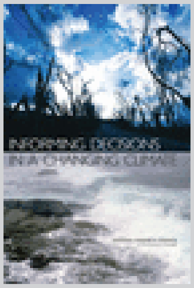

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INFORMING DECISIONS IN A CHANGING CLIMATE

Panel on Strategies and Methods for
Climate-Related Decision Support

Committee on the Human Dimensions of Global Change
Division of Behavioral and Social Sciences and Education

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Preface

Earth's climate is changing, with the global temperature now rising at rates unprecedented in the experience of human society. While some historical changes in climate have resulted from natural causes and variations, the strength of the trends and the patterns of change that are now emerging indicate that human influences, resulting primarily from increased emissions of carbon dioxide (CO_2) from fossil fuels and other greenhouse gases and the deforesting of the tropical rain forests, have now become the dominant factor. Recent studies by a global team of carbon cycle scientists concluded that anthropogenic CO_2 emissions have been growing four times faster since 2000 than in the 1990s and are now above the worst-case emission scenario projected by the Intergovernmental Panel on Climate Change.

These scientific projections of a warmer planet (from 1.5° to 4.5° Celsius) are taking place within a larger context of many other ongoing changes, including the globalization of markets and communications and continued growth in human population. There are also changes in cultural, governance, and economic conditions and in land use, as well as persistent poverty and hunger. Impacts on the environment and society result not from climate change alone, but from the interplay of all of these factors.

As the unparalleled challenges and opportunities of a changing climate have been recognized, there has been a growing demand from leaders in both the public and private sectors for information and more effective ways to support climate-related decisions. This report sets forth the foundations for improved decision support with a set of principles and a framework for decision support processes that include information, strategies, and methods. Meeting the nation's decision support needs will require involvement of organizations across the country. Leadership from the federal government will be essential. The report concludes that the federal government's efforts should be undertaken through a new integrated, interagency initiative with both service and research elements. The panel offers nine recommendations to facilitate effective development of climate-related decision support capabilities across many levels of governments and the private sector in our nation.

It is our hope that this report will prove useful for those who are faced with climate-related changes in their operating environments. The fact that climate is no longer stable, but will continue to change in new and often surprising ways, demands decisions and decision making that will be different—though often subtly so. The response of governments at all levels, businesses and industries, and civil society is only starting, and much is still to be learned about the institutional, technological, and economic shifts that have begun. Thus, we know our work is not the final word, but we believe our conceptual framing and recommendations offer important guidance to more productive climate-related decision support processes. Decision support, seen in this light, is a large task—one that should play a large role in the federal climate research enterprise in the years to come.

The panel has had the benefit of counsel, insights, and foundational ideas from the many individuals, representatives of federal government, state and local governments, business and industry, and from members of the scientific and other expert communities with whom we have had the privilege to consult. We are particularly grateful for support of this study from the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) and for the counsel of Dr. Joel Scheraga, the national program director for EPA's Global Change Research Program, and Ms. Claudia Nierenberg, special projects manager at NOAA's Climate Program Office. They have provided invaluable assistance and insights for the panel's work. We also thank Megan O'Grady of the NASA Goddard Institute for Space Studies for sharing her work on community involvement in PlaNYC, which was useful in preparing Appendix A.

We have had the honor to work with a most remarkable team of scientists and other experts and a staff with a profound array of insights and intellectual talent. We are particularly grateful for the remarkable talent and scientific capabilities of the panel's staff director, Paul Stern, and his National Academies team, Jennifer Brewer and Linda DePugh.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the Report Review Committee of the National Research Council (NRC). The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. The following individuals reviewed this report: William Asher, Applied Physics Laboratory, University of Washington; Patrick R. Atkins, independent consultant, Pittsburgh, PA; Robert W. Fri, independent consultant, Bethesda, MD; Jeanine A. Jones, California Department of Water Resources, Sacramento, CA; Roger E. Kasperson, George Perkins Marsh Institute, Clark University; Denise Lach, Department of Sociology, Oregon State University; Jay R. Lund, Department of Civil and Environmental Engineering, University of California at Davis; Robert Palmer, independent consultant, Gainesville, FL; and Gary W. Yohe, Department of Economics, Wesleyan University.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Barbaba Entwisle, Carolina Population Center, University of North Carolina at Chapel Hill, and George M. Hornberger, Department of Civil and Environmental Engineering, Vanderbilt University. Appointed by the NRC's Report Review Committee, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

We thank the reviewers and the review coordinator and monitor for their diligent analysis and scrupulous comments, which have significantly improved the quality of the report.

Robert W. Corell, *Chair*
Kai N. Lee, *Vice Chair*
Panel on Strategies and Methods for
Climate-Related Decision Support

Contents

Summary

Government agencies, private organizations, and individuals whose futures will be affected by climate change are unprepared, both conceptually and practically, for meeting the challenges and opportunities it presents. Many of their usual practices and decision rules—for building bridges, implementing zoning rules, using private motor vehicles, and so on—assume a stationary climate—a continuation of past climatic conditions, including similar patterns of variation and the same probabilities of extreme events.

That assumption, fundamental to the ways people and organizations make their choices, is no longer valid. As a result of human activity, the average temperature of Earth will soon leave the less-than-1° Celsius range that it has maintained for more than 10,000 years. Moreover, despite 15 years of intense international climate negotiations, atmospheric CO_2 concentrations have been growing 33 percent faster during the last 8 years than they did in the 1990s.

Climate change will create a novel and dynamic decision environment. The parameters of the new climate regime cannot be envisioned from past experience. Moreover, climatic changes will be superimposed on social and economic changes that are altering the climate vulnerability of different regions and sectors of society, as well as their ability to cope. Decision makers will need new kinds of information and new ways of thinking and learning to function effectively in a changing climate.

Many decision makers are experiencing or anticipating a new climate regime and are asking questions about climate change and potential responses to it that federal agencies are unprepared to answer. Anticipating a continuing increase in the demand for such "decision support," the U.S. Environmental Protection Agency and the National Oceanic and Atmospheric Administration asked the National Academies to undertake this study, to provide a framework and a set of strategies and methods for organizing and evaluating decision support activities related to climate change. In response to this charge, the Panel on Strategies and Methods for Climate-Related Decision Support examined basic knowledge of decision making; past experiences in other fields, such as hazard response, public health, and natural resource management; experience with early efforts in the climate arena; and input from a range of decision makers.

Our study found that climate change poses challenges not only for the many decision makers it will affect, but also for federal agencies and for the scientific community. The end of climate stationarity requires that organizations and individuals alter their standard practices and decision routines to account for climate change. Scientific priorities and practices need to change so that the scientific community can provide better support to decision makers in managing emerging climate risks. Decision support—that is, organized efforts to produce, disseminate, and facilitate the use of data and information in order to improve the quality and efficacy of climate-related decisions—is essential for developing responses to climate change. The information that is needed is not only about climate, but also about changes in social and economic conditions that interact with climate change and about the state of knowledge and uncertainty about these phenomena and interactions.

Considering the great diversity of climate-affected decisions and decision makers, it is useful to organize decision support around constituencies. We identify four roles for the federal government in climate-related decision support. Federal leadership is essential in serving the constituencies of federal agencies, participating in international efforts related to climate decision support, providing decision support services and products that serve a public good that would not otherwise be provided, and facilitating distributed responses to climate change. The last of these is important because central management is neither feasible nor effective for providing decision support for the many climate-affected constituencies in the nation. All four roles are consistent with federal responsibilities under the U.S. Global Change Research Act of 1990 and can be pursued under that mandate.

We found that the same core principles that characterize effective decision support in such areas as public health, natural resource management, and environmental risk management apply to informing decisions about responses to climate change.

> **Recommendation 1: Government agencies at all levels and other organizations, including in the scientific community, should organize their decision support efforts around six principles of effective decision sup-**

port: (1) begin with users' needs; (2) give priority to process over products; (3) link information producers and users; (4) build connections across disciplines and organizations; (5) seek institutional stability; and (6) design processes for learning.

Recommendation 2: Federal agencies should develop or expand decision support systems needed by the climate-affected regions, sectors, and constituencies they serve.

- **The National Oceanic and Atmospheric Administration (NOAA) should expand its Regional Integrated Sciences and Assessments (RISA) Program and Sectoral Applications Research Program (SARP) centers to serve the full range of regions and sectors of the nation where NOAA has natural constituencies.**
- **The U.S. Environmental Protection Agency (EPA) should expand its climate-related decision support programs to serve more regional and sectoral constituencies.**
- **Other federal agencies should take similar steps for their climate-affected constituencies.**
- **The federal government should selectively support state and local governments and nongovernmental organizations to expand their efforts to provide effective decision support to their climate-affected constituencies.**

Learning poses difficult challenges for climate-related decision making, especially by public agencies, because frequently there are multiple participants with varied and changing objectives interacting with uncertain and evolving knowledge. We found that the most appropriate model for learning under such conditions combines participatory deliberation with expert analysis in an iterative manner. This model is quite demanding in its needs for leadership and other resources.

Recommendation 3: Federal agencies in their own decision support activities and in fostering decision support by others should use the approach of deliberation with analysis when feasible. This is the process most likely to encourage the emergence of good climate-related decisions over time. The federal government should also fund research on decision support efforts that combine deliberation with analysis and that use other appropriate learning models, with the aim of improving decision support for a changing climate.

Recommendation 4: Federal agencies and other entities that provide decision support should monitor changes in science, policy, and climate-

related events, including changes outside the United States, that are likely to alter the demand and opportunities for effective decision support. Knowledge of such changes will help them to learn and to improve more rapidly.

Recommendation 5: Federal agencies should promote learning by supporting decision support networks to share lessons and technical capabilities. This may include support for expanding the capacity of boundary organizations and distributed entities for learning, such as internet sites. The federal investment should be selective and guided by the reality that networks operate satisfactorily only when their members see concrete benefits from participation.

Achieving decision support objectives requires research to understand, assess, and predict the human consequences of climate change and of possible responses to climate change. That research must be closely integrated with basic and applied research on climate processes.

Recommendation 6: The federal agencies that manage research activities mandated under the U.S. Global Change Research Act (USGCRA) should organize a program of research for informing climate change response as a component of equal importance to the current national program of research on climate change processes. This program should include research *for* and *on* decision support, aimed at providing decision-relevant knowledge and information for climate responses.

The research for decision support should have five substantive foci:

1. understanding climate change vulnerabilities: human development scenarios for potentially affected regions, populations, and sectors;

2. understanding the potential for mitigation, including anthropogenic driving forces, capacities for change, possible limits of change, and consequences of mitigation options;

3. understanding adaptation contexts and capacities, including possible limits of change and consequences of various adaptive responses;

4. understanding how mitigation and adaptation interact with each other and with climatic and ecological changes in determining human system risks, vulnerabilities, and response challenges associated with climate change; and

5. understanding and taking advantage of emerging opportunities associated with climate variability and change.

The research on decision support should have five substantive foci:

1. understanding information needs;
2. characterizing and understanding climate risk and uncertainty;
3. understanding and improving processes related to decision support; including decision support processes and networks and methods for structuring decisions;
4. developing and disseminating decision support products; and
5. assessing decision support "experiments."

Recommendation 7: The federal government should expand and maintain national observational systems to provide information needed for climate decision support. These systems should link existing data on physical, ecological, social, economic, and health variables relevant to climate decisions to each other and develop new data and key indicators as needed. The effort should be informed by dialogues among potential producers and users of the indicators at different levels of analysis and action and should be coordinated with efforts in other parts of the world to provide a stronger global basis for research and decision support.

Recommendation 8: The federal government should recognize the need for scientists with specialized knowledge in societal issues and the science of decision support in the field of climate change response. There should be expanded federal support to enable students and scientists to build their capacity as researchers and as advisers to decision makers who are dealing with the changing climate.

Fulfilling the federal roles in climate-related decision support will require coordinated efforts involving many federal agencies.

Recommendation 9: The federal government should undertake a national initiative for climate-related decision support under the mandate of the U.S. Global Change Research Act (USGCRA) and other existing legal authority. This initiative should include a service element to support and catalyze processes to inform climate-related decisions and a research element to develop the science of climate response to inform climate-related decisions and to promote systematic improvement of decision support processes and products in all relevant sectors of U.S. society and, indeed, around the world.

The service element of the initiative should support demonstration and development activities to promote the emergence of decision support systems, support networks to link decision support activities and facilitate learning among them, and help nonfederal actors develop decision support services (see Recommendations 2–5). The research element of the initiative should include research for and on decision support (see Recommendation 6). The initiative should also expand national observational and data systems, develop indicators, and invest in human resources (see Recommendations 7 and 8).

The initiative can and should be pursued under the authority of the USGCRA. However, the federal government, through the National Science and Technology Council, will need to comprehensively reformulate its plan for implementation of the act. Our recommendations imply significant change in the ways many federal agencies serve their constituencies, coordinate with each other and with nonfederal decision makers, and set research priorities. The panel notes that it does not recommend centralizing the initiative in a single agency. Doing so would disrupt existing relationships between agencies and their constituencies and formalize a separation between the emerging science of climate response and fundamental research on climate and the associated biological, social, and economic phenomena.

The recommended national initiative will require unusually effective collaboration among many federal agencies, since a great variety of agencies—many more than now participate in the Climate Change Science Program (CCSP)—need decision support, provide information needed for decision support, or serve constituencies that need decision support. The new initiative will demand strong leadership from the Executive Office of the President, including the science adviser and the new coordinator of energy and climate policy. For many of the agencies that need to be involved, decision support research or services are not part of their current missions, and they lack offices and personnel with the responsibilities and expertise needed to manage the research. In responding to demand for decision support, those responsible for the national research effort will need to induce the relevant agencies to find the needed funds and staff and ensure that appropriate managers in the agencies are given the responsibilities and resources needed to run the programs. The needs are especially acute in the social sciences, which include many of the historically undersupported research areas and for which many environmental agencies lack staff with the requisite expertise and organizational commitment.

Another National Research Council report identifies future priorities for the CCSP as a whole (National Research Council, 2009b). Together, these two studies call for significant change in research activities being conducted under the authority of the USGCRA, including developing underdeveloped areas of research and finding appropriate organizational homes for research that is now not being done.

The idea of a national climate service in or led by NOAA has received considerable attention in recent years. As of this writing, there is no agreed description of the purview, mandate, or organizational location of such a service. Yet it is clear that any form of national climate service should implement the principles of effective decision support. Thus, it should develop decision support products by means of communication between information providers and users that is likely to shape research agendas in ways that yield useful and usable research products. If a national climate service is created, it should be part of the decision support initiative we recommend and be closely linked to its research element. We believe that a national climate service located in a single agency and modeled on the weather service would by itself be less than fully effective for meeting the national needs for climate-related decision support.[1]

[1]This text was changed from the prepublication version to clarify the panel's meaning.

1

The Need for Climate-Related Decision Support

There is a growing need for information and for more effective ways to support climate-related decisions in both the public and private sectors as a result of the now rapid changes in Earth's climate. Government agencies, private organizations, and individuals increasingly find themselves unprepared at a fundamental level for meeting the challenges and opportunities of climate change. Many of their usual practices and decision rules—such as how bridges are built, which zoning rules are implemented, how much private motor vehicles are used, and so on—assume stability of climatic conditions, including the continuation of historical patterns of variation and the likelihood of extreme events. This assumption of "climate stationarity" has been fundamental to the ways people and organizations think about their choices, but it is no longer valid. Moreover, climate will continue to change—and at the same time, social and economic changes are altering the vulnerability of different regions and sectors of society to climate change, as well as their ability to cope with climate change.

These realities are making some long-established practices and decision rules counterproductive. However, decision makers do not know how much standard practices are likely to cost in a changing climate, which changes in those practices would make things better, and by how much. They need new kinds of information, as well as new ways of thinking, new decision processes, and sometimes new institutions, to function effectively in the context of ongoing climate change.

Human societies have historically adapted to their climatic settings, as exemplified by the use of dams of the western United States to store water during periods of low streamflow, farming practices that match crop varieties to growing seasons, and architectural styles matched to patterns of temperature and precipitation. As climates change, societies face new challenges of varying severity. The indigenous peoples of the Colorado Plateau centuries ago and, more recently, the farmers of the "dust bowl" in the 1930s experienced climatic shifts that dramatically transformed their economies, settlement patterns, and governance structures. And as societies and their technologies change, the trajectory and effects of climate change are affected. For example, the technology of air conditioning as indoor climate control has fostered the development of the U.S. sunbelt, a region now facing climate-driven challenges of droughts and depleted water supplies. Air conditioning has also increased U.S. greenhouse gas emissions.

THE CHANGING CLIMATE

The climatic changes of the past 10,000 years have occurred in a context of remarkable stability in the average temperature of Earth, which experienced variations of less than 1° Celsius in this period. Since the advent of the industrial revolution (about the mid-nineteenth century), when fossil fuels became the primary source of energy for economic growth and societal development, the climate state has been changing from this stable condition. It is expected soon to reach a global average temperature unprecedented in recorded history, as depicted in Figure 1-1.

The Intergovernmental Panel on Climate Change (IPCC) (2007a) projects that the planet will warm substantially in the coming decades as a result of the current concentrations of greenhouse gases and expected future emissions. The National Oceanic and Atmospheric Administration (NOAA) reports that in 2007, the global concentration of atmospheric CO_2 (carbon dioxide) emissions increased by 2.4 parts per million by volume (ppmv) to a level of 385 ppmv (see http://www.noaanews.noaa.gov/stories2008/20080423_methane.html).

If emissions continue at the 2007 level for a generation, atmospheric CO_2 concentrations would increase to about 450 ppmv, a level that would, if maintained over time, lead to a stabilized global average temperature 2° Celsius (or slightly more) higher than preindustrial levels, according to the best available scientific estimates (Intergovernmental Panel on Climate Change, 2007a). Although scientists cannot predict the precise level of temperature change, there is now a clear consensus that the resulting temperature will be considerably higher than anything experienced in the past 10,000 years. Even if the rate of emissions could be globally reduced to near zero, the result would still most likely be a global average temperature of about 1° Celsius higher—still more than ever in recorded history—due to the heat-absorbing capacity of the oceans.

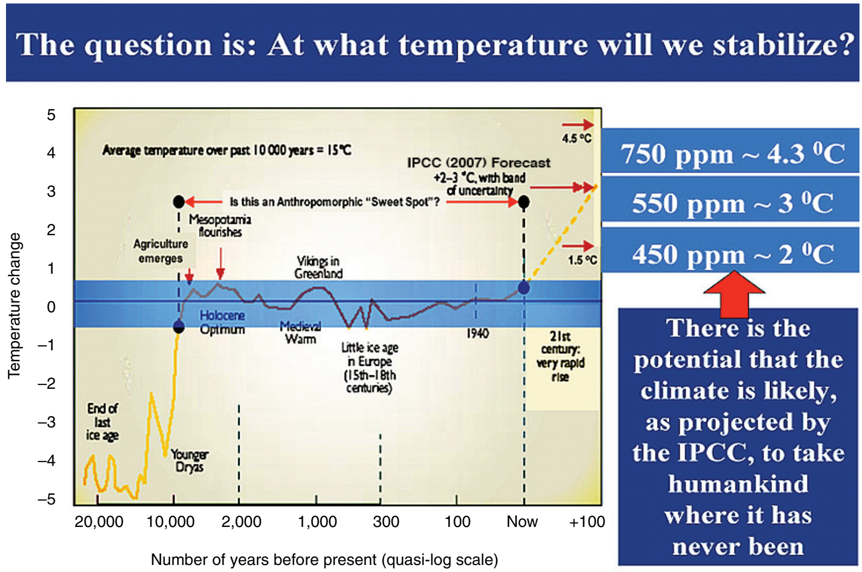

FIGURE 1-1 Average temperatures on Earth.
SOURCE: Adapted from World Health Organization, World Meteorological Organization, and United Nations Environment Programme (2003:Figure 1-1).

The consequences of a warmer Earth, although not precisely predictable, are already evident (Intergovernmental Panel on Climate Change, 2007b; Millennium Ecosystem Assessment, 2003; Arctic Climate Impact Assessment, 2005; National Research Council, 2008a) and are expected to increase across a range of areas vital to human well-being and the socioeconomic security of the United States (e.g., Intergovernmental Panel on Climate Change, 2007b; National Research Council, 2008b). The U.S. Climate Change Science Program (CCSP) concluded (with confidence greater than 90 percent) that temperature increases, increasing CO_2 levels, and altered patterns of precipitation are already affecting U.S. water resources, agriculture, land resources, and biodiversity (Backlund et al., 2008). There is also some evidence that more intense hurricanes are occurring more frequently globally (Webster et al., 2005; Chang and Guo, 2007; Holland and Webster, 2007; Kossin et al., 2007), and the scientific consensus is that such storms are likely to become more intense in the future (Intergovernmental Panel on Climate Change, 2007a). Climate change is also projected to have major effects on human health, water resources, ecosystems, and agriculture, as well as other systems and sectors (Intergovernmental Panel on Climate Change, 2007b; Campbell-Lendrum, Corvalán, and Neira, 2007), and many of the health effects of a changing climate are likely to fall disproportionately on poor, elderly, disabled, and uninsured people (U.S. Climate Change Science Program, 2008a).

Climate change will affect water quantity and quality through changes in precipitation, runoff and stream flow, glacier and snowmelt, and increased temperatures. Both droughts and floods are projected to increase through an intensified hydrological cycle (Intergovernmental Panel on Climate Change, 2007a, 2007b). Climate change also threatens terrestrial, coastal, and marine ecosystems: the IPCC concludes with high confidence that climate change, combined with other global changes (e.g., in land use, pollution, and resource exploitation), will stress the ability of many ecosystems to adapt naturally if greenhouse gas emissions and other changes continue at or above current rates (Fischlin et al., 2007). The Millennium Ecosystem Assessment (2003) found that climate change is one of the principal threats to biodiversity on the planet.

In sum, human activities are changing the climate globally, the predicted consequences of climate change are already observable around the world, the global average temperature will soon be higher than previously experienced in recorded history, and climatic changes and their consequences are likely to grow in magnitude. The changes are also occurring at a much faster rate than previously experienced in recorded history.

THE END OF BUSINESS AS USUAL

Climatic changes, and particularly the end of climate stationarity, present a major challenge for human decision making. Many past practices, routine ways of managing and coping, and apparently wise maxims garnered from experience will increasingly prove counterproductive, particularly in coping with climatic extremes. If a “once in a century” rainfall disaster in Iowa begins to occur once every few years, for example, a nearly total rethinking of many decisions will be required. Agricultural decision makers are already experiencing and having to come to terms with such uncertainty and volatility, sometimes by experimenting with new financial mechanisms or new technologies (International Service for the Acquisition of Agri-tech Applications, 2007; Henriques, 2008).

Instead of following standard practices, individuals and organizations will have to consider whether practices that have helped them adapt in the past will remain effective in the future and whether they need to replace standards and practices that have been presumed permanent with ones that provide for reconsideration and updating. Box 1-1 provides an example of the problem. People will also need to consider whether to change practices that drive climate change, such as building cities on the assumption that people will travel in private fossil-fuel-powered motor vehicles.

BOX 1-1
Water Resource Systems Operation and Infrastructure Design

For more than 25 years, the same standard methods have been used to estimate flood probability and frequency for flood plain mapping; in designing infrastructure systems, such as highway culverts, storm drains, and flood control systems; and for estimating the operational requirements of reservoirs and other engineered water resources systems. These methods underlie innumerable decisions by federal, state, and local governmental agencies and by thousands of private consulting companies providing services to communities. They rest in turn on statistical methods and guidelines established in the 1970s and 1980s, particularly on Water Resources Bulletin 17B (U.S. Geological Survey, 1981).

The methods and guidelines are based on the assumption of climate stationarity. In particular, it is assumed that a hydrologic variable such as annual maximum flow has a time-invariant probability distribution whose parameters can be deduced from available observations. For example, the flood-frequency equations provided in the Highway Design Manual for the state of California are based on regional regression analysis of instrumental data from nearly 700 stations observing stream flow, calculated in the 1970s.

The assumption of stationarity of such hydrologic variables has been questioned for some time, both because of the impact of human disturbances in watersheds (e.g., channel modifications, land-cover and land-use changes, drainage projects) and because of climatic changes affecting the intensity of storms and snowmelt events (see National Research Council, 1998a; Milly et al., 2008). Observations since the 1970s confirm the doubts about the adequacy of the equations, and the potential costs of water management systems that are inadequate for major floods are large.

There is clearly a need to reevaluate and update the standard methods. Analysts have recommended revising the equations based on nonstationary probabilistic models. However, there is still no national, comprehensive program to modify the outdated standards of practice to incorporate climate and land-use change or to allow for periodic updating.

Available scientific evidence supports three general observations about climate change that are especially worthy of note for decision making:

- ***Temperature and other climatic parameters are already outside the bounds of past human experience*** (Intergovernmental Panel on Climate Change, 2007a). Not only the averages, but especially the likelihood of extreme events, are already outside the bounds of experience. For planning and decision making, human society is already in terra incognita.
- ***Climate change is accelerating*** (Intergovernmental Panel on Climate Change, 2007a). As reported by the Global Carbon Project (2008):

> Anthropogenic CO_2 emissions have been growing about four times faster since 2000 than during the previous decade, despite efforts to curb emissions in a number of Kyoto Protocol signatory countries. . . . Emissions growth for 2000–2007 was above even the most fossil fuel intensive scenario of the Intergovernmental Panel on Climate Change (SRES-IPCC).

So long as the human population is growing and per capita demand for fossil fuels and other resources continue to grow in a compound-interest fashion, this trend will continue. Climate-driven events that have been seen in recent decades are very likely to accelerate substantially in the decades ahead because of emissions trends and because the physics and chemistry of the atmosphere and ocean ensure that, on average, the long-lived greenhouse gases now being emitted will continue to affect the climate for hundreds of years. Climate change is therefore likely to continue to accelerate for many decades even if emissions of greenhouse gases are stopped in the near future.

- ***Recently experienced climatic events are not likely to serve as guides to what to expect next.*** One reason for this is that climate changes that are evident on large spatial and temporal scales are difficult to discern in any one location or over a few years against the ongoing background of variability. And because climate change and increases in extremes in weather are still accelerating, past observed rates of change in climate-driven events are likely to increase in the future, so that even broad averages of past or current observations will underestimate what lies ahead.

These observations imply that, increasingly, practices and decision routines that assume the stability of historical patterns will be out of step with future climate, and so are likely to be suboptimal.

Science can project with some confidence future average global temperatures; see Figures 1-2 and 1-3. Science can also project many of the consequences, as already noted. But these projections are not of a new stable state. They involve continuing change in climate averages and in the probabilities of extreme events over time. And they are uncertain in multiple ways: the estimated probabilities themselves are uncertain, especially on the tails of distributions, which include catastrophes; the direction of change for some important potential consequences remains unknown; and scientists recognize the nonzero probability that climate change may have important consequences for environmental or human well-being that they have not yet imagined or attempted to model. As a consequence of these factors, the best decision rules for the climate of today are very likely not the best decision rules for the decades ahead. With regard to human adaptation to climate, business as usual is at an end, even with aggressive and

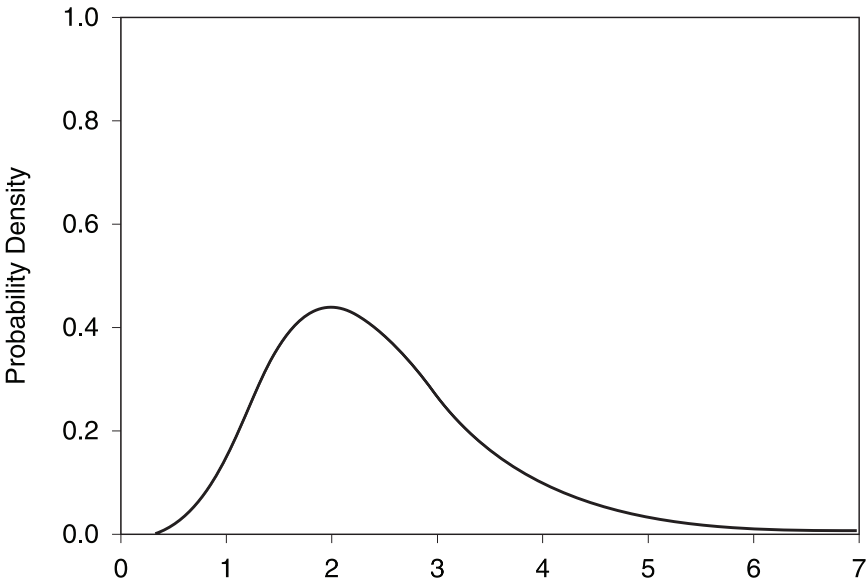

FIGURE 1-2 Probability density function of global mean surface temperature change 1990–2100 from a Monte Carlo analysis of climate uncertainties.
SOURCE: Adapted from Webster et al. (2003:Figure 6).

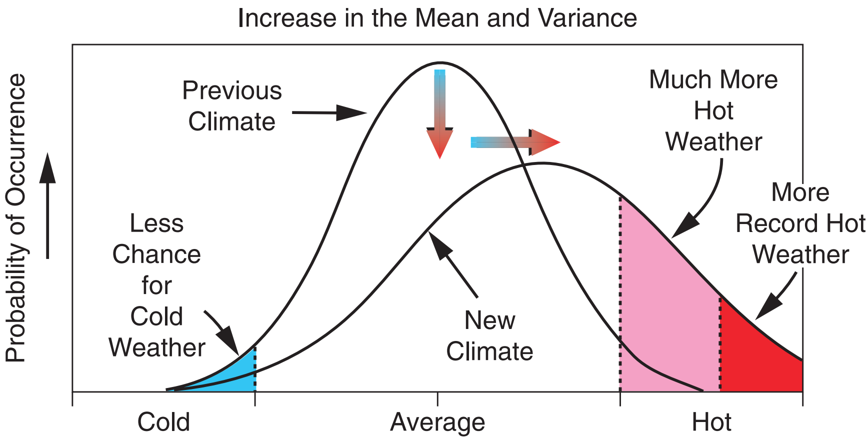

FIGURE 1-3 Effects of climate warming on the frequencies of hot and record hot weather.
SOURCE: Intergovernmental Panel on Climate Change (2001:Figure 2.32, 155).

successful mitigation. Decision makers are facing new choices, and accordingly, will need new kinds of knowledge and information from science.

Conclusion 1: The end of climate stationarity requires that organizations and individuals alter their standard practices and decision routines to take climate change into account. Scientific priorities and practices also need to change so that the scientific community can provide better support to decision makers in managing emerging climate risks.

Longer Time Horizons

The changes in the climate system will require a longer-term view than is usual in most decision-making contexts. The need for a longer perspective is especially acute for decisions that are hard to readjust in the future, such as those about development policy, long-lived infrastructure, and programs and policies that alter the driving forces of climate change itself.

A longer term perspective creates increased uncertainty as forecasting horizons exceed anyone's comprehension or grasp (Ascher, 1979, 2004). Economic decisions heavily favor the near and immediate term, while climatic processes have strong momentum that carries them far into the future. The differences between what Wall Street analysts expect from a corporation in the next quarter and what oceanographers worry about decades or centuries from now could not be more pronounced. Recognition of the processes of climate change creates a new imperative to expand the time horizons of economic decision makers (Nordhaus, 1998).

There are virtually no organizations that are designed to consider the consequences of current actions that will occur decades or centuries in the future. Nuclear energy production, which does not emit greenhouse gases, presents a clear example of such consequences because of the long-lived radioactive waste it produces. The nuclear energy industry has been plagued by the problem of designing institutions to manage waste disposal satisfactorily over the 10,000-year time frame often cited for safe disposal, and there has been some thinking about ways to handle the problem (e.g., National Research Council, 2000, 2001, 2003). The centuries-long time frames demanded by climate change, while not as long as this, are also poorly matched to present-day organizations and decision processes.

When long-term decisions must be made with limited knowledge of a changing future, mistakes and unexpected consequences or surprises will be common. People and organizations need to be prepared to learn from both. It is important to observe, document, and extract lessons from experiences with long-term decisions around the world so the lessons can be adopted or modified for use elsewhere. For example, the Netherlands provides data on adaptation to coastal threats over a very long time. Bangladesh is also adapting, but the specific decisions and actions taken in each place are not the same. The lessons to be learned from each might be modified and applied where the site characteristics are reasonably close analogues.

Place-Specific Effects

Climate change will have different effects in different locations and regions and on different ecosystems. These effects will be superimposed on place-specific aspects of social systems, such as characteristics of energy supply, human population change, water use, and the legal and institutional environment. Site-specific, sometimes unique, aspects of a place through time may be more important than general future trends. For example, the energy circumstances dominating the Ohio Valley create very different challenges and opportunities than those facing decision makers in the Pacific Northwest. Methods of making, understanding, and informing decisions that presume universal applicability are likely to lead to inappropriate decisions. Such “universal” approaches include some federal laws, as well as general organizational and decision rules based on profit maximization, risk aversion, altruism, or other human behavioral traits. Informing decisions for a changing climate will need site-specific and relevant baselines of environmental, social, and economic information against which past and current decisions can be monitored, assessed, and changed. Future decision-making success will be judged on how quickly and effectively numerous, ongoing decisions can be adjusted to changing circumstances and situational details.

Many of the consequences of climate change affect regions or ecosystems—spatial units that rarely match the responsibilities of human organizations. For example, there are very few ecosystem-based or regional authoritative organizations in the world, although some exist: The Northwest Power and Conservation Council (see http://www.nwcouncil.org) integrates planning for fish and wildlife with electric power in the hydropower-intensive Pacific Northwest; Australia’s Great Barrier Reef Marine Park Authority implements ecosystem-scale actions that include resource harvest as well as conservation activities associated with a park; and eight U.S. regional fisheries management councils (see http://www.nmfs.noaa.gov/councils.htm) that are charged with governing fish have an ecosystem mandate under legislation passed in 2006, although it has not been fully implemented. The existing global organizations, such as the U.N. Environment Programme and the U.N. Framework Convention on Climate Change, are ill equipped to decide or enforce decisions. These mismatches of scale between climate change problems and the decision-making authorities that can seek solutions are a cause for concern and a foundation for the rest of this report.

