The Science of Regional and Global Change: Putting Knowledge to Work

Committee on Global Change Research, National Research Council

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Preface

The National Research Council (NRC), the National Science Board (NSB), and many other planning bodies have worked to identify the scientific understanding needed to foster a productive relationship between society and the environment. Three recent reports, themselves syntheses of many other studies, are useful guides to the state of knowledge and the requirements for future progress. *Global Environmental Change: Research Pathways for the Next Decade,* produced by the NRC's Committee on Global Change Research, summarizes the past 10 years' accomplishments of global change research and proposes a strategy for global-scale research in the next 10 years. In this context, global change research attempts to improve understanding of those natural and human-induced changes in ecosystems, the atmosphere, and the oceans that are appreciable at the global scale. *Our Common Journey: A Transition Toward Sustainability,* a report of the NRC's Board on Sustainable Development, presents a strategy for the research needed to more closely link the evolving scientific agenda of global change research, addressed in the *Pathways* report, with growing social concerns for progress toward a transition to environmentally sustainable development—the reconciliation of society's developmental goals with its environmental limits over the long term. The comprehensive challenge is to meet the needs of a larger global population, substantially reduce hunger and poverty, and sustain the environmental support systems and biological diversity of the planet. Meeting this challenge will require closer, more interactive linkages between those who create new knowledge through natural and social sciences research, together with technology development, and those who use that knowledge in direct support of decision making and management. Completing this survey is *Environmental Science and Engineering for the 21st Century.* This is a strategic analysis by the NSB of changes in orientation, organization, and funding of the research enterprise that will be necessary to meet the challenges explored in the NRC reports and other recent analyses.

This report, *The Science of Regional and Global Change—Putting Knowledge to Work,* is intended to promote a dialogue between the scientific community and the government officials who will lead our nation in the coming years. Part I is a brief description of the challenges and proposed responses needed from the highest levels of the government. Part II provides more detailed discussion and is directed to agency-level issues and responses. Part III is a detailed bibliography that lists many of the specific reports on which the views outlined here are ultimately based.

Charles F. Kennel, *Chairman*
Committee on Global Change Research

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At the National Leadership Level

WHAT ARE THE CHALLENGES?

A central challenge facing the United States and other countries in the twenty-first century will be to enhance human well-being in a world where growing populations and the drive to improve living standards place potentially huge demands on natural resources and the environment. Whether we succeed or fail in meeting this challenge will be determined, in part, by how we respond to immediate demands to address human health and economic growth in the context of the wide range of crucial, environmentally related decisions made every day by insurance companies, water resource managers, agribusiness, households, city planners, public health officials, and countless others. Rising to this challenge will entail using natural resources as efficiently as possible, devising practical solutions that meet our immediate needs and also provide for long-run economic growth, while maintaining the environmental systems on which life depends.

To guide wise public policy decisions that continue to improve human and economic conditions and to clarify public debate, it is necessary to restructure the science and engineering framework addressing the biological, chemical, and physical integrity of our surroundings. Private-sector and governmental decisions will be made regarding air, water, and living systems that will fundamentally affect our nation's health and its economic and environmental vitality. Will the information that is necessary to adequately inform these decisions be available?

The answer to this question is not consistently “yes” because of several limitations that are beyond the capacities of individual agencies, including the following:

- The observing “system” available today is a composite of observations that do not provide the information needed nor the continuity in the data to support decisions on many critical issues.
- The United States today does not have the computational and modeling capabilities needed to serve society's information needs for reliable environmental predictions and projections.

- The necessary partnerships do not exist between both the physical and social science research communities and the public and private decision makers that are required to address multiple interacting and changing environmental factors in specific geographic areas.

Reliable and consistent observations are a critical first step in providing the scientific information necessary for decision making, and the federal government has a primary responsibility for providing them. The observations of the environment that are available today are useful but cannot provide the decisive information needed to make properly informed decisions on many crucial issues. Critical examples of these information gaps include the absence of a precise, sustained, and comprehensive climate observing system, inadequate coverage of carbon flux measurements that define sources and sinks, the inability to define ultraviolet dosage levels and the causes for midlatitude ozone erosion, and ineffective attempts at mapping sulfate–nitrate–organic–heavy-metal emissions on the urban-to-regional scale. To make vital, informed decisions on the basis of these and many other types of data, substantial improvements in observations of the atmosphere, surface and ground water, oceans, and ecosystems, as well as relevant economic and societal data, will be required. Individual researchers and research teams do not have the wherewithal to develop and maintain observing systems that can provide a comprehensive and consistent historical record in outcomes of interest. The federal government has been key to the success of past observing systems, whether the problem was measuring economic progress, demographic change, weather, or pollution levels. If critical chokepoints in our understanding of global environmental change are to be overcome, the federal government must make a substantial commitment to establishing and maintaining an observing system that is up to the job.

The nation's ability to create reliable short- and long-term environmental projections and analyses is promising but insufficient. Promising advances have been made in modeling and analysis in such fields as climate, hydrology, atmospheric chemistry, agronomy, and the economics underlying carbon dioxide emissions. But insufficient progress has been made in analyzing and modeling ecosystem and human responses to environmental change, as well as physical (e.g., climate, atmospheric and land surface chemistry) changes at the fine scales of human interest. The federal government should find a way to increase efforts in these areas of research to meet the needs of a diverse set of U.S. interests ranging from agriculture to fisheries, from environmental protection to energy production, and from commodity markets to public health. Improvements in the nation's observational and modeling capabilities will set the stage for dramatic new opportunities to reduce vulnerability and increase resilience to environmental change, maximize economic gains, protect the nation's natural resources, and better understand the sensitivity of our national security to the environment.

