual agencies are organizing their data for use in interagency arrangements or for their own purposes. Among the latter is the Council on Environmental Quality's Interagency Committee on Environmental Trends, which works to foster enhanced federal reporting on the collection, analysis, and dissemination of environmental data.

GLOBAL-CHANGE DATA MANAGEMENT

In recognition of the importance of effectively managing the massive quantities of data and information to improve understanding of global-change processes, the Office of Science and Technology Policy (OSTP) Committee on Earth and Environmental Sciences (CEES) maintains the IWGDMGC as an integral part of the U.S. Global Change Research Program (USGCRP). The interagency group is regularly advised by National Research Council (NRC) committees. An NRC report in 1991 recommended the coordinated development of an interagency global-change data and information management system. Toward that end, CEES's member agencies are organizing a Global Change Data and Information System (GCDIS) to take advantage of the mission-oriented resources and responsibilities of each agency and a Global Change Research Information Office (GCRIO) to coordinate information-gathering activities. As part of a program plan drafted by the agencies, they commit themselves to work together, with academe, and with the international community to make global-change data available to all (OSTP, 1992).

An appendix to the program plan describes the role of federal agencies in USGCRP data and information management. The following information, abstracted from that appendix, focuses on the types of information being collected and cooperative arrangements for their use.

Department of Agriculture

The U.S. Department of Agriculture (USDA) has several ecological and hydrological data bases, which continue to receive data from experimental forests, ranges, watersheds, and farms. The department's long-term hydrological observation programs exist to monitor hydrological variables, such as precipitation, soil-water infiltration and storage, evapotranspiration, stream flow, runoff, drainage, and reservoir storage. Long-term ecological data bases are part of the department's resource inventory programs including the Resources Planning Act (RPA) Assessments of the Forest Service, and the Soil and Water Resources Conservation Act (RCA) Appraisal of the Soil Conservation Service. USDA monitors trends shown by these data bases, as well as by long-term monitoring data sets, for early indications of global change and to identify sensitive indicators of global change. USDA's National Agricultural Library is initiating planning to participate in national and global networks to manage access to ecological and hydrological data and to assess computing capability for meeting the needs of USDA's program, particularly for predictive-model development.

The National Forest Health Monitoring program of the Forest Service uses remote sensing in combination with annual visits to permanent sample plots to detect and describe systems of changes in forest health, evaluate the role of stress factors in forest health, and understand and predict consequences so as to respond with appropriate management.

The Forest Inventory and Analysis program seeks to improve the understanding and management of the nation's forests by maintaining a comprehensive inventory of the status and trends of the country's diverse forest ecosystems, their use, and their health. Statewide inventory information, which has been collected continuously for over 50 years, covers all 50 states and 731 million acres of forested land. Each year, over 60 million acres of land is inventoried in the United States. The rate of coverage translates into an average inventory cycle of 10 years for the nation.

The Current Research Information System (CRIS) is USDA's computer-based documentation and reporting system for continuing agricultural and forestry research. It provides ready access to information about research conducted primarily within the USDA-State agricultural research system. This information is used to plan research, avoid unnecessary duplication, determine current emphases, and establish contacts. The system contains over 30,000 descriptions of current, publicly supported agricultural and forestry research projects.

The Weather Information Management System (WIMS) is a comprehensive system to manage forestry-weather information nationwide and is designed to accommodate the weather-information needs of users throughout the Forest Service and other forestry and land-management communities. It provides access to many sources of forestry-weather data and related weather information; efficient tools for data management, processing, and display; and a supportive interactive user's environment with access to data-management and data-communications facilities.

Department of Commerce

The Bureau of the Census Center for International Research (CIR) cooperates in the worldwide collection of data on changing population trends. CIR collects population censuses and surveys from 205 countries. The data are evaluated, analyzed, adjusted, and projected to provide realistic estimates of population trends for selected countries, regions, and the world over the next 50 years. It cooperates with the Department of State, the Library of Congress, and the Defense Mapping Agency to map population data for many countries.

NOAA routinely collects large amounts of environmental data and information in its own work and is officially charged to maintain environmental records for the nation. NOAA has a comprehensive, long-term, and up-to-date store of data related to its missions to warn of dangerous weather, chart the seas and skies, guide the use and protection of ocean resources, and enrich understanding of the physical environment. In addition, it maintains special geophysical data such as solar, upper-atmosphere, cryosphere, land-surface, and solid-earth measurements. Its information-management responsibilities include the NOAA earth-system data directory and the corresponding support of the global-change master directory and development of a NOAA data active archive system, which will both integrate into NASA's Earth Observing System Data and Information System (EOSDIS) and serve the longer-term management needs of the climate and global-change community.

NOAA's earth-system data and information management program builds on existing national data centers and independent centers of data in NOAA, which contain data from meteorological stations and satellites on snow and ice, tides, fisheries, bathymetry, geodesy, nautical charts, sea level, and hydrology. The data provide extensive information on climate, marine ecosystems, coastal oceanography, and tides.

Among several international activities, the agency participates in the World Data Center Program by maintaining centers on meteorology, oceanography, solid-earth geophysics, solar-terrestrial physics, marine geology and geophysics, and glaciology. It participates in U.S. interagency programs, including the IWGDMGC, the NASA EOSDIS program, and the EPA Environmental Monitoring and Assessment Program.

Department of Defense

The naval Oceanographic Command provides meteorological, oceanographic, and mapping, charting, and geodetic products for the Department of Defense (DOD) and Navy operations. It maintains a Navy Environmental Data Network focusing on the above subjects. The Navy-NOAA Joint Ice Center provides global ice observations, analyses, predictions, and advisory information to Weather Service forecast offices with sea and lake ice responsibilities. The Navy and Army cooperate in research on basic oceanography and terrestrial processes, including high-latitude dynamics, regional resolving models, boundary-layer dynamics, ocean ecological dynamics, and ocean measurements.

The Air Force possesses satellite and other data primarily on clouds and meteorological measures. The data are available to U.S. government agencies and their contractors and to non-DOD requesters through the National Climatic Data Center. The Air Force and NASA are jointly funding efforts to digitize satellite information for transfer to the National Geophysical Data Center. The Air Force is working with NOAA to make the data available to the research community.

The U.S. Army Corps of Engineers maintains the Cold Regions Research Engineering Laboratory, which conducts research on snow, ice, and frozen ground, cooperates in providing corps observations to Army meteorological teams, and collects data in support of specific continuing projects, such as measurement of temperature; salinity; water quality;

precipitation; river stage; wave height, period, and directions; and beach erosion rates.

The Defense Mapping Agency is the DOD manager for the mapping, charting, and geodesy surveys around the world. The data collected might aid in determining watershed and shoreline changes, sea-level rise, and variations in coastal currents.

Department of Energy

The Department of Energy (DOE) provides stewardship for energy-related data and information relevant to global change and ensures the quality and availability of such data. It has established the Energy Sciences Network. Global-change information is available through three DOE centers: the Carbon Dioxide Information Analysis Center (greenhouse-gas emissions; concentrations of greenhouse gases in the atmosphere, oceans, and terrestrial ecosystems; and long-term climate data), the Energy Information Administration (total fuel cycle and cost-benefit relationships of environmental impacts for energy production and use and socioeconomic analyses), and the Office of Scientific and Technical Information. The DOE programs also provide data to national data centers and to the international World Data Center System sponsored by the International Council of Scientific Unions (ICSU). A new program, the Atmospheric Radiation Measurement (ARM) program, is targeted to acquire environmental data necessary to characterize the cloud-climate feedback mechanism in climate-prediction models. The ARM data will be integrated with those of the National Weather Service and satellite data. DOE has several international working relationships related to global-change data and has nominated its Carbon Dioxide Information Analysis Center to become a world data center in the ICSU network of centers.

Department of the Interior

The process of identifying which existing Department of the Interior (DOI) data sets are most pertinent to global change has been initiated in the DOI bureaus, with overall coordination and assistance at the department level. DOI bureaus will maintain and make available such data and information in support of their mission programs as well as global-change research. For example, USGS recently compiled and released a historic (1874-1988) streamflow data set, called the Hydro-Climatic Data Network, which is specifically suitable for the study of surface-water conditions under fluctuations in the prevailing climatic conditions. Data sets characterizing the land cover, elevation, soils have also been developed and will be available on CD-ROM. They are particularly useful for research on land-atmosphere interactions. DOI is working with participating agencies to create the Global Change Data and Information System that builds on existing resources in federal agencies and the academic community. The U.S. Geological Survey (USGS) has established a cooperative agreement with the National Geophysical Data Center of NOAA for the exchange of paleoclimate data sets. The eventual GCDIS would be distributed and consistent across agencies and coordinated with other countries.

DOI resources supporting the GCDIS include USGS's Earth Resources Observation Systems (EROS) Data Center (EDC) and other data archives in DOI bureaus. USGS is developing the Global Land Information System (GLIS), an on-line land-data directory, guide, and inventory system. The goal of GLIS is to provide earth-science data-users with a single interactive source for information about, and access to, a wide variety of land data from satellite-and ground-based sources archived by USGS and other agencies. USGS and NASA are also establishing a land processes distributed active archive center operated at EDC as part of EOSDIS.

DOI is addressing the need to ensure that all relevant data are preserved for long-term access and use. For example, USGS is rescuing the deteriorating archive of early Landsat data by converting it to stable archival media. DOI bureaus are also developing regional, continental, and global databases by reformatting existing digital data sets and converting nondigital data into digital formats. In addition those products, DOI bureaus are sharing a wealth of derived data, such as outputs of modeling efforts (e.g., digital elevation models and normalized difference vegetation indexes) and the vast quantity of data sets produced and used for geographic information system analysis.