Mitigation of carbon emissions illustrates the difficulties, because many long-term effects of emissions, such as flooding of low-lying islands and droughts in subsistence agricultural regions of developing countries, are felt in places far from where most of the emissions are produced and where most of the emissions reductions need to take place. In this case, reducing the effects of climate change in some places depends largely on choices and decisions that are made in other places. International coordination is needed to address such place-specific phenomena.

Designing and operating situationally appropriate organizations are essential challenges. Moreover, individual organizations and networks of individuals and organizations will have to adapt and evolve in the new climate change regime. We return to the problems of adaptation, evolution, and learning in Chapter 3.

Surprise as Normal

The nature of climate change and the incompleteness of scientific understanding of its consequences mean that decision makers must expect to be surprised—probably with increasing frequency (e.g., "hundred-year" storms may recur every decade). Climate is an extremely complex system with innumerable parts and even more relationships among them: for instance, it is now clear that the species on Earth and their ecological relationships are shaped by past climate (Millennium Ecosystem Assessment, 2003). Science has developed a general understanding of parts of the system—such as the effects of greenhouse gas emissions on global average temperature—but understanding other parts of the system is much less well developed, such as the effects of climate change on the spread of human, animal, and crop diseases. When climate changes in an ecological system such as a watershed, some species may adapt by moving while others lag behind or even die off (Arctic Climate Impact Assessment, 2005), but these interactions are not well enough understood to predict which will occur. The more the climate system diverges from historical experience, the more the relationships between the parts of the system enter the realm of the unknown, where past scientific understandings may no longer hold.

Decision makers must expect and prepare for surprises—the likelihood that the results of climate change will include events not now predicted by scientific models and even events not yet imagined by scientists. The surprises could include more (or less) rapid changes in environmental processes already linked to climate change or even the appearance of totally unexpected environmental or human-environmental phenomena that emerge from poorly understand relationships in complex physical or ecological systems. The challenges may prove manageable: Rapid technological change in areas, such as medicine and communications, has spawned numerous surprises over the past century, and human institutions have been able to react to many of them in ways that benefit people and institutions. Through increasing environmental awareness and its accompanying institutions, people are already responding to the surprising realization that humans are changing the structure and functioning of the Earth at many scales.

Climate Change in a Changing World

As the climate is changing, human systems are changing and affecting their local environments. The results are that the human consequences of future climate change will be different from what those consequences would have been if they occurred in the current world. One important change will be an increase in the cost of fossil fuels as a result of increasing demand pressing against limited supply and as a result of regulation, taxation, or the imposition of cap-and-trade regimes. The futures of consumers of these fuels, manufacturers of energy-using equipment, and of producers of alternative energy supplies will depend on how well they anticipate the future costs.

Changes in human systems also alter the effects of climate change. For example, the past few decades have featured U.S. population movements to the coasts, to urban areas, and to the arid Southwest—all regions that, for different reasons, are more vulnerable to climate change than the areas that the people left. Human demand for food from agriculture and fisheries and demand for fuel from forests and crops are increasing the vulnerability of food and water systems and other systems that produce essential commodities. The prospect of climate change is also resulting in increased investment in technologies to substitute for fossil fuels. The results of these efforts will alter the kinds of responses people will need to make to protect themselves against the adverse effects of climate change.

The capability to respond to climate change is also changing. In the United States, for example, expected strains on governments create concern that emergency response, public health, and other systems that can help in responding to extreme climatic events will be less effective in the future than they have been in the past. For example, preparations for major storms are not only intricate, but also costly, and the strain on the resources of governments at all levels may affect emergency preparedness and response organizations. Because of these multiple concurrent changes, thinking about the climate future and how to cope with it needs also to take into account the simultaneously changing future of human systems and human-modified ecological systems.

MAKING AND SUPPORTING DECISIONS

Although the climate future and some of its effects are known in general, the details are uncertain in terms of precise average conditions and the probabilities, especially of extreme events. Yet these details critically affect the areas of responsibility of those who manage water supplies, farms, protected areas, etc. Even with major efforts to "downscale" climate models, prediction is hampered by fundamental uncertainties about how the parameters of climate change will affect each other once their values exceed past limits and about their interactions with concurrent changes in human and ecological systems. Those limits to prediction may frustrate scientists, but from the standpoint of people making decisions whose consequences will be shaped by climate change, the probabilistic and uncertain nature of predictive information is a fact of life.

Decision makers need to take the information into account, with its attendant uncertainties, in assessing the potential future benefits of changing their policies, practices, and decision rules against the costs of change, which are immediate and much easier to specify. For example, the costs of policies to mitigate and adapt to climate change are obvious and may be considerable, but the costs of not making such changes in a changing climate, which could be much greater, are rarely estimated. In some situations, in which standard practices are increasingly out of date and error is costly, the need for better information is urgent, but the information is not readily available. (Box 1-1 provides an illustration from water management.) Decision makers will also have an increased need to learn, adapt, and adjust.

An Uncertainty Management Framework

When predictive certainty is elusive and probabilistic information is all that is available, decision making can benefit from an "uncertainty management" framework. This approach considers the range of plausible futures and the key characteristics of each, the best estimates of the likelihood of each, and the likely magnitudes of the associated consequences. Such a framework permits more detailed and realistic analysis of the choice options available and better insight into what kinds of information about the likely future would be most valuable to produce, from a decision maker's perspective.

A recent study illustrates the use of risk-management methods to assess the risk for insurance companies due to extreme weather events. It emphasizes that major hurricanes will continue to strike the Atlantic and Gulf Coasts and that, given increasing residential and commercial development in those areas, increasing levels of damage can be expected to people, property, insurance and financial markets, and the public sector. The study calls for leadership in developing "economically sound policies and strategies for managing the risk and consequences of future disasters" (Doherty et al., 2008:i).

A risk management framework, applied to climate change, implies developing best estimates of the probabilities of the various consequences of climate change and related changes in relation to the options available for particular decisions and using techniques such as sensitivity analysis to suggest the best strategies given the likely imperfections in the probability estimates or the underlying models. Figures 1-2 and 1-3 illustrate part of this analysis by showing probability distributions for expected global average temperatures and temperature extremes. Much more is involved, as indicated in the chapters that follow and in a vast literature on risk analysis and risk and uncertainty management (e.g., Edwards and Newman, 1982; Hammond et al., 1999; Keeney, 1992; National Research Council, 1996b; von Winterfeldt and Edwards, 1986).

Because climate change is moving the environment beyond human experience and doing so at a rapid and accelerating rate, there is an urgency to informing both adaptation planning and mitigation actions, at all levels of social organization, and in both the public and private sectors. Because few human organizations are currently equipped to manage these challenges, new efforts will be required to help them obtain such capabilities.

Need for High-Quality Decisions

Good decisions depend not only on the quality and availability of information, but also on the ways people—working individually or in groups—process information and evaluate options. Research in the decision sciences has identified five general principles that characterize high-quality decisions and decision-making processes (Gregory, 2000; Hammond et al., 1999; Keeney, 1992; National Research Council, 2005a; Wilson and Arvai, 2006):

1. ***Problem Definition*** High-quality decisions depend on defining a problem in a way that opens it to a more thoughtful consideration and later, to the creation of alternative courses of action from which to choose.
2. ***Clear Objectives*** A high-quality decision is clear about the objectives that it attempts to realize; a good decision process asks those involved to think carefully about their objectives as they relate to addressing a given problem or opportunity.
3. ***Alternatives Linked to Objectives*** A high-quality decision depends on identifying alternatives that are linked to the problem and the objectives.

4. ***Assessment of Consequences*** A high-quality decision includes efforts to estimate the anticipated consequences of each alternative in terms of agreed-upon measures.

5. ***Confronting Tradeoffs*** A high-quality decision recognizes that conflicting objectives are in play and encourages explicit consideration of them. Several useful methods exist for helping people to reconcile complex tradeoffs, including methods of formal tradeoff analysis and decision structuring tools.

In an uncertain and changing environment, it is also important for decision-making processes to be designed to adapt to changing conditions and information and to learn from experience. Thus, even though the information on which decisions affected by a changing climate are based may become less certain, it is possible—indeed, increasingly necessary—to work toward decisions of higher quality, making good use of the information that is available.

Conclusion 2: Decision support—that is, organized efforts to produce, disseminate, and facilitate the use of data and information in order to improve the quality and efficacy of climate-related decisions—is essential to effective decision-making responses to climate change. Decision makers have an increasing need for such information but cannot always get it on their own.

Demand for Decision Support

Over the past few years, a significant change has been occurring in thinking about climate change in the United States. More and more of the decision makers already concerned with climate change, including those in the federal government, have shifted their focus from the question of whether anthropogenic climate change is happening to questions about how to reduce the risks and take advantage of opportunities that climate change presents. Along with this shift has come a rapid increase in demand for climate-related decision support. Demand comes from federal government agencies such as NOAA and the Environmental Protection Agency (EPA) (evident by their request for this study), the National Park Service, the Forest Service, the Fish and Wildlife Service, the Minerals Management Service, and the nonresearch parts of the Department of Energy. Some of the most urgently communicated needs stem from the recognition in federal agencies that they may soon be unable to fulfill their legal and regulatory responsibilities because of climate-related changes and from fear of litigation about those responsibilities. Demands for decision support are also coming from Congress, from state and local coastal managers, from urban and regional water managers, and from nongovernmental conservation, community development, and social justice organizations.

The panel has seen the growing demand in the remarks of participants in our workshops and in interviews and personal communications between panel members and senior executives in business organizations, state and local governments, and the nonprofit sector, and even in expressions of interest from citizens in relation to personal decisions. A few examples—on greenhouse gas emissions in California, coastal management, green products and services, climate change and drought, and court decisions—illustrate recent demands for decision support.

Reducing Greenhouse Gas Emissions in California

Information on the consequences of climate change for the state was instrumental in the California legislature's passage of AB32, a pioneering law that set state targets for reducing greenhouse gas emissions. Legislators considered and requested information to compare the historic extent of Sierra Nevada snowpack loss to the present extent and projections under various global warming scenarios; project daily ozone formation in the Los Angeles and San Joaquin Valley areas under conditions of low and moderate global warming; project sea-level rise resulting from climate change, including maps of possible flooding at the San Francisco airport; project heat wave days and energy demand resulting from warming; and consider future forest fire risks and forest yields. Since enactment of the law, greenhouse gas reduction timetables have led state agencies to seek information on other activities and factors, such as energy consumers' responses to various conservation programs, off-road vehicle usage, green building technologies, and the chemical properties of pavements.

Coastal Management

In anticipation of congressional reauthorization of the Coastal Zone Management Act, the Coastal States Organization surveyed its membership, which consists mainly of state and local coastal managers, and identified the following needs for mapping, monitoring, and research to support climate adaptation and assessment:

- inventories of features, conditions, and properties at risk;
- vulnerability assessments;
- cost-benefit and policy analyses;

- projections of interactions between shoreline processes, storms, and sea-level rise;
- strategies for ecosystem impacts, monitoring, and response;
- models linking coastal inundation with detailed shoreline erosion;
- sea-level-rise scenarios with detailed local monitoring, storm regime and storm surge models, especially for hurricanes and extra-tropical storms;
- information about impacts of sea-level rise on coastal habitats, especially wetlands;
- information on the role of sea-level rise in beach renourishment planning; and
- support for risk and vulnerability assessment, cost-benefit analyses, and priority setting.

Information was also sought on climate effects on invasive species, ocean acidification, ecosystem migration, and freshwater resources. Managers also expressed a desire to be more involved in research coordination. Lastly, a need was expressed for integration of socioeconomic dimensions of issues, including policy analyses for wetland restoration, shoreline protection and retreat strategies, and infrastructure siting; assessments of social, legal, and economic issues related to shoreline change management alternatives; and best practices, case studies, training, and workshops focused on local- and state-level vulnerabilities and implementation options for coastal management approaches (Coastal States Organization, 2008).

Green Products and Services

State and federal regulatory agencies, investors in green markets, and environmentally conscious consumers and businesses planners are increasingly seeking reliable, standardized, and accessible information about the climate impacts of specific products and technologies. In response, quantitative indicators of "life-cycle climate performance" are being calculated to measure the total effect of a product or technology on greenhouse gas emissions. For example, the indicator for an air conditioner would reflect both its direct emissions (e.g., from coolant leakage during manufacturing and transport, normal operation, accidental damage, maintenance, and product disposal or recycling) and indirect emissions (e.g., from energy use in its manufacturing, operation, disposal, or recycling). Such indicators require validation and standardization, which in turn requires substantial analysis of chemical and physical attributes of product components and of the behavior of actors all along the product chain.

Climate Change and Drought

A recent report of the Subcommittee on Disaster Reduction of the National Science and Technology Council (2005), *Grand Challenges for Disaster Reduction*, found that among all natural hazards, droughts are the leading cause of economic losses, accounting for average annual losses of $6–$8 billion and affecting more U.S. residents than any other natural hazard. The report called for "a national instrument system capable of collecting climate and hydrologic data to ensure drought can be identified spatially and temporally" and "an integrated modeling framework to quantify predictions of drought and drought impacts useful in decision-making" (Subcommittee on Disaster Reduction, 2005:14). Such an instrument would necessarily support decisions about local, state, and regional responses to one key manifestation of climate change.

In a similar vein, at a congressional hearing on *H.R. 5136, the National Integrated Drought Information System Act of 2006*, the Western Governors' Association (Smith, 2006) testified that important physical and drought impact information is lacking. Information is needed at the local and state levels, in real time, and from centralized providers. In addition, the information needs to be in formats that are useful to water users—including farmers, ranchers, utilities, tribes, land managers, business owners, recreationalists, and wildlife managers—to plan for and mitigate drought impacts.

Court Decisions

In April 2007, in *Massachusetts v. EPA*, the Supreme Court handed down its first decision explicitly focused on climate change. The Court supported the standing of states to sue the federal agency (EPA) on greenhouse gas emissions, found that the agency is authorized to regulate carbon dioxide and other greenhouse gases emitted by motor vehicles, and found that the agency is not authorized to subject such regulatory decisions to policy considerations. The decision gave EPA the responsibility to make scientific assessments of the effects of carbon dioxide from vehicle emissions on public health and welfare. Because these effects are in considerable part mediated by climate change, the agency will need to develop new analyses of the effects of climate change on health.

Other litigation now in process may have similar implications. For example, one federal court is considering a claim that environmental impact statements required by the National Environmental Policy Act or by state law must consider climate-related impacts of proposed projects or agency actions. Such a decision could require agencies to develop information and analytic methods to measure greenhouse gas emissions from any project, impacts on ecological carbon sinks, and the adaptive capacity of the relevant system to climate change (Gerrard, 2008). Another federal court is considering the claim that climate change must be considered in decisions under the federal Endangered Species Act. Such consideration would require detailed scientific analyses of the ecological effects of climate change, and it might also require consideration the economic costs of various strategies for reducing those effects.

Many other examples could be given. Senior industry and business leaders often note the need for objective, credible, and open-source information and for institutions or processes to make them widely available to business, industry, government agencies, and others in the public and private sectors. Some corporations are now making decisions by using two parallel committees at the level of the chief executive office, both with equal power, to gather and assess information for decisions: one evaluates the economics and business efficacy of a proposed company action and the other evaluates its long-term sustainability for the company, society, and the environment. This decision process requires reliable information that includes characterizing the available knowledge and uncertainty about climate change and the likely implications of available responses.

The panel recognizes that climate-affected decisions are affected by many considerations in addition to those discussed here and that climate-related information will often not be determinative in a given decision. However, such information will affect the decision tradeoffs in some settings, and in others, it may draw attention to standard procedures that deserve reconsideration. Thus, in several ways, climate-related information may help improve decisions by drawing attention to past decision processes and decisions that have become unproductive.

GOALS AND SCOPE OF THIS STUDY

As the above discussion illustrates, governments at all levels, businesses and other organizations, and individuals are increasingly seeing the need for knowledge and information to help them meet the challenges and opportunities of climate change. The needs arise for decisions at large scales—such as urban design—and at small ones—such as household choices about how to reduce energy consumption. They arise from the need for decisions that can limit the rate of climate change, as well as for decisions, large and small, that can alter the consequences or take advantage of the opportunities that arise from a changing climate.

These emerging demands, as well as needs that have not yet become demands, led EPA and NOAA to ask the National Academies to conduct this study. The statement of task appears in Box 1-2. In requesting the

BOX 1-2
Statement of Task

A study panel working under the Committee on the Human Dimensions of Global Change would elaborate a framework for organizing and evaluating decision support activities for the U.S. Climate Change Science Program (CCSP), with special attention to sectors and issues of concern to the sponsors. The panel would examine the objectives of decision support evident in the CCSP strategic plan and in the activities of key CCSP agencies. It would consider the range of relevant decisions, decision makers, decision contexts, and spatial and temporal frames. It would consider the strategies and activities now being used for organizing decision support efforts to meet such objectives, as well as other plausible strategies and applicable tools. As input to the panel's deliberations, it would develop some illustrative case examples in sectors and issues of interest to the sponsors, such as local and regional management of drinking water supplies, waste water management, or coastal resource management. It would consider the fact that in some sectors, the desired outcomes of decision support activities may not be clear in advance.

The panel would consider such decision support objectives as:

- identifying decision makers' important information needs that could be met by scientific efforts of the CCSP;
- making scientific information about change in climate and related environmental systems more understandable to decision makers;
- making relevant scientific information more accessible to decision makers;
- inducing decision makers in potentially affected sectors to use relevant scientific information, including information about scientific uncertainties;
- improving communication between producers and users of scientific information to close gaps between available and desired information;
- setting research priorities to increase the anticipated societal benefit of research results;
- implementing research programs so the outputs more effectively meet decision makers' information needs, better inform their decisions, and promote societal values; and
- improving adaptive management in target sectors (that is, promoting decisions that are more successful at exploiting opportunities and minimizing risks associated with changes in climate and related environmental systems).

The panel would consider these objectives and means to achieve them in light of decisions likely to be made over the coming years and decades in climate-sensitive sectors of interest to the sponsors and in light of scientific information that might lead to better-informed decisions and better societal outcomes in those sectors.

study, EPA and NOAA noted that the CCSP agencies[1] generally would benefit from a clearer conceptual and operational framework for designing and evaluating decision support activities. They have asked the National Academies to provide "a framework for organizing and evaluating decision support activities for the U.S. Climate Change Science Program, with special attention to sectors and issues of concern to the sponsors." In response, the National Academies created this panel, operating under its standing Committee on the Human Dimensions of Global Change.

Although this request is recent, the federal effort on climate change has long recognized the central importance of decision support for responding to climate change. It is clearly implied in the U.S. Global Change Research Act of 1990, which states that the purpose of the Act is to "assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change." This recognition is even more explicit in the vision statement of the CCSP: "a nation and the global community empowered with the science-based knowledge to manage the risks and opportunities of change in the climate and related environmental systems" (U.S. Climate Change Science Program, 2003:3). In this vision, the ultimate objective of the entire program appears to be one of providing decision support.

Study Process

The panel met five times in 2007 and 2008, conducted numerous telephone conferences, reviewed relevant research and interacted with a number of decision makers affected by climate change to get a better understanding of their situations, concerns, and information needs. We focused especially on sectors and issues of concern to EPA and NOAA, the cosponsors of this effort, but we also examined concerns across the federal, state, and local governments, among businesses and industry, and among nonprofit organizations. We sought information on climate-affected decisions and decision makers from the sponsoring agencies, in interviews with participants in various climate-affected decisions, and in two day-long workshops in which we interacted with key climate-affected decision-making groups (see Appendix C for a list of participants). These interactions and the experiences of our informants and their organizations aided our understanding of

[1]They are the Agency for International Development, the Department of Agriculture, the Department of Commerce (including NOAA and the National Institute of Standards and Technology), the Department of Defense, the Department of Energy, the Department of Health and Human Services (including the National Institutes of Health), the Department of State, the Department of the Interior (including the U.S. Geological Survey), the Department of Transportation, EPA, the National Aeronautics and Space Administration, the National Science Foundation, and the Smithsonian Institution.

the expanding range of climate-affected decisions and the met and unmet societal demand for climate-related decision support. We drew on these experiences as sources of practical knowledge about effective strategies and methods for decision support.

We also sought insight from theory and research in the decision sciences, as well as experience in other fields in which scientific information has been developed, characterized, and discussed with the aim of contributing to practical decisions. Researchers and practitioners in these fields, which include agricultural extension, risk and hazard management, public health, and environmental communication, do not typically refer to what they do as decision support. Nevertheless, their work offers valuable insights into how to conceptualize and organize decision support in the context of climate change. We also examined research on climate-related decision support efforts and research on ways that decision makers and providers of decision support can learn and adapt in the face of a changing environment.

Scope of the Study

Decision support is a policy strategy that relies on communication and information to facilitate action. It provides a vital complement to policy strategies that generate change through regulations, technology, and infrastructure development, or financial incentives. The characteristics of climate change make information and communication critically important as policy instruments. For example, climate change is likely to generate events that will require quick and distributed decision making that is sensitive to local conditions and to changing climatic events and national policy concerns.

The study concerns ways to better inform decisions made by individuals and organizations whose futures may be affected by climate change (thus, decisions related to adaptation) or whose choices may change the course of climate change (decisions related to what is often called mitigation). It seeks to develop strategies and methods that federal agencies and others may use to better inform these decisions or to facilitate actions by others to better inform these decisions.

Our analyses, conclusions, and recommendations are addressed to EPA and NOAA (the sponsors of the study), to the participating agencies in the CCSP, to other federal agencies (e.g., natural resource management agencies such as the Bureau of Land Management and the National Park Service), and to the extent possible, to state and local governments, businesses, nonprofit organizations, and individuals. We recognize that much of the nation's response to climate change is occurring outside the federal government—in state and local governments, businesses, nonprofit organizations, and households—that this will continue to be the case, and that in many ways distributed responses to climate are necessary and appropriate. Thus, we offer recommendations to federal agencies and to all other providers of decision support regarding effective ways to serve the constituencies for which they offer decision support. We also offer recommendations to federal agencies about ways to facilitate the provision of decision support by others.

In developing our recommendations, we have carefully considered the appropriate federal roles in relation to the national need for decision support. We recognize that as climate change is experienced across the country, millions of decision makers—state and local governments and their agencies, large and small businesses, nonprofit organizations, and individuals and households—will need supporting knowledge and information. The federal government is not the only appropriate source of this knowledge and information, and in many cases it is not the best source for meeting specific decision makers' needs.

We have identified four appropriate roles for federal agencies in climate-related decision support. Our recommendations are made in relation to these roles: (1) constituency service, (2) international collaboration, (3) provision of public goods, and (4) facilitating distributed responses.

Constituency Service

Federal agencies can provide climate-related decision support services and products to themselves and to the constituencies they are bound by statute or mandate to serve. For example, EPA provides funds to states and localities to help them comply with requirements under the Clean Water and Clean Air Acts. EPA itself needs information in order to set priorities regarding where the greatest effort will be most needed to maintain air and water quality standards, and states and localities need decision support from EPA to help them consider their options for meeting those standards. Other federal agencies and offices, including many that are not now part of the Climate Change Science Program, have similar needs to provide climate-related decision support to themselves and their constituencies. Federal agencies may also provide decision support to climate-affected constituencies related to their mandates when the constituencies are unable to provide it for themselves. For example, major corporations and large public jurisdictions, such as the state of California and the city of New York, may be able to develop climate forecasts and mitigation and adaptation plans using their own technical and financial resources, but this is not true for smaller jurisdictions, small businesses, Native American tribal groups, and households, among others.

International Collaboration

The federal government has the responsibility to link to and participate in international efforts related to climate decision support. For example, it participates in developing measures and monitoring systems for climate vulnerabilities that can be applied globally to assess the potential consequences of climate change and the avoided costs from various mitigation and adaptation actions. It also develops methods and data for international efforts to monitor greenhouse gas emissions, climate-related events and their human consequences, and the effects of mitigation and adaptation activities.

Public Goods

Federal agencies can provide decision support services and products that serve a public good that would not otherwise be provided. Examples include the development of indicators for monitoring climate change and its impacts, national maps of vulnerabilities to climate change, valid and reliable methods for measuring carbon emissions and emissions avoided, and updated standards for the design of transportation infrastructure to withstand extreme climate-related events. Much research also provides important public goods. It is appropriate for the federal government to support research to provide information that is needed throughout the country for high-quality decision making about climate responses, as well as research on ways to provide decision support more effectively. Observational systems and human resource development are also public goods that federal agencies can help provide.

Facilitating Distributed Responses

Federal actions can catalyze and facilitate decentralized decision support efforts in state and local governments and in nongovernmental organizations. This can be done, for example, by funding demonstration projects and facilitating communication and learning between activities in different parts of the country. We note that federal agency actions can also impede effective decentralized action. In developing our recommendations, we have attempted to be alert to this possibility and to propose approaches we consider likely to be facilitative.

The Report

Following this introductory chapter, Chapter 2 defines some key terms, including decision support and decision support products, services, and systems. It identifies the attributes of effective decision support that have been identified in research in the decision sciences in studies of efforts to make scientific information useful to decision makers in agriculture, public health, environmental risk management, energy conservation programs, and other applications. The chapter also identifies and explains the key principles of effective decision support and identifies key barriers to achieving effective decision support and ways to overcome them.

Chapter 3 elaborates on one of the principles of decision support—that decision support systems should learn from experience, including from failures. It discusses four modes of learning and shows why an approach that we call deliberation with analysis, which integrates scientific information into a broadly participatory and iterative process of appraisal and reconsideration, is best suited to the kind of decision environment that is typical in responding to climate change.

Chapter 4 turns from issues of process to those of knowledge and information needs. It sketches the great variety of information needs of decision makers that arise from the great variety of climate responses and the many considerations that arise in choosing among them. The chapter outlines the contours of the research needed and also identifies needs for observational systems, indicators, and a stronger workforce for understanding and providing decision support.

Chapter 5 summarizes and integrates our main conclusions and recommendations.

2

Effective Decision Support: Definitions, Principles, and Implementation

Recognizing the trend of climatic changes described in Chapter 1, the U.S. Climate Change Science Program (CCSP) (2003:3) has adopted as its guiding purpose the vision of "a nation and the global community empowered with the science-based knowledge to manage the risks and opportunities of change in the climate and related environmental systems." This vision casts the program as a decision support program: to provide knowledge that people need to make better decisions and to do so in ways that enable and empower decision makers to use it appropriately.

We see this vision as entirely appropriate for the federal research program, and we believe it could apply and be adopted more broadly for the nation, including for decision support activities at other levels of government and in the private and civic sectors. However, the program has not in fact been organized so as to implement this vision. As this and subsequent chapters make clear, realizing this vision will require significant changes both in the federal program and in the *modus operandi* of many other research and decision-making institutions. The most important of these changes is to put users' needs at the center of the processes of decision support. That means, in turn, paying close attention to those processes, in addition to the products provided.

This chapter explains what we mean by climate-related decisions and by decision support. We draw on a wide range of literature to distill six key principles that characterize effective decision support systems and to document the benefits of following them. The chapter identifies the types of services or activities decision support systems provide, the barriers that can prevent effective implementation of the principles, and strategies for overcoming the barriers. We end with a set of conclusions and recommendations meant to inform the initiation, design, and implementation of decision support activities sponsored by federal agencies and others.

DEFINITIONS AND KEY CONCEPTS

The term "decision support" has recently come into common use in the climate context, but the underlying idea is far from new. The core idea—making scientific knowledge useful for practical decision making—is evident in many fields, ranging from public health to risk assessment, software development, resource management, and many more. Decision support is often narrowly understood as an activity that provides data, tools, and other types of information products that make scientific information more accessible to decision makers: for example, translating it into nontechnical language. In this spirit, the CCSP has made major efforts to enhance the technical and modeling basis on which climate-related risk management decisions may be based. This focus on information products can also be found in other federal agencies, at other levels of government, in the private sector, and in other countries.

Yet there is a broader view of decision support which is increasingly being adopted in some federal agencies and nongovernmental efforts and is also reflected in studies of science-practice interactions and of decision support needs (see, e.g., National Research Council, 2007a, 2008d). In this view, decision support consists of a set of processes intended to create the conditions for the production of decision-relevant information and for its appropriate use. Ongoing communication between the producers and users of information is at the center of these processes, and information products are one result, but not the exclusive one. This view stems from decision support activities "on the ground," including some that are sponsored by federal agencies, such as the Global Change Research Program of the Environmental Protection Agency (EPA) (in particular, its ongoing Great Lakes Regional Assessment); the Regional Integrated Sciences and Assessments (RISA) Program and Science Applications and Research Program (SARP) at the National Oceanic and Atmospheric Administration (NOAA); and the Forest and Agricultural Extension Services at the U.S. Department of Agriculture (USDA) (see National Research Council, 2006b, for additional examples), as well as in activities at the state and local levels in the private and public sectors. We adopt this broader understanding of decision support to include both products and processes. The rest of this section elaborates our usage of concepts and terms fundamental to this report.

Climate-Related (or Climate-Sensitive) Decisions Climate-related, or climate-sensitive, decisions are choices by individuals or organizations, the results of which can be expected to affect climate change or to be affected by climate change and its interactions with ecological, economic, and social systems. Choices to mitigate or adapt to climate change are obviously included, but also included are decisions about matters that may be only indirectly related to climate (e.g., changing educational requirements for grades K–12 in ways that may better enable the next generation to deal with climate change challenges). One important implication of this definition deserves special emphasis. Decisions are climate sensitive regardless of whether or not decision makers recognize them as such at the time of decision making. Many decisions and decision-making routines that were well suited to past climatic conditions will be less so under future conditions of climate and climate-society interactions—but not all the affected decision makers may yet realize it. Although decision support can potentially help all climate-affected decision makers get better results, a decision maker who does not yet realize that a decision at hand is climate sensitive will not perceive a need for such support. Thus, one of the challenges of decision support is to identify climate-sensitive decisions that are not being treated as such, help decision makers realize how climate change may affect them, and then support subsequent climate-cognizant decisions.

Decision-Relevant Knowledge (or Information) Knowledge or information is decision relevant if it yields deeper understanding of a choice or if, incorporated in making a choice, it yields better expected results for decision makers and their constituencies than would be achieved if the choice were made without that knowledge or information. We note that decision-relevant information is useful for decisions only when it is also accessible and understandable to decision makers and in a timely manner.

It is important to make explicit that decision-relevant information for climate-related decisions is not only about climate. It may also include information about:

1. basic characteristics of climate variability and change and the implications of these processes for climate-related decisions and for things people value;
2. the expected effects of climate change on hydrological, ecological, and other biophysical systems at particular places and times;
3. the social and economic processes that drive climate change;
4. the socioeconomic and human-environmental processes that alter the vulnerability of human or ecological systems to climate variability and change (e.g., changes in the numbers and socioeconomic characteristics of people living in vulnerable areas);
5. the expected effects of climatic processes on human systems taking into account other ongoing environmental, economic, and social

processes (sometimes called multiple stresses, such as potential property damage to coastal homes considering changes in both climate and regional development);

6. the range of strategies available at different scales for mitigation (technologies, policy options, market mechanisms, etc.) and for coping or adaptation (e.g., engineering, economic, behavioral, etc.);

7. the likely costs and consequences of potential policies and other actions to respond to climate change (e.g., ecological effects of developing biofuels, economic effects of different options to protect against hazards, and co-benefits of increasing the resilience of vulnerable regions, sectors, or communities); and

8. the barriers to success for potential responses to climate change and ways to overcome them.

As discussed in Chapter 4, meeting these various information needs will require a considerable expansion of the national scientific effort in the areas described by 3 through 8 above.

Climate-Related Decision Support Climate-related decision support involves organized efforts to produce, disseminate, and encourage the use of information that can improve climate-related decisions. It includes various kinds of activities, products, and services, including efforts to identify decision makers' information needs; production of decision-relevant information; creation of information products based on this information; dissemination of these products; efforts to encourage the use of decision-relevant information; ongoing communication among producers and users of decision support products and services to evaluate and improve the quality of information, relationships between information producers and users, and ultimate decisions; and development of organizations, networks, and institutions to serve those purposes. Decision support cannot lower actual risks directly or immediately, but it can influence humans' awareness of and responses to risk in ways that can, over time, mitigate threats from the natural world, as well as the vulnerability resulting from human exposure to threats.

Decision Support Products Decision support products are the tangible deliverables developed in the course of decision support (including data, maps, projections, images, tools, models, or documents) that contain information intended to be useful for decision making. The media or channels developed to deliver this information (brochures, web pages, etc.) may also be considered decision support products.

Decision Support Services Decision support services are activities, consultations, or other forms of interaction that enable decision makers to make better use of decision-relevant information and decision support products, including formal and informal efforts to identify information needs, educate those involved in the decision process, and facilitate or evaluate decision support processes. Decision support services may be less visible to outsiders than decision support products, but they are equally important. The most appropriate services vary with the specific situation at hand, the larger decision context, and the phase in the decision process.

Decision Support Systems Sometimes also called knowledge-action systems or networks, decision support systems comprise the individuals, organizations, communication networks, and supporting institutional structures that provide and use decision support products and services. They include the people and organizations that develop the knowledge needed to produce those products and services, as well as the knowledge, information products, and services.