The previous decade of research on global environmental change reinforced the idea that, while understanding and predicting change requires a global perspective, solutions to these changes must work at the local and regional levels as well as the global level. This is true whether one is projecting long-term climate, transboundary air pollution, crop prices, or the effects of proposals to limit greenhouse gases on U.S. industrial competitiveness. Indeed, the effects of environmental change on societies and ecosystems can vary profoundly from place to place, due in part to the set of multiple stresses and conditions that are unique to

each locality. As suggested above, the ability to provide regionally specific information pertaining to environmental change calls for an entirely new management philosophy for the environmental research enterprise. This approach must encompass several disciplines, include public- and private-sector participation, and must involve end users and stakeholders as well as researchers at all steps of the process from basic research to decision making. One of the challenges will be to embrace a new regionally specific approach while continuing to foster and even strengthen the global-scale environmental research enterprise, which produced remarkable advances in knowledge over the past decade.

In addition:

- The current situation in the federal government does not sufficiently promote delivery of resources to key research, observational, and technological endeavors that either cross or transcend formal agency responsibilities.
- There are many areas where science has advanced but where research funding has been inadequate to develop effective technologies and assess potential responses to take advantage of this knowledge. For instance, the application of advances in physical science knowledge is particularly hampered by lack of knowledge pertaining to human–environment interactions and their linkage to natural environmental changes.

Consequently, the committee concludes that the federal government's research on earth sciences and the environment, including the U.S. Global Change Research Program and other environmental research that we now see as increasingly interconnected with global environmental change, needs to address these obstacles. Doing so will catalyze the study of global change and human–environment interactions, thereby providing the foundation for a healthy society, economy, and environment—all three of which are inextricably intertwined.

KEY DECISIONS AT THE NATIONAL LEADERSHIP LEVEL

The NRC's Committee on Global Change Research recommends the establishment of an institutional arrangement positioned with sufficient authority to coordinate global and regional environmental research and decision making by ensuring adequate resources over the long term and directing them to the highest-priority issues. Decentralized research management has served U.S. research programs well in many areas and should remain a significant component of global change research. Decentralized research management is successful at creating a diverse set of research activities, which is important when there are several competing hypotheses. However, a weakness of a decentralized approach in, for example, the U.S. Global Change Research Program, is that important areas may not have strong advocates in the existing agency structure and the needed observation systems are too costly for each agency to build its own. A high-level focus is thus needed to ensure that:

1. The federal government's resources can be directed into emerging and underfunded research areas that do not fall within the purview of a single agency. Success depends in part on appointments of agency directors and high-level staff who have the vision to support broad research with potential long-term benefits that may be difficult to defend under narrow interpretations of agency missions.

2. Organizational and resource obstacles to a sustained and flexible program of observations are removed. An integrated observing strategy must be established to effectively monitor climate, environmental chemistry, and ecosystems as well as concomitant socioeconomic factors.
3. Integrated multidisciplinary modeling and information systems on global, national, and regional levels are developed and sustained. These systems, which depend on strong disciplinary knowledge bases, should be designed in close cooperation with those whose decision making they are designed to support in both the public and private sectors.
4. Regionally focused environmental research and assessments are developed to complement global-scale research and transform its advances into usable information for decision making at all spatial scales. This will require building the necessary resource base, as well as new partnerships between the relevant sciences and the public and private sectors.

There are a number of institutional options that could ensure that these critical tasks are fulfilled. Several high-level approaches were considered by the committee, including the following:

1. Creating a new National Environmental Council at the level of the National Economic Council and the National Security Council.
2. Strengthening the existing interagency structure through the National Science and Technology Council.
3. Broadening the mandate of the Council on Environmental Quality to give it oversight of the relevant research.

Whatever approach is chosen, it must be able to cream a national framework that will encourage an intimate connection between research, operations, and the support of decision making. Specific responsibility and resources must be assigned to the integration of multiple-agency programs.

Only by recognizing the nature of the challenges that will be present during the next few years and by showing early and innovative leadership can the tremendous capacity of the research community, the operational mission agencies, state and local governments, and the private sector be brought together to serve society and the environment.

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At the Agency Level

INTRODUCTION

The problems and opportunities briefly described in Part I require actions at all levels of government. With a high-level focal point in the new administration and the needed resources to support critical linkages, new research areas, and the sustained observations, modeling, and information systems, agencies should be able to carry out their missions while contributing to a larger societal imperative. Whether addressing weather, climate, water quality, environmental protection, natural resources, or health and human services, certain steps need to be taken to understand and effectively respond to the complex needs, not only globally but also of particular populations in particular locations (i.e., "place-based" research and decision making).

What is done in the next 10 years will strongly influence what is possible in the next 50. We emphasize that critical environmental issues are emerging rapidly. Some of these issues (e.g., fisheries declines) require immediate attention, and others, relating to the long-term viability of the earth's life support system (e.g., climate change effects), may become critical in this century. For these, the long-term risk is sufficiently high that we should prepare now through improved understanding and information for the decisions that might be needed later.

The recent progress of science and technology gives real reason for hope that the nation's environmental challenges can be successfully addressed. The challenge of sustainable development—the reconciliation of society's developmental goals with its environmental limits—can only be met by advances in basic knowledge, flow of information, and technological capabilities, together with the political will and social capacity to make use of them. The report *Our Common Journey* concluded that there is no scientific or technical reason why the challenge cannot be met. The accelerating pace of discovery in science and technology is driving explosive growth in the production of new knowledge, often with the power to induce profound changes in society. For example, combining environmental observations and new information technologies (viz, Internet and geographic information systems) will readily make available information that has the potential to improve decision making and protect life and property. If organized properly, connecting scientific discovery

and decision making can help bring about a much more productive relationship between society and the environment.