DOI has been very active in encouraging public access to earth-science information through such sources as the Earth Science Data Directory, Earth Science Information Centers, and the National Water Data Exchange. The USGS Library System supports global-change research with its comprehensive earth-science collection of 1.3 million volumes and 450,000 maps. The Bureau of Mines and USGS jointly operate a Minerals Information Office.

DOI chairs the interagency Federal Geographic Data Committee (FGDC) to promote the coordinated development, use, sharing, and dissemination of surveying, mapping, and related spatial data. The objectives of the FGDC include providing guidance and promoting cooperation among federal, state, and local government agencies and the private sector. The

FGDC was established through the revised Office of Management and Budget (OMB) Circular A-16, which assigned leadership responsibilities to various federal departments for various types of spatial data. Those activities are intended to reduce wasteful duplication of effort and foster development of a national spatial geographic data infrastructure.

OMB Memorandum No. 92-01 (M-92-01) delegates to the USGS lead responsibility for a Water Information Coordination program (WICP), which coordinates the water data acquisition and information sharing activities of all federal agencies. Agencies are to ensure that plans to initiate new water information programs or expand old ones are coordinated with other agencies in advance. Participants in WICP are required to collaborate with other groups coordinating related categories of information, including meteorology and spatial data. An Advisory Committee on Water Data for Public Use solicits input from 16 national organizations involved in water issues, and the Interagency Committee on Water Data has representatives from 30 Federal organizations that either collect or use water data.

Environmental Protection Agency

The process of identifying data sets most relevant to global change has been initiated by EPA laboratories with overall coordination and assistance at the headquarters level.

EPA is participating in NASA's pre-EOS Landsat Pathfinder and AVHRR Pathfinder projects. The global-change research program at the environmental research laboratory in Athens, Georgia, is using both a database from a cooperative effort with the University of New Hampshire and the EPA-NOAA global ecosystem database on CD-ROM. A spatial database of carbon in U. S. agricultural soils and site-specific databases from the Great Plains and the corn belt are under development. The laboratory is considering databases containing data on agricultural plant-crop waste and animal waste and the related carbon emissions.

Both the stratospheric ozone and global-change research groups at the environmental research laboratory in Corvallis, Oregon, use the Global Network MetaData File (GNMDF), a working database consisting of about 50 geographic data files with information on land use, vegetation and soil classification, hydrology, and elevation.

The Global Emissions Database (GLOED) software is a database management tool being developed by scientists at the Air and Energy Engineering Research Laboratory in Research Triangle Park, North Carolina. GLOED will have the ability to manage data on global greenhouse-gas sources and sinks. GLOED will also have the capability to store new compilations of emission data and calculate emission data by gas, country, source, and sector.

National Aeronautics and Space Administration

NASA's Mission to Planet Earth (MTPE) and Earth Observing System (EOS) are NASA's institutional response to the requirements of the U.S. Global Change Research Program (USGCRP). As a consequence, those activities are being designed to be directly responsive to research and policy-making priorities as delineated by the Intergovernmental Panel on Climate Change (IPCC).

EOS, the cornerstone of MTPE, is a 15-year-long interdisciplinary and multidisciplinary research mission. Launch of the first satellite in a series is scheduled for June 1998. The EOS project will study global-scale processes through simultaneous observation from a suite of instruments in low-earth orbit and from data collected in situ, integrated with NASA and other federal activities, such as multisensor aircraft campaigns. The EOS space component is also part of a partnership with European and Japanese EOS platforms and will be able to incorporate the data from existing operational satellites. Earth probes, another component of the MTPE, involve single instruments or missions focused on specific parts of the earth system. Earth probes are dedicated both to yield near-term observations of specific earth processes and to complement EOS observations when smaller satellites or nonpolar orbits are needed; EOS itself focuses on a broader range of interrelated phenomena that require simultaneous observations, an integrated information system, and an interdisciplinary science strategy. Indeed, EOS supports the required investigations of the earth system with four distinct mission objectives:

- Creation of an integrated scientific research program that will support the study of the earth's climate system, hydrological cycle, and biogeochemical cycles.
- Acquisition and assembly of a global database of established quality and reliability, mainly from remote sensing measurements.
- Development of a comprehensive data and information system to serve the needs of scientists in a variety of disciplines studying the earth.
- Improvement of predictive models of the earth system, focusing on interaction of system components, such as air-sea coupling and biological effects on climate.

To address those goals, EOS can be considered as having three components: the space-based observatories; the data and information system (EOSDIS), which will help to acquire and analyze data and control the spacecraft and instruments; and the interdisciplinary studies to be carried out by the EOS-funded investigators.

The EOSDIS provides the infrastructure to enable continuing interdisciplinary research on the earth system. It will operate with an unrestricted data policy, so that data for research purposes can be made available to anyone at a reasonable cost. EOSDIS will provide geophysical and biological information, not simply radiance measurements from the instruments. The goal is, therefore, that EOSDIS be a useful information system for the earth-science community, not only a data system. The data from EOS space-based observatories and other sources will be processed within a few hours to a few days after observations are made, and researchers will be able to cross-correlate data sets and gain access to data easily through an information management and data distribution system. EOSDIS is the first component of EOS that will be available to the scientific community, offering useful tools at several stages of its evolution. For example, through a precursor system known as Version 0, it will support research and analysis with existing data and establish common protocols for the transfer of data sets. By 1994, EOSDIS will provide improved access to current satellite data with Pathfinder data sets of geophysical and biological products.

EOSDIS, based on NASA's existing stores of earth-science data including data from other space missions and from nonspace observations) will help to integrate all agency observations. It will establish a capability for providing easily accessible data sets, and information describing them, for EOS and related non-EOS earth-science data as a whole. The EOSDIS architecture will include operation of the space measurement system (the command and control functions) and the production, archiving, and distribution of data and products in support of the EOS scientific research program and general earth-science research worldwide. EOSDIS will serve as NASA's earth-science data system and will begin with a process of consolidating and improving NASA's existing earth-science data-management capabilities, beginning as soon as possible to improve support for interdisciplinary global-change research efforts.

The goals of EOSDIS will be to support the planning and execution of data acquisition from the EOS space measurement system; to support the development of data-analysis products for scientific research; and to process, archive, and distribute data products for EOS and other earth-science data holdings. A related goal is to facilitate extremely wide and easy access to potentially vast holdings. The design is best characterized as flexible and resilient, and the implementation will be incremental and evolutionary. EOSDIS will consist of the following components:

- *Flight operations segment*. Consisting of the EOS Operations Center (EOC) and Instrument Control Centers (ICCs), this segment will provide mission and instrument planning, scheduling, control, and monitoring. Instrument Support Terminals (ISTs) will provide ICC capabilities at the investigator's home facility; interfaces with international partners will also be provided.
- *Science data-processing segment*. This segment will consist of the Distributed Active Archive Centers (DAACs), including the Product Generation System (PGS), the Data Archive and Distribution System (DADS), and the Information Management System (IMS). The primary purpose of this segment is to perform higher-level science processing of instrument data. Field Support Terminals (FSTs) will provide mobile communication to coordinate platform data acquisition and to support visualization and analysis tasks for field campaigns.
- *Science computing facilities*. These facilities will be at investigators' sites and will be used to develop and maintain data-processing software, produce special data products, validate data products, and perform scientific analyses.
- *EOS data operations system*. This system will perform first-level processing (Level 0) and archiving of EOS data, distributes Level 0 data to the DAACs.
- *Communication and system management segment*. This segment will consist of the System Management Center (SMC) and the EOSDIS Science Network (ESN) and provides overall management, coordination, and adjudication of the ground-system resources.

EOSDIS will also provide linkages to non-NASA data centers, which provide related data sets required to support generation of EOS products or of critical importance for the EOS scientific research program, or data centers–Affiliated Data Centers (ADCs)–that perform functions critical to the overall EOS effort and complementary to the functions performed by EOSDIS.

Beyond the operational lifespan of EOS, NASA has negotiated agreements for long-term data archiving with NOAA for oceanic and atmospheric data and with USGS for land data.

Other space missions offer the opportunity to collect important data before the EOS flight missions. The Upper Atmosphere Research Satellite will support the study of atmospheric-chemistry issues. The TOPEX/Poseidon mission will collect data on the roughness of the ocean surface. Other earth probes will provide data on ocean-surface wind velocity, total atmospheric ozone concentrations, and tropical rainfall. The data from all these missions will become part of the holdings of EOSDIS.

A key component of pre-EOS launch activity is the reassessment of previous satellite and other data sets to produce a longer baseline from which we can determine the rate of global change. For example, one major EOS activity is the reprocessing of the NOAA satellite-temperature data set with a consistent set of algorithms and estimates of instrument variances within the NOAA series. The concept of Pathfinder data sets was initiated by EOS program personnel at NASA headquarters to provide EOS investigators and other researchers access to large data sets applicable to global-change research before the availability of EOS data. Pathfinder data sets are long time-series global or regional data sets from which higher-level geophysical products can be derived that are applicable to the study of global-change questions.

National Science Foundation

In the case of large, coordinated National Science Foundation (NSF) research programs and projects (e.g., World Ocean Circulation), substantial efforts are made to ensure that data are collected, processed, subjected to quality control, analyzed, archived, and made available to the research community in internationally adopted standard formats. Where standards do not exist, suitable archive and exchange formats are developed within the project. Data-management plans are coordinated with other participating agencies, and the data are archived at existing national and international centers, e.g., the National Center for Atmospheric Research data centers and the World Data Centers. The research data sets produced under such projects are also documented and reviewed by the research community. As a general policy, all research data sets produced with NSF support are available to all other researchers. In the case of individual projects, principal investigators are allowed exclusive use of their own data sets, if desired, for a limited period before deposition in a data center or dissemination to other investigators.