Effective Decision Support The effectiveness of decision support can be judged by the extent to which it increases the likelihood that decision-relevant information is produced and enables and empowers decision makers to use it appropriately. The many elements of effective decision support can be usefully grouped under three categories:

1. *Increased usefulness of information*. Decision support is effective to the extent that the information provided is considered by the intended users as credible, legitimate, actionable, and salient in terms of their decision deadlines and other concerns (e.g., Jones, Fischhoff, and Lach, 1999; Cash et al., 2003; Mitchell et al., 2006; National Research Council, 1999b, 2008d; Reid et al., 2007).
2. *Improved relationships between knowledge producers and users*. Decision support is effective when it engages scientists and decision makers in mutual learning and the coproduction of knowledge that could not have emerged from either side alone and when it yields increased mutual understanding, respect, and trust (see, e.g., Jasanoff, 1987; Gunderson, Holling, and Light, 1995; National Research Council, 1996b; Global Environmental Assessment Project, 1997; Cvetkovich and Lofstedt, 1999; Sidaway, 2005; Hahn et al., 2006; McNie, 2008).
3. *Better decisions*. Decision support is effective when the resulting decisions have the qualities of good decisions identified in Chapter 1 (including productive problem definitions and clear objectives) and when the decision makers and key constituencies view the decision as having been improved by the support received (e.g., Haas, Keohane, and Levy, 1993; Coglianese and Snyder Bennear, 2003; Clark, Mitchell, and Cash, 2006; Farrell and Jäger, 2006; National Research Council, 2006b, 2007a, 2008c, 2008d; Newig, 2007; Rowe et al., 2008).

The effectiveness of decision support is thus a multidimensional construct. Consequently, tradeoffs may be necessary if some objectives are considered paramount. Moreover, participants in decision support systems may differ in their judgments of the attributes of information (salience, legitimacy, credibility, and efficacy) and of the quality of relationships, processes, or decision outcomes. These differences help shape the political context in which decision making takes place and in which decision support systems strive to function effectively. In general, however, long-term engagements with deliberate efforts to learn and improve interactions achieve these objectives more fully than limited interactions. Processes for enhancing such learning are discussed in more detail in Chapter 3.

PRINCIPLES OF EFFECTIVE DECISION SUPPORT

As noted above, decision support has a long history in fields other than climate, including public health; hazards management; natural resource management; environmental management and policy making; land use planning; environmental risk communication; sustainability science and promotion of sustainable behavior; stratospheric ozone, air quality, and climate change mitigation; and specific efforts in coping with and adapting to climate variability and change in various sectors or regions: see Box 2-1. To understand what makes decision support systems effective, we examined empirical research from these fields and also from studies of the relation of science to its uses in policy, resource management, and society. Some of these rely heavily on the authors' judgment and some are syntheses of extensive bodies of research and experience (e.g., Gibbons et al., 1994; National Research Council, 1996b, 2005a, 2008c; Jasanoff, 1990; Nowotny et al., 2001; Pielke, 2007; Pohl, 2005; Slaughter and Rhoades, 2005; Stokes, 1997). We also examined core social science theory and research on communication, decision making, organizational behavior, and social change (e.g., Bell, Raiffa, and Tversky, 1988; Drabek, 1986; Brewer and deLeon, 1992; Gutteling and Weigman, 1996; Kahneman and Tversky, 2000; Rogers, 2003; Edwards, Miles, and von Winterfeldt, 2007). We have also drawn on a limited body of observational research and the experiences of professionals and scientists engaged in climate-related decision support, including those working on decision support efforts supported by NOAA, EPA, other federal agencies, state and local governments, and the private sector. A noteworthy source of insights specific to climate-related decision support is a recent NOAA review of efforts to provide decision support related the use of information on seasonal-to-interannual climate variation in the water resources sector (U.S. Climate Change Science Program and Subcommittee on Global Change Research, 2008).

BOX 2-1
Sources of Evidence About Effectiveness in Decision Support

Public health:
Valente and Schuster, 2002; Totlandsdal et al., 2007; Jackson and Shields, 2008

Hazards management:
Quarantelli, 1991; Cutter, 1994; Mileti, 1999; Drew, Nyerges, and Leschine, 2004; Morss et al., 2005

Natural resource management:
Feller et al., 1984; Healey and Ascher, 1995; McDaniels, Gregory, and Fields, 1999; Wondolleck and Yaffee, 2000; Jacobs and Pulwarty, 2004; Mascarenhas and Scarce, 2004; Power, Sadler, and Nicholls, 2005; Rayner, Ingram, and Lach, 2005; Nyerges et al., 2006; Corringham, Westerling, and Morehouse, 2008

Environmental management and policy making:
Lemmons and Brown, 1995; Sexton et al., 1999; Steel et al., 2004; Francis et al., 2005; Stoll-Kleemann, 2005

Land use planning:
James, 1999; Forester, 1999; Dortmans, 2005; Francis et al., 2004; Richardson, 2005; Szaro, Boyce, and Puchlerz, 2005; Lejano, 2008

Environmental risk communication:
National Research Council, 1989; Covello, McCallum, and Pavlova, 1989; Kasperson and Kasperson, 2005

Sustainability science and promotion of sustainable behavior:
Gardner and Stern, 1996; National Research Council, 1999c; McKenzie-Mohr and Smith, 1999; Kates et al., 2001; Clark and Dickson, 2003; Kasemir et al., 2003; Kaufmann-Hayoz and Gutscher, 2001; van Kerkhoff and Lebel, 2006

Stratospheric ozone, air quality, and climate change mitigation:
Haas, 1992; Liftin, 1994; Glasser, 1995; Alcamo, Kreileman, and Leemans, 1996; Shackley, 1997; Social Learning Group, 2001; Parson, 2003; Bergin et al., 2005; Cimorelli and Stahl, 2005; Engel-Cox and Hoff, 2005; Grundmann, 2006; Gupta and van Asselt, 2006; Crutzen and Oppenheimer, 2008

Coping with and adapting to climate variability and change in various sectors or regions:
Berkes and Folke, 1998; Cash, 2001; Jacobs, 2002; Pulwarty and Melis, 2001; Pulwarty, 2003; Georgakakos et al., 2005; Jacobs, Garfin, and Lenart, 2005; Lemos and Morehouse, 2005; Cash, Borck, and Patt, 2006; Moser, 2006a, 2007a; Welp et al., 2006; Tribbia and Moser, 2008

Several recent attempts have been made to integrate this wealth of practical insights and the more theoretical literature to accelerate and foster learning throughout the research community (e.g., Cash et al., 2003; van Kerkhoff, 2005; McNie, 2007; Mitchell et al., 2006; National Research Council, 2005b, 2006b, 2008c, 2008d; Singh et al., 2002; Vogel et al., 2007; Welp and Stoll-Kleemann, 2006). Drawing on the primary sources and these integrative efforts, we note a convergence of these literatures on six general principles for designing effective decision support systems that are appropriate for all phases of decision support efforts. We believe the principles apply to climate-related decision support. Additional research is needed to learn how to implement those broad principles effectively in specific climate decision contests. (We discuss the need for research on decision support in more detail in Chapter 4.) Decision support efforts are more likely to be judged effective when they follow the principles, which we summarize here and discuss in more detail in the next sections.

1. **Begin with users' needs:** Decision support activities should be driven by users' needs, not by scientific research priorities. These needs are not always known in advance, and they should be identified collaboratively and iteratively in ongoing two-way communication between knowledge producers and decision makers. The latter can usefully be thought of as constituencies—collections of decision makers who face the same or similar climate-related events or choices and therefore have similar information needs.
2. **Give priority to processes over products:** To get the right products, start with the right process. Decision support is not merely about producing the right kinds of information products. Without attention to process, products are likely to be inferior—although excessive attention to process without delivery of useful products can also be ineffective. To identify, produce, and provide the appropriate kind of decision support, processes of interaction among and between decision support providers and users are essential.
3. **Link information producers and users:** Decision support systems require networks and institutions linking information producers and users. The cultures and incentives of science and practice are different, for good reason, and those differences need to be respected if a productive and durable relationship is to be built. Some ways to accomplish this rely on networks and intermediaries, such as boundary organizations (see below).
4. **Build connections across disciplines and organizations:** Decision support services and products must account for the multidisciplinary character of the needed information, the many organizations that share decision arenas, and the wider decision context.
5. **Seek institutional stability:** Decision support systems need stable support. This can be achieved through formal institutionalization, less formal but long-lasting network building, establishing new decision routines, and mandates, along with committed funding and personnel. Stable deci-

sion support systems are able to obtain greater visibility, stature, longevity, and effectiveness.

6. **Design for learning:** Decision support systems should be structured for flexibility, adaptability, and learning from experience.

Begin with Users' Needs

Effective decision support needs to begin with collaborative problem definition, including all the parties involved, and to support interactions and learning among them. The rationale is obvious—to identify which knowledge is needed by decision makers (and when and how) and what is feasible for science to deliver. Yet much research that is intended to be decision relevant is begun and conducted without consultation with the envisioned end users (e.g., McNie, 2007; Sarewitz and Pielke, 2007). Numerous reviews have found that effective assessment and decision-making efforts related to hazards and other scientifically complex issues require communicative and iterative interactions between scientific and decision-making groups (see National Research Council, 1996b, 2007a, 2008c, and sources cited there). Such ongoing interaction, two-way communication, and collaboration allow scientists and decision makers to get to know each other; develop an understanding of what decision makers need to know and what science can provide; build trust; and, over time, develop highly productive relationships as the basis for effective decision support. One-time or sporadic interactions do not usually yield these benefits; ongoing relationships can do so. An extensive literature on social trust in relation to risk management indicates that when people lack direct experience with a risk, their judgments of risks are strongly affected by trust in the authorities who are responsible for managing them, and that trust is in turn affected by characteristics of the interactions between authorities and those potentially affected (e.g., Siegrist and Cvetkovich, 2000; Kasperson et al., 2003). The literature suggests the value of participatory processes that address the principal values and concerns of those involved.

The intensity and form of communication and collaboration may vary over time and across situations, but it is essential for problem definition. The First U.S. National Assessment of the Potential Consequences of Climate Variability and Change (1997–2001), for example, began with regional and sectoral scoping workshops in which scientists, stakeholders, and program sponsors jointly defined the potential challenges to be further investigated. After such initial problem definition workshops, interactions ranged from occasional updates, to involvement in the review of the emerging science, to data sharing and collaborative research, and to joint dissemination of results (Moser, 2005b; National Research Council, 2008c; see also Appendix A).

Provided that appropriate boundaries between science and policy making are maintained, collaborative interactions to define problems, identify information needs, share data, investigate options, and review and communicate results can increase the credibility, relevance, and perceived legitimacy of the scientific information, enable decision makers to make decisions or solve problems (perceived efficacy) and increase public understanding of risks, uncertainties, and action alternatives (see, e.g., Holling, 1978; Walters and Holling, 1990; Scheraga and Smith, 1990; Crowfoot and Wollondeck, 1990; Cash et al., 2003; Jacobs, Garfin, and Lenart, 2005; Mitchell et al., 2006; National Research Council, 2007c; Chilvers, 2008).

Give Priority to Processes Over Products

Interpersonal interactions are critical to effective decision support. If ignored or poorly managed, the resulting disconnects can reduce the quality of relationships between users and producers of information, the usefulness and ultimate use of the information, and even the quality of decisions (Global Environmental Assessment Project, 1997; Mitchell et al., 2006; National Research Council, 1989, 1996b, 2007a, 2008c, 2008d; Reid et al., 2007).

Perhaps the most important interpersonal processes involve relationship building and maintenance, which require time, patience, care, and social skill. Prior experience in collaboration across apparent divides is also useful in building relationships among decision support providers, among decision makers, and between these two groups. Having staff whose time is dedicated to managing and coordinating these relationships and to external communication can be particularly helpful (Pulwarty, Simpson, and Nierenberg, 2009). Decision makers who participate in relationship building can effectively facilitate and extend outreach to other decision-making groups if they are linked into these networks, understand those groups' cultures and languages, and are trusted there (Jacobs, Garfin, and Lenart, 2005; McNie, Pielke, and Sarewitz, 2007).

Another process that is key to effective decision support is the development of a culture of learning among decision support participants (for further discussion, see Chapter 3). Individuals generally hold expertise in their respective fields and spheres of responsibility but lack expertise in others' fields. To communicate effectively, they need to learn from each other. Pilot projects, exploratory research, and interactions about short-term needs can hasten such learning (Lemos and Morehouse, 2005; National Research Council, 2006b; Pulwarty, Simpson, and Nierenberg, 2009). For many with experience in decision support, this ongoing opportunity to learn and grow is itself a benefit (Moser, 2005b).

Two-way communication is an essential process for decision support which involves "a shift from a view of knowledge as a 'thing' that can be transferred to viewing knowledge as a 'process of relating' that involves negotiation of meaning among partners" (Roux et al., 2006:1). It cannot be overstated how critically the success of an entire decision support enterprise depends on the quality of communication among all involved.

Leadership is also necessary for the effective functioning of decision support systems. Leaders serve as flag bearers, advertisers, sources of credibility and legitimacy, conflict mediators, seekers of funding, role models, mentors, and innovators. Leaders set expectations and tones, develop rules and demand delivery on obligations, and engender trust (e.g., Zand, 1997; National Research Council, 2006b). Leaders can also be essential in fostering the trial and spread of new practices, keeping difficult processes going, and learning from inevitable mistakes (e.g., Valente, 1995; Rogers, 2003). Absent or ineffective leadership has obstructed the successful establishment of climate-related decision support efforts (Grundmann, 2006; McNie, Pielke, and Sarewitz, 2007; Pulwarty, Simpson, and Nierenberg, 2009).

Link Information Producers and Users

Science and decision making have different purposes, concerns, languages, and norms (e.g., Jasanoff, 1986; Rhodes, 1997; Guston, 2001; Blockstein, 2002; Dabelko, 2005; Nagda, 2006). Decision makers are accountable to particular agencies, publics, stakeholders, or shareholders. Scientists, by contrast, are primarily accountable to their funders and their academic institutions and disciplines, and their social contract with society is implicit (e.g., Lubchenco, 1998; Gibbons, 1999; Kellogg Committee, 1999; McDowell, 2001; Slaughter and Rhoades, 2005). To collaborate with each other, these communities need to respect these differences, find forums and ways to mediate between them, and, if necessary, involve organizations or individuals that can cross and yet maintain and manage the boundary between science and practice.

Specialized "boundary organizations" have sometimes proved instrumental in enabling scientists and users of scientific information to work productively together by improving communication, translation, and mediation between the two communities and establishing useful rather than antagonistic tension between them (Fennell and Alexander, 1987; Guston, 1999, 2001; Gieryn, 1995, 1999; Cash, 2001; Cash et al., 2003). NOAA's RISA centers are an example in the climate area; other federally sponsored boundary organizations, such as the EPA's Great Lakes National Program Office, which are already performing linking functions, can expand their work on climate. Boundary organizations are commonly defined as "institutions that straddle the shifting divide between politics and science. They draw their incentives from and produce outputs for principals in both domains and thus … facilitate the transfer of useful knowledge between science and policy" (Guston et al., 2000:7).

Ideally, the functions that boundary organizations perform include linking science and practice while keeping them distinct, creating mechanisms of mutual accountability, and using the process of creating reports, models, assessments, and other products to facilitate and focus interaction (e.g., Cash et al., 2003; Cash, Borck, and Patt, 2006; National Research Council, 2006b). When scientists and decision makers are not already skilled in working with each other, boundary organizations may be necessary to produce fruitful interactions and effective decision support.

Ongoing communication is also important because most climate-related decisions involve multiple and shifting arrays of interested and affected groups (Lindell et al., 1997). Decision support systems are generally more effective if participants recognize and accommodate group differences, encourage transparency and accountability, and thereby build the trust that is essential to constructive intergroup coordination, information exchange, and risk-taking (e.g., Earle and Cvetkovich, 1998; Rupesh, Murphy, and McIntosh, 2003; Drew, Nyerges, and Leschine, 2004). Both formal and informal arrangements can effectively bridge these differences (National Research Council, 2002a; Moser and Dilling, 2007; Jackson and Shields, 2008). Allowing all participants to interact directly can help manage group differences, if this is done carefully (see National Research Council, 2008c). It is important that decision support systems at least consider the diversity of influences on a given decision, including the beliefs, attitudes, values, perceptions, social norms, and resource allocation tradeoffs of the affected parties.

Build Connections Across Disciplines and Organizations

Well-informed responses to climate change almost always require combining information from different disciplines, and decision makers are increasingly asking for knowledge and information that integrates across disciplines (e.g., Adger et al., 2003; Aram, 2004; Brechin et al., 2002; Brewer, 2007; Cimorelli and Stahl, 2005; Cundill, Fabricius, and Marti, 2005; Edwards and Steins, 1999; Jacobs, Garfin, and Lenart, 2005; Kinzig et al., 2000; Malone and Yohe, 2002; National Research Council, 1999a, 2004c; Quinlan and Scogings, 2004; van Kerkhoff, 2005). For example, reducing greenhouse gas emissions requires knowledge not just of how these gases affect the climate system, but also about the available technological and policy options at different scales of decision making and their likely economic and societal costs and benefits. Adaptation questions raise similar challenges of integration across disciplines, sectors, and scales.

It takes time and care for multidisciplinary teams to come together and collaborate productively (e.g., Brewer, 1999; National Research Council, 2004c; Cummings and Kiesler, 2005; Pulwarty, Simpson, and Nierenberg, 2009). Decision support efforts that do not take the time and care needed for multi- and interdisciplinary collaboration may produce considerable frustration among scientists and partial or misleading information for decision makers.

It is similarly important to connect decision makers and stakeholders from different sectors or organizations to enable collaboration and information exchange. In governments, this typically means collaboration among different agencies. Even when individual agency representatives bring the necessary motivation, initiative, and leadership, formal interdepartmental and interagency mechanisms or reorganizations are frequently needed to permanently bridge divisions caused by different enabling laws, regulations, missions, procedures, budgets, and agency "cultures" (e.g., Galloway, 1996; Jacobs et al., 2005; Moser, 2006a; Miles et al., 2006; Corringham et al., 2008; Pulwarty, Simpson, and Nierenberg, 2009). In seeking the needed integration, it is critical not to exclude or undermine decision makers' and stakeholders' sense of ownership, processes of engagement, or valuable local knowledge (e.g., Farrelly, 2005). This process takes care and time, and—if ignored—is likely to undermine the decision-making processes (and by extension, the intent of decision support).

It is also important to build connections across geographic scales and levels of social and political organization. For example, integrative scientific assessments at the global or national levels do not provide detailed understanding of local environmental, climatological, or social processes and are therefore not typically very useful for local decision making (e.g., Berkes, 2002; Cash and Moser, 2000; Cash et al., 2006; Jacobs, Garfin, and Lenart, 2005; Ludwig and Stafford Smith, 2005; Mitchell et al., 2006; Reid et al., 2007; Wilbanks, 2007; Young, 2002). Similarly, although policy mechanisms at higher levels provide broad frameworks, incentives, guidance, or mandates (e.g., setting a cap on carbon emissions or providing funds for reducing vulnerability to climate change impacts), local and regional jurisdictions still need to find effective ways to act within those frameworks. It can be helpful or necessary to build cross-scale engagement mechanisms or networks to remove barriers to action and to produce the scientific understanding, collaborative learning, and information sharing, innovation, and relationship and trust building needed to achieve a productive linking of policies and practices at different levels of organization.

Seek Institutional Stability

Research and experience shows that decision support is more effective when it continues over time. Formal institutionalization of new entities is not always necessary for success: pilot projects or small, short-lived decision support interactions can help get a process started, and decision support can rely on existing boundary organizations, such as federally supported extension services or private-sector service providers. But when well-established organizations do not exist to provide decision support, it can be difficult to attract funding, to convey a sense of longevity to potential information users, to establish trust among information users, or to get the institutional support needed in academic settings for space, time, scientific staffing, and instrumentation. Thus, in many instances, formal institutionalization of decision support will be critical to its longevity, recognition, and success.

The model of establishing focused decision support centers within or affiliated with academic institutions has often been judged successful at the regional level (e.g., RISA centers, the Great Lakes Regional Assessment, the International Research Institute for Climate and Society, cooperative extension services, and many others cited in National Research Council, 2006b). Other decision support institutions may be formalized to serve a particular temporary policy purpose (e.g., specifically appointed advisory councils in support of state or national policy decisions) or to provide long-lived technical support for international policy regimes. An example is the Technology and Economic Assessment Panel (TEAP), which was initially instrumental in building consensus around technological solutions to replace ozone-depleting substances and has become a permanent technical advisory body to the parties of the Montreal Protocol. Box 2-2 describes various models of institutionalized decision support, but the universe of potentially effective decision support models is not restricted to these few.

BOX 2-2
Selected Models of Institutionalized Decision Support

Cooperative Extension

The USDA's cooperative extension system provides almost a century of experience in decision support process that is directly relevant to emerging climate-related needs, even if not yet concerned with climate change. The system benefits from multitiered organization and the public mandate of land-grant universities. Over time, it has faced challenges common to all decision support activities: cultural and institutional differences and barriers between science and decision making, undue influence of specific interest groups, funding limitations, and changing communication technologies and interaction.

The roots of the system go back to 1862, but it formally began with the 1914 Smith-Lever Act, which established cooperative extension services in every state (National Research Council, 1995; McDowell, 2001; Comer et al., 2006). Today,

BOX 2-2 continued

the federal Cooperative State Research, Education, and Extension Service funds state and local extension programs through a network of state, regional, and county extension offices in every state and territory and more than half of all U.S. counties. The target audiences for extension now include not only farmers, but also a broader range of individuals, households, businesses, and governments (National Research Council, 1996a; Kellogg Committee, 1999; McDowell, 2001; U.S. Department of Agriculture, 2008).

Extension incorporates diverse and mutually reinforcing personnel and funding mechanisms. States provide matching and additional funds for research and extension, and most counties also provide support. Thousands of extension staff, mainly based at land-grant universities, conduct outreach activities and respond to public inquiries in person, by telephone, and through internet, print, video, or other formats. They collaborate with colleagues at land-grant universities; other researchers; federal, state, county, and local government agencies; nonprofit associations; professional and business organizations; private industry; citizen groups; foundations; the military; and other groups (U.S. Department of Agriculture, 2008).

Land-grant universities typically hire faculty with significant extension obligations, often in lieu of classroom teaching. Extension faculty and staff are often generalists rather than specialists, to meet diverse and changing public needs. Many aim to foster two-way communications between decision makers and researchers and two-way relationships between inquiry and application (National Research Council, 1996a; Kellogg Committee, 1999; McDowell, 2001). With the advent of the internet and web-based communication technologies, relationships between extension agents and their clients continue to change.

The NOAA Regional Integrated Sciences and Assessments Program

NOAA established the RISA Program in the mid-1990s to help "realign our nation's climate research to better serve society" by supporting "research that addresses complex climate sensitive issues of concern to decision makers and policy planners at a regional level" (see http://www.climate.noaa.gov/cpo_pa/risa/). RISA teams are typically based at universities, though some team members may come from government research facilities, nonprofit organizations, and private-sector entities. The teams commonly conduct research on climate-sensitive aspects of fisheries, water, and wildfire management; agriculture; and, more recently, public health and coastal management issues.

This small NOAA Program, with an annual budget of only around $3 million, currently sponsors nine RISA centers. Some are well into their second decade of existence, including the Climate Impacts Group in the Pacific Northwest and the Climate Assessment of the Southwest; others are relatively new, including the Southern Climate Impacts Planning Program and the Carolinas Integrated Sciences and Assessments; at least one, in New England was not sustained.

RISA projects typically feature participatory problem framing and problem solving; strong stakeholder involvement; an emphasis on ensuring that scientists live in the regions where they are conducting assessments; team building to integrate physical and social science experts; and starting with pilot projects that engender collaboration among scientists and decision makers. Fundamental to RISA Programs is the notion that decisions are improved both through the incorporation

BOX 2-2 continued

of scientific information and through developing and sustaining knowledge-action networks. RISA Programs have been important test beds for learning how to apply the principles of effective decision support in informing decisions about adapting to climate change.

The Montreal Protocol

A well-organized decision support system contributed significantly to the success of the Montreal Protocol of 1987, the treaty that orchestrated international efforts to reduce the atmospheric concentration of substances that deplete stratospheric ozone. Understanding that information and understanding would not be static, the authors of the protocol included provisions for regular assessments of the relevant information and review of the control provisions. These assessments are organized under the Technology and Economic Assessment Panel (TEAP; see Canan and Reichman, 2002) and combine disciplinary knowledge from chemical engineering to economics. With scientifically grounded estimates of both the costs and benefits of control, deliberations have focused on solving the problem of ozone depletion.

More than two-thirds of TEAP members have been from affected industries, with most of the others from government organizations and universities. Including technologists from the private sector has had several positive effects: it ensured that the reports contained up–to-date information on alternative technologies; it led to sharing of technological information among people in industry who could facilitate the changes necessary to reduce use of ozone-depleting substances (ODSs); and it added to the credibility of the reports in industry. TEAP reports have informed the parties to the protocol about which control measures were feasible and sped the global introduction of low or non-ODS-emitting technologies. Involvement of industry experts in TEAP, as well as their partnerships in developing ozone science, provided their firms with a good understanding of the issues involved, lowered resistance to change, and developed industry support for the international process as well as national implementation of the protocol's ODS restrictions.

Consensus among the TEAP members created reasonable assurance that businesses would comply with rules structured around those agreements. In this way, changes in the protocol in response to new information reflected rigorous science and gained political acceptability. The TEAP model, while reflecting the principles of effective decision support described in this chapter, cannot simply be copied for responding to climate change, because the latter problem is much more complicated in its technological and economic aspects, and the political issues are far more difficult to address.

Design for Learning

As Chapter 1 describes, the climate is continually changing and interacting with a world that is changing independently; the science of climate change is also rapidly changing and will continue to change; and the climate policy environment is evolving. Decision makers and decision support systems must respond effectively in this uncertain, continuously evolving decision environment or risk perpetuating errors and becoming obsolete.

The needed learning orientation has several dimensions. First, decision makers need to consider multidisciplinary scientific information along with various other inputs, political factors, leadership directives, and priorities (Clark, Mitchell, and Cash, 2006; Morss et al., 2005). Both scientists and decision makers need to understand the necessity of tradeoffs across sectors, concerns, interests, and temporal and spatial scales (Carbone and Dow, 2005; Pulwarty, Simpson, and Nierenberg, 2009).

Second, information products created in isolation from specific decision contexts will not necessarily meet decision makers' needs, especially in rapidly changing decision environments. Useful information reflects attention to the different dimensions of the decision support interaction and decision context; to emerging opportunities; to the strengths, advantages, and capacities of those involved; and to situational constraints.

Third, certain events create "policy windows" for action—that is, convergences of problem recognition and pressure for policy solutions (see, e.g., Sabatier and Jenkins-Smith, 1993; Solecki and Michaels, 1994; Kingdon, 2002; Moser, 2005a). For climate-related decision support, recent first-hand experience of a disaster, such as a heat wave, drought, storm, or flood, can dramatically increase decision makers' desire for and openness to new information and action, at least for a short period of time (Russell et al., 1995; Birkland, 1997). Individuals involved in decision support systems can prepare for and respond to such windows of opportunity by establishing relationships, communication channels, information products, and policy proposals in advance, then using relationships and making information widely available in the wake of a trigger event (Mileti, 1999). If they are not prepared in these ways, the chance to provide decision support and implement change may pass as political pressure produces demands to "get back to normal" as quickly as possible (e.g., Moser, 2005a).

Maintenance of learning networks for decision support, especially for vulnerable groups, remains important in noncrisis times (e.g., Mileti and Peek, 2002). Participants need to remain aware of changing conditions and opportunities while choosing to be selectively responsive (e.g., Lee, 1993; Gunderson, Holling, and Light, 1995; Pulwarty, Simpson, and Nierenberg, 2009). Choices about funding, personnel, and research priorities should reflect the need for continued learning, effective delivery of promised decision support, maintaining good relationships, and providing strong leadership over time (see Chapter 3).

DECISION SUPPORT SERVICES

We emphasize above that decision support includes more than providing information tools and products. In this section we discuss what those engaged in effective decision support actually do. To begin, it is important to recognize that decision support activities and services vary over the course of a decision support relationship and differ depending on the phase of the policy or decision-making process.

Different Services at Different Stages in the Decision Process

A rich and varied literature conceives of policy making and decision making as progressing in stages or phases (e.g., Brewer, 1973; Brewer and deLeon, 1992; Birkland, 2005). These stage models vary in detail and by context, but for understanding the needs of decision support, certain similarities among the models are particularly important. One is that decision makers need different kinds of knowledge and information at different stages, and so the most appropriate input from science is stage dependent. Most stage models also note that decision making is an iterative and ongoing process, which implies that decision support relationships should be ongoing to be effective and should be prepared to revisit old questions from time to time. Some of the phase models also emphasize that information and influence flows not only from scientists to decision makers, but also from decision makers and affected parties to science, in such forms as framing decision-relevant questions, expressing values and concerns to be considered, and providing specialized knowledge of local conditions (National Research Council, 1996b, 2008c).

In the early stages of a process, scientists may play a principal role—as they have with climate change—in detecting a problem and framing it to initiate a policy debate or decision process. Among the principal tasks for decision support at that time may be raising awareness, providing basic education about the problem, and translating scientific knowledge into lay language (e.g., Ogunseitan, 2000, 2003; Schreurs et al., 2001; Pielke, 1997). At later stages, decision support may focus on exploring the local effects of climatic events, systematically assessing policy alternatives, along with their costs and implications, or developing models and incentives for behavioral change. During policy implementation, decision support may focus on developing tools that help routinize decisions, defining professional ethics, and training and skills building for decision makers. In the appraisal or evaluation stage of decision making, decision support may emphasize monitoring and assessing, leading to termination, a change in decisions, or another round of decision making in an iterative process (Vogel et al., 2007; see also Chapter 3). Engagement of various audiences is critical in all phases, although their specific concerns, needs, and potential contributions vary. Those involved in providing decision support may change over time because different expertise is required to meet different decision support needs. Box 2-3 describes some options for beginning a decision support relationship and describes how that relationship may change over time.

Because needs change with the phases of a decision process, continual engagement between researchers and decision makers is needed to identify what support is most needed, when, and by whom. Sometimes new science will be needed, while at other times the greatest need is for translating and interpreting existing knowledge to make it more accessible and useful to policy and management. Effective decision support addresses not only decision makers' expressed concerns and needs, but also the potential concerns they, or affected parties, might raise if they had more knowledge, understanding, and capacity to participate.

Communication

Communication services include facilitating dialogue about the issues of concern, framing the problem, translating and visualizing existing knowledge, and interpreting it for different audiences. What is needed at any one time depends on the phase of the decision, the people involved, and their needs and current understanding of the issues at hand.

Communication research shows that generally, communication is more effective when targeted to specific rather than generic audiences and when it includes specific information about vulnerabilities and alternative response options (e.g., Turner et al., 1979; Key, 1986; Bolton and Orians, 1992; Moser and Dilling, 2007). Including multiple information sources can help reach multiple audiences, since different groups trust different sources (e.g., Key, 1986). Different information sources and formats are perceived differently by different audiences in terms of their relevance, clarity, certainty, and trustworthiness, and so are differentially effective (e.g., Turner et al., 1986; Vaughan and Nordenstam, 1991; Lindell and Perry, 1992; Mileti and Fitzpatrick, 1993; Vaughan, 1995; Gutteling and Weigman, 1996; Mitchell et al., 2006). Perceptions of irrelevance, inconsistency, confusion, or doubt can delay action.

Awareness of a climate-related hazard does not necessarily lead to specific risk-averse decisions and behavior (e.g., Drabek, 1986; Slovic, 1989, 2000; Redman, Spencer, and Sanson-Fisher, 1990; Weinstein and Nicolich, 1993; Lindell and Perry, 2004; Folke et al., 2005). Decision makers are more likely to act to reduce vulnerability if they perceive the need for, and appropriateness of, such measures through processes of discovery that are informed by expert knowledge, not externally imposed (Mileti, 1999).

BOX 2-3
Initiating and Changing Decision Support Relationships

In principle, there are at least four ways to open communication channels between scientists and decision makers for decision support. They may be used sequentially or selectively (National Research Council, 2008d):

(1) Informal conversations initiated by scientists, decision makers, sponsoring agencies or boundary organizations. Informal consultations help by identifying potential ways to meet information needs with existing or new information and by building essential relationships and trust.

(2) Formal needs assessments through surveys and semi-structured interviews, conducted by personnel of existing decision support teams, independent third parties, or agencies interested in sponsoring decision support (e.g., Moser and Tribbia 2006/2007; Tribbia and Moser, 2008; Corringham et al., 2008). Such assessments produce insight into what information decision makers currently use, how is it used, what rules and regulations govern its use, and what real or potential barriers exist to changing existing procedures (e.g., Rayner, Ingram, and Lach, 2005), as well as insight into what additional information would be useful.

(3) Workshops that bring together a range of scientific experts with individuals, organizations, or existing networks of potential users of climate-related information to identify climate-related issues that are important to a sector, region, or community, characterize the range of information needs, and determine to what extent existing information can provide that information or new scientific research is needed. Such workshops can be done periodically to reassess changing information needs.

(4) Small-scale pilot projects that create or enhance knowledge-action networks and test decision support in a climate-affected sector or region (see Georgakakos et al., 2005, for a description of the INFORM project testing alternative management procedures and information inputs in California water reservoir operations; see also the water planning exercise described in Box 4-2).

These initial modes of contact serve the purpose of *mutual* education, not just information elicitation from one side of the knowledge-action continuum. Effective facilitation of any of these processes can be essential in establishing good working relationships, developing useful insights, and engendering a spirit of curiosity and collaboration. They also make clear which decision support services are most needed initially.