SCIENTIFIC AND ORGANIZATIONAL ISSUES

A great deal of knowledge, know-how, and capacity for learning about sustainable development is already assembled in various observational systems, laboratories, and management regimes around the world—but these resources are not widely known or used. Changes in the environmental research enterprise must ensure that this gap is closed and that knowledge is put into action. Key enabling steps will be a framework of standards and organizational incentives, including the necessary resources that encourage integration. Given such a framework, webs of observing and information systems can grow by capturing initiatives that have many different origins, funding sources, and motivations. To do so, the organizational approach must be designed from the start to be able to evolve with time.

The Fundamental Research Agenda

The first steps must be to implement the research agenda that is clearly defined in this report's primary references (see section A of the Bibliography) and discussed thoroughly in the many more detailed reports on which the primary references are based (see section B and section C of the Bibliography). Here we restrict ourselves to several very general observations.

For global change research there is a need to create more focused programs of research and multidisciplinary process studies related to the six critical areas identified in the *Pathways* report: changes in the biology and biogeochemistry of ecosystems, changes in the climate system on seasonal-to-interannual timescales, changes in the climate system on decadal-to-century timescales, changes in the chemistry of the atmosphere, long-term historical changes in the earth system, and the human dimensions of global environmental change. Fundamental to these research endeavors are high-quality, long-term environmental observations and the information systems to provide access to and to interrelate these data.

For sustainability research, strategies should be developed and employed that improve understanding of human reliance and human effects on environmental systems, by combining research with real-life experiments that are carefully planned to provide opportunities to improve the process as we go along. These strategies must incorporate fundamental research on such understudied issues as consumption, social transitions, and carrying capacity. They must bring together both global and local perspectives from the natural and social sciences so that the multiple cumulative environmental stresses of a particular location can be understood, resulting risks identified, and coping strategies formulated. And these strategies will have to include new resources for emerging areas of research such as ecosystems and human dimensions of global and regional environmental change.

For environmental and ecosystem research, the overall challenge is to sustain and strengthen a diversity of research efforts in the many supporting fields of science and engineering, to promote the aggregation of these efforts into multidisciplinary studies of critical systems, and to recognize the essential complexity of these systems. The role of ecosystems in providing essential products and services must be better understood—in particular how broader environmental changes and human interactions might affect these products and services. It will be important to exploit advances in such areas as ecosystem

sciences, biotechnology, and information science to advance the research effort and to plan to use new technologies to solve environmental issues before they reach criticality.

The unifying themes are to better understand the interactions of the earth system and social system, how those interactions contribute to changes in the environment, and how to develop new strategies for mitigating and adapting to the changes. Effectively addressing these challenges will require stronger connections between the natural sciences, social sciences, and engineering.

Implementing an Effective Research Agenda

In addition to the fundamental research areas outlined above, the committee recommends eight actions that apply to all areas of the environmental enterprise and that need to be carried out by agencies collectively and individually. Each of these action elements is discussed below.

1. *Ensure an "intimate connection" between research, operational activities, and the support of decision making.*

A change in the research enterprise dealing with environmental change and environment–society interactions is urgently needed. Organization of this research should no longer be exclusively defined by academic discipline but should encourage an intimate connection between research, operational activities, and the support of decision making. There are two principal reasons for this. First, the interplay of natural and human factors is not understood well enough to fully inform many of the policy decisions that will be made. Second, and more fundamentally, in many cases the physical (e.g., meteorological and biogeochemical), ecological, economic, and societal data simply do not exist to adequately address these problems. When they do exist, they are often collected and configured in a manner that makes them difficult, if not impossible, to relate to one another. The NRC has described each of these issues in an extensive series of reports over the past several years, including the lack of long-term, sustained climate and ecological observing systems and the lack of societal and economic data necessary to assess environmental challenges in an integrated fashion. Dealing with numerous simultaneous environmental and societal stressors will demand a new level of integration of agency programs. This integration must encompass not only different disciplines but also the identification and transfer of useful products created in the research arena to an operational (i.e., routine and adequately funded) status. Moreover, effective lines of communication need to be established to convey the needs of information users (e.g., decision makers, the public, scientists) to those producing the data to ensure that the data products that are intended for a certain purpose are indeed of maximal utility.

2. *Participate in and support interdisciplinary research relating physical, biological, and human systems.*

Interdisciplinary programs are called for when there is a long-term commitment to understanding issues that require a multiplicity of perspectives. Research systems must be developed that can integrate global and local perspectives to shape a geographically specific ("place-based") understanding of the interactions between environment and society. Such systems will need to be built on the disciplinary intellectual foundations of the geophysical, chemical, biological, social, and technological sciences, as well as on their interdisciplinary research programs in areas such as earth systems science and industrial ecology—the relationship between industrial activities, their products, and the environment. Among the

central challenges to such research systems will be to better understand how multiple cumulative stresses come together in particular settings to shape the vulnerability of social and ecological systems to change. Establishing such a focus is also necessary to provide a conceptual and operational approach for monitoring progress in integrated understanding and management. Across all of these domains, research programs must be designed to support and learn from assessment processes that delineate the complex interplay of socioeconomic and environmental systems.