Programs also exist in NSF outside the focused USGCRP that support interdisciplinary research and infrastructure for scientific databases relevant to the USGCRP. For example, the Division of Information, Robotics and Intelligent Systems (IRIS) and the UNIDATA program in the Division of

Atmospheric Sciences strive to make the best use of atmospheric and related data for enhancing education and research.

The Long-Term Ecological Research (LTER) sites maintain an electronic network linking each other and the network office. Each site also keeps databases on at least five core subjects; archived data are accessible via the Internet. The network office maintains an LTER electronic-mail network (Internet.edu) to facilitate communication among investigators in many institutions.

NSF maintains an electronic communication system (NSFNET) that facilitates contact and collaboration among researchers and research institutions. NSF also provides gateways for access both nationally and internationally to other academic and government networks, e.g., the Interim Interagency National Research and Education Network (NREN).

FEDERAL GEOGRAPHIC DATA COMMITTEE

Under provisions of revised OMB Circular A-16, the DOI, through USGS, chairs the Federal Geographic Data Committee (FDGC) to promote the coordinated development, use, sharing, and dissemination of surveying, mapping, and related spatial data. The data resources being compiled are wide-ranging and are potentially of value in environmental research. A report of the National Research Council Mapping Science Committee (NRC, 1990b, p.38) states that

> in an era of increased awareness of global change (e.g., climatic warming, tropical deforestation, and reduced biological diversity), the scientific community will need to employ new techniques and methodologies for enhancing sustainable development on national, continental, and global scales–advanced cartographic research is imperative. Mapping is the key. Without accurate maps we cannot hope to understand the dynamic social and environmental changes that are occurring in our own country let alone the global system.

Fourteen departments and independent agencies are members of the FGDC: USDA, DOC, DOD, DOE, DOI, EPA, NASA, The Department of Housing and Urban Development, the Department of State, the Department of Transportation (DOT), the Federal Emergency Management Agency, the Library of Congress, the National Archives and Records Administration, and the Tennessee Valley Authority. The committee has developed a concept of a National Geographic Data System that would initially provide an index to federal geographic-data holdings.

OMB Circular A-16 establishes a process to reduce duplication of effort among federal agencies and to foster the development of a spatial framework for collected data. The geographic-data coordination responsibilities assigned by the circular are as follows:

Geographic Data Category:	*Lead Agency*:
Base cartographic	USGS (DOI)
Bathymetric	Coast and Geodetic Survey (DOC)
Cadastral	Bureau of Land Management, (DOI)
Cultural and demographic	Bureau of the Census, (DOC)
Geodetic	Coast and Geodetic Survey, (DOC)
Geologic	USGS, (DOI)
Ground Transportation	Federal Highway Administration, (DOT)
Portrayal of certain international boundaries	Office of the Geographer, (DOS)
Soils	Soil Conservation Service, (USDA)
Vegetation	Forest Service, (USDA)
Wetlands	Fish and Wildlife Service, (DOI)

The Office of Management and Budget (OMB) provided guidance to the heads of executive agencies about water-information coordination in Memorandum 92-01 (M-92-01), signed December 10, 1991. This guidance supersedes Circular A-67 on water-data coordination signed in 1964. The memorandum delegates lead responsibility for the Water Information

Coordination Program (WICP) to USGS, and requires other agencies to assist in the process. The memorandum expands the scope of the previous circular in some significant aspects–including investigations and interpretive products. Specific emphasis is placed on the need to establish more effective working relationships with state and local agencies, Indian tribes, and the private sector. Participants in the WICP are required to collaborate with other groups coordinating related categories of information, including meteorology and spatial data. The requirement to develop consensus standards, guidelines, and procedures is included, as is the need to establish a National Water Information Clearinghouse. Of particular interest is the requirement that agency heads ensure that plans to initiate new water-information programs or expand old ones be coordinated with other agencies in advance. The memorandum specifically requires the participating agencies to conduct a nationwide review and evaluation of water-quality monitoring activities.

OTHER FEDERAL AGENCY DATA ACTIVITIES

Federal agencies have been collecting data in fulfillment of their missions for decades. Many of the data sets are being used by the consortia of agencies that have been formed to manage data for the U.S. Global Change Research Program and the Spatial Data Committee, for example, USDA data on vegetation and soils and DOI data on wetlands. Other focal points for the management of data are being established, for example, the EPA Center for Environmental Statistics. The following describes some of the agency efforts. It is a partial list whose purpose is to show the large amount of effort being expended to collect and manage data.

Environmental Protection Agency

EPA is expanding or initiating a variety of data-collection and data-management activities related to human exposure and health effects of substances in the environment, as well as ecological measures.

A development staff is working within the EPA Office of Policy, Planning, and Evaluation on an Environmental Statistics Initiative. Impetus has been provided by the draft bill elevating EPA to a Department of the Environment that also calls for a Bureau of Environmental Statistics. However, EPA sees the need for a Center for Environmental Statistics as independent of events related to the creation of a Department of the Environment. The goals of the initiative are to provide critical data on the state of the environment to decision-makers inside and outside EPA and the federal government. It is anticipated that the resource will provide the information needed for better resource allocation among different environmental hazards and for targeting efforts on problems of the environment. The center plans to publish reports regularly on national and regional environmental conditions and trends and a directory of federal environmental-data sources. The initial volume in the latter series, *A Guide to Selected National Environmental Statistics in the U.S. Government* (EPA, 1992b), was published in April 1992. The reports will describe environmental conditions and trends and present statistics showing the current status of and historical trends in selected measures of environmental quality, such as ambient environmental pollution; threats to the environment, such as releases or discharges of pollutants; toxicity of contaminated environmental media; human and other exposure to environmental contaminants; health and ecological damage related to environmental degradation; and demographic factors that could affect environmental quality.

The development staff plans to work closely with other EPA program offices, the EPA Office of Research and Development, and other federal agencies to avoid duplication of effort. It sees its activity as complementary to the Council on Environmental Quality's production of an annual report on trends in the environment. The *Guide* lists data sets from most agencies involved in environmental research. The center includes among its information bases such other extensive resources as the Global Change Master Directory, the Guide to Selected Spatial Environmental Data, and the Guide to Selected Ecological Information and Statistics.

In addition to collecting and analyzing data existing in EPA and other federal agencies, the center will concern itself with infrastructural issues, such as the development of statistical methods and training in statistical analysis, and on making information available to the public.

The Environmental Monitoring and Assessment Program (EMAP) is an ambitious program designed to assess the nationwide distribution of ecological resources in the United States and to assess trends in their condition. A unique aspect of the program is its reliance on probability-based selection of sampling locations for both those major goals (NRC, 1992d).

EMAP's specific goals are to

- Estimate the current status, extent, changes, and trends in indicators of the condition of the nation's ecological resources on a regional basis with known confidence.

- Monitor indicators of pollutant exposures and habitat condition and seek associations between human-induced stresses and ecological condition.
- Provide periodic statistical summaries and interpretive reports on ecological status and trends to resource managers and the public (EPA, 1991).

The program's objectives are to understand status and trends in environmental measurements, study associations and diagnose problems, and publish findings in annual reports. Input elements include landscape characterization; stressor data on air and deposition; field sampling of wetlands, estuaries, the Great Lakes, arid ecosystems, surface waters, forests, and agrosystems; and data from other sources (E. Martinko, EPA, personal communication, 1992).

EMAP envisions itself as a focal point for federal-level data coordination, and it plans to amass the maximal amount of quality data while designing its own data system to be compatible with data being gathered as part of the U.S. Global Change Research Program.

U.S. Geological Survey

The National Geologic Mapping Act (PL 102-285), passed May 18, 1992, directs USGS to establish a national geological-map database. Complementary components of this database include a national geophysical-map database, geochemical-map database, and a geochronological and paleontological data base. USGS maintains other databases that have particular relevance to the environmental community. These include the National Geochemical Data Base, consisting of geochemical information for over two million rock, soil, sediment, plant, and water samples. The Mineral Resources Data System contains information on over 80,000 mineral occurrences in the United States and the world. A geophysics database contains information on the distribution of uranium, thorium, and potassium in surficial materials at a national scale.

USGS's Earth Resources Observing System (EROS) Data Center (EDC) is carrying out the goals of PL 98-365 and 102-555 through its satellite-data processing activities. These activities include meeting the following objectives:

- Establishing and operating a data management facility to acquire, process, archive and distribute products from Landsat satellite remotely sensed data.

- Supporting commercial value-added use of Landsat data by distributing minimally processed Landsat data products at the cost of distribution and processing.
- Producing Landsat data products required for global environmental-change research activities in DOI.
- Establishing and operating a Distributed Active Archive Center to provide permanent archive support for and process and distribute land processes data acquired by NASA's Earth Observing System (EOS) as part of the EOS Data Information System (EOSDIS).

The National Water Quality Assessment (NAWQA) program is designed to address national water-quality concerns through comparative studies in a large set of hydrological systems that are distributed in a wide range of environmental settings throughout the nation. The goals of the NAWQA program are to

- Describe the status and trends in the quality of a large, representative part of the nation's surface-water and groundwater resources.
- Provide a sound, scientific understanding of the primary natural and human factors affecting the quality of these resources.