Decision support collaborations change over time and, if well designed for learning, develop increasingly effective mechanisms and practices for engagement. Common, overlapping phases of growth can be distinguished. In the initial phase, decision support teams select and integrate researchers across disciplines, define a few key issue areas, develop cooperative relationships with constituencies, and start accumulating relevant knowledge bases, methodologies, and datasets. Later, teams clarify critical issues, learn more about decision problems, identify key vulnerabilities, and begin to produce integrated assessments and other decision-relevant information. When teams have established functional networks, communication processes, and norms for integration, they can produce information and knowledge products and tools of practical utility. Teams then have greater capacity to engage in more open and cross-sectoral dialogues and projects (Lemos and Morehouse, 2005; Pulwarty, Simpson, and Nierenberg, 2009).

Thus, effective public health and hazards-related decision support strategies often do not direct audiences to take specific actions; rather, they offer risk-related information that responds to public questions and concern, then offer clear decision options with associated costs and benefits (Morgan and Henrion, 1990; Nathe, 2000; Mileti, 2003). This approach allows decision makers to develop a sense of ownership of an issue and process and manage their own learning, mobilization, and action in full concert with the learning, mobilization, and action of important peers or stakeholders (Evans and Stoddart, 1994; Patrick and Wickizer, 1995; Mileti and Peek, 2002).

Risk-related information is not always understood in the ways its purveyors intend. For instance, there are well-known biases in humans' understandings of risk information, as well as difficulties in the communication process (e.g., Turner, Nigg, and Paz, 1986; Vaughan and Nordenstam, 1991; Lindell and Perry, 1992; Mileti and Fitzpatrick, 1993; Vaughan, 1995; Gutteling and Weigman, 1996; National Research Council, 2006a; Moser and Dilling, 2007). Messages that emphasize the negative potential of hazards without advising on practical responses can increase public apathy, avoidance, and denial (e.g., Lopes, 1992; Moser, 2007b). In contrast, conveying a sense of personal efficacy and realistic avenues to reducing risk and vulnerability makes action more likely (Rogers, 1983; Weinstein and Sandman, 1992; Mulilis and Duval, 1995; Vaughan, 1995; Gardner and Stern, 1996; Lindell and Whitney, 2000). Effective decision support activities have to address these challenges in producing relevant information, making it available through mediated and direct communication channels, and fostering its appropriate interpretation and use.

Communication research shows that information is most effectively delivered when repeated in clear, consistent, and incremental messages over time; when it includes honest articulation of uncertainties; and when it is made easily available through multiple channels and formats, including mediated, print, and personal contacts (Sorensen, 1983; Bolton and Orians, 1992; Mileti and Fitzpatrick, 1994; Nathe et al., 1999; Nathe, 2000; National Research Council, 2006a). Disseminating strategic and coordinated messages requires close communications and planning across knowledge-action networks.

Unidirectional communications—such as through the mass media—can help to raise public awareness of an issue and influence attitudes and beliefs, but interpersonal contacts are typically necessary to effect changes in human behavior (Lazarsfeld et al., 1948; Eulau, 1980; Hornik, 1989; Redman, Spencer, and Sanson-Fisher, 1990; Valente et al., 1996; Campbell et al., 2000; Dunwoody, 2007). Social relationships filter, screen, interpret, and validate the messages and information that people receive. Even if awareness increases, human attitudes can be deeply entrenched and so deter action (Katz, 1960; Rogers, 1983; Turner et al., 1986; Mileti, 1999; Ajzen, 1991). Peer approval and social norms can strongly influence behavior when outcomes are uncertain, as is often the case in climate change-related contexts (McCay and Acheson, 1987; Valente and Saba, 1998; Schultz, 2002). These findings add further weight to the central importance of social and professional networks in communicating decision-relevant information.

Decision support systems can build on these findings when providing specific communication services. For example, because facts do not have unambiguous meanings and action implications, it is important to frame messages in ways that connect with the concerns of the audiences. Expertise in science writing and visual communication can help in connecting with audiences. Visual presentations can be very powerful aids, although they are vulnerable to manipulation (see Sheppard, 2005). Visual presentation of climate-related phenomena deserves further research as a tool for decision support. "Road shows" involving repeated, yet slightly varied delivery of presentations to different audiences can be important for reaching and maintaining the knowledge base of all affected groups, even if time consuming and unattractive to some scientists. The need for extensive outreach to various groups illustrates the advantages of a team-based approach in which responsibilities are shared and in which dedicated staff support the preparation of outreach materials and are responsible for maintaining communication networks.

Finally, both public and private forums for dialogue among scientists, decision makers, and other parties can provide important decision support services. The right formats for such forums depend on the intended goal (Forester, 1999; Rowe and Frewer, 2000; Creighton, 2005; National Research Council, 2008c). The uncertainties and high stakes involved in some climate-related decisions place particular demands on communication. Decision makers' understandings of climate-related uncertainties are affected by their experiences, perceptions, capacities, and interests, as well as their familiarity with concepts of uncertainty and risk (Carbone and Dow, 2005; National Research Council, 2006a; Pulwarty, Simpson, and Nierenberg, 2009).

Mediation and Brokerage

In some instances, the most important decision support service is to establish or "broker" the connection between existing information and those whose decisions may be improved by it. Brokering can involve convening decision makers and stakeholders and helping them to identify and clarify their respective interests and goals, negotiate decision criteria, and determine acceptable outcomes (e.g., Cash et al., 2003; Kramer and Wells, 2005; Richardson, 2005). As decision makers may want information that science cannot provide, an important decision support service is to help match what they want with what science can deliver for specified timetables. Such mediation helps mobilize science for decision support while helping its credibility with decision makers. According to Cash et al. (2003:8,088), mediation works "by enhancing the legitimacy of the process through increasing transparency, bringing all perspectives to the table, providing rules of conduct, and establishing criteria for decision making."

Some RISA centers and other boundary organizations make this sort of decision support their primary service. Establishing trust among participants is essential to success, as is the trust and "credibility that comes through long-term, sustained engagement" (McNie, Pielke, and Sarewitz, 2007:16). The likelihood of success also increases if researchers and practitioners have a sense of shared responsibility for their interaction and for the use of knowledge in decision making and both sides are fully aware of the larger systems of power and knowledge in which they function (van Kerkhoff and Lebel, 2006).

Brokering also involves overcoming various cognitive, institutional, and political barriers to information use. It is especially difficult for decision makers to modify policies and decisions in light of new scientific information when the potential consequences are significant, uncertainty is high, experience is limited, or equity issues are a principal concern. In such situations, decision makers need assistance in the critical consideration and assessment of different knowledge claims and the practical integration of information in decision processes. Getting decision makers to pay active and considered attention to the policy implications of new information may require deliberative involvement in decision forums by scientists or boundary organizations (Jacobs, Garfin, and Lenart, 2005; Lemos and Morehouse, 2005; Pulwarty, Simpson, and Nierenberg, 2009). It may require research teams to acquire new skill sets or to involve individuals with experience in this set of decision support services, and it may call on decision makers to take more risks, rely more heavily on personal judgment, or operate more iteratively (Jacobs, Garfin, and Lenart, 2005).

Research to Generate Decision-Relevant Information

When decision makers begin to think about the relevance of climate change to their decisions, they may ask scientific questions that scientists have not yet investigated. An important decision service is to answer some of these questions through what has been called use-inspired research (Stokes, 1997). Such research may be focused on a very specific question, such as how to design an appliance energy efficiency label to convey its information most effectively, or on a much more basic research question, such as how to measure the vulnerability of communities to sea-level rise. Use-inspired research typically responds to the questions of decision makers or stakeholders, but is designed and carried out by scientists, sometimes incorporating specific "local knowledge" from nonscientists; it is vetted for its scientific quality through peer review and for its usefulness and salience by decision makers.

Use-inspired research questions sometimes arise from formal or informal needs assessments that explore the concerns, responsibilities, and decisions of climate-affected individuals or groups. Needs assessments may involve narrowly or broadly focused stakeholder engagement processes, which require experience and expertise in participatory processes to be conducted effectively (e.g., Rowe and Frewer, 2000; Kasemir et al., 2003; Stringer et al., 2006; Newig, 2007; National Research Council, 2008c). At other times, research questions arise from integrative assessments that draw on a wide range of data and findings from many sources to help identify important decision-related knowledge gaps (Pulwarty, Simpson, and Nierenberg, 2009; also see Appendix A). They may also arise from scientific reviews that focus on research needs for decision making (e.g., National Research Council, 2005a; Stern and Wilbanks, 2008). This sort of research often requires contributions from multiple disciplines to most usefully inform decisions.

User-driven questions have led to advances in basic scientific understanding. An often cited example is the work the Climate Impacts Group (the Pacific Northwest RISA center at the University of Washington-Seattle) undertook in response to resource managers' desire to better understand the link between salmon fishery management and climate variability. The research led to the discovery of the Pacific Decadal Oscillation and opened a line of research that both informed decisions and generated basic scientific advances. Given the complexity of the climate and the Earth system, it is extremely likely that use-inspired questions will continue to require basic research in many fields of environmental, ecological, social, economic, and physical science, and in engineering. We discuss the link between decision support needs and scientific research in detail in Chapter 4.

Decision Structuring

An overwhelming emphasis on climate modeling and information products has drawn attention away from an extensive body of relevant knowledge from the decision sciences that shows that poor decisions come not just from a lack of good technical information (e.g., Kahneman et al., 1982; Kahneman and Tversky, 2000; Plous, 1993; Simon, 1956; Slovic et al., 1977; Tversky and Kahneman, 1981). In addition, judgment varies with how information is presented and with contextual and experiential cues that are available to people during the decision-making process (Arvai et al., 2006b; Payne et al., 1992; Slovic, 1995; Slovic and Lichtenstein, 2006).

Given these potential problems, getting the best available knowledge and making it accessible to decision makers and other affected groups may not be sufficient. It may also be necessary to organize decision processes so that the most relevant science will be done and so that it can be interpreted coherently and constructively (National Research Council, 1996a). Decision structuring is therefore an important decision support service.

Recent analytic and behavioral research on decision making provides much-needed guidance on how to structure decisions about responses to climate change. This work emphasizes qualitative discussions about how climate change might affect the operations of a particular system or about the feasibility and likely results of various possible responses to climate change (some recent studies include Arvai, Gregory, and McDaniels, 2001; Gregory, Arvai, and McDaniels, 2001; Gregory, McDaniels, and Fields, 2001; McDaniels, Gregory, and Fields, 1999; Edwards, Miles, and von Winterfeldt, 2007). These discussions have five basic elements:

1. Defining the boundaries of the problem: What is the question being addressed? What factors are included and excluded from consideration?
2. Defining the objectives: What is trying to be achieved? What would constitute success for all involved?
3. Laying out the alternative options: What alternatives are available to achieve the objectives?
4. Estimating the consequences of each alternative option by certain criteria: What can be expected to happen if a given option is adopted? What is unknown about each course of action? How will the expected outcomes match the objectives?
5. Evaluating the tradeoffs among the options: What may be gained and lost by choosing one option over another?

Specialists draw on insights from the decision sciences to help inform and guide decision processes through these elements, with ongoing input from decision makers and stakeholders. Discussions may lead to calls for research on specific options and their consequences. For example, research on relationships among policy regimes and goals (e.g., interactions between the U.N. Framework Convention on Climate Change and the Montreal Protocol or the Biodiversity Convention; integration of sustainability, millennium development goals, and climate change) may provide critical input into the design of new or modified international agreements. Decision structuring, by providing more thorough consideration of the parts of a decision problem, can result in greater clarity about a problem and affect the ways decision participants see it and its possible solutions. Framing and clarifying decisions can also build and mobilize some constituencies and disenfranchise others. These effects may be difficult to discern, especially immediately, but may have a lasting impact on the decision environment (Birkland, 2005; Mitchell et al., 2006).[1]

Evaluation

Any continuing decision support effort has to respond to changing demands, decision environments, and scientific knowledge. Some decision support providers assist in conducting explicit assessments of how well the effort is doing; others may involve less formal evaluations. Thus, a final set of decision support services concerns evaluation of the systems' own internal workings and external effects (deliberate learning and evaluation are discussed further in Chapter 3). In the past, formal evaluations have not commonly been undertaken as part of decision support efforts, but they are increasingly recognized as an important element of deliberate efforts to improve decision support services. For example, the RISA Program was at first experimental, in the sense that different RISA teams developed activities at different scales and engaged with constituents through different decision venues, organizational structures, and mechanisms. A handful of evaluative activities and publications on these experiments have produced a small literature on lessons learned. They also have identified "evaluation" as maybe the most prominent gap in RISA activities to date (e.g., Lemos and Morehouse, 2005; McNie, Pielke, and Sarewitz, 2007; McNie, 2008; Pulwarty, Simpson, and Nierenberg, 2009).

Most of the available evidence on the results from the RISA centers takes the form of experience-based judgments by RISA funders, staffs, and users. Some of the users' judgments have been strongly positive, and the positive judgments appear to be associated with recognition that the programs have followed principles of effective decision support, particularly beginning with users' needs and linking information producers and users. For example, the Western Governors' Association passed a resolution in May 2007 to "give a high priority to funding for federal programs, such as the RISAs that provide the translation function between basic scientific re-

[1]Some decision researchers have demonstrated that in a range of difficult decision contexts, nonscientists and their organizations use fairly simple cognitive heuristics quite effectively to arrive at decisions (e.g., Gigerenzer and Selten, 2001; Zsambok and Klein, 1997; Hodgkinson and Starbuck, 2008). We are not persuaded that this skill will apply well to climate-related decisions for the foreseeable future because of certain characteristics of climate change: It involves events outside anyone's experience, proceeds at an accelerating rate, evolves on a very long time horizon, and has consequences that are uncertain not only in magnitude but also in kind. The most obvious simple heuristics, such as relying on past experience and climate averages, are more likely to be misleading than helpful as bases for estimating the consequences of possible actions. Of course, the efficacy of simple heuristics is an empirical question. We return to this issue in Chapter 4.

search on climate variability and change and the application of that research to real-world water management situations at the regional, *state,* and local levels" (see http://www.westgov.org/wswc/050407%20risa%20resolution.pdf; emphasis in original).

One reason formal evaluation is often neglected may be that program goals, which must be measurable to make formal evaluation possible, are not often articulated clearly enough for measurement, especially at the outset. Resources (e.g., funding, staff time, and evaluation expertise) are also scarce. Finally, weak evaluation results can increase a program's vulnerability to budget cuts and staff reallocations (Jacobs, Garfin, and Lenart, 2005; Pulwarty, Simpson, and Nierenberg, 2009).

Evaluation is a challenge when the ultimate results of a decision are not obvious or are delayed (e.g., Global Environmental Assessment Project, 1997; Parson, 2003; Lemos and Morehouse, 2005; Pulwarty, Simpson, and Nierenberg, 2009). Moreover, some dimensions of "effectiveness" are difficult to assess, and different evaluators will judge effectiveness from different perspectives and by different criteria (Jacobs, Garfin, and Lenart, 2005; National Research Council, 2006b; Pulwarty, Simpson, and Nierenberg, 2009). It is critical but difficult for evaluation to assess candidly the partnership between scientists and decision makers and the quality of relationships. Sometimes, the greatest value of evaluation is not to provide the equivalent of a final grade, but to elicit qualitative feedback (Jacobs, Garfin, and Lenart, 2005) that can be shared with those involved in order to enhance transparency and legitimacy, build trust, and foster the ongoing collaboration. In short, evaluation may be most useful as part of a learning process, to facilitate the evolution of decision support efforts and inform leaders about how to promote needed change (Lemos and Morehouse, 2005; McNie, Pielke, and Sarewitz, 2007; Pulwarty, Simpson, and Nierenberg, 2009). In Chapter 3, we discuss the role of evaluation in learning in greater detail.

BARRIERS TO EFFECTIVE DECISION SUPPORT

The scientists and practitioners who interact with each other around climate decisions do so outside the boundaries of familiar disciplinary, institutional, and professional expectations, and occasionally at considerable personal and professional expense. Working through boundary organizations may reduce some of these costs, but that can involve its own challenges and resource commitments (Cash et al., 2003; Sarewitz, 2004). Successful interactions between scientists and decision makers face persistent institutional, organizational, and cultural barriers. We turn here to a discussion of these barriers and then to some strategies to overcome them.

Resistances to Change

In Chapter 1 we note several aspects of climate change that are challenging for decision making, including the difficulty of seeing climate change signals against a background of variability, the need to consider risks from potentially unprecedented events, the long time horizon before these events may arise, and the deep uncertainties associated with forecasts and projections of climate change. These attributes of climate change provide multiple justifications for inaction, such as attributing climate-related events to variability rather than change or waiting for unequivocal evidence of climate change or scientific unanimity. People can readily use these justifications to postpone the search for decision support and discount information that might require a change of practices. In addition, well-funded interests have long engaged in concerted efforts to bolster the justifications for inaction by disputing scientific evidence of climate change, its current impacts, and its likely consequences. The results in the United States have included relatively weak and slow public policy responses to climate change and a focus of the climate science agenda on demonstrating with very high confidence that climate change is happening and is anthropogenic to the exclusion of efforts to find the best ways to reduce the risks of climate change or to inform responses to those risks. The legacy of these efforts can be seen in some of the other barriers to decision support listed below.

Institutional and Legal (Structural) Barriers

Institutions and organizations and their associated formal and informal norms and rules impose powerful constraints on the interaction between researchers and decision makers. These constraints reflect professional performance standards, job descriptions, promotion criteria, ethical norms of conduct, contractual obligations, administrative procedures, decision protocols and schedules, and legal requirements for inclusion or exclusion of certain considerations (e.g., National Research Council, 2006b; Moser, 2006a). For example, scientific information about an area's vulnerability to storm damage, if it is collected with a pledge of confidentiality, may become publicly available only if there is a legal showing that the public interest in the information outweighs the loss to property owners who face decreased values of their holdings due to climate-related risk. As already noted, collaboration among agencies can be impeded by different enabling laws, opposing missions, or incompatible budgetary rules. As claimed in the National Research Council (2006b:15) report, for many federal agencies, "the federal research support system is geared more toward knowledge generation than problem solving." Such barriers—whether formalized or implicit—

can lead to disconnects, conflicts, and turf battles rather than productive cooperation.

As we also note in Chapter 1, few decision-making organizations are well matched to the long time scales and the multiple spatial dimensions of climate change. For example, there are very few organizations that are tasked to take responsibility for the consequences of their actions decades or centuries in the future or that can act at the levels of ecosystems or the Earth system. These mismatches bring into focus questions about how to effectively link institutional mechanisms established at one level to policy frameworks at another (e.g., the emerging regional and national cap-and-trade systems vis-à-vis an effective global climate treaty), how to establish mechanisms for enforcement at all levels, and how to link policy instruments across levels of organization and across time. These misfits between problem and response create disincentives to act and therefore to seek and use relevant decision support.

Organizational and Cultural Barriers

Organizations, and the people in them, are slow to change. Past practices, disciplinary and agency perspectives, and organizational cultures and the norms and rules that underlie them are remarkably resistant to change. Rapidly evolving and emerging decision contexts are set against a backdrop of organizational inertia, presenting a challenge to any efforts to improve decisions. Decision support practitioners need to constantly assess the "fit" between situational realities and decision processes. They also need to consider organizational styles, norms, priorities, and expectations; priorities regarding whose insights and interests are considered important; and attitudes about science, all of which can resist change.

Cultural barriers, reflecting differences in such organizational characteristics, exist between organizations in academia, in the policy and business worlds, and among these worlds. Box 2-4 presents a concrete example of these kinds of barriers. It is not uncommon for scientists to give "standard" scientific talks to resource managers, apparently and incorrectly assuming that the decision makers will absorb the information they need and make logical, science-based decisions. When this happens, science and scientists have failed to cross the threshold of salience, learning is thwarted, and stereotypes are reinforced that practitioners do not care about science and that scientists pursue their own interests without regard to practical concerns. Most decision makers must focus on solving today's or tomorrow's problems, and they pay much less attention to long-term issues, the focus of most climate research, unless they are strongly linked to near-term decisions.

BOX 2-4
Barriers to Effective Decision Support: The Case of the Florida Everglades

Resource management is organized around efficient exploitation or protection of a resource, while science is organized around producing valid knowledge of the natural and social worlds. Although there is no conflict between these missions, and effective resource management in fact depends on sound science, each produces demands on the other that require mutual understanding, learning, and a willingness to adjust efforts and attitudes in order to connect science and management effectively. Efforts to restore the Florida Everglades illustrate the challenges of overcoming the persistent tensions between the organizational cultures of resource management and environmental science.

In response to complaints from resource managers about the irrelevance of research to their information needs, science managers at the U.S. Geological Survey (USGS) made a concerted effort to meet with Fish and Wildlife Service and National Park Service leaders to identify science information that would be useful in their decisions. What resulted was a list of short-term, tactical issues that required very short-term tactical scientific approaches that were not consistent with most research programs in the USGS. The needs of the managers were real and important, but the scientific work and human resources needed to meet them were not readily available without changes that seemed likely to weaken the future quality of needed science (Mitchell et al., 2006). For example, although decision makers need timely information, scientific observations cannot be rushed, and there may be too few historical observations to provide a clear indication of long-term trends. Although scientists are cautious in expressing judgments in the absence of statistically reliable data, managers must address urgent issues and meet deadlines, and need informed judgment even, or especially, when conclusive findings are not available. The need to act on the best information available, however imperfect, underlines the importance of decision structuring and facilitation as elements of decision support.

The Science Impact Program at the USGS, designed to increase the use of science in decision-making, encountered challenges on several levels within the organization. Some research scientists and science managers questioned the value of time-consuming meetings that mixed scientific and other issues, concluded that agency managers were uninterested in the main scientific issues, and resisted redirecting some of their scientific objectives to meet more tactical needs and taking on decision support functions. The USGS has nevertheless made significant efforts to increase the relevance of its science to resource and environmental management issues and the awareness of decision makers of the availability of information developed by USGS research and monitoring programs. Although there has been progress, the need remains to better understand how the agency can best inform decision makers.

Omissions in Professional Training and Education

Most climate and environmental experts still do not receive adequate training, mentoring, or incentives for working across disciplines, across issue areas, or at the science-practice interface (except for some communications training). They are typically unaware of the lessons learned by those examining such transdisciplinary interactions and are often hesitant to get involved with policy and decision makers (e.g., Hartz and Chappell, 1997; Moser, 2006b; The Royal Society, 2006). Similarly, policy makers do not receive adequate training prior to or in the course of their professional careers in climate and related social and environmental sciences. In some instances, there are also challenges from constraints in hiring practices and lack of interest in or incentives to innovate (National Research Council, 2006b). In light of the rapidly changing climate and policy contexts, these omissions in professional education and training will lead to a situation where human resource constraints seriously undermine the nation's ability to respond to the rapidly growing demand for climate-related decision support.

Time Constraints Versus Urgency

Ideally, decision support efforts are anticipatory and forward looking, ahead of needs. Reality is far from that ideal. The key problems include ever-changing decision needs, lack of needed knowledge, and changing scientific understandings of what was previously not known or thought to be well understood. For example, the rapid melting of the great ice sheets is leading to fundamental shifts in glaciology. With global climate rapidly moving into uncharted territory, many decisions will need to be made without well-established scientific input. This growing urgency stands against the fact that collaborative relationships require careful building and long-term maintenance (Jacobs, Garfin, and Lenart, 2005; Lemos and Morehouse, 2005; McNie, Pielke, and Sarewitz, 2007; Pulwarty, Simpson, and Nierenberg, 2009). Meanwhile, specific decisions may require information on very short notice, on specified schedules, or for time horizons and spatial scales that science is unable to deliver (Carbone and Dow, 2005; Cash et al., 2006; Jacobs, Garfin, and Lenart, 2005; Lemos and Morehouse, 2005; McNie, Pielke, and Sarewitz, 2007; Corringham et al., 2008).

Lack of Funding and Other Resources

Shortages of funding for all kinds of science are frequently bemoaned. However, the situation for climate-related decision support is arguably more extreme than most. With the growing demand for decision support comes increased demand for answers for scientific questions that were never a major part of federally supported research on climate change. (We discuss this point in more detail in Chapter 4.) In addition, needs for decision support and stakeholder engagement activities, which include the implementation and monitoring of decision outcomes, will only become more pressing as the consequences of climate change become more evident. More funding and better use of existing funding and resources are needed to enhance training in decision support skills; to support relatively neglected, but much needed scientific inquiries (see Chapter 4); to establish additional decision support institutions and equip them adequately; and to advance formal evaluation of decision support activities.

Funding barriers can also be critical for decision makers. For example, to overcome institutional separation, improve the sharing of information, and enhance collaboration, government agencies and other organizations may decide to form interdepartmental, interagency, or multi-institutional working groups. In addition to the other barriers mentioned here, these coordinating mechanisms may be constrained from innovating or may not even receive basic financial support (National Research Council, 2006b, 2007b).

STRATEGIES TO OVERCOME BARRIERS

Several strategies for overcoming the above barriers logically emerge from the foregoing discussion.

Leadership

Leadership and effective organizational management by top-level individuals in government institutions and in business, as well as at all other levels, is necessary to effectively overcome the deeply engrained barriers to effective decision support and to carry out the daily work of decision support: define scopes of work, maintain project momentum, attend to administrative tasks, initiate efforts to bridge decision-research gaps, maintain independence and integrity, and sustain internal and external relationships. Leadership is also needed to overcome barriers to change and initiate innovative practices. At a time when "business as usual" is over for the world's climate, for traditional decision-making processes, and for science (see Chapter 1), leadership will be indispensible, even if its value and importance are often unrecognized or underestimated in academia and even in some decision-making organizations (Carbone and Dow, 2005; Jacobs, Garfin, and Lenart, 2005; Lemos and Morehouse, 2005; Clark and Holliday, 2006; McNie, Pielke, and Sarewitz, 2007; Pulwarty, Simpson, and Nierenberg, 2009).

Mandates

Mandates to provide information, outreach, technical support, and extension services can create an institutional environment in academia that pushes science outside the ivory tower. Similarly, policy mandates that require decision makers to consider relevant climate and related science in planning or implementation contexts create an information demand that brings practitioners to experts. For example, a 2006 California law that established the goals of reducing the state's greenhouse gas emissions to 1990 levels by 2020 and to 80 percent below that by 2050 has created an enormous demand for technical information to create reliable greenhouse gas inventories; establish practical yet verifiable accounting systems; implement technological, market, and behavioral strategies to reduce emissions; and estimate costs and possible savings for each option. A 2008 California law requires disclosures of greenhouse gas emissions in the state environmental review process and thereby creates a new information need for regulatory agencies and regulated entities, some of whom may supply this information for themselves.

Business can be affected both by such new laws and by shareholder resolutions that require that certain types of scientific or technical information or concerns be considered in long-term planning and investment decisions. Legal requirements can also have a powerful impact in forging channels of communication, exchange, and collaboration.

Mandates are powerful, but they may be insufficient by themselves. Mandates are more likely to be effective when they are aligned with job expectations and reward systems and are supported with adequate funding, staffing, and training to enable individuals to carry out new mandated responsibilities.

Institutional Changes and Institution Building

If scientists and decision makers are to change familiar patterns of professional behavior, they must have incentives to do so (e.g., professional recognition), protection from disincentives to work at the science-practice interface, and overt support (e.g., training, support staff, other resources). Often clear institutional changes in the rules of conduct, job descriptions, and agency missions are needed.

To foster greater cross-disciplinary and cross-organizational integration, intellectual, attitudinal, and institutional changes may be necessary. For example, organizations might be more easily engaged in decision support if they are organized around decision problems rather than disciplines or issues. Making the needed linkages and supporting the needed communication and interaction across the usual divides requires more integrative and holistic perspectives and management approaches. Doing so will not only affect scientific analyses and management choices; it will also broaden the circle of stakeholders.

Sometimes integration is more easily achieved with a regional focus that includes attention to connections across scale, sectors, governance mechanisms, and issues. One advantage of such a focus is that regional specificity of knowledge products can engender greater constituent support and interest, long-term engagement, credibility, and acceptance (Jacobs, Garfin, and Lenart, 2005; Carbone and Dow, 2005; Corringham et al., 2008, Pulwarty, Simpson, and Nierenberg, 2009). Experience with decision support efforts in climate, agriculture, fisheries, coastal management, public health, and hazards suggests that creating, strengthening, and promoting institutions that provide decision support for regions or sectors not only helps overcome organizational barriers, but can also stimulate awareness of, and interest in obtaining, information to support decisions. Moving from informal to more formal institutional arrangements for decision support can help gain visibility, name recognition, stature, and legitimacy for decision support efforts.

When interactions between scientists and decision makers are not yet established or the decision context is highly contentious, it may be useful to draw on boundary organizations to facilitate the exchange and collaboration across the science-practice divide. Getting researchers and decision makers to agree to work with and through a boundary organization, and establishing trust in this collaboration, may take time; however, successful boundary organizations lower the transaction costs of working at the science-practice interface.

Funding for Decision Support

A careful assessment of financial needs, expenditures, and impacts may help redirect available funds toward effective decision support. Funding is essential for interactive processes in the decision support system, for decision support services, for decision support products, and for supportive research. Chapter 4 elaborates on these funding needs for specific types of information that has been relatively neglected. As funding insecurities from one budget cycle to the next can be detrimental to the process of establishing ongoing science-practice relationships, possibilities for creative financing over longer periods with local partners can be explored.

Training, Education, and Exchange of Experiences

To speed the development of the nation's decision support capacity (see also Chapter 4), training, internships, and information exchange among decision support providers and guidance and support from a concerted national decision support effort will be indispensible. To achieve efficiencies and greater effectiveness, it could be useful to draw on capacity in areas heretofore unconnected to climate and to promote closer connections and information exchange across regional decision support teams (Lemos and Morehouse, 2005; Pulwarty, Simpson, and Nierenberg, 2009). Linking networks of extension agents, public health service providers, and hazards managers, as well as other networks of relevant professionals (e.g., planners, engineers, educators), could further extend and rapidly build national decision support capacity. A national clearinghouse of decision support activities in the public and private sectors will further speed up the learning.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion 3: The most effective decision support efforts are organized around six principles: begin with users' needs; give priority to processes over products; link information producers and users; build connections across disciplines and organizations; seek institutional stability; and design processes for learning.

Following these principles improves the likelihood of achieving the three main objectives of decision support: increased usefulness of information, improved relationships between knowledge producers and users, and better decisions. Decision support systems promote these objectives by engaging in activities and providing services related to communication, mediation and brokerage, and research and observation to produce decision-relevant information, decision structuring, and evaluation. Some decision support efforts, including some of NOAA's RISA centers, are already striving to implement the principles of effective decision support in the climate response context and fulfill the main functions of decision support programs. These and other promising efforts serve as viable working models for new and broader programs.

Recommendation 1: Government agencies at all levels and other organizations, including in the scientific community, should organize their decision support efforts around six principles of effective decision support: (1) begin with users' needs; (2) give priority to process over products; (3) link information producers and users; (4) build connections across disciplines and organizations; (5) seek institutional stability; and (6) design for learning.

Recommendation 2: Federal agencies should develop or expand decision support systems needed by the climate-affected regions, sectors, and constituencies they serve.

- **The National Oceanic and Atmospheric Administration (NOAA) should expand its Regional Integrated Sciences and Assessments (RISA) Program and Sectoral Applications Research Program (SARP) centers to serve the full range of regions and sectors of the nation where NOAA has natural constituencies.**
- **The Environmental Protection Agency (EPA) should expand its climate-related decision support programs to serve more regional and sectoral constituencies.**
- **Other federal agencies should take similar steps for their climate-affected constituencies.**
- **The federal government should selectively support state and local governments and nongovernmental organizations to expand their efforts to provide effective decision support to their climate-affected constituencies.**

In developing new decision support activities or expanding programs to serve new constituencies, a useful way to begin is with dialogues about decisions that affect or are affected by climate change (see National Research Council, 2008d). Such dialogues can be organized for constituencies defined regionally, in terms of an affected sector or decision type, or in terms of a policy development that requires new responses. The dialogues should function to identify major climate-affected decisions facing the constituency; identify information needed to inform the decisions, and advise the sponsoring agencies about priorities for research and information development. Dialogues might focus initially on near-term decisions with long-term consequences that climate change will affect, such as investments in physical infrastructure and adoption of planning and development policies.

Dialogues should include agency officials, relevant decision-making authorities, scientists, other sources of decision-relevant information, and individuals and organizations that might serve as effective communication links between information providers and users. Dialogues should be designed to continue over time and to identify new climate-related decision issues as they emerge. Dialogues already established under NOAA's RISA and SARP Programs, and dialogues begun as part of the 2001 National Assessment of the Consequences of Climate Change, can serve as models for how dialogues could be organized. The Aspen Institute, another example, conducts its meetings and seminars as moderated dialogues using small group settings in which participants from various backgrounds and perspectives learn from each other through an interactive discussion of specific readings. Successful dialogues might develop into pilot programs and eventually into networks or formal organizations linking information providers and users.

Federal agencies can begin their efforts to develop decision support systems for their constituencies by adopting the mechanisms identified in Box 2-3 (above), building from initial dialogues, needs assessments, or workshops to pilot projects and then to larger or more permanent activities as judged appropriate, roughly as has been advised for NOAA's SARP activity (National Research Council, 2008d). The national decision support initiative we propose (described in Chapter 5) would include a program of grants to nonfederal groups, both governmental and nongovernmental, to initiate development of climate-related decision support systems for their constituencies, following a similar developmental process beginning with dialogues, workshops, or needs assessments and moving to pilot projects and beyond. Such a program would allow for innovative efforts, including web-based communication networks and centralized or interactive information systems for particular constituencies; coordination of networks; and public–private partnerships. Applicants would be asked to demonstrate that their activities would provide new, needed, and more useful climate information to an identified constituency; contribute to the development of lasting decision support networks or other institutions; and, for pilot projects, have a likelihood of becoming self-supporting.