New integrative strategies are needed. Since improvements in one sector do not necessarily imply improvements in others, and since interactions among sectors must be taken into account, strategies that study and manage the world as a dynamic and interacting system are needed. Process studies, which are investigations of limited duration designed to probe uncertainties in knowledge about complex environmental systems, should be an important part of the integration strategy. They are called for when understanding is insufficient for the purposes of modeling or, for instance, when an ensemble of model predictions does not encompass the actual observations. Concepts and theories that account for feedbacks and interactions among natural and social systems must be created and tested, and institutions and partnerships must be developed to create more tightly integrated and dynamic systems of research, assessment, and decision making.

3. *Plan and implement sustained and integrated observing networks and information systems that transcend traditional agency boundaries.*

Critical to the entire endeavor is the construction of webs of observing and information systems. The United States needs an observing system to establish key trends in critical variables to answer such fundamental questions as: To what extent has the surface temperature changed from state to state and globally? Are weather events becoming more severe? To what extent have ecosystems changed? These observations are critical for initializing and testing models used for environmental prediction and for developing and testing key hypotheses such as: To what extent are climate and ecosystem changes due to natural variation, to what extent to human activities such as land use change for forestry and agriculture, and to what extent to human activities that affect atmospheric concentrations of carbon dioxide, methane, nitrous oxide, ozone, soot, and sulfate aerosols? And how do the effects of these changes factor into the myriad societal changes that influence human and environmental health differently from region to region?

Observations pertaining to different disciplines must be integrated and sustained, thereby producing an observing system of immense utility to science and society. Observing and information systems need to be constructed through a collaborative process involving the scientific community, operational agencies, and those who will use the systems to support decision making and management in the public and private sectors. These systems must preserve the continuity of essential long-term measurements while accommodating technological change and addressing scientific and practical objectives simultaneously. From the outset the research design must include organizational planning for the continuity of useful environmental information. The current observational approach often relies on capturing opportunistic observations made through limited-duration research programs and/or single-purpose observations made for operational reasons. In the current approach, gaps are created because there is no long-term framework or funding for building an integrated, sustained, end-to-end capability. The criteria used today by agencies to make short-term funding decisions often impede the establishment of integrated long-term observing systems that will be needed for regionally focused decision support services.

Moreover, observations used to understand global and regional change are made by dozens of individual governmental entities, often in a manner that is driven solely by an agency's focused mandate, without consideration of low- or no-cost steps that could be taken to make the data more useful to a much broader range of users. The nation must establish an observational approach to address these problems.

4. *Plan to incorporate scientific and technological advances into ongoing research and operational programs.*

The continuing information revolution will make it easier and easier to connect new research results with decision making. From the search for understanding microbial processes in Antarctic ice to tracing contaminant effects in the Arctic ocean, from the investigation of nanoscale interactions on mineral surfaces to the influence of solar flares, from the properties of DNA to animal migration patterns, from the physics of the oceans and atmosphere to the behavior of the climate—all are part of the search to understand earth's life forms and their complex relationship to the physical habitat. That search can be propelled by new tools for discovery, including new genomic methods, increased observational and computational capacities, and more sensitive and versatile analytical instrumentation. Concepts and tools such as these should then be assembled and applied to studies of terrestrial, freshwater, and marine systems and their interactions with human populations around the world. What is needed are increases in the speed and efficiency with which useful scientific and technological advances are incorporated into subsequent research and transferred to an operational mode for utilization by business and science.

5. *Develop improved models and new predictive capabilities.*

Prediction and scenario projection are central to translating knowledge into economic value, improved human welfare, and sustenance of the environment on which life depends. Every citizen appreciates knowing when it will rain, and the emergency management agencies want to know when a big storm is coming and how much damage it may cause. Demands for new forecasting products of air quality, energy demand, water quality and quantity, ultraviolet radiation, and human health indexes are growing. The demands are driven by the beneficial planning and adaptation to potential environmental changes that are enabled through the provision of predictions and projections. At the global level, many key questions relate to what will happen if the atmospheric concentration of greenhouse gases doubles or triples in this century. The only way to approach these questions is through numerical modeling, which requires better scientific understanding and much more supercomputing capacity to improve the capability to project long-term climate and chemical consequences of possible changes in such factors as greenhouse gases and land use. Also required are observations to set the models' initial conditions and to use as a basis for diagnosing model output. Some of the most significant gaps in numerical simulation exist in the analysis and modeling of ecosystem and human response to environmental change, as well as physical (e.g., climate, atmospheric and land surface chemistry) changes at the fine scales of human interest and certain physical phenomena (e.g., clouds).

6. *Develop improved assessment capabilities for integrating scientific knowledge into effective decision support systems*.

Assessment and policy analysis are essential to understand the overall impact of changes in human behavior and natural processes, to link research agendas with decision needs, and to monitor the results of policy actions. Effective assessment aims to integrate the concepts, methods, and results of the physical, biological, and social sciences into a decision support

framework. Unfortunately, our ability to create effective and efficient assessments is limited. Assessments that provide useful, credible scientific information to decision makers in a timely and politically acceptable manner remain the exception rather than the rule. At the same time, assessment activities are consuming an ever-increasing portion of the limited time and money resources of the scientific community. Research on how to do more effective, credible, and helpful scientific assessments is badly needed. Of particular importance will be the development of assessment processes that link knowledge producers and users in a dialogue that builds a mutual understanding of what is needed, what can credibly be said, and how it can be said in a way that maintains *both* scientific credibility and political legitimacy.