The Core Program Hydrologic Research Program uses the sciences of hydrology, mathematics, chemistry, physics, ecology, biology, geology, and engineering to conduct basic and problem-oriented research in the fields of groundwater hydrology and chemistry, surface-water hydrology and chemistry, geomorphology and sediment transport, and ecology. Encompassing a broad spectrum of scientific investigations, the emphasis of research activities changes through time, reflecting the emergence of promising new fields of inquiry and the demand for new tools and techniques with which to address water-resources issues and problems. Research is focused on gaining a fundamental understanding of the processes that affect the availability, movement, and quality of the nation's water resources.

USGS administers two research programs authorized by the Water Resources Research Act of 1984: the State Water Resources Research Institute program and a national competitive water resources research grant program. The institute program provides matching grants for partial support of 54 water-resources research institutes at land-grant universities across the nation. The institutes conduct programs of research, education, and information transfer on all topics related to water resources.

The Toxic Substances Hydrology program conducts investigations designed to understand the processes affecting the movement and fate of hazardous substances in surface water and groundwater. The program provides information needed to prevent future contamination problems and mitigate existing problems. Interdisciplinary studies are conducted at selected field sites that represent the most important types of contaminants.

National Oceanic and Atmospheric Administration

NOAA's extensive data activities have been described for the most part in the section on global-change data systems. The agency serves as a primary data-collection and data-management agency and engages in cooperative arrangements with, for example, NASA, the Navy, EPA, and USGS. For several cooperative arrangements, it serves as the chair or lead agency. It chairs the interagency working group on global-change data. Its National Climatic Data Center has legal standing as a joint NOAA-Navy-Air Force Weather Records Center. Because of its large role in environmental-data matters, the scope of NOAA's data activities, including and beyond global change, is briefly summarized here.

NOAA manages six world data centers, three national data centers, and over 30 centers of data. The world data centers cover the subjects of glaciology, meteorology, marine geology and geophysics, oceanography, solar-terrestrial physics, and solid-earth geophysics. The national data centers maintain data on geophysics, climate, and oceanography. The 30 centers of data span the mission interests of the agency in atmospheric, oceanographic, and fisheries subjects. NOAA categorizes the environmental variables it deals with as follows:

- Solar (surface) irradiance.
- Concentrations of radioactively and chemically important trace species, such as carbon dioxide, stratospheric ozone, and nitrogen oxide.
- Atmospheric response variables, such as temperature, winds, and tropospheric water vapor.
- Earth-surface data, such as bathymetry, coastline position, and topography.
- Earth-surface properties, such as index of vegetation cover, snow cover, surface albedo, and soil moisture.
- Paleoclimate-atmospheric composition, ice volume and extent, land and ocean temperature, and vegetation.
- Geophysical fields, such as gravity and geoid, magnetic fields, and thermal vents.

- Ocean variables, such as sea-surface temperature, surface radiation budget, dissolved oxygen, nutrients, and sea level.
- Marine-resource information, such as primary productivity, survey species composition, fish pathology (heavy metals), and ecosystem surveys.

National Science Foundation

NSF's Long-Term Ecological Research network has 19 sites from Alaska to Antarctica with a network office in Seattle. Each site gathers data on the five core subjects: primary production, population and tropic structure, organic-matter accumulation, inorganic inputs, and site disturbance. The data sets are published in a Core Data Catalog, and access to them is provided via the Internet. Each site also maintains a geographic information system (GIS) and is capable of analyzing remote-sensing data.

NSF also is funding the computerization of data from the nation's natural-history museums. Data models and programs for standardizing databases are being developed for different types of collections (e.g., MUSE for fish collections and SMASCH for botanical collections). Local data are being geo-referenced to allow mapping entry into a GIS.

NSF is developing a plan for a National Center for Ecological Synthesis and Analysis. The center would serve as a "think tank" where single investigators and groups might come for several weeks or months to use computers and data to analyze and model ecological questions. The center is not envisioned as a gatherer of new data, but as a user of existing data.

APPENDIX B

BIODIVERSITY

HOW MUCH IS THERE?

Biodiversity is the term used to refer to the variety of organisms, their genetic diversity, and the types of ecologic communities into which they are assembled. It can refer to such units as the biota of the entire earth, to the biota of some selected region, to the number and magnitude of differences among evolutionary lineages of organisms, or to the genetic variability within a species. Biodiversity is usefully treated at many different levels, because both basic scientific issues and practical problems focus on different measures of biodiversity.

A basic measure of biodiversity is number of species. Approximately 1.5 million living species and 300,000 fossil species have been described and given scientific names. Estimates of the number of living species vary widely, because they are based on a variety of sources of indirect evidence. The inventory of most species of vertebrates is nearly complete; only minor adjustments are expected in the future. The inventory of vascular plants is not as complete, but we probably know the number of species to within a factor of 2 or 3. However, the vast majority of invertebrates and microorganisms are yet to be described. Most of the insects collected by fogging the canopies of tropical trees, for example, belong to undescribed species (Erwin, 1991). The taxonomy of nematodes is in a very primitive state, and we lack even a reasonable guess of the number of species of bacteria. On the basis of various methods of estimating numbers of species, current workers believe that the total number of species is greater than 15 million, probably as high as 30 million, and possibly over 50 million (May, 1988). That is, we do not know even to within an order of magnitude the number of living species on earth today. Thus, a large fraction of the species likely to be exterminated during the next century will disappear before they have been named, let alone understood ecologically. To the extent that there is merit in the dictum expressed by Aldo Leopold, that the first rule of intelligent tinkering is to save all the pieces, we are engaged in very dangerous tinkering.

Genetic diversity within species is a useful measure of biodiversity, because many species are divided into local populations that are uniquely adapted to the environments in which they live. The study of the causes and consequences of such local adaptations is an important part of population biology. Programs to restore populations in areas from which they have been almost eliminated must pay careful attention to the genotypes of the individuals to be introduced. Maintaining genetic diversity is an essential component of successful captive propagation efforts for rare and endangered species, and much valuable biodiversity can be lost when local populations are exterminated, even if the species survives.

Another important component of biodiversity is the distinctness of evolving lineages. Numbers of the higher taxonomic categories (phyla and classes) in the universally used hierarchic biologic classification system provide a rough measure of distinctness of lineages. By that measure, marine biodiversity is much greater than terrestrial biodiversity, even though there are far fewer marine than terrestrial species. Of the 32 extant phyla of multicellular animals, for example, 31 are marine, and 14 of the 31 are exclusively marine. From this perspective, preservation of marine biodiversity is more important than might be suggested if one simply compares the numbers of species in marine and terrestrial ecologic communities.

Organisms do not live in isolation, but are embedded in a physical environment and a complex matrix of interacting species; and the richness of ecosystems is another measure of biodiversity. Preservation of these systems is essential for the preservation of the species living in them. Although a rich array of terms is used to describe different ecologic communities, there is no generally accepted classification of ecosystems. Species can be defined objectively, but there is no objective basis for deciding how finely ecosystems should be divided. Efforts are under way to develop classification systems for ecosystems that can guide conservation efforts.

WHERE IS IT?

Living species are not uniformly distributed over the surface of the globe. To describe the complex spatial patterns of biodiversity, ecologists and biogeographers have found it useful to divide diversity into two major components: a-diversity and ß-diversity. a-*diversity* refers to point diversity, that is, to the number of species found in a small homogeneous area. *ß-diversity* refers to the rate of change in species of composition across habitat and landscape gradients. A high ß-diversity means that the cumulative number of species recorded increases rapidly as additional areas along some environmental gradient are subjected to a census. Species can also drop out rapidly along such gradients and cause a high rate of species turnover.

a -diversity is characterized by several widespread patterns. First, for most taxa, tropical regions have many more species than higher-latitude ecologic communities. The presence of a few well-known exceptions–such as marine algae, coniferous trees, bees, and salamanders–does not detract from the great importance of tropical regions, both marine and terrestrial, as the home of most of the world's living species.

Second, the diversity of species in most other taxa is positively correlated with the structural complexity of the ecologic community. That is, structurally simple habitats–such as the open ocean, grasslands, and cold deserts–support fewer species of organisms than structurally more complex communities, such as forests and coral reefs. The reason is believed to be fact that in most terrestrial environments plants provide the major components of physical structure within which the activities of all other organisms are carried out. Coral reefs serve the same function in marine environments. Thus, complex communities provide a greater variety of microclimates, a greater variety of resources, more ways in which to exploit those resources, and more places from which to hide from predators and the physical environment.

Third, among most ecosystems there is a positive correlation between productivity and number of species. That is due to the existence of a greater variety of resources above some critical minimum in more productive systems. There are, however, conspicuous exceptions. For example, some extremely productive ecosystems–such as salt marshes, sea-grass beds, and hot springs–are relatively species-poor. Most such systems are distributed as relatively small, fragmented patches that differ strikingly from the surrounding, dominant ecosystems. Evolutionary ecologists believe that the combination of major physical differences and isolation of the patches prevents many species of organisms from evolving adaptations to those unusual environments.

Fourth, island communities are species-poor, compared with mainland communities. In general, the number of species found on islands is inversely correlated with distance from the mainland and positively correlated with island size and topographic diversity. The low species richness on islands is usually attributed to low colonization rates, high extinction rates (because populations are usually small and subject to decimation by local catastrophes and stochastic variation), and lack of particular kinds of resources typically provided by species that are poor dispersers across ocean barriers. Also, island communities have experienced extremely high extinction rates of species during the last century, primarily because of the introduction of mammalian predators (mammals disperse poorly across ocean barriers) and mainland diseases (against which island species have no defenses).