3

Decision Support and Learning

A changing climate presents two major challenges to decision makers and to those who provide decision support. As discussed in Chapter 1, some decisions and decision-making routines will need to change to reflect the changing climate. Also, since climate change and its interactions with society are dynamic, the rules for making those decisions will need to continue to change over time. That is, decision makers must not only change, but be prepared to continue changing. In a sense, decision makers will need to plan to be surprised.

The systems that support climate-related decisions must become adaptive systems, learning through a variety of means. Some decision support systems are already adapting in this manner. For example, the climate decision support system for New York City has evolved as scientists, government officials, and activists develop working relationships to tackle some problems and transform their understanding of the situation they face; see Appendix A.

This chapter first addresses the challenges of learning in the context of climate-related decision support. We next consider four modes of learning and explain why one, which we call deliberation with analysis, is the most appropriate for meeting the challenges of response to climate change. We then recommend ways that the federal government can apply this mode of learning in its own decision support activities and facilitate decision makers around the country in making adaptive responses to climate change and learning from their own and others' experiences.

CHALLENGES

Climate change and many other environmentally related policy problems are members of a class of "wicked problems" (Rittel and Webber, 1973)—problems with no definite formulation and no clear point at which the problem is solved. They have been described as having five key characteristics (see Dietz and Stern, 1998):

1. Multidimensionality: A single environmental process or policy can have many different types of effects, distributed unevenly so that those affected face unequal shares of the costs, risks, and benefits.
2. Scientific uncertainty: Current understanding is primitive in comparison with what decision makers want to know—and sometimes the degree of uncertainty is itself uncertain. In addition, the consequences unfold at an unfamiliar tempo, with some effects delayed and others disconcertingly prompt.
3. Value conflict and uncertainty: People differ in the importance they attach to the different effects of any action, and these judgments change as people experience how their own and others' actions affect the things they value.
4. Mistrust: Decision makers are often mistrusted by those their decisions affect; their analyses are also often mistrusted.
5. Urgency: It is not feasible to postpone action until scientific uncertainties are resolved.

In addition to these characteristics, climate change presents a dynamic decision context and unfolds over a time scale that extends beyond the planning horizons of most organizations and over a geographic scale that exceeds their control.

Learning by doing under such conditions creates challenges for leadership. Although it makes sense to treat all decisions as provisional, such an approach is not easily reconciled with conventional notions of accountability. Decision makers will have to discard well-accepted standard procedures that offer them a kind of protection in favor of new ones that may be more effective, but that will open them to criticism when, inevitably, errors occur. Another challenge is that most climate change decisions will be undertaken in a decentralized fashion, as local and state governments, firms, and other institutions respond to a changing climate.

Thus, the federal role in decision support will have to be aimed at creating and informing a *distributed* capacity to make sensible choices. This is both functionally necessary and advantageous to the nation as a whole, since decentralized decision making will generally be better able to cope with surprises and specific local conditions. Nevertheless, federal agencies should also be prepared to address issues that arise repeatedly in multiple localities or sectors and might therefore benefit from national-level attention.

LEARNING MODES

The panel examined four kinds of learning in organizations in terms of their suitability for meeting these challenges. As Table 3-1 indicates, these four modes of learning span a range of assumptions about the context and processes of decision making. We analyze the modes of learning in relation to the main challenges of decision support in a changing climate.

1. *Unplanned learning* is a default mode: actions are undertaken without any explicit consideration of learning, and any change that occurs is unplanned and often unbidden.
2. *Program evaluation* involves formal assessment, often by outside parties, of a program's effectiveness, with the expectation that adjustments will be made in response.
3. In *adaptive management,* actions are designed as experiments so that they will perturb the decision environment and thereby generate information useful for future adjustment and improvement.
4. *Deliberation with analysis* is an iterative process that begins with the many participants to a decision working together to define its objectives and other parameters, working with experts to generate and interpret decision-relevant information, and then revisiting the objectives and choices based on that information.

Each mode of learning offers different strengths and weaknesses, and there is insufficient evidence to draw definitive conclusions about which mode is best for which situation. Nonetheless, the panel judges that deliberation with analysis provides the learning mode best suited to a wide range of climate-related decision support applications. We note, however, that deliberation with analysis is not easily implemented. The rest of this section discusses each mode of learning.

Unplanned Learning

As has long been recognized by researchers (e.g., Cyert and March, 1963; Lindblom, 1959; Kingdon, 1984), much learning in organizations is unplanned. An organization may respond to events as they occur, but it devotes little attention or resources to making the learning process more effective. Unplanned learning may be attractive because it imposes no immediate costs in staff time and financial resources. It also weakens ac-

TABLE 3-1 Modes of Learning

	LEARNING MODES			
Characteristics	**Unplanned**	**Program Evaluation**	**Adaptive Management**	**Deliberation with Analysis**
Assumed decision environment	Stable	Stable	Changing	Changing
Assumed decision maker	Unitary	Unitary	Unitary	Diverse
Goals	Implicit	Set by decision maker Stable	Set by decision maker Stable	Emerge from collaboration Potentially changing
Data for learning	Unsystemic	Explicit indicators Evaluation at end	Explicit indicators Continual monitoring	Explicit indicators Continual monitoring
Means of appraisal	Ad hoc	Formal assessment Usually summative	Formal or informal Continuing	Formal assessment with deliberation on its import Continuing
Incorporation of learning	Unplanned	Adjust after evaluation complete	Continual	Continual

countability and makes shortcomings and errors hard to identify. Such attractions are understandable in a decision environment that makes errors likely. (Unplanned learning is not the same as deliberate trial and error or adaptive management, described below.)

However, the underlying assumptions of unplanned learning—that the decision environment is stable and the decision maker is unitary—do not fit at all well with the decision environment created by climate change. With no systematic attempt to make goals explicit or monitor performance, an organization may persist in ineffectual activities and fail to respond effectively to change. Eventually, there are likely to be failures that are large and readily apparent.

Program Evaluation

Program evaluation has become a well-established field of applied social science and professional practice, as well as the most familiar means of formal learning in large organizations (see, e.g., Russ-Eft and Preskill, 2001; Chelimsky and Shadish, 1997; Shadish et al., 1995; Weiss, 1972, 1998). As defined by Mark et al. (2000:vii), evaluation helps people, individually and collectively, make sense of policies and programs "by providing systematic information about such things as the outcomes or valued effects of a social program, the cause of program success or failure, and the degree to which policy directives are being followed."

To learn from program evaluation, decision makers need to identify explicit goals for a program, develop indicators of performance towards those goals, and gather data on the indicators. Evaluators compare post-program indicators with preprogram measures or with a scenario or situation in which the program was not adopted and an alternative course of action or no action was implemented (Newig, 2007; Rowe and Frewer, 2000, 2004). Program evaluation for climate-related decision support might make assessments at some designated end point or at each stage of the policy process. In either case, the evaluation might lead to adjustments in the budget, staffing, or other aspects of the program.

Standard program evaluation presumes a stable decision environment and clear, stable goals. It has value for assessing climate-related decision support, although there are practical challenges: diverse participants in the decision may have different goals, and processes as well as outputs require evaluation (Moser, in press). If a decision support effort aims to help reduce vulnerability to drought of a county's agriculture, outcome measures for the underlying components of vulnerability, such as exposure, sensitivity, and coping capacity or resilience, are required (e.g., Adger, 2006; Cutter, 1996; Luers et al., 2003; Schröter, Polsky, and Patt, 2005; Turner et al., 2003). If a goal of decision support is to change decision makers' understandings of the importance of climate change to their operations, program evaluation must assess the content and quality of dialogue, the types of questions asked, and the level of concern and interest, since all of these may be relevant indicators. Such processes and outcomes may be measured in many ways (see Morgan et al., 2005; Moser, 2005b; Shackley and Deanwood, 2002; Tribbia and Moser, 2008).

Program evaluation has proven valuable for strengthening accountability in government programs. It can be an effective framework for supporting learning and improvement in programs, particularly when a program's goals can be clearly defined, there is a single decision maker (or organization) with clear responsibility and authority to achieve those goals, and a relatively unambiguous connection can be made between observable data and the organization's progress toward those goals. Unfortunately, the conditions for good program evaluation do not characterize many applications of climate-related decision support. Climate-related decision support may often occur in novel, poorly understood, and changing circumstances, with multiple decision makers pursuing multiple goals. Moreover, the connection between measurable indicators and an organization's progress towards goals may remain ambiguous and a subject of contention among the parties to the decision. Conventional program evaluation offers no means to resolve such ambiguities, although a practice of "developmental evaluation" (Patton, 1994, 2007) is gaining adherents. Developmental evaluation puts the evaluator into a role of facilitating the process that we call deliberation with analysis (see below).

Adaptive Management

Adaptive management is a mode of learning intended for situations in which decision makers have a poor a priori understanding of the connection between their actions and their goals and therefore have much to gain if they learn by doing (Holling, 1978, 1996; Ludwig, 1996; Walters, 1986). A central argument of adaptive management theory is that learning from policies uncovers uncertainties and improves managers' ability over time to respond to inevitable environmental, social, or economic surprises. Adaptive management theory calls for policy interventions to be treated explicitly as experiments: carefully planned and monitored with replication and comparison of management treatments (or lack of treatments) at appropriate spatial and temporal scales. Rather than presuming that managers make one-time decisions on the basis of the best existing knowledge, adaptive management regards policy choices for complex environmental problems as part of a carefully planned, iterative, and sequential series that emphasizes monitoring and learning as the system changes, both in response to external stimuli and in response to managers' actions (Walters, 1986). Adaptive management differs from conventional management models in its explicit emphasis on iteration.

Adaptive management embraces potential failures as data that provide opportunities for learning and the basis for better future decisions. For obvious reasons, however, this double-edged sword of "successful failures" has served as an institutional, political, and emotional barrier to the implementation of adaptive management (Lee, 1993, 1999).

Adaptive management presumes that a policy intervention, such as decision support, operates in a changing environment and that it might perturb that environment. In this respect, it is well suited to the decision environments presented by climate change. However, few adaptive management efforts have approached the ideal of iterated policy experimentation. It is difficult in practice to provide a control case in which a policy intervention that was believed to be beneficial was withheld. Local political interests often prevent the adoption or implementation of ideal experimental designs, for example, because of reluctance to accept the role of control group.

Moreover, because of the cost of complex experimental designs, the strong practical incentives against documenting failure, which lead to a tendency to design implementations that do not have adequate statistical power, make it difficult to be sure whether the policy made a difference.

In climate-related decision support, adaptive management may be difficult to implement because goals are diverse, outcomes delayed or hard to measure, and the relationships needed to manage the experiment are fragile. Gregory et al. (2006) thus suggest that adaptive management be adopted cautiously. They identify four clusters of conditions under which they hypothesize that those involved are likely to find it useful:

1. Spatial and temporal scale: Adaptive management is most easily implemented on relatively small scales that allow for management control.
2. Dimensions of uncertainty: Adaptive management is more likely to be considered worth the cost if, given the uncertainties in the process and the time available for learning, an experimental approach can produce results that are clearly interpretable to decision makers.
3. Costs, benefits, risks: Adaptive management designs are more likely to be considered useful if they include rules for stopping and changing course which can keep the risks to all stakeholders at an acceptable level.
4. Institutional support: Adaptive management is more likely to be accepted if the participating institutions and affected groups have good leadership, the capacity to design and execute adaptive management, and the flexibility to learn, adjust, and avoid unacceptable tradeoffs.

Given all the conditions that must be met, explicit experimentation is rarely practical in climate change applications. The field thus distinguishes active adaptive management, in which policy actions are explicitly designed to help generate learning as well as achieve program goals, from passive adaptive management, in which information collection is explicitly designed to improve the prospects of reliable inference from observing the effects of policy actions taken solely to achieve program goals.

Arvai et al. (2006a) have argued that passive adaptive management is an important element of the decision support provided by the Intergovernmental Panel on Climate Change (IPCC). Many different management actions are now being undertaken globally by the multitude of sovereign political actors, private organizations, and institutions responding to changing climates. Spatial variations in economic, social, and climatic conditions and in policies provide the potential for a database with variation on multiple decision-relevant factors. Although these activities have developed unintentionally, they can provide an important source of observational data for climate policy that could be the basis for an intentional, international effort to learn.

Ongoing decision support efforts can generate a similarly useful database for learning how to make decision support more effective. However, the necessary information network does not exist to track, measure, monitor, and interpret the results of those experiences—especially with geographically dispersed and vulnerable groups. For adaptive learning, it is important that decision support initiatives have resources for data collection and to develop new understandings from the experiences.

Adaptive management (passive or active) can be a powerful tool for learning. The conceptual apparatus is well developed, together with specific ideas about implementing an adaptive approach (see Margolis and Salafsky, 1998). These ideas have been adopted by several international nongovernmental organizations working on biodiversity conservation (see http://www.conservationmeasures.org/CMP/).

Although progress in these areas is promising, in many cases adaptive management may prove difficult for climate-related decision support, because of the institutional setting of decision making. As shown in Table 3-1, the approach assumes stable goals set by a unitary decision maker that endure for the life of the experiment. Leaders also need to understand the experimental paradigm and to sustain a commitment to experimentation as the learning process unfolds. These conditions are demanding.

Deliberation with Analysis

The modes of learning discussed above do not take into account two key attributes of the climate-sensitive decision makers needing decision support—that decision environments (climatic and societal conditions and the state of knowledge) change over time and that decisions must consider multiple actors with different objectives and partly conflicting values. Deliberation with analysis addresses these attributes explicitly and, for this reason, we believe it provides the best model for learning in climate-related decision support, though one that still needs further development and research.

This model was developed in an earlier National Research Council (1996b) study of decision support in the broad context of environmental risks: *Understanding Risk: Informing Decisions in a Democratic Society*. The study described a learning process that begins with a broadly based effort involving the range of interested and affected parties to formulate the decision problem (e.g., the risk to be assessed and managed) and to identify the values and interests at stake, so that the likelihood or extent of harm to the system, as well as its various consequences, can be measured or predicted. In this initial deliberation, decision participants interact with technical experts and analysts to develop a shared understanding of the issues at stake, of what needs to be understood and how scientific research and assessment and the interpretation of available knowledge are likely to feed into decision making. On the basis of such deliberation, analysts can develop knowledge and information that are likely to be used in further decision-focused deliberations (National Research Council, 1996b).

A subsequent National Research Council report (2008c:234) reviewed evidence from multiple sources and concluded that across a broad range of environmental assessment and decision-making contexts, including the 2001 U.S. National Assessment of Climate Change, such "collaborative, broadly based, integrated, and iterative analytic-deliberative processes" provide the method of choice for organizing scientific analysis to serve public decision making. The report also stressed that because of variations in decision contexts, it could not recommend any standard "best practice" way of implementing the model to be applied regardless of the situation. Rather it recommended (National Research Council, 2008c:237):

> [a] "best process regime consisting of four elements: (1) diagnosis of the context to identify likely difficulties; (2) collaborative choice of techniques to address those difficulties; (3) monitoring of the process to see how well it is working; and (4) iteration, including changes in tools and techniques if needed, to overcome difficulties.

In short, it recommended that deliberation with analysis be implemented in different ways in different contexts and structured to learn from its own experience.

We, too, conclude that this kind of iterative, analytic-deliberative process is better suited than other modes of learning to the sorts of changing decision contexts that climate change will present. How well it will work in practice in its various implementations is, of course, an empirical question—one to which techniques of program evaluation could usefully be applied.

As the complexity and uncertainty surrounding a risk to be managed increase, so, too, does the degree to which the process of deliberation with analysis becomes iterative. It might proceed through several successive rounds of deliberation by the parties involved and analysis by technical experts on the way to a risk management decision and in reconsidering the decision once implemented (National Research Council, 1996b, 2008c). Each round of analysis and deliberation can yield clearer understanding of the parties' objectives and of the effects of actions taken. In this sense, the process synthesizes information from assessments of both risks and management actions and thereby informs ongoing decision-making processes.

The deliberation with analysis mode of learning resembles program evaluation and adaptive management, but with two important differences. First, the substantive goals of decision support, unlike those of program evaluation, are adopted only provisionally, with an explicit commitment from all parties to reconsider them in light of deliberation about what decision support is useful and affordable. The provisional character of the substantive goals resembles adaptive management, although the choice of goals is the result of deliberation rather than a scientific process of hypothesis testing.

Second, deliberation with analysis emphasizes wide participation in order to generate a consensus among affected parties on what information is needed for decision support, even if not on how to weigh this information. This open process aims to enhance the ability of the organization sponsoring the decision support activity to implement any decisions reached and sustains the ability to continue to deliberate (National Research Council, 2008c).

As shown in Table 3-1, the deliberation with analysis approach aims to address situations with a multiplicity of participants, evolving goals, and fluidity in both the natural and social environments. Thus, it presumes a qualitatively different situation than the ones envisioned in conventional program evaluation or adaptive management in which a single decision maker is assumed. As noted above, responding to climate change often involves parties with different perspectives, including both the typical differences between scientists and decision makers and the divergent values and interests among the decision makers. As the effects of a changing climate become apparent, the already wide diversity of objectives among affected parties may well increase. Climate change is likely to continue to create the kinds of tensions over decisions and decision support for which deliberation with analysis was developed.

Deliberation with analysis has one other possible advantage in the context of climate risks. It provides a process that might deal effectively with the great cognitive difficulties of comprehending risks that involve many possible outcomes, over long time periods, and with uncertain probabilities of occurring. Decision analytic tools may help decision makers comprehend such risks, but they may also generate confusion. Similarly, nonspecialists' modes of cognition may lead to useful simplifications or to confidently held misunderstandings. A process that allows scientists and decision makers to discuss their understandings has the potential to identify and address such problems. Whether or how analytic-deliberative processes can be designed to produce this kind of benefit is a subject for empirical study.

Finally, deliberation with analysis acknowledges the need for iterative learning when climate responses and climate-related decision support can both produce surprising outcomes—an approach that has been described by organization theorists as "double-loop" learning (Argyris and Schon, 1978); see Box 3-1.

Deliberation with analysis is iterative, and that means that it may not lead quickly to convergence on an answer or action. The learning process

BOX 3-1
Double-Loop Learning

Effective response to climate change may require transformations in existing management practices, technologies, and organizational structures. The organizational analysts Argyris and Schon (1978) pointed out a generation ago that an organization embodies a model of reality—a simplified representation of the situation it faces, embodied in its operating procedures. That model is tested against reality every day. Often, experience produces surprises.

Some of those surprises fit with the implicit theory of the organization; for example, when a water management agency faces a drought by calling for conservation measures, and then steps up the urgency of its appeals to reduce demand until the rains resume. Making responses that reaffirm the basic model built into an organization is a pattern of adaptation that Argyris and Schon called "single-loop learning." The organization can learn because the problem is recognized, a solution is implemented, and it works—a feedback loop in action.

Sometimes, however, solving a novel problem may require steps outside the organization's model. A severe drought may prompt proposals to reuse water from treated sewage, for example, engendering conflict that threatens the water agency's budget or leadership. Finding responses to novel problems is what Argyris and Schon dubbed "double-loop learning": Adoption of those responses requires an organization to revise not only its practice but also its operating theory, its rules and culture. There are two feedback loops needed in facing such problems: one to overcome existing commitments and one to develop and adopt a response to the problem. Double-loop learning is a change process, often a wrenching one. A changing climate is likely to produce many situations requiring double-loop learning.

can sharpen conflicts among participants by clarifying who wins and who loses if particular choices are made. In addition, the analytic process often increases rather than decreases perceived uncertainty, as more precise questions lead to more detailed and elaborate information about what is not known. In these ways, learning can raise the cost of decision making and delay the formation of consensus or consent.

The deliberation with analysis model as developed in 1996 strongly emphasized broad public participation as a way to achieve an actionable understanding of the choices facing a decision-making body—in other words, as a part of decision support. More recently, a set of principles has been identified for effective public participation in environmental decision making (National Research Council, 2008c); see Box 3-2. Many of these prin-

BOX 3-2
Lessons for Decision Support from the Study of Public Participation

When government agencies engage in public participation, they should do so with

- clarity of purpose,
- a commitment to use the process to inform their actions,
- adequate funding and staff,
- appropriate timing in relation to decisions,
- a focus on implementation, and
- a commitment to self-assessment and learning from experience.

Process design should be guided by four principles:

1. inclusiveness of participation,
2. collaborative problem formulation and process design,
3. transparency of the process, and
4. good-faith communication.

These elements of design are appropriate to all participatory processes, although the way they are implemented will vary across contexts. There is no single best format or set of procedures for achieving good outcomes in all situations.

Decisions with substantial scientific content should be supported with collaborative, broadly based, integrated, and iterative analytic-deliberative processes (i.e., deliberation with analysis). In designing such processes, the responsible agencies can benefit from following five key principles for effectively melding scientific analysis and public participation:

1. Ensure transparency of decision-relevant information and analysis.
2. Pay explicit attention to both facts and values.
3. Promote explicitness about assumptions and uncertainties.
4. Include independent review of official analyses and/or engage in a process of collaborative inquiry with interested and affected parties.
5. Allow for iteration to reconsider past conclusions on the basis of new information.

SOURCE: National Research Council (2008c:2–3).

ciples echo those discussed in Chapter 2. The 2008 study emphasizes that difficulties in implementing the principles often arise in specific contexts and that these difficulties have to be addressed in a process suited to the situation. The study recommends (National Research Council 2008c:237):

practitioners, working with the responsible agency and the participants, should adopt a best-process regime consisting of four elements: diagnosis of the context to identify likely difficulties; collaborative choice of techniques to address those difficulties; monitoring of the process to see how well it is working; and iteration, including changes in tools and techniques if needed to overcome difficulties.

Deliberation with analysis has several implications for climate-related decision support. First, the responsible agencies need to take public participation seriously in their decision support activities, putting in resources and, more importantly, being ready to learn from and to listen to affected parties. The intensity of engagement with the public should be tailored to the level of public attention and anticipated conflict. Agencies need to establish expectations about how they will use public input in ways that are consistent with their legal authorities and responsibilities (National Research Council, 2008c). In some situations, they may need to modify their usual procedures to make it possible to use public input.

Second, inclusiveness matters. The implications of a changing climate are becoming apparent to constituencies ranging from agriculture to tourism to local governments, and their responses are still taking shape. New groups, such as professional societies and public health agencies, are becoming participants in decision support, joining those, such as water resource managers, who have long used products from climate forecasters. As more decision makers recognize the need for decision support, they are likely to need novel information in new forms. Agencies need to work with the emerging constituencies and assist other organizations conducting their own climate decisions support.

Third, transparency of content matters. Information for climate-related decision support is often derived from models whose workings are often incomplete and nonintuitive; uncertain in terms of the location, time, and magnitude of forecast events; and difficult for nonspecialists to understand. Transparency, particularly to new constituencies, accordingly requires deliberate two-way communication and interpretation of science.

Fourth, the legitimacy of science relies on its transparency, both to peer experts and the public. Independent peer review of scientific content can provide an important measure of credibility and legitimacy by creating a mechanism to counteract bias, correct error, and reveal the range of competent scientific judgment. Since formal external review is a costly process, its use is sensibly limited to situations where the content is likely to be both salient and controversial. Part of the learning that is needed includes a better sense of when to use independent reviews or other approaches to identify error, bias, and conflicting judgments.

Fifth and most challenging, there is a need to learn and to adapt the way that decision support is provided, based on the experience gained through implementation. Public participation shares two characteristics with program evaluation. Both subject the practices of government agencies to scrutiny that can be uncomfortable, and both can alter agency staffs' initial sense of how best to pursue their missions. These frictions are also signs of learning. What needs to be learned, over time, is how to temper internal judgment with the knowledge that comes from taking the public seriously. This is double-loop learning.

Meeting the conditions for effective implementation of deliberation with analysis presents significant challenges. These challenges have been successfully met in many contexts, but decision makers will have to learn how to meet them in the new dynamic decision environments climate change will present. Dedicated research on this problem will help practitioners develop effective modes of organizational learning for climate-related decision support.

Conclusion 4: Climate-related decision making, especially by public agencies, typically involves multiple participants with varied and changing objectives interacting with uncertain and evolving knowledge. The most appropriate mode of learning under such conditions combines deliberation with analysis. This mode is also quite demanding in its needs for leadership and other resources.

Recommendation 3: Federal agencies in their own decision support activities and in fostering decision support by others should use the approach of deliberation with analysis when feasible. This is the process most likely to encourage the emergence of good climate-related decisions over time. The federal government should also fund research on decision support efforts that combine deliberation with analysis and that use other appropriate learning models, with the aim of improving decision support for a changing climate.

FEDERAL ROLES IN FACILITATING LEARNING

The federal government can contribute to adaptive learning in response to climate change in three ways: designing its own decision support activities for learning; encouraging nonfederal decision makers to take climate change into account in various ways; and providing support to enable those decision makers to learn more effectively from their own and others' efforts to respond to climate change.

It is important to emphasize that the national response to climate change will be widely distributed and will involve literally millions of decision makers. Thus, it will be important to provide distributed intelligence about the vulnerabilities and opportunities of decision makers and about the potential value of different decision support activities (Lempert, 2007). Doing this is likely to increase the pace of learning and lower its social cost.

Distributed intelligence can take many forms. For example, it can involve information clearinghouses, monitoring systems, and advisory bodies, organized for long-term consistency and to help translate varying experiences into useful guidance for new decisions. Arvai et al. (2006a) suggest that the IPCC holds considerable promise as a reporting body for assessing the wide range of experiments that have occurred around the world if the IPCC and the Secretariat of the U.N. Framework Convention on Climate Change could be strengthened to provide concrete guidance on methods and approaches for adaptation and management. Internet-based mechanisms such as blogs, Wikis, and user-based reporting systems may also help provide distributed intelligence on decision support innovations.

The rest of this section illustrates some of the strategies the federal government might use to facilitate adaptation and learning by others: supporting the diffusion of innovations, using price and quality signals to guide consumer behavior, and supporting networks and boundary organizations; see Table 3-2.

Supporting the Diffusion of Innovations

Since the nineteenth century, the federal government has provided decision support by fostering the adoption of new technologies and practices, notably in agriculture. An extensive research literature on the diffusion of innovations (Rogers, 2003) offers useful lessons for climate change decision support. The classic example is federal support for the diffusion of agricultural innovations through the land-grant university system, established under the Morrill Act of 1862.

Diffusion processes usually begin with innovators outside the federal government, and innovations usually spread by example, though sometimes by persuasion. The federal government can facilitate this process in at least three ways: by supporting the development of innovations (e.g., in the agricultural example, by funding research that produces new crop varieties), by encouraging initial adoption (e.g., by having extension agents work with farmers who are willing to try the new seeds), and by helping spread information about successful innovations. This process reflects the panel's approach for climate change decision support in that it is user oriented, with ultimate choices determined by those who use the innovation on the basis of information about it.

The federal government can help generate innovations in decision sup-

TABLE 3-2 Federal Roles in Promoting Learning

Opportunity for Decentralized Learning	Goal	Federal Roles	Principles of Effective Decision Support
Diffusion of innovation	Adoption of practices or products, particularly in production	Sponsoring invention Promoting diffusion Supporting internet-based information exchanges	User oriented Rely on networks of communication
Market signals	Guide consumption choices	Create markets Support and implement certification and labeling Create scarcity through regulatory controls	Affect user choices Use marketing channels and tools, such as advertising Flexible in the sense that prices adjust
Networks	Promote solving of organizational problems hindering responses to changing climate	Participate in some networks Fund some network functions in important problem areas	Users populate networks and drive cross-sector and multidisciplinary problem solving Flexible and adaptable, though network may be ephemeral

port in serving its agencies' own constituencies and by supporting innovative approaches to decision support for constituencies that cannot obtain it without federal support. Federal agencies have done this: One example is the Regional Integrated Sciences and Assessments (RISA) centers supported by the National Oceanic and Atmospheric Administration and through efforts to develop new information to meet the needs of specific sectors (see Box 4-1 in Chapter 4). Boundary organizations such as the RISA centers can promote the use of innovative decision support products by "early adopters" and, by linking decision makers to the early adopters, help spread useful decision support innovations. Research on diffusion demonstrates that direct contact with peers and peer organizations is critical to diffusion and plays a role complementary to scientific expertise (Rogers, 2003).

In addition to directly supporting boundary organizations that help diffuse decision support innovations, federal agencies can help move these innovations into nonfederal networks that can provide a durable institutional structure. For example, some engineering and consulting firms that serve the water management sector are now starting to incorporate federally developed climate change information into their portfolio of specialized services. Such private-sector entities will likely rely on technical support and data from federal agencies, similar to the way the National Weather Service provides meteorological data and expertise that mass media and private firms use to develop services and information for users. Federal agencies could also support organizations that produce and maintain Internet-based information exchanges such as blogs, Wikis, and user-based rating and reporting systems for decision support efforts. Such exchanges should be subjected to research that monitors the ways information on the sites is understood and used and the quality control processes used on the sites.

Financial Incentives as Stimuli for Learning

Changes in markets, especially in the relative prices of fossil fuels and their alternatives, are important for the mitigation of climate change. Federal government policies—such as cap-and-trade or taxation systems for greenhouse gas emissions—can be forms of decision support in that they send signals to consumers about likely future prices, which are likely to influence decisions. Financial incentives, such as tax credits for renewable energy development, similarly send signals to investors and energy producers. Both kinds of signals induce change toward actions with smaller effects on climate than would otherwise be the case.

Of course, price signals alone are so limited as a form of communication that they hardly qualify as decision support. Prices do not directly foster understanding of the wider implications of a changing climate, and they provide little information on which behavioral changes are most efficacious. This is notably the case with household consumers, many of whom appear to harbor systematic misconceptions about how best to reduce energy consumption (Kempton et al., 1985; Gardner and Stern, 2008). Prices are therefore most useful for decision support when combined with other policy instruments, including providing more conventional forms of information (e.g., Gardner and Stern, 1996; Stern, 1986).

Required Labeling and Certification

Regulations can be used to require the provision of some forms of decision support. This approach is illustrated by the Energy Star Program of the Environmental Protection Agency, the organic food label requirements of the U.S. Department of Agriculture, and by many voluntary certification approaches for sustainably caught fish (see Highleyman et al., 2004), sustainably harvested wood (see Conroy, 2007), and "green" buildings (see http://www.usgbc.org/; also see Cole et al., 2005). Certified products may then carry a label that assures buyers that the product was produced in compliance with the certification process. Labels ideally condense complex information about the consequences of a choice into a simple signal. Voluntary certification has been called private regulation (Bartley, 2007) because government does not directly modify the behavior of economic actors. In a globalizing economy, the potential for labeling to influence behavior across national boundaries is noteworthy.

Credible labels often require complex auditing and verification systems built on analyses, standards, and practices that can reach from initial production to retailer (Cole et al., 2005). Information provided by government sources is essential to both voluntary and government-sponsored labeling and certification efforts, as is technical support for advancing assessment methods, such as life-cycle analysis. These are essential elements of decision support.

Labeling and certification can meet a user's need for simple guidance in consumption choices, and are accordingly useful for organizing large-scale social responses, especially by households and other small actors. Certification processes tend to be multidisciplinary and need to be well enough institutionalized for labeled products to gain significant market share. Relatively little is yet known about how to make labeling systems flexible and capable of continuous improvement and learning. There is accordingly a need for research to illuminate and to strengthen this significant form of decision support.

Networks and Boundary Organizations

As Chapter 2 discusses, networks and boundary organizations can play essential roles in decision support. We focus here on their relevance to learning to improve decision support and on what the federal government can do to make them more effective for this purpose.

Network relationships have grown in importance in knowledge-intensive activities, such as public administration and service industries, in which novel problems or opportunities arise that are outside the experience or craft of the professionals in the organization. Networks provide ways to tap experience in other organizations. They are typically user focused and flexible, as well as capable of crossing organizational and disciplinary lines.

Responses to climate change can benefit greatly from good networks: Networks can facilitate decision makers' access to sophisticated knowledge and information drawn from science, engineering, law, and other professions, as well as to each other's experiences. The federal government can play an important supporting role in facilitating the networks necessary for climate change decision support by helping reduce the costs of communication and coordination. And federal agencies can also benefit from networks for their own decision support activities. A more effectively networked government can respond more fluently to the multifaceted manifestations of changing climate. Interagency teams can work quickly across the mandates of different government departments without waiting for organizational changes in those departments. Federal agencies can also benefit from participating in and sometimes supporting networks and boundary organizations that reach beyond the federal government to state and local government, the private sector, and civil society.

Federal financial support for networks, particularly those serving constituencies with limited resources, has several important benefits. As the long-term relationships built through the RISA centers illustrate, networks that link federally supported researchers with users of the knowledge they produce increase the utility of federally sponsored research on climate phenomena and facilitate deliberation informed by analysis. Among the kinds of capabilities likely to be cost-effective are support for convening network participants for face-to-face meetings, such as regional conferences, funding a webmaster for a weblog, providing space on an internet server, and providing start-up funds for networks that might be able to develop nonfederal support for their continued activity once members recognize their value.

However, the continuation of a network depends on members' seeing concrete returns on their participation. As with other innovations, some networks will fail to meet this test. Thus, decision support networks should be designed in the expectation that they may be ephemeral.

Conclusion 5: An important role of the federal government in climate-related decision support is to facilitate the development and improvement of decision support systems by nonfederal entities.

Recommendation 4: Federal agencies and other entities that provide decision support should monitor changes in science, policy, and climate-related events, including changes outside the United States, that are likely to alter the demand and opportunities for effective decision support. Knowledge of such changes will help them to learn and improve more rapidly.