The need to design efficient assessment processes that effectively balance scientific credibility and political acceptability is particularly acute in the realm of transnational or global environmental issues. An important result of the observations and analyses conducted over the first 10 years of the U.S. Global Change Research Program is that we now have a far greater appreciation of the linkages among earth systems. These include feedbacks between the terrestrial ecosystems (soils, plants, and animals), the atmosphere, oceans, and human activities (e.g., emissions from industrial processes such as ore smelting and solvent use, energy use, and agriculture). In turn, we have found that environmental change has broad and subtle effects on forests, ocean and freshwater fisheries, and agriculture and that these effects are a potential threat to human well-being. We still do not have sufficient knowledge or analytical capability to fully assess the magnitude of these changes or exactly when or how changes might beneficially or adversely affect particular regions of the country or sectors of the economy. This limits the nation's ability to capitalize on the positive aspects of the changes and adapt to the negative ones.

In support of such strategic efforts to build more effective assessment systems, further development of a number of policy analysis tools will be needed, including integrated assessment models. These models seek to link formal models of the environment and society. They probe uncertainties in our understanding of the human–environment interface and the significance of those uncertainties for future implications of current decisions. They are now being extensively applied to the large-scale interactions between economic development and the atmosphere (e.g., ozone depletion, acid rain) and to address the risk of climate change (e.g., the Intergovernmental Panel on Climate Change). The federal government must renew and increase its commitment to supporting integrated modeling and assessment.

Also critical to the assessment process are repeated observations of key indicators of natural and social phenomena, obtained at regular intervals, to inform society about progress in achieving sustainable development. A variety of indicators and approaches, including national capital accounts, policy assessments, monitoring basic trends and transitions, and diagnosing risks of surprises, will be needed. Resources must be provided and support given to develop and continue assessment processes.

7. *Define and carry out programs of regional and sectoral multiple-stress research and demonstration projects.*

Most of the individual environmental problems that have occupied the world's attention to date are unlikely in themselves to prevent substantial progress in a transition toward sustaining the environmental systems on which humans and other biota depend. More troubling are the environmental threats arising from multiple, cumulative, and interactive stresses, driven by a variety of human activities. Most research and policy currently focus on single causes and single effects. This approach is proving inadequate for advising on

comprehensive management strategies and has the potential to produce unintended consequences because it does not account for the inherent complexity of interacting human and natural systems.

Therefore, it is time to get started on programs of regional and sectoral multiple-stress research and demonstration projects. Support is needed to encourage the new partnerships and integration of observing and information systems required to build decision support capability. New funding can be a critical stimulus to the new partnerships among researchers and users, federal and state agencies, universities, and industry needed to get regionally specific, multiple-stress research started. The NRC's Board on Sustainable Development has proposed regional efforts related to water, atmosphere and climate, and species and ecosystems. Several pilot projects could be started relatively soon. The successful ones would serve as hubs for further coalescence of a more comprehensive effort.

8. Connect research, education, and outreach.

Fundamental change will be possible only if education and outreach efforts communicate the progress of understanding to all concerned. A requirement for education and outreach permeates all of the organizational levels mentioned above. We need to sustain the nation's supply of scientists, train the people who will manage our environment, alert decision makers, communicate to the public the reasons for decisions, and support a knowledgeable electorate. The quality, diversity, inclusiveness, and timeliness of education and outreach efforts are probably the most important factors determining success or failure in the long run.

3

Bibliography

A. PRIMARY REFERENCES

The following three major reports, which are the primary references cited in this document, summarize current progress and outline a set of strategies for advancing understanding of global change and sustainable development. These benchmark reports are actually syntheses of syntheses—they build on a much larger set of important disciplinary overview and strategy reports (see section B).

Environmental Science and Engineering for the 21st Century: The Role of the National Science Foundation, National Science Board, 2000

Global Environmental Change: Research Pathways for the Next Decade, National Research Council, 1999

Our Common Journey: A Transition Toward Sustainability, National Research Council, 1999

B. A SAMPLING OF BENCHMARK REPORTS AND RESEARCH AGENDAS

The following documents are illustrative examples of the wide range of reports that have helped set the national and international research and policy agendas in each of the disciplines they encompass. Each is a synthesis document based on a massive body of literature on global change and sustainability produced by both the NRC (see section C) and others.

Agenda 21, United Nations Conference on Environment and Development, 1992 Provides a comprehensive plan of action to be taken globally, nationally, and locally by organizations of the United Nations system, governments, and major groups in every area in which humans affect the environment.

Biodiversity II: Understanding and Protecting Our Biological Resources, National Research Council, 1996

Calls attention to a most urgent global problem: the rapidly accelerating loss of plant and animal species to increasing human population pressures and the demands of economic development.

Building a Foundation for Sound Environmental Decisions, National Research Council, 1997

Describes a framework for acquiring the knowledge needed to solve current recognized environmental problems and to be prepared for the kinds of environmental problems likely to emerge in the future.

Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution, National Research Council, 2000

Explains technical aspects of nutrient over-enrichment and proposes both immediate local action by coastal managers and a longer-term national strategy incorporating policy design, classification of affected sites, law and regulation, coordination, and communication.

Earth Observations from Space: History, Promise, and Reality, National Research Council, 1995

Reviews the recent history of U.S. earth observation programs involved in environmental monitoring. The focus is on monitoring programs related to civilian needs.

Ecological Indicators for the Nation, National Research Council, 2000

Identifies ecological indicators that can support U.S. policy making and also be adapted to decisions at regional and local levels.

Effects of Past Global Change on Life, National Research Council, 1995

Explores what earth scientists are learning about the impact of large-scale environmental changes on ancient life—and how these findings may help us resolve today's environmental controversies.

Environmentally Significant Consumption: Research Directions, National Research Council, 1997

Demonstrates that the relationship of consumption to the environment needs careful analysis by environmental and social scientists and conveys some of the excitement of treating the issue scientifically.