Patterns of ß-diversity are much less well understood. We do know that, on the average, terrestrial tropical species have smaller ranges than species of higher latitudes, but there are many exceptions. A key question is whether a given change in physical environmental conditions causes a greater species turnover in tropical environments than in higher-latitude environments. The question is difficult to answer, because ranges of tropical species are poorly known and physical conditions cannot be matched between tropical and higher-latitude environments.

An important corollary of patterns of species richness is that areas with high a-diversity inevitably have many rare species. For example, a typical tropical wet forest in Central America or South America might harbor 300 - 400 species of trees per square kilometer, and a temperate-zone forest 30-40 species of trees. Given that the number of trees per hectare is roughly the same in tropical and temperate forests, it follows that most of the tree species in tropical forests must be present at very low densities. The same argument applies to most taxa. Because risk of extinction is, in general, inversely proportional to population size, areas with high biodiversity are at greatest risk of losing many of their species.

WHAT ARE THE THREATS TO BIODIVERSITY?

Extinction is a normal evolutionary process. Many species become "extinct" because they evolve into forms that are so different from their ancestors that we assign them different names. Evolutionary biologists usually refer to these as "pseudoextinctions," because there has been *no* extinction of an evolving lineage. What is of central concern is true extinction, that is, the termination of an evolutionary lineage.

Six major episodes of extinctions have punctuated the history of life on earth. Paleontologists do not agree as to the causes of those episodes, but evidence suggests that there is no common cause. The extinctions at the end of the Cretaceous Period were probably caused by collision of a large meteor with earth. Other extinctions were associated with the breakup of Pangea, massive alterations of oceanic circulation, and retreat of ocean waters from large areas of the continental shelves. The last major episode, which involved primarily large vertebrates, was probably caused by humans.

After each episode, biodiversity gradually recovered to the point where overall biodiversity has tended to increase. We might be living today in the period of greatest biodiversity in the history of earth. However, recovery from massive species loss was slow, requiring many millions of years to return to the levels present before to the extinction episode. Thus, recovery rates were lower than extinction rates. Speciation processes, although they will continue, will not save biodiversity from high rates of extinction in time frames relevant to human life and human policy decisions.

Current extinctions differ from previous ones both in their rate and in their cause. The loss of species today is due not to major physical changes on earth, but rather to the activities of a single species. Human population densities and rates of resource use are so high that massive changes in the earth's ecosystems and possibly, as a corollary, its climate are under way. About one-third of the gross primary production of the earth's terrestrial ecosystems is now being co-opted by humans (Vitousek et al., 1986), and the fraction is rising. If the human population doubles during the next 50 years–as appears extremely likely, barring major catastrophes–we will be co-opting more than half the primary terrestrial production. All other species, except human commensals, will have to survive on the fraction that remains. A much smaller fraction of marine productivity is being co-opted by humans, but co-option of coastal productivity, particularly that of the estuaries on which many marine organisms depend, is extensive.

The International Union for the Conservation of Nature and Natural Resources *Invertebrate Red Data Book* (1983) estimates that, among the species threatened by human activities, habitat destruction is contributing to the endangerment of about 73%, displacement by introduced species to 68%, hybridization to 38%, and overexploitation to 15%. The numbers total to more than 100% because many species are being adversely affected by more than one of these factors.

OVEREXPLOITATION

Historically, overexploitation was the major cause of human-induced species extinctions. When humans arrived on Pacific islands, New Zealand, Australia, Madagascar, and North America, they exterminated many species of large birds and mammals (Anderson, 1989, Martin and Klein, 1984). Overexploitation of terrestrial organisms continues today, but much of it is not due to local killing for subsistence, but is driven by lucrative international markets in animal products (such as ivory, rhinoceros horn, and furs), the pet trade (parrots and tropical fish), and plants (such as orchids).

Because the problem is international, it is amenable to international solution. The major tool now being used is the International Convention on Trade in Endangered Species (CITES). Many countries, including the United

States, are signatories to this convention, and substantial results have been obtained in many, but not all, cases. Overexploitation of marine organisms is also a serious problem, but its extent and magnitude are poorly understood because of the extreme difficulty of estimating population sizes of marine organisms and determining the factors most strongly influencing their population dynamics.

INTRODUCTIONS

Humans, inadvertently or deliberately, move large numbers of species around the world. Such introduced species have caused major ecologic and economic problems (witness European rabbits in Australia and chestnut blight and Dutch elm disease in North America), and they have been responsible for many species extinctions. Especially destructive have been mammals introduced to oceanic islands that previously lacked mammals, disease organisms, and weedy plants. For example, the flora of California now includes over 1,000 species of exotic plants, and exotic species dominate many lowlands of California today.

Total elimination of international traffic in species is probably unattainable, because many small organisms travel as undetected or unwanted passengers in human baggage, in holds of ships and aircraft, and in other hideaways. However, international movements of larger organisms can be controlled to a large extent. Importation of game birds and mammals has been largely stopped, but fish introductions continue and the horticulture profession still imports and experiments with exotic plants from throughout the world. Also, the practice of biologic control of pests (most of which are introduced species) often depends on the importation of an exotic predator or disease organism from the original range of the pest. Although such introductions have caused remarkably few problems in the past, they are not riskfree.

HABITAT DESTRUCTION

By far the most important cause of extinction of terrestrial species today is loss of habitats. It is also the most intractable of the causes, because preservation of habitats requires allocation of large areas of land, and land usually has high-value alternative uses. The scenic national parks of the United States were established primarily around geologic marvels, and most of them were established in areas of limited alternative use (except for mining). If we are to preserve biodiversity, more parks and reserves must be established on land with high alternative-use value. Note that biodiversity preservation contradicts a basic dictum of much of economic analysis, namely that lack of a market for a resource guarantees its preservation.

In addition, research by conservation biologists has shown that the parks and reserves we have already established and those likely to be established in the near future will inevitably be inadequate for the preservation of most of the world's species. Much of the burden will have to fall on the exploited lands that dominate the landscapes within which parks and reserves are imbedded. Therefore, forests will have to be managed for a diversity of values, rather than for maximization of wood production, and agricultural practices will have to be modified so that agricultural lands play a greater role in providing habitats for species and corridors for their movements between reserves. The social and political implications of such changes are great. Indeed, the issue cuts to the heart of how much control society will concedes to landowners over the resources that their land contains.

APPENDIX C

PROPOSAL OF THE COMMITTEE FOR THE NATIONAL INSTITUTE FORTHE ENVIRONMENT

This appendix contains the proposal of the Committee for the National Institute for the Environment (CNIE) in the form in which it was reviewed by our committee at its last full meeting, on January 4, 1993. The CNIE proposal has evolved since that time, and the reader should refer to the latest draft of the proposal. A final report is expected to be released soon.

THE NATIONAL INSTITUTES FOR THE ENVIRONMENT

December 7, 1992

Mission

To improve the scientific basis for making decisions on environmental issues.

Goals

- Increase scientific understanding of environmental issues by supporting credible, problem-focused interdisciplinary research.
- Enhance decision making by comprehensive assessment of current environmental knowledge.
- Enlarge access to environmental information, and better communicate scientific and technological results.
- Strengthen capacity to address environmental issues by sponsoring higher education and training in the environmental sciences.

Guiding Principles

- Science and information mission only; no regulatory or resource management role.
- Commitment to problem-focused, interdisciplinary research to address strategic issues concerning environmental resources, systems, and sustainability.
- Research to complement programs of existing federal agencies.
- Extramural and competitive funding of peer-reviewed grants and contracts.
- Representation of governmental, academic, business, and other non-governmental sectors in determining needs, and cooperation among these sectors in research, education and training.
- Cooperation with international research and training agencies and organizations to assist in taking a comprehensive approach to cross-national and global environmental issues.

• December 7, 1992 •

The Research Function of the NIE	The NIE will be a science funding agency that competitively awards research grants and contracts on key cross-cutting environmental issues of national and global importance. Each research program will consider the human, biotic and physical dimensions of a given issue. A possible organization of NIE research, and sample programs, might be:
Inventories, monitoring, and characterization:	**Environmental Resources** Possible programs:
"What do we have?"	• Inventory biological diversity and cultural knowledge of biological diversity. • Monitor and forecast long-term changes in ecosystems. • Search for useful plant, animal and microbial products. • Identify cultural uses of animal and plant resources. • Describe the ways in which different human cultures interact with their environments. • Develop tools for environmental assessment and accounting.
Mechanisms, processes, and effects:	**Environmental Systems** Possible programs:
"How does it work?"	• Measure and evaluate the impact of climate change on natural ecosystems and on agriculture, forestry, and fisheries. • Determine the ecological and economic impacts of the loss of biological diversity. • Measure the effects of stratospheric ozone depletion on terrestrial and marine food chains. • Analyze the impact of government regulations on the condition of the environment and of the economy. • Analyze the ecological and social and economic impacts of using non-fossil fuels.
Strategies, technologies, and solutions:	**Environmental Sustainability** Possible programs:
"How do we keep it?"	• Evaluate strategies for sustainable use of renewable and nonrenewable resources. • Develop improved methods and technologies for environmental conservation, restoration and remediation. • Develop new solvents and chemical manufacturing processes that are environmentally neutral. • Evaluate ways to assess environmental risks and analyze costs and benefits of environmental actions. • Evaluate options for encouraging development and use of technologies that minimize environmental damage. • Consider options for sustainable development under different population projections and technological levels.

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EXECUTIVE SUMMARYTHE NATIONAL INSTITUTES FOR THE ENVIRONMENT A PROPOSAL

MISSION AND GOALS

The environment will be a dominant geopolitical, economic, and social factor of the coming century. To meet far-reaching environmental challenges, the United States needs a federal science agency, the National Institutes for the Environment (NIE), focused exclusively on environmental research, assessment, information management, and higher education and training. The NIE is needed because existing agencies and organizations are not meeting critical environmental needs. The NIE would complement and strengthen these existing efforts.