Recommendation 5: Federal agencies should promote learning by supporting decision support networks to share lessons and technical capabilities. This may include support for expanding the capacity of boundary organizations and distributed entities for learning, such as internet sites. The federal investment should be selective and guided by the reality that networks operate satisfactorily only when their members see concrete benefits from participation.

We conclude by suggesting that the federal government fund studies of social networking, boundary organizations, and other mechanisms that enable deliberation with analysis on climate-related response options among public- and private-sector organizations; build on models such as the RISA centers to expand the body of practical experience in using networks and boundary organizations to address the issues of climate change; and work with philanthropies and other nongovernmental organizations to develop innovative ways of coordinating networks and supporting boundary organizations to provide distributed mechanisms for learning to provide climate-related decision support.

4

Information Needs for Decision Support

The goal of the U.S. Global Change Research Act (USGCRA) of 1990 is to "assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change." This language makes it clear that the intent of the act is to foster both fundamental scientific investigations on global change and applied research designed to support appropriate responses to it. For climate change, the latter covers a range of mitigation and adaptation responses.

Providing decision support to those who are in charge of the responses is essential for carrying out the purposes of the act, and to provide a scientific basis for this support, the nation needs to develop the science of climate change *response*, as a complement to the science of climate change *processes*. Understanding the physical dimensions of climate is a necessary but not sufficient condition for supporting climate change responses. Also needed are contributions from a wide range of disciplines including behavioral and social science disciplines that are not currently well represented in scientific programs on climate and its impacts.

Chapters 2 and 3 address the process aspects of developing scientific support for climate-affected decisions. An important principle developed there is that decision support processes should take priority over information products, because unless attention is paid to process issues, particularly two-way communication between the likely producers and users of information for decision support, the products that are generated are unlikely to address decision makers' needs. Of course, information content is also critical for sound decision making. Decision support processes need to yield understanding of what decision makers' key information needs are and to lead to the development of information that is capable of supporting high-quality decisions.

This chapter focuses on information needs for decision support, seen from the perspectives of decision makers. It emphasizes the need for research *for* decision support—that is, research that provides various types of decision-relevant information not currently provided by U.S. climate science programs—and basic and applied research *on* decision support. It highlights challenges associated with providing use-relevant data across spatial and temporal scales and across sectors, along with ways of overcoming those challenges. Short case studies are used throughout to illustrate information needs and approaches that are successfully engaging decision makers at local and regional scales.

INFORMATION FOR DECISIONS

Individuals and organizations facing climate-sensitive decisions are not often concerned with climate change *per se*, but rather with how it may affect their responsibilities, commitments, and priorities. Thus, information for climate-related decision support must be salient to their priorities, or it is unlikely to be helpful.

It follows that decision support strategies should be built on an understanding of decision makers' values and priorities, as well as the constraints under which they operate. As highlighted in Chapter 2, this type of understanding is best developed through interaction between the decision makers and those who would inform them. Users' needs are diverse and their data and information requirements are similarly diverse. In particular, they need information matched to the spatial and temporal scales of their agencies or organizations and concerning climate parameters that are meaningful to them; for an example, see Box 4-1.

The types of information required for climate responses are many and varied, ranging from climate data to data on affected populations and ecosystems. Agencies and organizations that are responsible for responding to extreme climate events need to know what types of events to prepare for and the likely occurrence of such events as well as the potential effects on human populations, economic activity, and built and natural systems. Understanding these effects in turn requires knowledge about population characteristics, current and future settlement patterns, social vulnerability, trends within national, regional, and local economies, and ecological variables.

Information is required for a wide range of potential mitigation and adaptation strategies. Mitigation decisions may center on ways of reducing greenhouse gas emissions, decreasing atmospheric greenhouse gas concentrations, and changing land cover. On the adaptation side, decisions focus

BOX 4-1
The Pileus Project

The Pileus Project, conducted by researchers at Michigan State University, began as part of the U.S. National Assessment/Great Lakes Regional Assessment, with funding from the U.S. Environmental Protection Agency. Its objectives were to identify, with stakeholder assistance, the influence of climate on Michigan agriculture and tourism industries; create models to quantify the impacts of past and projected climate variability and change; and develop decision-support tools for climate-related risk management.

The project focused on one agricultural product—tart cherries, a crop that is extremely vulnerable to temperature extremes and also very important to Michigan's agricultural economy and to the nation, since Michigan provides more than 70 percent of the U.S. supply. Stakeholders provided input on assessment goals, identified information needs, provided expertise and data, and evaluated the decision support tools developed by the project. A suite of web-based tools was developed that included a historical climate tool, downscaled precipitation scenarios, a future scenarios tool, and tools to aid decision makers with respect to their future crop investments (see http://www.pileus.msu.edu/agriculture/tc_tools.htm). The Pileus Project officially ended in August 2007, but work continues with support from the National Science Foundation's Human and Social Dynamics Program.

The discussions with stakeholders revealed specific kinds of information they wanted—for example, the expected date of the last spring frost—that was not available from existing climate models. A key lesson of the project was that addressing decision makers' needs frequently requires the development of new forms of data.

SOURCE: Presentation by Jeffrey Andresen and Julie Winkler, Department of Geography, Michigan State University; available at http://www.pileus.msu.edu/.

on reducing the climate-related vulnerability of human systems and activities, improving the ability to respond to damage caused by extreme climate events, and encouraging people to take the future impacts of climate change into consideration in their own decision making. Decision makers also face choices with respect to the design and implementation of institutions and policies to enhance both mitigation and adaptation activities.

Those kinds of decisions require information about climate, but they also require a wide range of other types of information. Mitigation strategies designed to reduce greenhouse gas emissions from motor vehicles, for example, may need information on the most effective incentives for automobile manufacturers and purchasers, on appropriate urban design approaches, and on how to combine incentives, regulations, and information into effective policies. Also important are public opinion data on environmental concern and attitudes about fuel-efficient vehicles. Decisions regarding changes in agricultural practices depend on detailed information on how climate change affects growing seasons and crops—the kind of information sought by Pileus Project investigators—along with knowledge concerning both more robust and alternative crops. Decisions on infrastructure improvements for flood protection require information from sources as diverse as civil and structural engineering, infrastructure life-cycle analysis, environmental impact assessment, demography, public finance, and law.

Example: Natural Hazards Loss Estimation

Experience with natural hazards illustrates how diverse information sources are often needed for decision support. Hazard impact and loss modeling uses data on characteristics of the natural and built environment, provided by environmental scientists, engineers, and community building and planning departments; data on populations at risk, provided by demographers, geographers, urban planners, and other social scientists; algorithms developed by modelers; and data on direct and indirect economic and social effects, provided by economists, public health researchers, and other social scientists.

The hazard-related decision support software tool that is most widely used in U.S. communities is HAZUS-MH (Hazards United States, Multi-Hazard Version), which was developed by the National Institute of Building Sciences with funding from the Federal Emergency Management Agency. HAZUS tools and modules enable users to anticipate the physical, social, and economic effects of earthquakes, floods, and wind hazard events, including building damage, earthquake-induced fires, lifeline failures, the hardest hit geographical areas and population groups, direct losses, indirect economic losses, and the size of populations displaced by such events. Geographic Information Systems (GIS) provide an integrating platform for simultaneously analyzing different information inputs. HAZUS findings can be used to support decisions related to land use, building codes, evacuation planning, disaster response, and predisaster planning for postdisaster recovery (for more information, see http://www.hazus.org).

HAZUS was developed with federal government funding primarily for use by public entities, but private firms also engage in extensive modeling efforts, particularly for use by insurers and reinsurers. Some of these firms have moved into modeling the impacts of terrorist events and large-scale catastrophes and are now focusing their modeling efforts on the climate-related events.

Hazard loss modeling provides several lessons that have implications for the development of climate change decision support strategies and tools.

First, successful models seek to assist diverse decision makers by answering a wide range of questions, such as:

- In the next hurricane, how soon must evacuation orders be issued, when might evacuation routes become blocked by flooding, and what segments of the population will need evacuation assistance?
- How many residents will require shelter after a disaster, for how long, and what can be expected in terms of the demographic composition and needs of shelter populations?
- How much will a particular utility lose or save over the next 30 years by mitigating earthquake hazards in a high-hazard—or lower-hazard—region?
- In the next earthquake, how many people are likely to die and how many will require hospitalization?
- What is the magnitude of a particular insurance company's portfolio risk for wind hazards, both globally and in particular regions?

Second, modeling efforts are inherently multidisciplinary. For example, most California decision makers who try to reduce earthquake hazards have little interest in earth science and geophysics *per se*, but considerable interest in how the physical processes associated with earthquakes interact with vulnerable environments and how they affect valued assets and human populations. California has experienced many large earthquakes that were not disasters because they did not hit population centers or disrupt important economic activities. Data on physical earthquake effects become meaningful only in the context of data provided by other disciplines.

Third, models enable both decision makers and the public to visualize how disasters will affect valued assets. In 2006, for example, a model of the recurrence of the 1906 San Francisco earthquake, developed to coincide with the 100th anniversary of the event, illustrated for various audiences the range of effects that would result today. In 2008, a similar impact modeling scenario was released for an earthquake on the Southern San Andreas Fault, which would affect a large region in Southern California. The scenario serves as the basis for extensive disaster exercises and public education efforts. The scientific details of how the earthquake will propagate along the San Andreas are less important for decision makers than information on the event's effects on hospitals, schools, power lines, transportation networks, hazardous materials sites, and populations at risk.

Fourth, even though all elements in loss models contain uncertainty, and even though many modeling tools are quite crude by scientific standards, the tools help decision makers anticipate and act to reduce hazard impacts. Tools such as HAZUS became widely used because they were marketed to decision makers and planners and because user groups were created and sustained through governmental action. Finally, loss estimation projects have been designed specifically to encourage action to reduce disaster losses and impacts and not to fund basic science—even though scientists provide crucial data inputs.

Other Examples

As the above discussions show, useful information for responding to climate change requires climate information and many other kinds of information as well. The examples below illustrate the many types of data and information required to assess both climate impacts and the effectiveness of efforts to respond to a changing climate landscape.

Cities' Efforts to Reduce Greenhouse Gas Emissions

Approximately 700 mayors have endorsed the U.S. Mayors Climate Protection Agreement, and many cities have initiated large-scale climate change mitigation and sustainability programs. Such efforts require information to assess program effectiveness, costs, benefits, and both intended and unintended consequences of programs, as well as to set priorities among various mitigation and adaptation activities. Chicago's actions since 2000 include providing grants for plantings on rooftops and roadway medians, enhancing alternative transportation opportunities, retrofitting city buildings for energy efficiency, and encouraging energy efficiency in commercial, industrial, and residential buildings. Similarly, initiatives of the GREEN LA Program in Los Angeles range from producing electrical power from renewable sources to creating green space, implementing smart growth strategies, and reducing water consumption.

Coping with Climate Change in New York City

In New York, PlaNYC (see Appendix A) involves numerous mitigation and adaptation decisions by households, public and private organizations, and diverse economic sectors and authorities, spanning approximately 1,600 different governmental units. Climate-related information contained in global climate change models and regional climate scenarios based on downscaled data are needed to support those decisions. Decision makers also need other types of information, such as sociodemographic, economic, transportation, and building stock data; vulnerabilities of health, energy, coastal, and water systems; cross-sectoral interactions; and information on the effectiveness of a range of mitigation, adaptation, and sustainability strategies. PlaNYC activities also have monitoring and assessment components that require program evaluation data to encourage learning and improve program effectiveness.

Adaptation in the Great Lakes Region

Climate change predictions for the Great Lakes Basin point to warmer, dryer summers; shorter winters; more winter precipitation falling as rain; less ice; and irregular, higher intensity storms. This information becomes useful mainly as it is linked with other information to project how the physical climate changes will affect economic and other activities, including: the recreational infrastructure in the region (e.g., docks too high for use and navigational hazards from low lake levels); commercial shipping (e.g., ships will have to carry smaller quantities of cargo so that they can float higher); and the drying of wetland areas, which will affect wild rice crops and fisheries These consequences will in turn have an impact on jobs, livelihoods, and costs in a variety of economic sectors. New data will be needed to trace the effects of physical climate alterations on the economic and social activities affected by those alterations.

Western Water Management

Climate change confronts water managers in several western states with the prospect of serious droughts and decreased winter snowfall, leading to reductions in snowpack, which accounts for about 35 percent of California's usable annual surface water (California Department of Water Resources, 2006). Managers are considering major new investments in water storage and distribution infrastructure and policies to reduce demand. Some are asking how much reduction in water demand can be expected at what level of increase in water prices and as a result of public education programs. To consider these options, they need more careful monitoring of precipitation and snowpack, as well as better information about consumer response to incentives and information. Some managers also need information about the potential for saltwater intrusion into groundwater due to sea-level rise, and the ability of freshwater-bearing sediments to repulse intrusion.

Wildfire Management

Wildfire management strategies, such as decisions about where to allocate and pre-position resources for fire prevention, prescribed burns, and fire suppression, rely on a similarly wide range of information. Some needed information is climate related, including ambient temperatures; precipitation amounts, frequencies, and timing; amounts and timing of snowpack melt; changes in speciation that affect land cover; changes in high wind frequency and severity; and changes in the probability of fire ignition by lightning. Social information is equally needed, including about intensive development in the wildland-urban interface, which increases fuel loads; policies related to the management of public and private lands in wildfire risk areas; and social perceptions of land value as influenced by human habitation, recreational uses, species richness, and aesthetic and cultural attributes.

Ecosystem Management

Climate change is expected to affect ecological systems in many ways (National Research Council, 2008a). Organizations that manage conserved land require information on how terrestrial ecosystems will change as climate changes and what their conservation value will be after some species and habitats disappear and others replace them. Managers of marine mammals and fish concerned with determining sustainable rates of commercial, recreational, and subsistence harvest may soon require information about how species reproduction, growth, physiology, and migrations respond to changes of ocean water temperature, acidity, primary production, predator and prey populations, and change in hypoxic or anoxic zones (e.g., Chan et al., 2008). For anadromous species, changing water temperatures, water levels, flow rates, and seasonal timing of flows in streams and rivers cascade into changes in the availability of riparian habitat; water column stability and mixing; pollutant, nutrient, and oxygen concentrations; populations of other riparian species; and the prevalence of, and resistance to, diseases (National Research Council, 2004b). In northern latitudes, losses of stable ice cover may reduce the availability of refuge habitat for juvenile fish (National Research Council, 2004a). Climate-related changes can affect human uses of riparian shorelands and water, which can then produce further impacts on anadromous populations (National Research Council, 2004e).

Transportation

Transportation decision makers find it difficult to obtain climate-related information relevant to planning and design in usable formats and at the appropriate spatial and temporal scales (National Research Council, 2008b). Issues include changes in winter weather, which accounts for 40 percent of highway operating budgets in northern states: in the frequency of hurricanes on the Gulf Coast; and in spring melting and permafrost in Alaska, which affect bridges and oil pipelines. Decision makers need locally specific information about such variables to select materials and designs for foundations, subsurfaces, and drains. They need accurate digital elevation maps in coastal areas to forecast effects of flooding and storm surges. Including climate change will require recalculations of innumerable transportation engineering standards, and this effort in turn will require extensive and costly research and testing. At present, transportation planners generally incorporate projected land use patterns into their decision making, but not proposed climate adaptation and mitigation efforts that could dramatically alter land use, which would require corresponding changes in transportation plans (National Research Council, 2008b). In many instances, transportation professionals have not yet engaged with the scientific and agency communities that might develop and provide the needed information.

Because the transportation sector produces the fastest growing rate of carbon dioxide emissions, it is important to consider not only the effects of climate change on transportation infrastructure, but also the effects of the infrastructure on climate change. In the long term, better community and transportation infrastructure planning can reduce vehicle-miles traveled, thus slowing climate change and facilitating adaptation to a carbon-constrained world.

Heat Wave Warnings

Heat waves cause substantial mortality and suffering—more than 700 deaths in Chicago in 1995, and perhaps 70,000 in the deadly 11-day 2003 heat wave in Europe. Effective warning systems can reduce heat-related mortality: The system in Philadelphia saved an estimated 117 lives in a 3-year period (Ebi and Schmier, 2005). However, the most useful weather parameters for predicting danger are still debated and may be location specific. It is not yet clear whether a high nighttime or daytime temperature is more dangerous, and different cities use different weather criteria for health decisions (Bernard and McGeehin, 2004). These include temperature-humidity indices, the number of consecutive hot days, temperature combined with time of year (a heat wave early in the summer season is generally more lethal than one in mid- or late-summer), and parameters based on analyses of air mass parameters in relation to historical evidence of mortality rates (Kalkstein and Tan, 1996). The most effective heat health warning systems require reliable local weather forecasts and known dose–response relationships between climate conditions and health outcomes to allow appropriate activation and deactivation of response plans, as well as involvement and coordination of the proper agencies (Kovats and Ebi, 2006).

Anticipating West Nile Virus Outbreaks

Above-average temperatures are linked to transmission of West Nile Virus—especially the more lethal strain that emerged in 2002—through increased replication in the major mosquito vector, *Culex pipiens* (Dohm and Turell, 2001; Dohm, O'Guinn, and Turell, 2002; Reisen, Fang, and

Martinez, 2006; Kilpatrick et al., 2008; see Institute of Medicine, 2008, for more details). Thus, climate warming is expected to lead to increased outbreaks. Human and equine infection follows a known causal chain that determines the factors that require monitoring for anticipating outbreaks. These factors include early-season weather conditions (especially heat and dryness), mosquito abundance, mosquito infection, avian host populations and infection rates, and equine and human cases.

Reducing Household Greenhouse Gas Emissions

Homes and private motor vehicles account for nearly 40 percent of national carbon dioxide emissions in the United States and are therefore a major target for mitigation. The relevant decision makers include government policy makers at all levels, manufacturers of vehicles and appliances, builders, retailers, lenders, and households. Their decisions all need information, though the information is of different kinds. For example, households need information on where the greatest potential savings lie, how much they will need to invest to meet mitigation goals, and how to assess whether the claims of those providing energy-saving equipment and services are credible and verifiable. Some of this information is available in appliance and vehicle certification and labeling programs and from metering and feedback systems, but it is not always available in easily usable forms, from credible sources, or targeted to the choices at hand. Some needed information is not available at all.

Summary

These examples illustrate the needs of many kinds of climate-sensitive decision makers for many different kinds of information, as well as for related basic understandings of processes that affect the results of their decisions. It is important to emphasize again that despite the language of the USGCRA, these and many other information needs are not being addressed in the current U.S. climate research effort, which focuses overwhelmingly on understanding physical processes related to climate change and underemphasizes the various ecological, economic, and social conditions and processes that, together with climate processes, shape the consequences of human responses to climate change. (We discuss specific research and data needs below.)

Models for Meeting Information Needs

The eight Regional Integrated Sciences and Assessments (RISA) centers are explicitly problem focused and exemplify a promising approach to providing user-driven integrated scientific information at regional scales.

RISA goals include characterizing the state of knowledge regarding climate variation and change at appropriate scales for decision making; understanding knowledge gaps and elucidating the linkages that characterize climate–environment–society interactions; providing a framework for responding to climate-related risks; and establishing priorities for research that can address the needs of decision makers (Pulwarty, Simpson, and Nierenberg, 2009). Regional assessments, the precursors to RISAs, began over a decade ago; the new name reflects the notion that science and assessments should be "integrated," both in the sense of being interdisciplinary and in terms of their fit with regionally specific knowledge requirements.

Significant features of RISA projects include the use of participatory strategies in problem framing and problem solving; strong involvement on the part of stakeholders who represent a wide range of perspectives (academics, regional, state, and local agencies, extension networks, governmental bodies); an emphasis on assigning projects to scientists who live in the regions in which they are conducting assessments; team-building efforts designed to integrate physical and social science expertise; and the development of pilots and prototypes that serve as vehicles for collaborations among scientists and decision makers. Fundamental to RISA programs is the notion that better science does not necessarily lead to better decisions. Rather, as discussed in Chapter 2, they seek to improve decisions both through the incorporation of scientific information and by developing and sustaining knowledge-action networks.

The Climate Assessment for the Southwest (CLIMAS) is a RISA that was established in 1998 and is based at the University of Arizona. CLIMAS works with stakeholders on issues related to climate change and water availability: It does so in a context that includes significant ecological change, increasing population and urbanization, and specific economic trends. Like other RISA centers, CLIMAS develops information that is directly relevant to decision makers in the region and that spans a very broad range of sectoral and disciplinary concerns. For example, CLIMAS anthropologists have conducted research to better understand the historical, social, and economic roots of climate-change vulnerability and the specific needs of groups, such as ranchers and farmers, whose livelihoods are highly climate-sensitive. Because the health effects of climate change were deemed important by some stakeholders, CLIMAS researchers worked with the Arizona Department of Health Services, physicians, and other scientists to obtain data and create a model that enables health officials to better understand the potential for future disease outbreaks. CLIMAS personnel also worked with air quality managers on such issues as dust abatement at construction sites and ozone pollution rates and traffic congestion, as well as with water managers on reservoir-level projections.

In each case, different kinds of information were required. Based on their experiences, CLIMAS scientists observed (Jacobs et al., 2005:9):

> A first step in developing useful products and services involves understanding the context in which they will be used. With a worldview strongly influenced by the boundaries of their own research, scientists may not recognize that the new information they produce may be only a very small consideration in a manager's "decision space" although scientists might perceive that climate information is crucial to the management of a water system, they might fail to realize that multiple institutional, political, and legal issues dominate the decisionmaking process.

Other models are being developed throughout the country in response to decision makers' needs. Box 4-2 describes one example that addresses water management issues in Southern California.

BOX 4-2
Climate Change Vulnerabilities and Water Management in California

Only a few of the water agencies in California have begun to include climate-change projections in their planning activities. One exception is the Inland Empire Utilities Agency (IEUA) in Southern California, which has been working with the RAND Corporation on a study funded by the National Science Foundation to identify how climate change will affect its long-range urban water management plan. RAND customized a tool called Water Evaluation and Planning for the IEUA region, which made it possible to evaluate the performance of the agency's water management plan under a range of planning assumptions that took into account plausible future weather conditions; groundwater hydrology; increases in the intensity of water use resulting from future population projections; future water supply imports; future costs of different types of water supplies; and the effects of water-use efficiency programs. The National Center for Atmospheric Research developed weather data based on the best available climate projections for the region. Multiple future climate and weather scenarios were run, showing that the utility's current plan is appropriate if the region's climate does not change, or if it becomes wetter, but also that the plan could result in significant water shortages should the climate become drier. Other decision support activities centered on exploring the utility's options with respect to future planning, taking into account information on the costs associated with alternative scenarios and with different water-management strategies, such as replenishing groundwater, recycling water, and introducing efficiencies. The water agency is using results from this decision-support exercise in communicating with stakeholders and partner agencies.

SOURCE: Information from Groves et al. (2007, 2008).

THE SCIENCE BASE

The examples above illustrate the types of information that are needed to support a wide range of sectoral and problem-based decisions. Managing the risks associated with a changing climate requires greatly enhanced efforts to meet these information needs. Doing so will require engagement on the part of a broader range of disciplines than is currently represented in climate science activities. As the examples discussed throughout this report show, understanding climate processes is necessary but in no way sufficient to provide a sound foundation for climate-related decision making.

A long series of National Research Council (NRC) reviews (e.g., 1988, 1990, 1992, 2004d, 2007b) has pointed out the ways in which increased attention to the human dimensions of climate and other global environmental changes can provide both new research discoveries and practical strategies for climate-related mitigation and adaptation activities. The relevant science base has been reviewed in multiple studies since the 1980s, which also offer recommendations for future development in the area (e.g., National Research Council, 1984, 1985, 1989, 1992, 1994, 1997, 1999a, 1999b, 2002a, 2002b, 2004d, 2005a, 2008c). Although not all these studies explicitly address the question of climate-related decision support, they are valuable for mapping the scientific area, assessing its status and progress, and identifying key research needs. Most of these studies were recently reviewed for the purpose of identifying fundamental needs for knowledge on the human dimensions of climate change in the context of a forthcoming NRC study to offer strategic advice to the U.S. Climate Change Science Program (Stern and Wilbanks, 2008). This group of reports and a new study (National Research Council, 2009b) provide detailed guidance on research needs. The latest study calls for an expansion of the scientific effort from a focus on the climate system and its components to encompass the end-to-end climate problem—from understanding causes to supporting actions needed to cope with the social impacts of climate change. It also calls for better integration of natural and social science and of basic and applied research; see Box 4-3. These priorities are fully compatible with those in this report.

This section draws on those works and briefly identifies the key elements of the science base for climate-related decision support and related research needs. We begin with a discussion of broader research needs related to producing knowledge to inform climate-related decisions—termed science *for* decision support—and then consider the science *of* decision support, which treats decision support as a distinct field of inquiry. We then turn to associated needs for data, observations, and human resources.

BOX 4-3
Priorities for Expanded Scientific Effort

Restructuring Federal Climate Research to Meet the Challenges of Climate Change recommends restructuring the climate change research program to address the climate problem in an end-to-end way by better integrating natural and social science, as well as basic research and practical applications. It recommends six top priorities:

1. Reorganize the program around integrated scientific-societal issues to facilitate cross-cutting research focused on understanding the interactions among the climate, human, and environmental systems and on supporting societal responses to climate change.
2. Establish a U.S. climate observing system, defined as including physical, biological, and social observations, to ensure that data needed to address climate change are collected or continued.
3. Develop the science base and infrastructure to support a new generation of coupled Earth system models to improve attribution and prediction of high-impact regional weather and climate, to initialize seasonal to decadal climate forecasting, and to provide predictions of impacts affecting adaptive capacities and vulnerabilities of environmental and human systems.
4. Strengthen research on adaptation, mitigation, and vulnerability.
5. Initiate a national assessment process with broad stakeholder participation to determine the risks and costs of climate change impacts on the United States and to evaluate options for responding.
6. Coordinate federal efforts to provide climate services (scientific information, tools, and forecasts) routinely to decision makers.

Science for Decision Support

Climate change effects are the result of the conjunction of physical and biological events and their interactions with social and economic forces. As the cited NRC assessments of U.S. climate-related research have noted, the research effort has focused overwhelmingly on improving understanding of biophysical events in the climate system and very little on understanding the human and environmental processes on which the outcomes of practical decisions about climate response depend. What is now needed is an integrated effort that includes fundamental and applied climate research as well as fundamental and applied research on the social, economic, ecological, and cultural conditions that determine the human consequences of climate change and of responses to it.

On the basis of our review of past research assessments and of the information needs of climate-sensitive decision makers, we conclude that additional research in five focused areas is essential for providing critical missing pieces of the information these decision makers need: vulnerability, mitigation, adaptation, the interaction of mitigation and adaptation, and emerging opportunities from climate change. Fundamental research on human processes and institutions that interact with the climate system (e.g., risk-related judgments and decision making, environmentally significant consumption, institutions governing resource management) should also be part of the national research effort under USGCRA, even if this research is not tied directly to decision support needs. Priority setting for this kind of research is beyond the scope of this report (but see National Research Council, 1999a, 2005a, 2009b; Stern and Wilbanks, 2009).

Climate Change Vulnerabilities

Many climate-sensitive decisions require an improved ability to estimate, analyze, and project human vulnerabilities to climate change in particular regions, sectors, or communities. There is a need to build linked time-series databases covering these variables as a basis for the modeling needed to make projections on the future characteristics and geographic distribution of vulnerable populations (National Research Council, 2007d). Such efforts can benefit from research on social vulnerability to hazard events, as exemplified by the work of the Hazards and Vulnerability Research Institute at the University of South Carolina, which has developed indices of social vulnerability for counties nationwide (see http://webra.cas.sc.edu/hvri).

Future research is needed to examine the vulnerability of people, places, and economic activities on several dimensions: by type of climate-driven event (e.g., storm surge, crop failure, heat wave, changing ecology of disease); by location and scale; by relevant characteristics of affected populations (e.g., socioeconomic characteristics, age, disability); and by sector (e.g., market and subsistence agriculture, water supply and quality, insured and uninsured property, large-scale public works). Research that takes demographic and economic projections into account can yield scenarios of vulnerability that can be integrated with climate scenarios to produce improved projections of the future impacts of climate change (National Research Council, 1998b, 1999b, 2009a).

The Potential for Mitigation

The needed research would seek improved understanding of (a) the human sources of climate change (e.g., global warming potential associated with specific human actions, driving forces of activities with significant climate consequences); (b) phenomena relevant for evaluating policy options (e.g., the potential to change actions that drive climate change with particular kinds of interventions, limits of and barriers to change); and (c) the results of mitigation policies (including costs, effectiveness, and nonclimate consequences).

Discussions of options for climate change mitigation are often rooted in policy targets and models in which the behavior of individuals, organizations, and economies is extrapolated from past trends or derived from simple assumptions, rather than from empirical studies of how this behavior develops and responds over time to education efforts, policies, and regulations. Highly aggregated models of some of the drivers of climate change, such as energy and land use, have often been far off the mark in predicting future trends. Integrating into such models data on population dynamics, economic activity, energy and resource demand, and other social indicators has the potential to yield improved forecasts based on better understanding of the underlying processes (National Research Council, 1984, 1992, 1997, 1998b, 2005c). The social changes engaged by climate change will be difficult to predict with precision, however, and the iterative approach using analysis and deliberation suggested in Chapter 3 is an essential complement to modeling.

Efforts to mitigate climate change by altering anthropogenic driving forces depend on encouraging social and behavioral change among individuals, organizations, and institutions. Much of the needed change takes the form of inducing innovation and adoption of technologies for energy efficiency and low-carbon energy production and for the design of communities and other physical infrastructure, as well as changes in the use of existing technology and infrastructure. Change can be accomplished by various combinations of regulatory action, standard setting, provision of infrastructure, public education and social marketing, financial incentives, and voluntary action. Research is needed to identify effective initiatives and assess the efficacy of policy alternatives.

Adaptation Contexts and Capacities

Adaptation to climate change is the result of how regions, sectors, populations, and their governing institutions cope with their vulnerabilities (Adger et al., 2007). Adaptation strategies take place in and across multiple sectors and span a range of time periods, from long-range efforts, such as strengthening protections against riverine and coastal flooding and controlling development in areas prone to sea-level rise; through preparatory activity, such as planning and mobilizing resources to respond to extreme climate-related events; to planning and carrying out recovery activities following such events. Adaptation also involves the development of early warning systems for climate-related societal effects. The list of phenomena for which early warning systems are needed is a long one that includes disease outbreaks, drought, wildfire, landslides, famine and famine-induced migration, and potential conflicts over resources.

Research is needed to develop indicators of adaptive capacity that can address the diversity of types of disruptive events; assess effects by region, sector, human activity, and time scale; incorporate assessments of coping capacity (e.g., emergency preparedness and response systems, insurance systems, disaster relief capabilities); and consider diverse types of impacts (e.g., on life and health, economic systems, business organizations, governments, and communities; see Yohe and Tol, 2002; Brooks and Adger, 2005). Another need is to assess various generic and event-specific adaptation options in terms of their ability to reduce unwanted consequences of climate change while taking advantage of the opportunities such changes present.

Interactions of Mitigation and Adaptation

Along with the importance of improving the scientific understanding of mitigation and adaptation as separate research priorities, there is a rapidly emerging need to improve the ability to consider mitigation and adaptation as joint contributors to an integrated approach to climate change responses (Wilbanks et al., 2003; Klein, Sathaye, and Wilbanks, 2007).

Few decision-making entities choose only one set of mitigative strategies or adaptive measures; many communities are responding in multiple ways to climate change (see below). This type of research will be challenging, both because of the higher degree of emphasis that has been placed to date on mitigation than on adaptation and because researchers tend to specialize in one area or the other. The benefits of a more balanced and integrated approach include a more realistic and comprehensive understanding of climate response options, their interrelationships, and their joint effects on the human consequences of climate change.

Many ongoing activities provide test beds for research, sources of research questions, and potential audiences for and users of research results. For example, hundreds of cities and at least 30 states currently have some form of climate action plan. Most of the plans focus mainly on the mitigation of greenhouse gases; only six states have adopted climate change adaptation plans. Some states have not yet begun to consider either mitigation or adaptation, and many have plans that have not yet been implemented (Pew Center for Global Climate Change, 2008). Research is needed on these efforts, focusing not only on their effectiveness, but also on factors that influence program adoption, implementation, and content and on lessons learned.

Interactions between researchers and public officials may help focus research efforts on questions of pressing practical importance. Many community climate response programs already involve partnerships with universities, RISAs, and federal agencies, such as the Environmental Protection Agency, and some programs have explicit research components. These research efforts are just a beginning. The federal government can recognize the large and varied suite of climate response programs currently under way as a major research opportunity and develop mechanisms for funding research on and with such programs, including research with a specific decision support focus.

Emerging Opportunities

Research efforts are also needed for understanding and taking advantage of emerging opportunities associated with climate variation and change. As societies acknowledge the end of climate stationarity, there is an understandable tendency to focus on the negative aspects of future climate variability and change. While recognizing those challenges, it is also important to highlight the many opportunities that are emerging as a consequence of changing climate. Thus, paralleling the need to understand the risks and decision support requirements associated with future climate projections is an equally compelling need for information to support climate-related decisions that can be beneficial and profitable.

Climate change mitigation and adaptation strategies present numerous opportunities for entrepreneurship, creativity, investment, and economic growth. Opportunities for creative solutions to the challenges associated with climate change abound: examples include new climate-informed technologies for farming, effective measures for ecosystem restoration and carbon sequestration, green technologies, and alternative energy development. New information will also be required to support engineering, design, construction, and land-use measures to adapt to both climate change itself and new climate-related hazards.

At least some businesses and industries have come to recognize both the importance of adopting measures to mitigate and adapt to climate change and the business opportunities that are provided by such change. For example, in 2005, Goldman Sachs became the first investment bank to adopt a comprehensive environmental policy that included a commitment to invest in activities that preserve and enhance ecosystem services.