From Monsoons to Microbes: Understanding the Ocean's Role in Human Health, National Research Council, 1999

Examines the links between the ocean's role in climate and impacts on human health, including storm-related deaths and injuries, infectious disease outbreaks, and toxic algal blooms.

Global Change System for Analysis, Research and Training (START) Implementation Plan 1997-2002, International Geosphere-Biosphere Program, 1998

Describes START's goals to promote regional global change science and to enhance the capacity of individuals, institutions, and developing regions to undertake such research.

Global Environmental Change: Understanding Human Dimensions, National Research Council, 1992

Offers a strategy for combining the efforts of natural and social scientists to better understand how our actions influence global change and how global change influences us.

Grand Challenges in Environmental Sciences, National Research Council, 2000

Describes some of the most important research challenges facing the environmental sciences in the coming decades. It notes the following priority research areas: biogeochemical cycles, biological diversity and ecosystem functioning, climate variability, hydrologic forecasting, infectious disease and the environment, institutions and resource use, land-use dynamics, and reinventing the use of materials.

International Human Dimensions Programme on Global Environmental Change, International Human Dimensions Programme, 2000 (http://ibm.rhrz.uni-bonn.de/IHDP)

Outlines IHDP's role as an international interdisciplinary science program dedicated to promoting and coordinating research aimed at describing, analyzing, and understanding the human dimensions of global environmental change.

Linking Science and Technology to Society's Environmental Goals, National Research Council, 1996

Provides current thinking and answers to the questions: Where should the United States focus its long-term efforts to improve the nation's environment? What are the nation's most important issues? What role should science and technology play in these issues?

Nature's Numbers: Expanding the National Economic Accounts to Include the Environment, National Research Council, 1999

Responds to concerns about how the United States should make these measurements. Recommends how to incorporate environmental and other nonmarket measures into the nation's income and product accounts.

Opportunities in the Hydrological Sciences, National Research Council, 1991

Explains how the science of water has historically played second fiddle to its applications and how we now must turn to the hydrologic sciences to solve some of the emerging problems. This first book of its kind presents a blueprint for establishing hydrologic science among the geosciences.

Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base, National Research Council, 1992

Presents methods for assessing options to reduce emissions of greenhouse gases into the atmosphere, offset emissions, and assist humans and unmanaged systems of plants and animals adjust to the consequences of global warming.

The Atmospheric Sciences Entering the Twenty-First Century, National Research Council, 1998

Presents a comprehensive assessment of the atmospheric sciences and offers a vision for the future and a range of recommendations for federal authorities, the scientific community, and education administrators.

The Fifth Framework Programme of the European Community for Research, Technological Development and Demonstration Activities, 1998 to 2002, European Union, 1998 (http://www.cordis.lu/fp5/home.html)

Sets out priorities for the European Union's research, technological development, and demonstration activities for the period 1998–2002. These priorities have been selected on the basis of a set of common criteria reflecting the major concerns of increasing industrial competitiveness and the quality of life for European citizens.

The IGBP in Action: The Work Plan 1994–1998. International Geosphere–Biosphere Programme, 1994 (http://www.igbp.kva.se)

Outlines a major international program to describe and understand the interactive physical, chemical, and biological processes that regulate the total earth system, the unique environment that it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human actions.

World in Transition: The Research Challenge, German Advisory Council on Global Change, 1997

Identifies alternatives for restructuring the research landscape, focusing primarily on a new "syndrome approach" for global change research. By applying this tool, scientists can systematically describe and analyze the set of symptoms exhibited by the earth system that occur in response to natural and human changes and thus elaborate response options.

C. OTHER NRC REPORTS RELATED TO GLOBAL CHANGE AND SUSTAINABILITY

Over 160 other significant NRC reports produced since 1990 on topics relevant to global change and sustainability are listed below. These reports have generally been produced by expert committees and have been thoroughly peer-reviewed. Although the reports listed in this section have, in part, formed the basis for the committee's findings and recommendations, the committee has not systematically reviewed each of them. The reports are listed here to give an indication of the breadth and penetration of analysis that has been conducted on these topics by the NRC over the past several years. This body of NRC studies complements hundreds of other major relevant reports produced throughout the world; for the sake of brevity, this larger U.S. and international collection of reports is not given here. This vast array of major reports is itself based on an even more massive quantity of research documented in tens of thousands of peer-reviewed journal articles on topics related to global change and sustainability.

Atmospheric and Climate Variability and Change

A Decade of International Climate Research—The First Ten Years of the World Climate Research Program, 1992
A Plan for a Research Program on Aerosol Radiative Forcing and Climate Change, 1996
Adequacy of Climate Observing Systems, 1999
Atmospheric Change and the North American Transportation Sector, 1998
Capacity of U.S. Climate Modeling to Support Climate Change Assessment Activities, 1999
Coastal Meteorology: A Review of the State of the Science, 1992
Decade-to-Century-Scale Climate Variability and Change: A Science Strategy, 1998
Enhancing Access to NEXRAD Data: A Critical National Resource, 1999