The mission of this new agency would be to ***improve the scientific basis for making decisions on environmental issues***. To fulfill this mission, the agency would have the following goals:

- *Research:* Increase scientific understanding of environmental issues by supporting credible, problem-focused interdisciplinary research.
- *Assessment:* Enhance decision making by comprehensive assessment of current environmental knowledge.
- *Information:* Enlarge access to environmental information. and better communicate scientific and technological results.
- *Education and training:* Strengthen capacity to address environmental challenges by sponsoring higher education and training in the environmental sciences.

The NIE would be an inclusive agency with unique features. Major stakeholder groups would have a formal role in setting NIE research priorities and would benefit from its commitment to dispassionate research, analysis, and training. These groups include business and industry, environmental groups, academia, state and local research agencies. federal management and regulatory agencies, and other producers and users of environmental information. The NIE would not be a regulatory or resource management agency. However, NIE-supported scientific research would help these agencies make sound environmental decisions.

Research

The hallmark of NIE research would be a problem-focused, interdisciplinary approach that draws on the insights of scientists from all relevant research fields and sectors of society. NIE's special niche would be research that looks ahead to broad environmental challenges that are likely to have major national and international impacts.

A current example might include the effects of ozone loss (resulting in increased UV-B radiation) on the marine and terrestrial food chains, and consequently on the people who depend upon them. A coherent NIE program in this area would include input from biological, physical, and social scientists from academia, government and industry. They would identify the issues, do required research, and provide alternative solutions. The results of this research could help decision makers make plans to develop UV-B resistant crops, or to further speed the phaseout of the chemicals that are largely responsible for ozone depletion.

NIE-funded research would be organized under three broad categories: environmental resources; environmental systems; environmental sustainability. These three components organize the research into three logical ordered steps of understanding. The first component focuses on the question of "What do we have?" that can be addressed by inventories, monitoring studies, and descriptive characterizations. The second component focuses on the question of "How does it work?" and is concerned with mechanisms, processes, and effects. The third component addresses the question "How do we keep it?" and focuses on strategies, technologies, and solutions to environmental problems, and builds on the knowledge gained from the first two components. This organization of research also provides the flexibility needed to modify the research focus as problems and priorities change.

Environmental decision making is required in many areas where scientific knowledge is limited. Hundreds of distinguished specialists from all parts of the scientific community have identified dozens of broad environmental challenges that could have profound impacts on society, and which deserve far more attention than they are now getting. The following examples illustrate important research areas where more information would be helpful to decision-makers.

Environmental Resources: "What do we have?"

- Inventory biological diversity and cultural knowledge of biological diversity.
- Monitor and forecast long-term changes in ecosystems.
- Search for useful plant, animal, and microbial products.
- Identify cultural uses of animal and plant resources.

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- Describe the ways in which different human cultures interact with their environments.
- Develop tools for environmental assessment and accounting.

Environmental Systems: "How does it work?"

- Measure and evaluate the impact of climate change on natural systems and on agriculture, forestry, and fisheries.
- Determine the ecological and economic impacts of the loss of biological diversity.
- Measure the effects of stratospheric ozone depletion on terrestrial and marine food chains.
- Analyze the impact of government regulations on the condition of the environment and of the economy.
- Analyze the ecological, social, and economic impacts of using non-fossil fuels.

Environmental Sustainability: "How do we keep it?"

- Evaluate strategies for sustainable use of renewable and nonrenewable resources.
- Develop improved methods and technologies for environmental conservation, restoration. and remediation.
- Develop new solvents and chemical manufacturing processes that are environmentally neutral.
- Evaluate ways to assess environmental risks and analyze costs and benefits of environmental actions.
- Explore options for encouraging development and use of technologies that minimize environmental damage.
- Consider options for sustainable development under different population projections and technological levels.

NIE will set research priorities in response to the needs of various sectors: academia, business, government, and nongovernmental organizations (NGO's) will play a role. This will ensure that NIE research complements ongoing activities and addresses issues of high

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priority that are not covered elsewhere. It also ensures stakeholding in the questions that are addressed.

Research awards will be made through a variety of mechanisms, including investigator-initiated grants, multidisciplinary task forces, contracts with business and nonprofit groups. All awards should be peer-reviewed, and both grants and contracts should be competitively awarded. The NIE would not duplicate existing agency prerogatives with large, in-house, research laboratories.

Assessment and Evaluation

Assessments link findings of scientists to needs of decision makers and the public. The NIE Office of Assessment and Evaluation is essential to provide ongoing assessments of environmental knowledge on particular issues. Unlike the Office of Technology Assessment (OTA) and the National Academy of Sciences (NAS), which usually do one-time reports on various issues, often authorized by Congress, the NIE assessment office will conduct ongoing assessments. This will provide periodic feedback on progress on key environmental issues, and on the contribution of NIE research towards fulfilling its mission of "improving the scientific basis for making decisions on environmental issues." NIE will conduct assessments to provide timely, unbiased, and useable information about what is known, its potential significance, and its limitations.

The assessment function of the NIE has several objectives. One goal is to ensure that decision makers have access to alternative interpretations of the implications of results from environmental research. A major effort will be made to ensure that results are communicated in "user-friendly" formats to interested parties in the public and government sectors. Another goal would be to evaluate the degree to which NIE research programs are providing the scientific basis for sound policy. As a third goal, assessments will also provide a forward-looking early warning system for emerging problems. Assessments would be useful in identifying important gaps in ongoing research and suggesting priority areas for future funding.

Access to Information

Monitoring, understanding, predicting, and managing the environment is an information-intensive enterprise. A new kind of environmental data and information system (here called the National Library for the Environment (NLE)) will provide ready access to the entire spectrum of public environmental data and information. The NLE will conduct research to develop new ways of managing, abstracting, and disseminating the ever-increasing wealth of data and reports. The NLE will also cooperate with other groups concerned with environmental information systems and with evaluating the quality of environmental data in databases.

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The NIE system would be comprehensive, linking data, interpretations, and publications; it would also be interdisciplinary and geographically broad, linking disciplines across environmental specialties and institutions across the United States and world. The NLE is envisioned as a sophisticated electronic information retrieval system. It would have virtually no role as a physical repository of information on paper and plastic.

Anyone needing the NLE services would have electronic access. A survey of 40 industrial trade associations recently showed that an accessible and credible source of environmental information, such as the NLE, is needed.

Education and Training: Preparing the Next Generation

NIE will help ensure that the next generation of scientists and professionals are prepared for environmental challenges of the future, and that an environmentally literate public and informed media can better evaluate all sides of inherently complex environmental issues.

The NIE would support efforts to improve the general environmental awareness of college students, as well as to train future professionals to work in the environmental sciences in an interdisciplinary framework. Most NIE support for higher education will come through research grants and contracts to colleges and universities. Such support will include research grants that fund graduate and postdoctoral students and provide the incentive for academic institutions to hire faculty who teach courses in environmental subjects. Because a large number of environmental education efforts are being directed at K-12, the NIE would focus its initial efforts at the college and graduate level.

Direct support of students and development of student curricula are critical. Successful examples of such programs include the graduate training and facilities grants from the National Institutes of Health, and the undergraduate instructional grants from NSF. The NIE would support development of environmental courses and programs that are problem-focused and interdisciplinary, encompassing the natural, social, and engineering sciences and humanities relevant to environmental challenges.

WHO WOULD BENEFIT FROM THE NIE?

Everyone would benefit from environmental decisions based on sound science:

- The **public** would benefit. For example. NIE will save the public money because research should lead to more effective and less expensive ways of handling environmental problems. The nation spends $130 billion (about 2% of the GNP) annually on pollution prevention and mitigation. Appropriate research should help bring these costs down.
- **Business and industry** would benefit greatly from a more stable regulatory environment. As scientific uncertainties about environmental effects are reduced, both industry and the regulatory agencies are more likely to agree on what constitutes acceptable

regulation. Time-consuming, wasteful litigation should vastly decrease. In addition, business and industry would have a major role in determining NIE research priorities, which could include collaborative efforts to stimulate pre-commercial research on environmental technologies.

- **Federal agencies** with mandates in environmental regulation and management would gain from credible research relevant to environmental policy, and from a supportive environmentally literate citizenry. An increased supply of appropriately trained professionals should enhance the agencies' ability to carry out their environmental missions.
- **Colleges and universities** would benefit from research and training grants and funds for novel educational initiatives in the environmental sciences. Students are clamoring for these courses, and the NIE research grants would provide colleges and universities greater opportunities to hire environmental scientists.
- **Environmental groups** would benefit in many ways. They would be eligible to apply for contracts and grants for environmental research. If environmental policies are based on sound science, they may have less need to bring lawsuits. They will also have a role in setting NIE priorities. And a more informed citizenry should enhance their ability to achieve their environmental goals.
- **Museums, zoos and other educational institutions** would benefit from grants to support research and educational initiatives.
- **State and local environmental agencies** would benefit from cooperative support of research and educational programs, a more informed citizenry, and better science on which to base their decisions on environmental issues.
- **International agencies** would benefit because the NIE would cooperate with them in pursuing research on key global environmental issues and in sharing research results.

CONCLUSIONS AND SUMMARY

The NIE would be the only federal agency dedicated to environmental science, assessment, information, and training. The NIE emphasis would be on peer-reviewed interdisciplinary and disciplinary problem-oriented research that will help us understand and cope with environmental change.