The Constancy of Change

Two other points concerning information and science for decision support warrant emphasis here. First, as understanding of climate change and its consequences develops, and as decision makers identify new information requirements and pose new questions regarding mitigation and adaptation strategies, the research agenda of science for decision support will develop and evolve. This chapter offers examples of information needs and related data requirements, but we emphasize that it is impossible to anticipate in advance all the kinds of information decision makers may require or how those needs will change over time. Indeed, the specification of information needs is one key phase in the processes of engagement and collaboration discussed in Chapter 2. Providing decision support in a dynamic environment of change in climate and in climate understanding requires openness to decision makers' evolving information requirements. New and unanticipated problems and scientific questions can be expected to continue to emerge, sometimes with great urgency.

Second and in a related vein, the need for learning and adaptation in developing well-informed climate responses, discussed in Chapter 3, generates its own set of information needs. Decision support needs to draw on data on the outcomes of past and ongoing mitigation and adaptation choices, including both their intended and unintended consequences. Learning lessons and diffusing innovations in response to climate change requires a body of data and evidence, so that innovations that can be shown to be effective are widely known. New information will be needed to make such determinations.

The Science of Decision Support

The scientific base for informing and improving human decisions, about climate change as in other arenas, lies in the decision sciences, including seminal work and new fields, such as cognitive and brain science (e.g., Kahneman et al., 1982; Raiffa, 1968; Kahneman and Tversky, 2000; Trepel, Fox, and Poldrack, 2005; Platt and Huettel, 2008). Some of this work has been linked to climate change through the decision making under uncertainty research centers started in 2004 by the National Science Foundation (NSF). For example, the Decision Center for a Desert City at Arizona State University focuses on research related to urban growth and water resource management in the Phoenix area, and the Center for Research on Environmental Decisions at Columbia University conducts research on such topics as media effects on climate change risk assessment and the role of affect and direct experience in processing uncertain climate information. The Climate Decision Making Center at Carnegie Mellon University focuses on the challenges faced by insurance, forest, fisheries, ecosystem, and utility managers and on complex decision making in the Arctic region.

A recent review of research needs for improved environmental decision making (National Research Council, 2005a) emphasized the need for research on the kinds of decision support activities and products that are most effective, for which purposes and with which audiences. It recommended studies focused on assessing decision quality, exploring decision makers' evaluations of decision processes and outcomes, and improving formal tools for structuring decisions. These needs exist in the specific case of improving climate-related decision support. Research is needed on information needs, characterizing risk and uncertainty, communication processes, decision support product development, and decision support "experiments."

Information Needs

Both fundamental and applied decision research assume that a key step in applying the science of decision support to all types of decisions—including those related to climate—is to understand diverse stakeholders' information needs. The kinds of engagement processes discussed in Chapter 2 provide important insights, but there is also a place for formal research to identify the kinds of information that would add greatest value for climate-related decision making and to understand information needs as seen by decision makers. Such research would improve understanding of the kinds of information that can improve climate-sensitive decisions.

Climate Risk and Uncertainty

Informing responses to climate change means providing information about continually changing environmental conditions and about projected risks and benefits—and the information is always incomplete and uncertain. People's normal ways of understanding may not be adequate for processing this kind of information, with the result that they may sometimes misperceive useful information as too unreliable to support action, while at other times putting too much weight on a single recent event as an indicator of a major underlying change. Research on how people understand uncertain information about risks and on better ways to provide it, given knowledge about human understanding, can improve decision support processes and products. For example, although most risk analysts think of these issues in terms of presenting consequences and probabilities in terms of given values, most nonspecialists also consider qualitative aspects of risks, emotional reactions to risk information and risk-related decisions (Slovic et al., 2004; Rottenstreich and Hsee, 2001; Loewenstein et al., 2001), tradeoffs among values (Gregory, 2003; Tetlock, 2000; Keeney and Raiffa, 1993), and the context of choices (Arvai et al., 2006b). Insights from the literature on risk characterization suggest the need to develop and test novel ways of framing and presenting information for climate-sensitive decisions.

Decision Support Processes

Research is needed on processes for providing decision support, including the operation of networks and intermediaries between the producers and users of information for decision support. This research should include attention to the most effective channels and organizational structures to use for delivering information for decision support; the ways such information can be made to fit into individual, organizational, and institutional decision routines; the factors that determine whether potentially useful information is actually used; and ways to overcome barriers to the use of decision-relevant information (National Research Council, 1999b, 2005a, 2008d). It should also include research on processes—such as workshops, focus group discussions, stakeholder elicitation techniques, and decision framing exercises—for increasing mutual understanding between information producers and users. Another important topic is research on methods for organizing decision support processes, including the roles of boundary organizations, and on process-based approaches for improving understanding, such as those that combine deliberation with analysis (see Chapter 3; see also National Research Council, 1996b, 2008c). This research can help make decision support processes more effective by building on basic social science knowledge and past experience.

Decision Support Products

Research on the science of decision support includes studies of the design and application of decision tools, messages, and other products that convey user-relevant information in ways that enhance user understanding and decision quality. These products may include models and simulations, mapping and visualization products, websites, and applications of techniques for structuring decisions, such as cost-benefit analysis, multi-attribute decision analysis, and scenario analysis, among others (Keeney and Raiffa, 1993; Lempert et al., 2003; van Asselt, 2000; von Winterfeldt and Edwards, 1986). The products may also include tools to help decision makers manage uncertainty by identifying choices that are robust across multiple climate futures. Research can help clarify which tools, developed in which ways, can effectively link to decision makers' preferences for different types of decision aids.

Decision Support "Experiments"

Efforts to provide decision support for various decisions and decision makers are already under way in many cities, counties, and regions. These efforts can be treated as a massive national experiment that—if data are carefully collected—can be analyzed to learn which strategies are attractive, which ones work, why they work, and under what conditions. The efforts already under way also present an opportunity to learn more about how information of various kinds, delivered in various formats, is used in real-world settings; how knowledge transfers across communities and sectors; and many other aspects of decision support processes. Future efforts can benefit greatly from systematic assessment of past and present ones.

NEEDS FOR DATA AND OBSERVATIONS

The variety of climate-sensitive decisions and decision makers generates great variety in needs for information and for data that can become the basis for information. As noted elsewhere in this report, the scale at which data are provided can present serious challenges for usefulness. Although climate change projections have typically focused on global or continental scales, the vast majority of decision contexts require information on the consequences of climate change and of responses to it at national, regional, and local, and other appropriate scales (e.g., ecosystems, watersheds).

Various downscaling methodologies are currently in use, and useful climate information is now available at mesoscale levels. For example, the Lawrence Livermore National Laboratory has used statistical downscaling approaches in order to develop climate change datasets for use by researchers and decision makers. The Northeast Climate Impact Assessment uses downscaling methods to provide information on climate change impacts that are useful for decision making in communities in the northeastern states. Analyses show, for example, how temperatures will be affected over time as a function of different approaches to emission reduction. RISAs also rely extensively on downscaled climate information, since their activities focus on specific regions affected by climate change.

Scale is equally important for nonclimate data for climate-related decisions, and addressing inconsistencies in scale is a major challenge. Utility service and water management areas, for example, may or may not be consistent with city and county boundaries, which can in turn be inconsistent with scales at which climate data can be provided. Census data exist at various levels of aggregation, are standardized nationwide, and generally are of high quality, but the same cannot be said for other types of data that can be important to decision makers, such as building inventories. Input-output, computable general equilibrium, and other types of models used by economic geographers, regional scientists, and planners generate results for economic "regions," but definitions of what constitutes a functioning regional economy vary widely and economic regions are typically not consistent with political jurisdictional boundaries. Downscaling to county, city, or smaller levels of aggregation results in the loss of important data on economic interrelationships. Here again, data collected for particular purposes and at different levels of aggregation may or may not be consistent with users' decision requirements—or with downscaled climate data.

Providing data at appropriate time scales can also present a major challenge. Decision makers' time horizons differ, and the time scales for which they require information may vary from the scales for which climate and other forms of data are currently available. For those planning long-term infrastructure investments, decadal and longer term climate projections, combined with other long-term trend information, such as data on population growth, may be sufficient. In contrast, ranchers, farmers, fisheries managers, and emergency managers may require information on a seasonal scale. In sectors such as public health and disaster management services, information on climate trends, climate variation (e.g., El Niño/Southern Oscillation [ENSO] cycles), and weather may be needed and may need to be integrated with other relevant data (e.g., Glass et al., 2000; Westerling et al., 2006; Kitzburger et al., 2007). At the same time, as with reducing spatial scales, shrinking time scales introduces new uncertainties, increasing the need for appropriate ways of communicating uncertainty (National Research Council, 2006a).

Data Availability and Data Linkage

In some cases, data exist that are unavailable to the research community. An obvious example is data collected from respondents under promises of confidentiality (e.g., census data). Publicly held data of this type are typically made available to researchers only in aggregated form. Although specific locational information about respondents might be useful for some research purposes, such as identifying locations of greatest human vulnerability to coastal storms, providing it would violate confidentiality guarantees. Ways to resolve conflicts between the objectives of access and confidentiality with spatially explicit data are still being developed (see, e.g., National Research Council, 2007c). Another example is data collected by businesses and held as proprietary for competitive or other reasons. Although some such of these may also have value for informing climate-related decisions, there are no established ways to identify such data or to balance public interests in its use against the private interests of the data owners. Nevertheless, a climate regime that is no longer stationary makes it more pressing to find ways to make fuller use of existing data for supporting climate-related decisions.

In other cases, datasets on human activities are not usefully linked to environmental data, a challenge that has been noted in previous reviews (National Research Council, 1992, 2004d, 2005c). These include census data, economic input and output data, data on the natural and built environments, data on property values and insured and uninsured losses from past extreme weather-related events, the vulnerabilities of different populations in the United States, data on health and well-being (often survey-based data), and ecoregion assessments. All these data are relevant to climate-sensitive decisions and are collected in different units of analysis.

These issues have been noted before. More than 15 years ago, a National Research Council (1992:249) review recommended:

> The federal government should establish an ongoing program to ensure that appropriate data sets for research on the human dimensions of global change are routinely acquired, properly prepared for use, and made available to scientists on simple and affordable terms. There is a national need to (i) inventory existing data sets relevant to the human dimensions of global change, (ii) critically assess the quality of the most important of these data sets, (iii) make determinations about the quality of data required for research on major themes, (iv) investigate the cost-effectiveness of various methods of improving the quality of critical data sets, and (v) make decisions regarding new data needed to underpin a successful program of research.

These recommendations, written with an eye to research needs, are appropriate today for the practical purposes of building a scientific base for informed decisions about climate response. A more recent report, *Decision Making for the Environment*, reiterated the point and called for an intensive effort on the part of natural and social scientists to develop sets of indicators capable of characterizing "not only states of the biophysical environment but also human influences on nature and the impact of the physical world on humans" (National Research Council, 2005a:87–88). The nation is currently far from reaching this goal.

Similar needs exist in the area issues of climate and human health. A recent report in the *Annual Review of Public Health* notes that research on the relationship between climate change and health currently focuses mainly on impacts on infectious diseases, rather than on "individual, family, social, and nutritional risks to the population" (Jackson and Shields, 2008:66). Citing a lack of collaboration between agencies concerned with climate change and those that focus on health and public health issues, the report calls for the development of monitoring systems for increased data collection on such conditions as asthma and other respiratory diseases; research on how climate variation and change affect human health; studies to determine the extent to which climate change is already having an impact on health outcomes; and research on future health risks under different climate-change scenarios.

Significant data limitations also exist for climate science itself, and some existing and planned observing systems in the physical sciences have been cancelled or delayed or are deteriorating. A recent report (National

Research Council, 2007b), typical of many about climate modeling, emphasizes oceanic, terrestrial, and atmospheric observing systems and the need to ensure adequate coverage and reliability and linking these observing systems throughout the world by means of collaborative efforts, such as the Integrated Global Observation Strategy (Trenberth, Kark, and Spence, 2002; Trenberth, 2008). These needs are real. Our emphasis here is on observations relevant to linking human and environmental phenomena, an enterprise at an early stage of development.

Existing Data or New Data

An important data-related issue concerns deciding when new data have to be collected for a particular purpose, rather than using or customizing available data. Many decision support efforts involve some blend of newly collected and existing data. California provides a good example: The state used a combination of new and archived data in its efforts to chart the state's climate future. As part of these efforts, the state established the California Climate Change Center to facilitate research that would be responsive to decision makers' needs. It developed a 5-year research plan and, through this process and the ensuing research, identified some needs for new data. The state funded a nonprofit organization, the California Climate Action Registry, to collect emissions data from state organizations. It established linkages with a RISA program, the California Applications Program at the Scripps Institution of Oceanography, which conducted studies of climate change impacts in such areas as water resources, wildfires, and public health (Franco et al., 2008).

Research on the effects of climate change in California also uses existing climate models and data from existing national and regional assessment reports. For example, a report on the health, economic, and equity impacts of climate change (Redefining Progress, 2006) developed projections on future health impacts by combining data from the California Health Interview Survey (which focused on differences in insurance coverage statewide across different income and ethnic groups, a major factor in health outcomes); historic data on heat wave mortality, also by race and ethnicity, for the Los Angeles area; and data on the relationship between ozone levels and health conditions, such as asthma, along with asthma incidence rates for different social groups. These were existing data used in new ways to address concerns related to climate impacts.

Even with extensive efforts to use existing data and information sources, it is important to recognize that the very nature of the phenomena for which decision support is required—spanning climate, ecological, and societal processes and impacts—creates a continual stream of new information needs. Meeting those needs will necessitate new and diverse research activities, ranging along a continuum from basic research to narrowly focused and context-specific investigations, and create needs for new data.

Indicators for Climate Impacts and Responses

Social indicators research involves the systematic collection, analysis, and archiving of data from the social, economic, behavioral, and policy sciences, reflecting such concepts as quality of life, human health and well-being, social inequality, and political processes (see Land, 1983; also see the *World Handbook of Political and Social Indicators,* published by the Inter-University Consortium on Political and Social Research; the journal *Social Indicators Research*; and the social indicators used by the National Association of Planning Councils for examples of measures and applications). Integrated with climate data, such indicators can provide a sound basis for climate-related decision support.

Some relevant work has already been done. For example, a number of projects have sought to develop indicators of sustainability that can be applied at different levels of aggregation. Social indicator-based indices have also been used to measure population vulnerability to natural, technological, and socially generated hazards such as arise on humanitarian crises (National Research Council, 2007d). Vulnerability indicators include measures of income, education, poverty status, and household composition.

Other indicators—for example, of societal, regional, and community-level capacity to respond to climate change—are also needed, especially if they can be linked to actual climate change response efforts. For example, in the hazards area, a number of activities are currently under way to develop measures of resilience that can support local and regional decision making. Oak Ridge National Laboratories is currently leading the Community and Regional Resilience Initiative, which, in partnership with local communities, seeks both to develop resilience indicators for extreme events and to enhance local resilience. The National Oceanic and Atmospheric Administration's (NOAA's) Coastal Services Center is engaged in a multiyear effort to provide coastal communities with a suite of hazard, vulnerability, and resilience assessment tools to support community decision making to reduce the impacts of coastal hazards.

Developing existing and new social indicators relevant to climate change will make it possible to conduct assessments that are consistent across communities and countries and over time—assessments that are crucial for a deeper understanding of the relationships among climate change, society, and ecological systems. Such indicators will also yield important baseline and milestone measures. Indicator development can also be a vehicle for engaging decision makers. Climate-relevant social indicators are also useful for comparing the climate-related decision making across decision types, communities, and sectors and therefore for helping decision makers learn from the experiences of others. They could become central to a multidisciplinary observational system that integrates existing and new social indicators and data on the broad range of social experiments taking place throughout the nation in responding to climate change.

NEED FOR A MULTIDISCIPLINARY WORKFORCE

To develop the science of and for decision support, to produce useful decision support information, and to get it used, it is critical to build multidisciplinary and interdisciplinary teams whose members interact and work together to better integrate data for use by decision makers. Strong teams consist of members who have high levels of expertise in their own fields, but who are also willing and able to engage with counterparts from other fields and to cross the divide between science and its uses. Many well-documented challenges exist, including overcoming the transaction and opportunity costs associated with cross-discipline collaborations, attempting to launch multidisciplinary efforts within organizations that reward discipline-based work, training the needed workforce, and enabling scientists to develop careers in interdisciplinary science. This need has long been recognized with regard to research on human-environment interactions (e.g., National Research Council, 1992:Chapter 7). In one formulation (National Research Council, 2004d:28):

> In both the social sciences and the natural sciences there is considerable knowledge that has the potential to make major contributions to the current and long-term goals of the CCSP [U.S. Climate Change Science Program], however that knowledge has not yet been fully applied to these goals, nor has the broad set of interfaces between these disciplines been addressed. The necessary personnel to execute an enhanced level of research cannot be assumed to exist, particularly for research problems that cross disciplinary boundaries. In a number of fields, particularly in the social sciences, there are relatively few researchers in the position to undertake climate research. Furthermore, it takes years to increase workforce capacity. The achievement of these capacity-building goals will require systematic investments over a long period of time.

This overall assessment remains valid, even though some promising programs exist. One example is a new NSF-funded interdisciplinary graduate education and training program called C-CHANGE (Climate Change, Humans, and Nature in the Global Environment), based at the Center for Research on Global Change at the University of Kansas (see http://web.ku.edu/~crgc/IGERT). Other universities at which RISA centers and NSF-funded centers on decision making under uncertainty are located also represent test beds for cross-disciplinary educating and training.

Development of the needed workforce will not occur without sustained efforts on the part of NSF, NOAA, the Environmental Protection Agency (EPA), and other scientific and mission agencies concerned with climate and its impacts. Science agencies in the U.S. Global Change Research Program (GCRP) (created by the USGCRA),[1] including NSF, should expand current programs and initiate new programs aimed at supporting the development of a well-balanced, multidisciplinary climate response science/human dimensions workforce. This expansion is needed in order to address the climate-related decision support needs of the future. Efforts should target several levels simultaneously: undergraduate and graduate programs, junior and senior faculty, and scientists in the public and nonprofit sectors.

A particular need is for development of the scientific workforce at the interface of the environmental and social sciences. This area lags behind current needs for many reasons, including a dearth of federal research support over several decades and resistance in several social science disciplines to interdisciplinary work, applied research, and collaboration with natural science and engineering. In light of this history, developing the needed scientific workforce will require changes in academia as well as in government. A long-term commitment to supporting research for and on decision support, including funds for ongoing research centers, projects, data development efforts, and training, would provide critically important incentives for changes in academia. However, such investments may not be sufficient. We encourage the new America's Climate Choices project at the National Research Council to take up this issue.

Workforce enhancement initiatives also need to build capacity within sectors, organizations, and institutions that will increasingly need to use climate, climate response, and human dimensions information in their decision making. The need is not so much for researchers as it is for trained personnel who can help link research to its potential users. To achieve this goal, federal agencies might, for example, support training for people working in or with climate-affected constituencies to increase their ability to understand and interpret climate-related scientific knowledge, information, and data. And agencies might support scientists from the climate research community to spend time in climate-affected organizations so they can better understand the organizations' information needs. Agencies might also support the development of career paths for climate researchers to work in applied settings in both the public and private sectors.

[1]At the time of this writing, these agencies were the participants in the CCSP and the Climate Change Technology Program, the interagency groups responsible for implementing the USGCRA.

Workforce development can be achieved through a number of mechanisms, including enhanced funding to ongoing research and training programs; the expansion of interdisciplinary graduate programs; increased student involvement in research applications and demonstration projects; support for scholarships, fellowships, and internships; and training experiences for decision makers and other users of climate and climate response information. Workforce enhancement efforts should also extend to the training experiences that are routinely provided for upper-level federal employees in relevant agencies. Such efforts could also contain an international component linking researchers throughout the world through collaborative research and training projects and student and faculty exchange activities. In a broad sense, the federal climate research enterprise needs to pay more attention to identifying and finding effective ways to address the challenges of workforce development for decision support.

Two points deserve special mention with regard to the need for a changed workforce to provide climate-related decision support. First, research initiatives need to reflect the fact that climate-related decisions are made in complex decision contexts in which climate information constitutes only one set of inputs into decisions. Research to inform climate change responses requires a comprehensive, multidisciplinary approach and a commitment to the collection of data that both support decisions and enable learning through deliberation with analysis. Agencies that are part of the GCRP and other agencies concerned with energy and the environment can contribute to the needed changes by increasingly taking a multidisciplinary and decision-oriented approach to collecting data and information in their areas of responsibility.

Second, agencies need to recognize the need to support scientific research in fields other than climate science, whose inputs are required for fully informed climate decision making. Advances in decision support require the development of data and knowledge throughout the entire range of relevant disciplines and of a multi- and interdisciplinary science workforce focused on improving the quality of environmental and climate decision making. There is also a need to create and sustain settings in which authentic cross-disciplinary collaborations and stakeholder relationships can evolve over time.

CONCLUSIONS AND RECOMMENDATIONS

Climate-related decisions require integrated knowledge and information that includes both possible future climate conditions and socioeconomic information. Together, that information provides insights into climate vulnerabilities, impacts, and the costs and benefits of alternative mitigative and adaptive activities. Such data are particularly vital for long-term decisions that involve substantial investments.

The best way to meet the decision support objectives of the GCRP is to redefine priorities with the aim of producing information that is useful for decision-making processes. Such redirection will help fulfill the legal requirements of the USGCRA. As stated in that 1990 law, the purpose of the GCRP is to "assist the Nation and the world to understand, assess, predict, *and respond to* human-induced and natural processes of global change" [emphasis added]. Given that anthropogenic climate change has been established as a significant threat to human well-being, a shift of emphasis is required toward research relevant to climate change responses.

The central rationale for further development of the federal research effort under the USCGRA should be to ensure that decision makers at all levels have the information they need in order to address the opportunities and challenges arising from global environmental change, including climate change. Put another way, in light of the pressing need to move from science to action, decision support is the linchpin of the program. We note that this view is consistent with that in the National Research Council (2009b) review of the Climate Change Science Program.

A broad range of basic and applied climate science is still needed in the program and change in focus should not come at the expense of that need. At the same time, a key point of this report is that science is also needed to understand, assess, and predict the consequences of possible *responses* to climate variation and change. In addition, science is needed to improve the processes by which science supports climate-affected decisions. All these kinds of science should be use inspired (Stokes, 1997)—that is, they should contribute to informing or improving societal response to climate change. Both basic and applied science, and both natural science and social science, can meet this test.

Conclusion 6: Achieving decision support objectives requires research to understand, assess, and predict the human consequences of climate change and of possible responses to climate change. That research should be closely integrated with basic and applied research on climate processes.

Recommendation 6: The federal agencies that manage research activities mandated under the U.S. Global Change Research Act (USGCRA) should organize a program of research for informing climate change response, as a component of equal importance to the current national program of research on climate change processes. This program should include research *for* and *on* decision support, aimed at providing decision-relevant knowledge and information for climate responses.

The research for decision support should have five substantive foci:

1. understanding climate change vulnerabilities: human development scenarios for potentially affected regions, populations, and sectors;
2. understanding the potential for mitigation, including anthropogenic driving forces, capacities for change, possible limits of change, and consequences of mitigation options;
3. understanding adaptation contexts and capacities, including possible limits of change and consequences of various adaptive responses;
4. understanding how mitigation and adaptation interact with each other and with climatic and ecological changes in determining human system risks, vulnerabilities, and response challenges associated with climate change; and
5. understanding and taking advantage of emerging opportunities associated with climate variability and change.

The research on decision support should have five substantive foci:

1. understanding information needs;
2. characterizing and understanding climate risk and uncertainty;
3. understanding and improving processes related to decision support, including decision support processes and networks and methods for structuring decisions;
4. developing and disseminating decision support products; and
5. assessing decision support "experiments."

Research to understand decision support processes should include assessments of the transferability of knowledge gained from experience outside the United States, where in some cases decision support efforts have a longer and better documented history than in the United States. Requests for research support from this program should be reviewed for evidence that research results are likely to be useful to decision makers. This might include evidence that the research plan was influenced by actual researcher-user interactions, evidence of knowledge of the target decision makers' information needs and decision contexts, or a value-of-information analysis showing how particular decision makers could expect to benefit from using the information to be developed. Proposals for research on decision support might be examined for their value for improving decision support tools or systems that have already demonstrated value. Claims that a new decision support product ought to be of value would carry less weight than evidence that specific users want it or would benefit in specific ways from using it.

Recommendation 7: The federal government should expand and maintain national observational systems to provide information needed for climate decision support. These systems should link existing data on physical, ecological, social, economic, and health variables relevant to climate decisions to each other and develop new data and key indicators as needed. The effort should be informed by dialogues among potential producers and users of the indicators at different levels of analysis and action and should be coordinated with efforts in other parts of the world to provide a stronger global basis for research and decision support.

The expanded observational capability, by linking social and health data with climate and ecological data, will enable better forecasting and estimation of climate-related vulnerabilities and impacts, the costs of climate change to human well-being, and the effects on future vulnerabilities and costs of various mitigation and adaptation responses. This expansion should include, but not be limited to, the following elements:

- geocoding existing social and environmental databases and indicators relevant to climate impacts and responses at all governmental levels and in the private sector, with a special emphasis on longitudinal datasets;
- developing methods for aggregating, disaggregating, and integrating such datasets with each other and with biophysical data and reconciling inconsistencies, for example, through the use of spatial social science and GIS methods;
- creating new datasets to fill critical gaps in existing data;
- greater support for research (e.g., modeling and process studies) to improve methods for producing use-relevant information; and
- engaging decision makers at various levels and in governmental and nongovernmental sectors in the identification of critical data needs for climate-affected regions, sectors, and populations.

Datasets should be developed and maintained at levels of aggregation suitable to the needs of decision makers and matching the degree to which disaggregation can reasonably benefit them. Requests for support for developing datasets, observational systems, or indicators should be reviewed for evidence that the results are likely to be useful to decision makers or to contribute to international data development efforts. In evaluating such funding requests, plans to encourage the actual use of new data systems and indicators should also be considered.

Recommendation 8: The federal government should recognize the need for scientists with specialized knowledge in societal issues and the science of decision support in the field of climate change response. There should be expanded federal support to enable students and scientists to build their capacity as researchers and as advisers to decision makers who are dealing with the changing climate.

Encouraging multi- and interdisciplinary research on climate change impacts, decision making, and decision support is a daunting challenge, given the generally narrow focus of many scientists. A different approach is needed to meet the challenge of providing useful and timely decision support to the wide range of people and organizations that must take action to mitigate and adapt to climate change. Training and enabling a new generation of researchers on climate-change vulnerability, resilience, and response is key to meeting the challenges of climate change.

5

A National Initiative for Decision Support

As the impacts of climate change become apparent, people are beginning to realize that some of their decisions should take account of the changing climate. At least some of them have not previously thought of a changing climate as a factor relevant to the institutional choices for which they are responsible. Most of these climate-affected decision makers throughout the country need decision support. Climate change means that the future—sometimes, the near future—is going to produce situations for which the nation is currently unprepared. Standard practices—in fields from regional planning to infrastructure management to public health to emergency preparedness—that worked well in the past under an assumption of a stationary climate are no longer appropriate. Human institutions will need to change the processes by which they interpret and use climate-related knowledge. They will also need new kinds of information to help them change. And the change will need to be continual because climate will continue to change, sometimes in a foreseeable way and sometimes with surprises.

Decision support poses major challenges to decision makers and social institutions. The challenges include developing new approaches to communication between scientists and decision makers, adopting new ways of thinking and planning to incorporate longer time horizons and the major uncertainties of climate change, evolving new modes of social learning, and developing previously underdeveloped areas of science. Meeting these challenges will require a process of social learning at a large scale that occurs over decades, and its results cannot now be envisioned clearly.

Societal responses to industrialization—a fundamental change of the twentieth century—suggest the important role decision support can play when society faces major changes. Industrialization prompted the invention of new institutions—including labor unions and social security—and new decision support systems, including national economic statistics on inflation, unemployment, the gross domestic product, and the like. Those systems have become essential to the emergence of macroeconomic policies in the United States and other countries since the Depression (Stein, 1996; Hall, 1989). The indicators—together with the organizations that devise, monitor, validate, archive, and interpret them, the annual reports of the Council of Economic Advisers in the executive office of the President, and the debates they shape—are decision support systems for national economic policy. They have contributed to development of a common conceptual framework and a set of national and international institutions and have become indispensible to economic decisions in the public and private sectors. A lesson of this history is that decision support can make a difference when the federal government provides leadership in data gathering and analysis—even in that most decentralized of activities, a market economy.

Climate change will require a similarly wide-ranging process of social learning. It potentially affects all sectors of economic activity; all regions of the country; all levels of governmental and social organization; and a great variety of professions, communities, and individuals. It is useful to think of those needing climate-related decision support as constituencies—collections of decision makers that may be defined by the kinds of climate-related hazards or opportunities they face, the kinds of climate-affected decisions they must make, shared legal or regulatory mandates, a regional location, or the fact that they are already organized as a constituency. Focusing decision support efforts on constituencies is an effective way to organize them around users' needs. Some climate-affected constituencies are linked to government agencies with mandates to assist in their decision making—including local air and water quality agencies and the Air and Water Offices of the Environmental Protection Agency (EPA); coastal and water managers and the Climate Program Office of the National Oceanic and Atmospheric Administration (NOAA); emergency responders and the Federal Emergency Management Agency—and some are not. Some of those affected already have formal organizations that can collectively request and receive decision support; others do not. The key principles for implementation of decision support (see Chapter 2) are well established from research and experience in operations research and the decision sciences and in various endeavors to make scientific knowledge information useful for practical decision making, and apply across constituencies.

The principle of designing for learning is particularly important over the long run. As the climate is changing, change is also occurring in scientific understanding, in experience with response options, and in the needs identified as critical for decision making. In such an environment, effective decision support cannot be reduced to a stable bureaucratic formula or be optimally designed from the outset. Rather, climate decision support must be designed to recognize local contexts and surprises and to improve over time, as climate change unfolds, as more organizations across society come to address climate change on a regular basis, and as scientific understanding of climate changes. Several types of deliberate learning processes, including program evaluation and adaptive management, could prove effective. But an analytic-deliberative approach to decision making and learning, which integrates scientific information into a broadly participatory and iterative process of appraisal and reconsideration, is usually best suited to the kind of decision environment that is typical in responding to climate change: one characterized by changing physical conditions, changing information, and multiple participants with different and sometimes changing objectives.

THE FEDERAL ROLE IN DECISION SUPPORT

It is important to emphasize that in developing new structures and institutions for decision support, the federal government plays an important but not exclusive role. To change the energy system and learn to live with a climate system that is no longer stationary, millions of decision makers—state and local governments and their agencies, large and small businesses, nonprofit organizations, as well as individuals and households—will need information, and much of this information will be provided from sources other than the federal government. This multiplicity of information sources is desirable because there will be no one best source of information for the wide range and variety of decision makers with their varied needs.

A federal role and federal leadership are essential, however, for informing national responses to climate change. In Chapter 1 we identify four roles for federal agencies: (1) service to agencies' constituencies and to other climate-affected constituencies that cannot otherwise get the information they need; (2) international collaboration; (3) provision of public goods (research, observations, communications links, etc.); and (4) facilitation of decision-making processes by nonfederal entities. Chapters 2, 3, and 4 include several recommendations regarding ways to perform these roles.

Decision support requires resources: money, new kinds of expertise, training of people in new skills, new interorganizational relationships, and supportive forums and organizations. The federal government is not the only source of these resources. Businesses will find opportunities to profit by supplying decision support in the form of new services and products, as already occurs, for example, with consulting firms and with companies that highlight the need for—and then offer to sell—carbon offsets for air travel-ers. Professional associations, such as the Association of State Floodplain Managers, and philanthropic organizations also provide resources. For example, the Climate Works Foundation, formed with support from several major philanthropies, aims to assist India, China, the United States, Latin America, and Europe to undertake large-scale mitigation of greenhouse gas emissions. Communities at many scales, from Alaska native settlements facing melting permafrost to professional associations revising codes of practice to take account of changing climate, are already generating decision support for their members—with potential lessons for others. And of course, public and private scientific institutions, which were the first to recognize climate change, will also contribute. Still, none of these institutions and organizations can take the place of the federal government.

A NATIONAL INITIATIVE

Federal efforts to provide and promote climate-related decision support should be coordinated within a new integrated, interagency initiative. All the recommendations for federal action described in the previous chapters can be implemented in an integrated fashion under the umbrella of the initiative, as described below.

Recommendation 9: The federal government should undertake a national initiative for climate-related decision support under the mandate of the U.S. Global Change Research Act (USGCRA) and other existing legal authority. This initiative should include a service element to support and catalyze processes to inform climate-related decisions and a research element to develop the science of climate response to inform climate-related decisions and to promote systematic improvement of decision support processes and products in all relevant sectors of U.S. society and, indeed, around the world.

The Service Element in the National Initiative

The service element of the national initiative should support the creation and expansion of decision support networks and processes that implement the principles of effective climate-related decision support in federal agencies and beyond. To do so, it should support demonstration and development activities to promote the emergence of decision support systems to serve climate-sensitive constituencies that are currently underserved. Priority should be given to constituencies on the basis of agencies' mandated responsibilities, the vulnerability of their mandated and potential constituencies to climate change, and the difficulty of those constituencies in developing resources for themselves. These activities might include new or expanded programs to serve agencies' constituencies, support for decision dialogues, pilot programs to demonstrate effective processes for climate decision support in particular sectors, and other constituency-based activities to define decision support needs and build communication networks.