From Research to Operations in Weather Satellites and Numerical Weather Prediction: Crossing the Valley of Death, 2000
GOALS (Global Ocean-Atmosphere-Land System) for Predicting Seasonal-to-Interannual Climate, 1994
Learning to Predict Climate Variations Associated with El Niño and the Southern Oscillation: Accomplishments and Legacies of the TOGA Program, 1996
National Academy of Sciences Colloquium: Carbon Dioxide and Climate Change, 1997
Natural Climate Variability on Decade-to-Century Time Scales, 1996
Ocean-Atmosphere Observations Supporting Short-Term Climate Predictions, 1994
Organizing U.S. Participation in GOALS (Global Ocean-Atmosphere-Land System), 1995
Prospects for Extending the Range of Prediction of the Global Atmosphere, 1991
Reconciling Observations of Global Temperature Change, 2000
Rethinking the Ozone Problem in Urban and Regional Air Pollution, 1991
Solar Influences on Global Change, 1994
The Atmospheric Sciences Entering the Twenty-First Century, 1998
The Department of Energy's Atmospheric Chemistry Program: A Critical Review, 1991
Toward A New National Weather Service, Second Report, 1992
Understanding and Predicting Atmospheric Chemical Change: An Imperative for the U.S. Global Change Research Program, 1993

Behavioral, Health, and Social Dimensions

Building a Foundation for Environmental Research, 1997
Confronting Climate Change: Strategies for Energy Research and Development, 1990
Effects of Past Global Change on Life, 1995
Environmentally Significant Consumption: Research Directions, 1997
Global Environmental Change: Understanding Human Dimensions, 1992
Human Dimensions of Global Environmental Change: Research Pathways for the Next Decade, 1999
Human Exposure Assessment for Airborne Pollutants: Advances and Opportunities, 1991
Linking Science and Technology to Society's Environmental Goals, 1996
Making Climate Forecasts Matter, 1999
People and Pixels: Linking Remote Sensing and Social Sciences, 1998
Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base, 1992
Science Priorities for the Human Dimensions of Global Change, 1994
Technological Trajectories and the Human Environment, 1997
Understanding Risk: Informing Decisions in a Democratic Society, 1996

Coastal and Ocean Studies

50 Years of Ocean Discovery: National Science Foundation 1950–2000, 2000
Applications of Analytical Chemistry to Oceanic Carbon Cycle Studies, 1993
Bridging Boundaries Through Regional Marine Research, 2000
Environmental Science in the Coastal Zone, 1994
Global Ocean Science: Toward an Integrated Approach, 1999
Improving Interactions Between Coastal Science and Policy: Proceedings of the Gulf of Mexico Symposium, 1996; *Proceedings of the California Symposium,* 1995; *Proceedings of the Gulf of Maine Symposium,* 1995
Letter Report on Applications of Analytical Chemistry to Oceanic Carbon Cycle Studies, 1994
Managing Coastal Erosion, 1990
Oceanography in the Next Decade: Building New Partnerships, 1992
Opportunities in Ocean Sciences: Challenges on the Horizon, 1998
Physical Oceanography and Tracer Chemistry of the Southern Ocean, 1988
Priorities for Coastal Ecosystem Science, 1994
Research Opportunities in Oceanic Biology, 1993
Restoring and Protecting Marine Habitat: The Role of Engineering and Technology, 1994
Review of U.S. Planning for the Global Ocean Observing System, 1994
Science for Decision Making: Coastal and Marine Geology at the USGS, 1999
Science, Policy, and the Coast: Improving Decision Making, 1995
Sea-Level Change, 1990
The Global Ocean Observing System: Users, Benefits, and Priorities, 1997
The Meteorological Buoy and Coastal Marine Automated Network for the United State, 1998
The Ocean's Role in Global Change: Progress of Major Research Programs, 1994
The Ocean's Role in Global Change: The Contemporary System—An Overview of Major Research Programs, 1990

Hydrology and Water Resources

A New Era for Irrigation, 1996
A Review of the USGS National Water Quatity Pilot Program, 1990
Alternatives for Ground Water Cleanup, 1994
Emerging Global Water and Energy Initiatives: An Integrated Perspective, 1999
Estimating Bounds on Extreme Precipitation Events, 1994
Flood Risk Management and the American River Basin: An Evaluation, 1995
GEWEX–CLIVAR: Coordination of U.S. Activities, 1998
Ground Water Recharge: Using Waters of Impaired Quality, 1994
Hydrologic Hazards Science at the U.S. Geological Survey, 1999
Hydrologic Science Priorities for the U.S. Global Change Research Program: An Initial Assessment, 1999
Hydrologic Sciences: Taking Stock and Ahead, 1998
Identifying Future Drinking Water Contaminants, 1999
Innovations in Ground Water and Soil Cleanup, 1997
Managing Water Resources in the West Under Conditions of Climate Uncertainty, 1991
Meeting the Challenges of Megacities in the Developing World, 1998
Mexico City's Water Supply: Improving the Outlook for Sustainability, 1995
New Strategies for America's Watersheds, 1999
Nitrate and Nitrite in Drinking Water, 1995
Opportunities in the Hydrological Sciences, 1991
Regional Hydrology and the USGS Stream Gaging Network, 1992
Safe Water from Every Tap: Improving Water Service to Small Communities, 1996
Setting Priorities for Drinking Water Contaminants, 1998
The GEWEX Continental Scale International Project (GCIP): A Review of Progress and Opportunities, 1998
The GEWEX Global Water Vapor Project (GVaP): U.S. Opportunities, 1999
Valuing Ground Water, 1997
Water for the Future: The West Bank and Gaza Strip, Israel, and Jordan, 1999
Watershed Management for Potable Water Supply: Assessing the New York City Strategy, 2000
Watershed Research in the U.S. Geological Survey, 1997