Regional, national, and global environmental challenges seriously threaten our health, national security, and economic future. The NIE will help discover how environmental systems work, how human activities and institutions lead to environmental change, what the best means are of conserving and repairing environmental systems that threaten our interests, and how our society can ensure the most economically, socially, and technically feasible adjustments to future environmental change.

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INFORMATION ON COMMITTEE MEMBERS

Dale R. Corson (Chairman) is president emeritus of Cornell University. He is a nuclear physicist and engineer with a long record of advisory roles for the Department of Defense, the Department of Commerce, the National Science Foundation, the National Research Council, and the National Academy of Sciences (NAS) Government, University, Industry Research Roundtable. He is a member of the National Academy of Engineering (NAE) and a recipient of the NAS Public Welfare Medal, and the NAE Bueche Medal, and several honorary degrees. He is a foreign associate of the Japan Academy of Engineering.

Richard A. Anthes is president of the University Corporation for Atmospheric Research in Boulder, Colorado. He is an atmospheric scientist with expertise in numerical modeling of the atmosphere.

James D. Baker is president of the Joint Oceanographic Institute, Inc., in Washington, D.C. He is a physical oceanographer with interests in oceanographic, global climate, atmospheric, and polar research.

Eula Bingham is vice president and university dean of graduate studies and research of the University of Cincinnati and professor of environmental health at its College of Medicine. She served as assistant secretary of labor and director of the Occupational Safety and Health Administration at the Department of Labor from 1977 to 1981. Her research has focused on toxicology and environmental and occupational health. She is a member of the Institute of Medicine of the National Academy of Sciences.

Paul L. Busch is president and chief executive officer of Malcolm Pirnie, Inc., consulting environmental engineers, scientists, and planners headquartered in White Plains, New York. His professional career has focused on environmental problem-solving, environmental policy, and the education of environmental scientists and engineers. He is a past president of the American Academy of Environmental Engineers and vice-chairman of the Water Environment Research Foundation.

K. Elaine Hoagland is executive director of the Association of Systematics Collections. Her work has focused on population genetics and dynamics of marine invertebrates, molluscan systematics, and science policy. She has served on many advisory bodies on environmental issues and questions concerning systematics and collections.

Crawford S. Holling is Arthur R. Marshall Professor in Ecological Sciences and Eminent Scholar at the University of Florida, Gainesville. His research is on systems ecology, population dynamics, and ecologic policy analysis. He is a fellow of the Royal Society of Canada.

Theodore L. Hullar is chancellor at the University of California, Davis and professor of environmental toxicology. He has served as deputy commissioner of the New York Environmental Conservation Commission and as research director at the Cornell University Agricultural Research Station. He is the chairman of the National Research Council Board on Agriculture. His research interests include biochemistry, environmental toxicology, agriculture, and environmental policy.

Allen V. Kneese is an economist and senior fellow in the Quality of the Environment Division of Resources for the Future, Inc., and on adjunct professor at the University of New Mexico, Albuquerque. He has conducted research on the economics of water resources and is a recipient of the Volvo Prize for the Environment.

Kai N. Lee is director and professor of environmental studies at Williams College. He has worked at the Office of Technology Assessment and with numerous bodies studying a variety of environmental issues. His research interests include energy and environmental policy and politics, regional power development, fish and wildlife, nuclear-waste management, and environmental conflict and dispute settlement.

Simon A. Levin is George Moffett Professor of Biology in the Department of Ecology and Evolutionary Biology of Princeton University and Charles A. Alexander Professor of Biological Sciences at Cornell University. His research spans both theoretical and applied ecology ranging from modeling of ecosystem dynamics to the interface between science and policy. He is a past president of the Ecological Society of America and of the Society for Mathematical Biology.

Jane Lubchenco is a marine biologist and ecologist and professor of zoology at Oregon State University, Corvallis. Her research is on population and community ecology, plant-herbivore and predator-prey interactions, marine ecology, biogeography, and chemical ecology. She is a past president of the Ecological Society of America.

Richard S. Nicholson is executive director of the American Association for the Advancement of Science. He is a chemist and has served as assistant director and director of several National Science Foundation divisions in chemistry, mathematics, and physical sciences and as a consultant to the Office of Science and Technology Policy. His research interests include electrochemistry and the application of computers in instrumentation.

Gordon H. Orians is professor of zoology and environmental sciences at the University of Washington, Seattle. He is an ecologist and environmental scientist who conducts research on the evolution of vertebrate social systems, the structure of ecologic communities, plant-herbivore interactions, the ecology of rare species, and environmental esthetics. He has served on many National Research Council, government, and professional-society committees. He is a member of the National Academy of Sciences.

Kumar N. Patel is vice chancellor-research at the University of California at Los Angeles and former executive director of Mathematical Sciences Engineering and Academic Affairs Division of Bell Laboratories, Murray Hill, New Jersey. He is a physicist whose research has involved gas and high-power lasers, nonlinear optics, and pollution detection in the atmosphere and the stratosphere. He organized a meeting in 1991 on industrial ecology. Dr. Patel is a member of the National Academy of Sciences and the National Academy of Engineering and the recipient of numerous awards and honorary degrees.

Paul Risser is president of Miami University in Oxford, Ohio. He is an ecologist, and his research focuses on management of grassland ecosystems, landscape ecology, and global change. He is a past president of the Ecological Society of America and of the American Institute of Biological Sciences. He is the Commission on Life Sciences liaison to the committee.

Alan Schriesheim is the executive officer of the Argonne National Laboratory. He is an organic chemist with interests in the kinetics and mechanisms of organic chemical reactions and is a specialist in research administration.

Terry Surles is director of the Environmental Assessment and Information Sciences Division of Argonne National Laboratory. He is an analytical chemist with interests in environmental research, policy, remediation, and waste-management activities and has expertise in managing large-scale multidisciplinary programs. He is an advisor to the committee.

PERSONS INVOLVED IN THE STUDY

To assess the status of environmental research, the committee held a public meeting where it received both oral and written testimony. We also invited persons from the public and private sector to share their views with the committee at its meetings. Persons who assisted us in this way are listed as presenters in the list that follows. Many people were in attendance at parts of our meetings open to the public. They are listed under the heading of attendees. Lastly, we briefed and consulted with several members of Congress and others. They are listed under the heading briefings and consultations. We thank all who helped the committee in its work.

PRESENTERS

Ira Adelman, President, National Association University Fish and Wildlife Programs

*Braden R. Allenby**, Senior Attorney, AT&T

William Anderson, Executive Director, American Academy of Environmental Engineers

Mary Anne Ottinger, Secretary, American Society of Zoologists

Jesse Ausubel, Carnegie Commission on Science, Technology, and Government

C. Robert Baillod, President, Association of Environmental Engineering Professors

*Daryl Banks**, NY Department of Environmental Conservation

Doug Bannerman, Environmental Consultant, National Electric Manufacturing Association

George Barnes, Jr., Chairman, Water Environmental Federal Research Foundation

*Robert Barnes**, American Society of Agronomy,

Gordon Bellen, Chairman, American Chemical Society

Norman Berg, Washington Representative, Soil and Water Conservation Society

David Blockstein, Executive Director, Committee for the National Institutes for the Environment/American Ornithologists' Union

Brian Boom, Vice President of Botanical Science, New York Botanical Gardens

* represents persons that submitted written testimony only

Erich Bretthauer, Assistant Administrator, Office of Research and Development, U. S. Environmental Protection Agency

Allan Bromley, Director, Office of Science and Technology Policy

Robert Bruck, Professor, Office of the Governor (NC)

John D. Buffington, Regional Director of Region 8, U.S. Fish &; Wildlife Service, Department of the Interior,

Anthony Buonicore, Vice President, Air & Waste Management Association

Mary E. Carter, Special Assistant to Assistant, Secretary Science and Education, U.S. Department of Agriculture

*__Charles Chambers__, Executive Director, American Institute of Biological Sciences

*__William Chandler__, Conservation Director, National Parks and Conservation Association

Mary Clutter, Assistant Director, Directorate for Biological Sciences, National Science Foundation

Rita Colwell, Professor of Microbiology, University of Maryland, American Society for Microbiology

Robert Corell, Assistant Director, Geosciences Directorate, National Science Foundation

*__Bob Costanza__, International Society of Ecology and Economics University of Maryland

*__Ellis Cowling__, NC State University

Joel Cracraft, President-elect, Society of Systematic Biologists

Terry Davies, Executive Director, World Wildlife Fund

*__Jonathan Deason__, Director, Environmental Affairs Office, U.S. Department of the Interior

Mike Deland, Chairman, Council on Environmental Quality

Thomas Dietz, President, Society for Human Ecology

*__Christopher D'Elia__, President, Sea Grant Association

Eric Dinerstein, Conservation Scientist, World Wildlife Fund

*__Faye Duchin__, Institute for Economic Analysis, New York University

James Edwards, Acting Director, Division of Environmental Biology, National Science Foundation

Robert Ehrhardt, Chairman, National Association of Environmental Professionals

W. Hardy Eshbaugh, President, American Society of Plant Taxonomists

Jeffery Foran, Chair, Government Affairs, Society of Environmental Toxicology and Chemistry

Robert W. Fri, President, Resources For The Future, Co-chair, Carnegie Commission Committee on Science, Technology, and Government

*__Vicki A. Funk__, Botanical Society of America, National Museum of Natural History, Smithsonian Institute

*__Cliff Gabriel__, American Phytopathological Society, U.S. Department of Agriculture

David Galas, Associate Director for Health and Environmental Research Department of Energy

Steve Garrison, Senior Vice President, Association of Engineering Geologists

Isaiah Gellman, President, National Council of the Paper Industry for Air and Stream Improvement

David Gibbons, Deputy Associate Director, Natural Resources Division Office of Management and Budget

*Neva Goodwin**, Director, Program for the Study of Sustainable Change Development

James Gosz, Chairman of EMAP Review Panel, NRC, Ecological Society of America/Sustainable Biosphere Initiative

Kathleen Gramp, Senior Program Associate, Program in Science, Policy, and Government, American Association for the Advancement of Science

*Joe Guth**, NRDC

*Fren Hansen**, Oregon Department of Environmental Quality

Frank Harris, Deputy Assistant Director, Directorate Biological Sciences National Science Foundation

Edward Hiler, President, American Society of Agricultural Engineers

Marjorie Holland, Director, Public Affairs Office, Ecological Society of America

John C. Holmes, Chair, American Society of Parasitology

*Sarah Horrigan**, National Association of State Universities and Land-Grant Colleges

Stephen Hubbell, Chairman, Committee for the National Institutes for the Environment

*J. Stuart Hunter**, American Statistical Association,

*Michael Hutchins**, Director, American Association of Zoological Parks and Aquariums

*Bernard Johnson**, State of Vermont, Agency of Natural Resources

John Katzenberger, Co-Founder/Director, Aspen Global Change Institute

John Knauss, Administrator, National Oceanic and Atmospheric Administration, Department of Commerce

William Knight, Executive Director, American Institute of Professional Geologists

****John Lehman**, President-Elect, American Society of Limnology/ Oceanography

Felice Levine, Executive Officer, American Sociological Association

Rick Linthurst, Senior Scientist, U.S. Environmental Protection Agency

***Roger Maickel**, American Institute of Chemists Inc.

Thomas Malone, Director, Sigma Xi Center, North Carolina State University

Edward Martinko, Director of EMAP, U.S. Environmental Protection Agency

Vern May, Director, Dow Chemical Company

James McElifish, Jr., Senior Attorney, Environmental Law Institute

***Joseph Mitchell**, Secretary, American Society of Ichthyologists, and Herpetologists/The Herpetologists' League/Society for the Study of Amphibians and Reptiles

Kenneth Mitchell, Professor of Geography, Rutgers University, Association of American Geographers

Thomas Moore, Director, Exhibit Museum, University of Michigan

Emilio Moran, Chair, American Anthropological Association

Harry C. Mussman, Deputy Assistant Secretary, U.S. Department of Agriculture

Stephen Nelson, Director, Program in Science, Policy, and Government American Association for the Advancement of Science

***Michael Novacek**, American Museum of Natural History,

John Perry, Director, Committee on Global Change, NRC

*__Michael Pierle__, Vice President, Monsanto

*__George Rabb__, Chicago Zoological Society

William Raub, Special Assistant for Health Affairs, Office of Science and Technology Policy

Katherine Reichelderfer, Executive Board, American Agricultural Economics Association

Phillip Ross, Director of ESID, Environmental Statistics and Information Division, U.S. Environmental Protection Agency

Amy Rossman, Research Leader, Mycological Society of America

Sherwood Rowland, Donald Bren Professor of Chemistry, University of California, Irvine

James Saxton, Congressman

Mark Schaefer, Senior Staff Associate, Carnegie Commission on Science, Technology, and Government

*__David Schlegel__, Chair, Experimental Station Committee, Organization and Policy

*__Francis Schwindt__, Chief, North Dakota State Department of Health and Consolidated Laboratories Environmental Health Section

Ken Sexton, Director, Office of Health Research, U.S. Environmental Protection Agency,

Howard Silver, Executive Director, Council of Social Science Associations

*__Richard Sinding__, State of New Jersey Department of Environmental Protection and Energy

Philip Smith, Executive Officer, National Research Council

*W. R. Stevens, III**, Manager, DuPont (Environmental Affairs Division)

H. Guyford Stever, Co-chair, Carnegie Commission Committee on Science, Technology, and Government

Albert Teich, Head Science & Policy Programs, American Association for the Advancement of Science

*Paul Templet**, Department of Environmental Quality State of Louisiana

Gene Thorley, Assistant Division Chief for Coordination and Requirements, U. S. Geological Survey, Department of the Interior

Shelby Tilford, Director, Earth Science & Applications Division National Aeronautics and Space Administration

*Robert Varney**, Commissioner, State of New Hampshire, Department of Environmental Services

Stephen Viederman, President, Jessie Smith Noyes Foundation

Judith Weis, Professor, Department of Biological Sciences, Rutgers University

Richard Weismiller, Professor, Department of Agronomy, Soil Science Society of America

*David Wildt**, Co-Director, National Zoological Park, Smithsonian Institute

Gregory Withee, Deputy Assistant Administrator for Environmental Information Services, National Oceanic and Atmospheric Administration/ NESDIS

Terry Yosie, Vice President for Health and Environment, American Petroleum Institute

ATTENDEES

Karim Ahmed, Secretary-treasurer, Committee for the National Institutes for the Environment

Francisco Ayala, Donald Bren Professor of Biological Science, University of California, Irvine

Robert Barnes, American Society of Agronomy

Gerald Barton, National Oceanic and Atmospheric Administration, Department of Commerce

John Beldock, Department of Energy

David Blockstein, Executive Director, Committee for the National Institutes for the Environment

David Bottimore, Versar, Inc.

Walter Boyhan, American Telephone and Telegraph Company

Laurel Bryant, Professional Staff Member, Congressman Saxton's Staff, U.S. Environmental Protection Agency

Jack Cornman, American Anthropological Association

Rick Cothern, U.S. Environmental Protection Agency

Emily Currie, Chemical Manufacturers Association

Jonathan Deason, Director, Environmental Affairs, U.S. Department of the Interior

Peter Farnum, American Society of Biochemistry

John Farrell, Chief, Division of and Marine Resources, U.S. Department of the Interior

Penelope Firth, National Science Foundation

Lawrence Flick, Council on Environmental Quality

Carolyn Fulco, Department of Health and Human Services

Vicki Funk, Botanical Society of America, National Museum of Natural History, Smithsonian Institute

Cliff Gabriel, American Phytopathological Society

J. Stuart Hunter, American Statistical Association

Conrad Istock, National Science Foundation

Larry Jahn, National Association of Fish and Wildlife Program

Clive Jorgensen, U.S. Department of Energy

Kheryn Klubnikin, U.S. Department of the Interior

Rick Kutz, Acting Deputy Director (EMAP), U.S. Environmental Protection Agency

Franklin Long, Professor School of Natural Sciences, University of California, Irvine

Barbara Mandula, Research Director, Committee for the National Institutes for the Environment

Edward Martinko, Director of EMAP, U.S. Environmental Protection Agency

Suzanne Mayer, Contractor, U.S. Department of the Interior

Roy McDiarmid, National Museum of Natural History

John Morris, U.S. Department of Energy

Steve Nelson, Director, Science Policy & Government, American Association for the Advancement of Science

Terry Nipp, Soil Science Society of American

Susan Offutt, Board on Agriculture, National Research Council

Peggy Overbey, American Anthropological Association

Ari Patrinos, Acting Director, Environmental Science Division, U.S. Department of Energy

Fred Pfander, Institute of Environmental Studies

Priscilla Reining, American Anthropological Association

Miriam Rodon-Naveria, U.S. Environmental Protection Agency

Walter Rosen, Consultant

Kathy Rosica, Chemical Manufacturers Association

Gregg Ruehle, National Cattlemen's Association

Michael Saltzman, U.S. Department of Energy

Mark Schaefer, Senior Staff Associate, Carnegie Commission on Science, Technology, and Government

John Schaeffer, American Association for the Advancement of Science

Craig Schiffrief, American Geological Association

Rick Schwabacher, Cousteau Society

Samuel Silverstein, Federation of American Societies for Experimental Biology

W. Ross Stevens, DuPont Company

Paul Stone, Dow Chemical Company

John Ulrich, Dow Chemical Company

Jim Waddell, Office of Science and Technology Policy

Matthew Weinberg, Office of Technology Assessment

Pat Werner, Division Director, Biotic Systems and Resources National Science Foundation

Cecelia Wheatley, Bureau of Mines, Department of the Interior

Robert M. White, President, National Academy of Engineering

Gwen Williams, U.S. Department of the Interior

William H. Wing, EPA Fellow, American Association for the Advancement of Science

BRIEFINGS AND CONSULTATIONS

Senator Bill Bradley
Congressman George E. Brown
Laurel Bryandt, Congressman Saxton's Staff
Radford Byerly, Congressman Brown's Staff
Robert W. Fri, President, Resources For The Future, Co-chair, Carnegie Commission Committee on Science, Technology, and Government
David J. Galas, Department of Energy
Frank Harris, National Science Foundation
Chuck Herrick, Council on Environmental Quality
Henry Howe, Committee for the National Institutes for the Environment
Tony Inderbitzen, U.S. Geological Survey
William K. Reilly, Administrator, U.S. Environmental Protection Agency
Robert M. White, President, National Academy of Engineering
J. Michael Nelson, Senator Gore's Staff
Ned A. Ostenso, National Oceanic and Atmospheric Administration
Eugene Peters, Senator Bradley's Staff
Michael Rodemeyer, Congressman Brown's Staff
Congressman John Saxton

Mark Schaefer, Senior Staff Associate, Carnegie Commission on Science, Technology, and Government

Colonel Sterrett, Department of Defense

H. Guyford Stever, Co-chair, Carnegie Commission Committee on Science, Technology, and Government

David Struhs, Chief of Staff, Council on Environmental Quality

Russell Train, World Wildlife Fund