Observational and Data Systems

1993 *Review of the World Data Center-A for Meteorology and the National Climatic Data Center,* 1994
A Scientific Assessment for a Third Flight of the Shuttle Radar Laboratory (SRL), Committee on Earth Studies Letter Report to Dr. Charles Kennel, NASA, April 4, 1995
Assessment of Satellite Earth Observation Programs, 1991
Climate Processing and Archive Strategies for NPP and NPOESS, 2000
Development and Application of Small Spaceborne Synthetic Aperture Radars, 1998
Issues in the Integration of Research and Operational Satellite Systems for Climate Research: I. Science and Design, 2000
Issues in the Integration of Research and Operational Satellite Systems for Climate Research: II. Implementation, 2000.
On Climate Change Research Measurements from NPOESS, Committee on Earth Studies Letter Report to Dr. Ghassem Asrar, NASA, and Mr. Robert S. Winokur, NOAA, May 27, 1998
On NOAA Requirements for Polar-Orbiting Environmental Satellites, Space Studies Board letter report to Mr. Russell Koffler, NOAA, 1992
On Research Uses of LANDSAT, Committee on Earth Studies Letter Report to Dr. Shelby Tilford, NASA, and Mr. Russell Koffler, NOAA, September 12, 1991
Research Opportunities in Remote Sensing 1993
Solving the Global Change Puzzle: A U.S. Strategy for Managing Data and Information, 1991

Polar Science

Arctic Contributions to Social Science and Public Policy, 1993
Arctic Marine Monitoring, 1991
NOAA's Arctic Research Initiative: Proceedings of a Workshop, 1997
Ocean Drilling Research: An Arctic Perspective, 1999
Opportunities and Priorities in Arctic Geoscience, 1991
Science and Stewardship in the Antarctic, 1993
The United States in Antarctica: Comments from the Polar Research Board, 1997

Sustainable Development, Global Change, Natural Resources and Agriculture, and Environmental Technology

A Review of the U.S. Global Change Research Program and NASA's Mission to Planet Earth/Earth Observing System, 1995
A Review of the U.S. Global Change Research Program, Letter Report, 1996
An Assessment of the Atlantic Bluefin Tuna, 1998
Aquaculture and Schistosomiasis, 1992
Assigning Economic Value to Natural Resources, 1994
Designing an Agricultural Genome Program, 1998
Dolphins and the Tuna Industry, 1992
Ecologically Based Pest Management: New Solutions for a New Century, 1996
Finding the Forest in the Trees: The Challenge of Combining Diverse Environmental Data, 1995
Forested Landscapes in Perspective: Prospects and Opportunities for Sustainable Management of America's Nonfederal Forests, 1997
Green Tech-Knowledge-y: Information and Knowledge Systems for Improving Environmental Efficiencies, 1999
Improving Fish Stock Assessments, 1998
Improving the Management of U.S. Marine Fisheries, 1994
Industrial Environmental Performance Metrics: Challenges and Opportunities, 1999
Letter Report by the CGCR and BSD Reviewing the USGCRP, 1996
Marine Aquaculture, 1992
Measures of Environmental Performance and Ecosystem Condition, 1999
Mineral Resources and Sustainability, 1996
Nature and Human Society: The Quest for a Sustainable World, 1999
On the Full and Open Exchange of Scientific Data, 1995
One Earth, One Future: Our Changing Global Environment, 1990
Regenerating Agriculture: Policies and Practice for Sustainability and Self-Reliance, 1995
Research Strategies for the U.S. Global Change Research Program, 1990
Review of Northeast Fishery Stock Assessments, 1998
Saline Agriculture: Salt-Tolerant Plants for Developing Countries, 1990
Sharing the Fish: Toward a National Policy on Individual Fishing Quotas, 1998
Soil and Water Quality: An Agenda for Agriculture, 1993
Sustainable Agriculture and the Environment in the Humid Tropics, 1993
Sustainable Agriculture Research and Education in the Field: A Proceedings, 1991
Sustaining Marine Fisheries, 1998
The Community Development Quota Program in Alaska, 1998
The Greening of Industrial Ecosystems, 1994
The Industrial Green Game: Implications for Environmental Design and Management, 1997
The U.S. Global Change Research Program: An Assessment of the FY 1991 *Plans,* 1990
The United States Global Change Research Program: Early Achievements and Future Decisions, 1992
Toward Sustainability: A Plan for Collaborative Research on Agriculture and Natural Resource Management, 1991
Toward Sustainability: Soil and Water Research Priorities for Developing Countries, 1991
Upstream: Salmon and Society in the Pacific Northwest, 1996
Use of Reclaimed Water and Sludge in Food Crop Production, 1996

Terrestrial and Aquatic Ecosystems, Biodiversity, and Biogeochemistry

Biodiversity II: Understanding and Protecting Our Biological Resources, 1996
Biodiversity Conservation in Transboundary Protected Areas, 1996
Biological Nitrogen Fixation: Research Challenges, 1994
Conserving Biodiversity: A Research Agenda for Development Agencies, 1992
Ecological Indicators for the Nation, 2000
Environmental Issues in Pacific Northwest Forest Management, 2000
Forestry Research: A Mandate for Change, 1990
Freshwater Ecosystems: Revitalizing Educational Programs in Limnology, 1996
Global Change Ecosystems Research, 2000
Material Fluxes on the Surface of the Earth, 1994
Perspectives on Biodiversity: Valuing Its Role in an Ever-Changing World, 1999
Research to Protect, Restore, and Manage the Environment, 1993
Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy, 1992
Science and the Endangered Species Act, 1995
Stemming the Tide: Controlling Introductions of Nonindigenous Species by Ships' Ballast Water, 1996
The Bering Sea Ecosystem, 1996
The Decline of the Sea Turtles, 1990
The Role of Terrestrial Ecosystems in Global Change: A Plan for Action, 1994

Understanding Marine Biodiversity: A Research Agenda for the Nation, 1995
Wetlands: Characteristics and Boundaries, 1995