The national initiative should also support learning networks that link multiple decision support activities and thus facilitate informal learning across the activities and support state and local governments in developing decision support services with and for them and their constituencies, following the federal model if they have not already developed their own. Recommendations 2 (in Chapter 2) and 5 (in Chapter 3) offer details. The initiative should also build national decision support capacity by making investments in human resources and in institutionalizing practices that consider climate change in decision making. For example, federal support will be needed for training people to produce and use knowledge, methods, databases, and indicators inspired by the need for climate-related decision support and to improve communication between the producers and users of decision support products (see Recommendation 8 in Chapter 4 and the discussion of the research element below).

The national initiative and participating agencies can develop the national capacity to identify climate-sensitive constituencies and interact with them by providing human resources, funds, professional training and education, and leadership in federal environmental and climate agencies, encouraging a systematic perspective, and in some instances establishing mandates to use climate-relevant information. Moreover, federal agencies can work with climate-sensitive constituencies to develop draft rules, standards, and procedures for the appropriate use of climate-related information for making decisions, such as for infrastructure construction in low-lying coastal areas and water and fire management in areas expected to see increasingly severe droughts. Agencies can also support pilot-scale demonstrations of such new standards and procedures.

Federal agencies that serve constituencies that need climate-related decision support should provide such services, following the principles of effective decision support process and using the model of deliberation with analysis where feasible. These include agencies now participating in the Climate Change Science Program (CCSP), but also many others. As noted above, federal agencies can also encourage and facilitate the provision of decision support by state and local governments and nongovernmental organizations to nonfederal constituencies around the nation. The Regional Integrated Science and Applications (RISA) Program centers of NOAA provide operational examples that show how a government agency can facilitate the development of effective decision support processes.

The service element of the national initiative should include the periodic assessment required under Section 106 of the USGCRA, to integrate and interpret scientific findings and uncertainties related to the effects of global change and current and projected major trends in global change. In discharging this legislative mandate, the Global Change Research Program should follow the principles of effective decision support: In particular, the assessment should flow from a participatory process that is driven by users' needs. In recent years, a series of synthesis and assessment products has been put forward as a response to the requirement of Section 106. Although several of these products and the "Unified Synthesis Product" now in preparation provide useful information for decision making, a systematic user-driven process should underlie the development of these assessments in the future to increase the usefulness and use of the information they provide.

The Research Element in the National Initiative

The research element of the national initiative should develop the science of climate response with two foci: research *for* decision support, aimed at providing decision-relevant knowledge and information; and research *on* decision support, aimed at making decision support activities and associated decision processes more effective, efficient, and capable of learning.

A major new scientific research effort is needed to better inform responses to climate change. Attention to the needs of the users of scientific information—a cornerstone of decision support process—will help generate some of the new scientific research priorities. As noted above, this effort needs to draw on many fields of scientific inquiry, scholarship, and analysis, of which climate science is only one. The effort would particularly include the social, behavioral, and economic sciences and integrate them with research, concepts, and methods from the natural sciences and engineering.

To provide the needed research for informing climate change response, the national initiative should expand the current federal research effort from its current focus on climate processes and technology. That expansion would add research on changes in society that determine the trajectory of climate change and shape its impacts, about the ability of people and organizations to respond, about effective ways to respond, and about the likely intended and unintended consequences of the various responses people are considering. A major expansion of research on these topics is already required simply to meet the needs identified by the existing constituencies of NOAA and EPA—and the demand is likely to expand both in substance and in breadth as climate changes continue.

In Chapter 4 we identify some general rubrics under which much of the needed research is likely to fall (see Recommendation 6). However, the research program for decision support cannot be fully defined in advance because it will emerge in part from dialogue between those who need decision support and those who will produce it. Such discussions can be expected to generate research questions that are not yet on anyone's agenda. For example, dialogue will often identify needs for knowledge and information focused on very specific questions of importance to particular decision makers.

Achieving the objectives of the research focus on decision support will require investments in monitoring and evaluation of decision support activities, processes, and products and the institutional resources and infrastructure to support analysis, deliberation, and iterative learning. To achieve these objectives, the national initiative should include support for a clearinghouse function—either a formal organization or a set of distributed organizations and activities (e.g., research centers, websites, interactive databases, Wikis) that collect information on the results of decision support efforts, conduct research on these results, and make the knowledge gained widely available to facilitate learning by future decision support activities. Such organizations and activities would gather both formal evaluations of decision support efforts and case histories and other qualitative information on these efforts and make them accessible so that those developing new decision support activities and products can learn from the experiences of others. The national initiative should provide leadership in developing ways to assure the quality of information provided by those organizations and activities. Some of the research recommended in this report would use those organizations and activities both as sources of data and as disseminators in making research results broadly available.

Observations and Human Resources in the National Initiative

The national initiative should also expand observational systems to provide information needed for decision support and strengthen the workforce needed to conduct the recommended research and better link the providers and users of information for climate-affected decisions; see Recommendations 7 and 8 (in Chapter 4). The expansion of observational systems will link existing data on physical, ecological, social, economic, and health variables relevant for climate-related decision support from many sources and develop new data as needed. Important efforts in this expansion will include improving accessibility of data at relevant scales, developing effective ways to link data of different kinds, developing useful indicators from the data, and linking U.S. data systems with international data development efforts.

ORGANIZATION OF THE INITIATIVE

Although the idea of a national initiative could be interpreted as implying a new organizational entity, we do not think it advisable to centralize the initiative in a single agency. Doing so would disrupt existing relationships between agencies and their constituencies and formalize a separation between the emerging science of climate response and fundamental research on climate and the associated biological, social, and economic phenomena. However, our recommendations do imply significant change in the ways many federal agencies serve their constituencies, coordinate with each other and with nonfederal decision makers, and set priorities for research. They also identify an important new federal responsibility—to facilitate distributed responses to climate change—that has no obvious agency home. And they call for significant changes in the nation's research program related to climate change, including the development of scientific fields that have received little support in the past, that have not recently been mission priorities of any federal agency, and that the agencies are ill prepared to develop.

A major organizational effort will be needed to ensure that the recommended activities form a coherent initiative in which the whole will be more than the sum of the parts. Significant restructuring from the current structure of the CCSP and the U.S. Climate Change Technology Program (CCTP) with their interagency working groups will be required. Most of the elements of the initiative will still require an interagency coordination structure, but its form will be different from the current one (see below).

The most effective organizational form for implementing our recommendations is best left to the new national administration to decide, as it may simultaneously be reorganizing other activities of the relevant agencies. We note, however, that we do not believe any new legislative authorization is needed. The necessary coordination can be achieved under the USGCRA of 1990, which provides the necessary responsibility to the National Science and Technology Council (NSTC). The NSTC can develop the recommended initiative in coordination with the new climate and energy office in the Executive Office of the President. The following sections discuss the main issues for restructuring and offer our suggestions for them.

More Participating Agencies

Understanding responses to climate change and serving climate-affected constituencies will require the involvement of many more agencies than now participate in the CCSP, as well as of offices that are in CCSP member agencies but are not now part of the program. For example, land and water management agencies, such as the Bureau of Land Management, the National Park Service, and the Bureau of Reclamation, are affected by climate change, need decision support, and would benefit from being better integrated with climate research. Agencies that produce data on human activities that drive or are affected by climate change, such as the Census Bureau, the Bureau of Economic Analysis, and the Energy Information

Administration, also need to be involved in the initiative. Agencies that support science education should also participate. With such an increase in the number of organizations and a proliferation of tasks—including providing services, doing research, and developing observation systems—the existing interagency working group organization will require modification. For example, a special interagency working group might be needed to coordinate the development of data systems to link environmental and socioeconomic data.

New Tasks

It makes sense to organize the decision support efforts for particular constituencies in the agencies that serve those constituencies, as is done by the NOAA Sectoral Applications Research Program for coastal and water managers. But, in many cases, the most obvious agencies do not consider such decision support activities as part of their missions and lack offices and personnel with the responsibilities and expertise needed to manage the research. For example, it would make sense to locate decision support research and services related to energy-efficient choices in homes in the Department of Energy (DOE). However, such activities have been peripheral to the DOE mission for quite some time, and the department has not supported research on household energy choices since the early 1980s.

Many environmental agencies, like DOE, define their research missions mainly in terms of studying environmental phenomena as physical, biological, and engineering questions, not in terms of studying human–environment interactions. With such foci, human–environment research is neglected in terms of budgets, the available staff may not have the skills or training to manage the efforts, and this research area may not receive the requisite support from higher levels in the agency. There is a lack of integration across bodies of knowledge and practice needed for effective decision support throughout the federal government, as shown in the analyses presented in Chapter 2.

Thus, in responding to demands for decision support, officials responsible for the national research effort will need to find ways to ensure that the relevant agencies have the needed funds and staff and that agency managers are given the responsibilities and resources needed for the programs. The lack of expertise and funds is especially acute for the social sciences: many environmental agencies have historically lacked staff with the requisite expertise, funds, and organizational commitment in those fields.

Some of the new tasks in the decision support initiative do not have obvious homes in the federal government. One of these is research on climate-related decision support. Research on decision support for particular constituencies can usefully be decentralized to mission agencies, but research on decision support processes and methods of general applicability has no obvious home in any environmental agency. The National Science Foundation (NSF) does and can support some such research through its Division of Behavioral, Social, and Economic Sciences, which supports basic research on communication and decision making. However, still lacking is a place for enterprises that would link basic research studies to environmental and socioeconomic observations, to workforce development in decision support science and services, or to the federal agencies and other organizations that provide decision support. NSF might serve as an appropriate coordinating point. However, because these linking functions do not currently fit comfortably within the central mission of NSF, leadership and skillful coordination would be needed by the agency and its partners to make scientific research on decision support useful.

Relationship to Ongoing Research

The decision support initiative we recommend would complement the existing efforts of the federal research program (the CCSP and the CCTP) by adding the foci of research for decision support and on decision support. We believe that the research program needs expansion in other ways as well, in order to develop fundamental knowledge in areas that provide the scientific underpinnings of research for decision support (such as research on the social drivers of energy consumption, land-use change, and climate vulnerability; on decision making under uncertainty; and on institutional mechanisms for controlling resource use; see Stern and Wilbanks, 2008).

A new report from the Committee on Strategic Advice to the U.S. Climate Change Science Program (National Research Council, 2009b) provides recommendations on future priorities for the CCSP. We believe that the research recommendations of that study and ours are mutually supportive. The Strategic Advice Committee report addresses fundamental research issues that are beyond the scope of this report. However, its advice on ways to expand fundamental knowledge to inform decision making is consistent with our recommendations for the research element of the national decision support initiative. Together, the two reports call for significant change in research activities being conducted under the authority of the USGCRA, including developing underdeveloped areas of research and finding appropriate organizational homes in the federal research program for research areas that do not now have them. Both reports also call for development of research along a continuum from fundamental to narrowly applied, but linked together by their relevance to understanding and responding to climate change.

Central Authority and Collaboration

The current CCSP office has a coordinating function and as such, has a minimal operational budget. It has no direct authority over the participating agencies' climate science research agendas or related programmatic activities. Continuation of this situation is likely to pose a serious roadblock for expanding the research program and adding a service element, especially because the participating agencies will likely face considerable budgetary pressures. There are several possible ways to address this challenge, such as providing a central budget to the coordinating office or offices and using the national budgetary process as described in the USGCRA (through the Office of Management and Budget) to allocate needed funds to the relevant agencies. Because some of the new tasks entail change in agencies' traditional missions, effective leadership by the new White House coordinator of energy and climate policy will be needed to ensure that any distributed funds are used for the national initiative. It seems likely that successful implementation of the initiative will also require high-level commitment in the participating agencies to the new decision support mission.

The federal effort on climate-related decision support will have to involve unusually effective collaboration among federal agencies because many agencies need decision support, provide information needed for decision support, or serve constituencies that need decision support. Thus, the effort should extend far beyond the agencies currently involved in the CCSP. This breadth will require strong leadership from the Executive Office of the President, including the science adviser and the new coordinator of energy and climate policy.

To fully meet the mandate under the USGCRA to "assist the Nation and the world to . . . respond to human-induced and natural processes of global change," we believe that the federal government, through the NSTC, will need to comprehensively reformulate its plan for implementation of the act. The next phase of that implementation should include research on the fundamental biophysical and human dimensions of climate change, as well as research for and on decision support, improvement of observational system and indicators, and monitoring, service provision, and human resource development. The research effort should expand on the activities currently being pursued under the CCSP and the CCTP and be closely integrated with those research activities. Any federal activities that might be included in a national climate service (see below) should be part of the initiative.

The current climate research enterprise is organized under two interagency working groups: the CCSP and the CCTP, with other interagency groups functioning under them. We believe a similar general structure will be appropriate in the future, although with the groups defined differently. Organizing by climate-related societal issues, such as suggested by the

Committee on Strategic Advice on the CCSP (National Research Council, 2009b), is an attractive possibility. Within that recommended organization, some decision support research and service activities could be organized topically, but others, such as development of observational systems and human resources and research on decision support processes and methods, might require a cross-cutting organization. Such a structure could help coordinate research and development on technology with research on its costs, benefits, adoption, and use—an important coordination need for climate response.

Relationship to a National Climate Service

The idea of a national climate service in or led by NOAA has received considerable attention in recent years. As of this writing, the idea is in flux, with no agreement on its purview, mandate, or organizational location. In our view, any form of national climate service should implement the principles of effective decision support. Thus, it should develop decision support products by means of communication between information providers and users. If this communication is productive, scientists will alter some of their research priorities to make their research more useful. For this reason, we believe any national climate service should be part of our recommended decision support initiative and linked to its research element.

There are different views regarding whether decision support activities, including a National Climate Service, should be separate from or integral to the research program. For example, the Committee on Strategic Advice on the CCSP (National Research Council, 2009b) recognizes the need for strong linkages between the research and service components, but raises the argument that demands for service could overwhelm the research program. Because of the evidence that decision support is most effective when it emerges from a process that is guided by users and that such a process can shape research agendas in ways that yield more useful research products, this panel concludes that close coordination between service and research functions is critical for making research useful for decision support. Moreover, we believe the lesson from past experience is that research and service functions both do better when they collaborate than when they proceed separately.

One concept of a national climate service is that a new organizational entity would be created in NOAA, modeled on the Weather Service, that would transform data from climate models into decision support products intended for use by various kinds of decision makers and would disseminate that information publicly. We do not believe this model by itself would meet national needs for climate-related decision support because it does not fully implement the principles of effective decision support. In particular, this model does not make adequate room for communication with an input from information users, especially those who do not normally interact with NOAA. Such a climate service would not be user driven and so would likely fall short in providing needed information, identifying and meeting critical needs for research for and on decision support, and in adapting adequately to changing information needs. In addition, this model of a climate service is focused only on providing information about climate: It would therefore fail to develop and provide the many kinds of nonclimate information that climate-affected decision makers also need.[1]

If a national climate service is created, we believe it should follow a much more user-driven and interagency organizational model, be closely linked to the research program, and have a purview that goes beyond developing and providing information about climate. We also believe that in addition to any new organizational entity, such as a climate service, individual federal agencies should develop efforts to provide decision support for their climate-affected constituencies.

The realization throughout the nation that Earth's climate is changing frames a moment of need and opportunity. The need, emerging over the years ahead, is for knowledge to inform Americans about the implications of the changing climate in their personal choices, organizational responsibilities, and public policies. Growing out of the strong base of analysis in the natural and applied sciences of weather and climate forecasting and with additional investment in the science of climate response, there is an opportunity to empower people to face a transition to a world that people have remade and continue to remake.

[1]This text was changed from the prepublication version to clarify the panel's meaning.

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Appendix A

Climate Change and the New York Metropolitan Region

The New York metropolitan region has a population of more than 21 million people, spans three states (New York, New Jersey, and Connecticut), and consists of more than 1,000 municipalities. New York City, its core, is the most populous city in the United States, with 8.2 million people and an operating budget of about $60.2 billion. A million more residents are projected by 2030 (see http://www.nyc.gov/html/planyc2030/html/home/home.shtml [accessed December 2008]). The region has been grappling with the risks posed by climate change actively for at least a decade and is now a leader in responding to climate change both nationally and internationally.

This appendix first focuses on the processes that led to the region's efforts to respond to climate change and how the region's experiences exemplify many of the key points about decision support in the report. Those points include the multiplicity of climate-related decisions faced by the region (Chapter 1), characterization of effective decision support processes (e.g., what works and what does not work) (Chapter 2), identification of information needs for both climate and nonclimate information (Chapter 4), and ongoing learning by decision support systems (Chapter 3).

The appendix then describes three phases of active involvement with climate change: The Metropolitan East Coast Regional Assessment of Climate Variability and Change (MEC) released in 2002; the New York City Department of Environmental Protection Climate Change Task Force, which operated from 2004 to 2006; and PlaNYC, the sustainability plan formulated by Mayor Bloomberg and the Office of Long-Term Planning and Sustainability in 2006 (see http://www.nyc.gov/html/planyc2030/html/home/home.shtml [accessed February 2009]).

THE NEW YORK REGION'S EXPERIENCE

A Multiplicity of Climate-Related Decisions

The climate change decision landscape of the New York Metropolitan Region has many dimensions and is inhabited by many decision makers. The first decisions directly related to reducing climate change involved setting an ambitious goal for mitigation, which is set in the city's plan, PlaNYC, as a 30 percent reduction of greenhouse gas emissions by 2030 from 2005 levels, and then the implementation of actions to accomplish that goal. One of the first actions was an announcement by Mayor Bloomberg of a long-term plan to reduce energy consumption and greenhouse gas emissions from the city's municipal buildings and operations by 30 percent much earlier—by 2017. This reduction would cut the city's annual output of greenhouse gases by nearly 1.7 million metric tons and reduce peak demand for electricity by 220 megawatts (see http://www.nyc.gov/news [accessed July 2008]).

Accomplishing the goal will take literally thousands of individual decisions in order to upgrade existing municipal buildings, including firehouses, police precincts, sanitation garages, offices, and courthouses. Such decisions include determining choices of energy-efficient facility lighting; refrigeration units; boilers; office equipment; and heating, ventilating, and air conditioning systems. In addition to purchasing decisions, the city is focusing on ways to operate buildings more efficiently, especially through developing and implementing preventive practices in buildings that consume large amounts of energy. For example, leaking pipes, clogged steam traps, and inefficient air distribution, pumps, and fan systems will need to be systematically identified and repaired.

As a coastal megacity, New York City also faces complex decision challenges on climate change adaptation. The decision environment consists of intertwined jurisdictions of city, state, two-state, and federal agencies. For example, for adapting regional transportation to potentially more damaging coastal floods, New York State has several corporate public authorities to further public interests, including the Metropolitan Transit Authority (MTA) and the Port Authority of New York and New Jersey. Complications in decision making and funding arise since New York State, New York City, and surrounding counties all share in the governance of these bodies.

This complex decision landscape, the multiplicity of decision makers, and the evolving nature of climate change together create a complicated and evolving set of information needs for New York City and the region. The processes that have emerged combine analysis, deliberation, and ongoing revisiting of choices to inform mitigation and adaptation policies as they are implemented. Some decisions need to be made immediately, while others are set on the horizon as decision-making frameworks are devised, climate indicators tracked, and technologies and policies tested.

What Worked and What Did Not

The New York Metropolitan Region can be considered a test of decision support processes for climate change since it has been addressing the issue in a variety of ways for about a decade. Such processes appeared to be more effective when there was active and open engagement among regional decision makers and climate change experts from a range of disciplines, including physical, biological, and social science. Creating an environment of mutual learning, respect, courtesy, and trust was also important to effective outcomes, with balanced contributions from both the decision makers and the experts. For the most part, these interactions were then able to guide the production of decision support products that were salient, credible, and legitimate.

For example, the MEC explicitly created a partnership with representatives from institutions responsible for managing key sectors and services (see below). The stakeholders from the transportation, water, health, and energy sectors (among others) and climate change expert partners collaborated on developing assessment questions, provided ongoing feedback throughout the entire process, reviewed products, and helped to shape key conclusions and messages arising from the assessment.

Of course, differences among stakeholders coming from the public sector and experts from research institutions did arise, sometimes as a result of differing constraints in terms of providing open access to data. Another challenge for the process was that social and political processes beyond the influence of those directly involved sometimes determined whether and how the information was used effectively.

At the community level, community involvement was and is a key aspect of the decision environment in New York City, since there are numerous activist groups focused on environmental justice and urban ecology. For PlaNYC, in which responding to climate change plays a central role, the community was involved in the creation of PlaNYC through website interactions and through town hall, neighborhood, and advocacy organization meetings. However, these early interactions were limited by time and opportunity. The ongoing engagement of communities with climate change adaptation is a specific focus on PlaNYC, with a neighborhood-based education effort planned for 40 communities.

Finally, a key element to successful "mainstreaming" of climate change in the region could be termed buy-in from the top. For example, the ground-breaking work on climate change in relation to the New York City water system was actively initiated and then supported by two commissioners with great foresight and courage (see below). Just as those responsible for creating the upstate water system for the city in the 1840s had a planning horizon of 100 years, these present-day commissioners took on the challenges that climate change poses to the city's water system in the coming century. The engaged leadership of the mayor for PlaNYC has been essential to the attaining goals in terms of both mitigation and adaptation.

Information Needs

Among the information needs for climate change decision making in the New York Metropolitan Region is an understanding of current and future climate risks. This understanding has been found to be a critical prerequisite for the assessment of effective and efficient adaptation and mitigation strategies and policies in this complex urban area. A risk-based framework has been devised that combines physical science, geographical, and socioeconomic components (climate indicators, global climate change scenarios, downscaled regional scenarios, change anticipated in extreme events, qualitative assessment of high-impact and low-probability events, associated vulnerabilities, and the gap between existing responses and the flexible adaptation pathways needed) that can be used by the hundreds of municipalities in the region to create and carry out climate change action plans (Rosenzweig et al., 2007). Attention has been paid to articulating the differential effects on poor and nonpoor urban residents, as well as on drawing practical lessons from successful policies and programs at the city level.

The climate risk framework used in the region is composed of a set of quantitative and qualitative indicators, used as inputs to climate change action planning; see Box A-1. The indicators are used to track current climate trends and variability so as to enable comparisons with historical data and future scenarios. Recent simulations of global climate models are used as the basis of regionalized urban climate change projections, with statistical downscaling and regional climate models to make higher-resolution (both temporal and spatial) nested scenarios. Since many climate change effects are experienced in urban areas in relation to extreme events, specific analyses are presented of how probabilities of such events may change in the future. An especially challenging part is the presentation of information regarding low-probability but high-impact changes in the climate system, such as dramatic reductions in continental ice, leading to sea-level rise, and its effect on the region. These indicators are used to conduct assessments of the key vulnerabilities of the region, especially of the urban poor, and to devise climate protection levels and flexible adaptation pathways.

BOX A-1
Climate-Risk Framework Used in New York Metropolitan Region

Current Climate
- Current climate trends, indicators, and variability

Global Climate Models and Emissions Scenarios (Update ~5 years)
- Global climate models characterize climate uncertainty (International Panel on Climate Change, 2007a, 2007b)
- Greenhouse gas emissions scenarios span a range of development futures—population, gross domestic product, technology

Regional Climate Scenarios for Key Variables
- Downscaled model-based probabilities for New York City characterize risks
- Regional climate model simulations

Extreme Events
- Frequency and intensity of heat waves, flooding, droughts, and hurricanes and other storms

High Impact Scenarios
- Ice sheet melting and Greenland/Arctic Sea ice extent are monitored and evaluated

Monitor and Reassess

Presentations on climate change in the New York Metropolitan Region often end with the words, "monitor and reassess!" Decision support in the region, now beginning its second decade, is a diverse, dynamic process that is continuously adapting. Not only is the climate system itself changing (as is scientific understanding of those changes), but the decision environment is also constantly changing. These evolving circumstances highlight the importance of following good decision-making process, since mitigation and adaptation decisions made one decade surely require monitoring, evaluation, and very likely revision in the next.

One means of monitoring and reassessing climate change in the region (and beyond) is a loose "knowledge network" of experts who have worked on a broad spectrum of climate change research. Periodically, those experts get together for wide-ranging discussions on evolving understanding of key issues and innovative approaches for decision support tools. Such meetings of the knowledge network support the collection and sharing of knowledge from the experience of developing decision support and function as clearinghouses of information on these experiences.

THREE MAJOR INITIATIVES

The following sections of the Appendix describe three major climate change initiatives undertaken in the New York Metropolitan Region, beginning in 1998.

Metropolitan East Coast Regional Assessment

MEC laid the foundation for engagement with climate change in the New York Metropolitan Region (Rosenzweig and Solecki, 2001). As one of the regional components of the U.S. National Assessment of the Potential Consequences of Climate Variability and Change, MEC investigated potential risks of climate variability and change, identified key vulnerabilities to the stresses that climate change is likely to introduce, and examined feasible adaptation strategies. It also drew attention to the need to mitigate atmospheric greenhouse gas concentrations in order to reduce long-term risks.

The process of the MEC strongly linked researchers and stakeholders and consisted of four major activities: workshops, stakeholder involvement, sector assessments, and integration. For example, the Metro East Coast Climate Impacts Assessment Workshop, in March 1998, brought regional stakeholders, government representatives, scholars, nongovernmental organizations, and members of the general public together to explore the creation of an integrated regional assessment of climate impacts. This workshop served to develop a network of stakeholders, to initiate the assessment of vulnerabilities and opportunities posed by climate change, and to recommend future steps to develop partnerships among stakeholders, researchers, and the federal government regarding climate variability and change.

The MEC assessment focused primarily on stakeholder institutions, whose activities are and will be affected by climate variability and change and thus have a stake in being involved in research of potential climate adaptations. From its inception, MEC created a partnership with representatives from institutions with responsibility for managing key sectors and services. The stakeholder partners collaborated on developing assessment questions, provided ongoing feedback throughout the entire process, reviewed products, and helped to shape key conclusions and messages arising from the assessment.

The assessment examined climate variability and change impacts and adaptations related to six sectors: coasts, wetlands, infrastructure, water, health, and energy. A seventh sector—decision—analyzed decision making across all the other sectors. The sector teams, composed of researchers from local universities and stakeholder partners from relevant agencies, focused on identifying vulnerabilities, adaptation strategies, policy recommendations, and gaps in knowledge. The sector studies addressed climate impacts and adaptation through analyses of historical climate trends, case studies of responses to extreme climatic events in the region, and scenario projections.

The assessment examined how three interacting elements of large cities react and respond to climate variability and change: *people* (i.e., sociodemographic factors), *place* (i.e., physical and ecological systems), and *pulse* (i.e., decision-making and economic activities). This focus on integration helped to avoid the common isolation of sector analyses and was instrumental in elucidating one of the major conclusions of the assessment: that key urban effects of climate variability and change are likely to occur simultaneously at the intersection of sectors. For example, heat stress in the poor and elderly (a concern of the public health sector) will probably increase during energy blackouts (the responsibility of the energy sector). The MEC assessment found that effects will be dynamic and that their intersections will change over time.

New York City Department of Environmental Protection (NYCDEP) Climate Change Task Force

Following the federally led MEC, work on climate change proceeded in the region in individual agencies. For example, the New York City Department of Environmental Protection (NYCDEP) has responsibility for the New York City water system, which supplies water for 9 million people. The MEC study found that it is a mature infrastructure system, that its managers are skilled at dealing with existing hydrologic variability, and that there are many potential adaptations to the possible effects of climate change in the city's water supply, sewer, and wastewater treatment systems. In 2004, the NYCDEP created a Climate Change Task Force, with the mission to "ensure that all aspects of Departmental planning: (1) take into account the potential risks of climate change on the City's water supply, drainage, and wastewater management systems, and (2) integrated GHG emissions management to the greatest extent possible" (New York City Department of Environmental Protection, 2008). Noteworthy in this mission statement is the inclusion of both adaptation and mitigation climate change response goals for the department.

The work of the NYCDEP Climate Change Task Force focused primarily on the water supply, sewer, and wastewater treatment systems, but the approach would have wide application for other urban areas, especially those in coastal locations, as well as for other coastal and upland infrastructure. Since many climate change adaptations identified help to increase the robustness of current systems, the task force had immediate benefits by improving responses to present-day climate variability.

Task Force Process

The task force included representatives from all of the operating and planning bureaus in NYCDEP, along with experts from Columbia University's Center for Climate Systems Research and other universities and engineering firms. A key element of the process was that it was agency wide, allowing the development of an integrated climate change program throughout the entire organization. An agencywide approach provides organizational benefits even beyond climate change planning in fostering communication among bureaus within the agency.

From October 2004 to December 2005, the task force held a series of monthly meetings, each focused on particular elements of its work, provided advice to senior agency planners on climate change, held climate change workshops for agency personnel, and engaged in outreach to other city and regional agencies to build links for work on projects and programs of mutual and interrelated interest, with the ultimate aim of building a regional climate change program. The work of the task force included science, adaptation, mitigation, outreach, and coordination.

As part of the task force activities, the climate scientists developed climate information and adaptation assessment frameworks in conjunction with agency and private-sector partners. The climate information framework consists of current and historical climate observations, downscaled climate change scenarios from global and regional climate models, projections of changes in the risks of extreme events (including hurricanes, northeastern storms, heat waves, droughts, and floods), and focused analyses of sea-level rise and storm surges, including recent ice-sheet melting. The scientists also helped to coordinate climate impact projects to yield maximum benefits from research.

The adaptation assessment framework set out six goals:

1. gain understanding of current climate risks,
2. anticipate future climate change risks,
3. determine climate protection levels,
4. evaluate flexible adaptation pathways,
5. utilize insurance and policy strategies, and
6. monitor and reassess.

The sixth step is important in order to provide mechanisms for updating climate observations and scenarios over time and to track the dynamics of a changing climate.

Task Force Products

The major product task force is a Climate Change Assessment and action plan for the agency (New York City Department of Environmental Protection, 2008). The action plan consists of five tasks:

Task 1: Work with climate scientists to improve regional climate change projections.

Task 2: Enhance DEP's understanding of the potential impacts of climate change on the Department's operations.

Task 3: Determine and implement appropriate adaptation to DEP's water systems.

Task 4: Inventory and manage greenhouse gas emissions.

Task 5: Improve communication and tracing mechanisms.

The main conclusions of the NYCDEP task force are that climate change will have wide-ranging, pervasive impacts on the city's water supply, sewer, and wastewater treatment systems and that managing the climate change risks is an important element in the department's efforts to fulfill its operating, investment, and fiduciary obligations.

PlaNYC

In September 2006 Mayor Michael Bloomberg created the Office of Long-Term Planning and Sustainability, with the goal of developing a sustainability plan for the city. Building on the ongoing work of the NYCDEP Task Force on Climate Change, the city administration decided that responding to climate change would play a prominent role in that plan, now known as PlaNYC (see http://www.nyc.gov/html/planyc2030/html/home/home.shtml).

A Sustainability Advisory Board was formed, comprised of leading citizens with relevant backgrounds to guide the effort by identifying the major issues affecting the city's future. Working groups were also created comprised of a broader group of experts in key areas, including urban design, green buildings, climate change, and transportation. Mayor Bloomberg presented the goals of the sustainability program, PlaNYC 2030, in December 2006 and the actual plan in April 2007.

The plan includes specific goals in five areas: land, water, air, energy, and transportation—with an overarching climate change goal to reduce global warming emissions by more than 30 percent below 2005 levels by 2030 (see Table A-1). Over 100 proposed actions are associated with the goals, including ways to reduce New York City's contribution to greenhouse emissions on the changing climate and also how to adapt to the projected climate changes in the city in the next two decades and beyond.

Decision Environment

The plan includes a detailed structure for implementation, including the identification of lead agencies and budget allocations. The oversight of each initiative is assigned to a lead agency. These lead agencies range from city agencies, such as the Department of Parks and Recreation, to joint

TABLE A-1 Six Focus Areas and Ten Goals of PlaNYC 2030

Area	Goal
Land	
Housing	Create homes for almost a million more New Yorkers, while making housing more affordable and sustainable.
Open space	Ensure all New Yorkers live within a 10-minute walk of a park.
Brownfields	Clean up all contaminated land in New York City.
Water	
Water quality	Open 90% of waterways for recreation by reducing water pollution and preserving our natural areas.
Water network	Develop critical backup systems for our aging water network to ensure long-term reliability.
Air	
Air quality	Achieve the cleanest air of any big city in America.
Energy	
Energy	Provide cleaner, more reliable power for every New Yorker by upgrading our energy infrastructure.
Transportation	
Congestion	Improve travel times by adding transit capacity for millions more residents.
State of good repair	Reach a full "state of good repair" on New York City's roads, subways, and rails for the first time in history.
Climate Change	
Climate change	Reduce global warming emissions by more than 30%.

SOURCE: PlaNYC (2009).

agencies, such as the MTA. Responsibilities that must be taken outside city jurisdiction are also identified. Additionally, the plan sets future milestones by the years 2009 and 2015, such as "plant 15,000 street trees per year," and project budget allocations are made. Required New York City investments in both capital and operating budgets are identified, as well as other funding sources. However, funding the PlaNYC initiatives has proved challenging, since a significant portion of the New York City budget comes from the state, and state support is necessary for major new initiatives such as congestion pricing to control motor vehicle travel in parts of the city.

Climate Change Agenda

In April 2008 the mayor's Office of Long-Term Planning and Sustainability issued a "report card" indicating the status of the many PlaNYC initiatives (see http://www.nyc.gov/html/planyc2030/downloads/pdf/progress_2008_climate_change.pdf [accessed December 2008]). In regard to climate change mitigation, the report card identified significant progress in transit-oriented rezoning, fuel-efficient taxis, tree planting, reflective roofing requirements in new building codes, and rules allowing fuel-efficient microturbine generators that directly reduce the city's carbon footprint. Transport of solid waste out of the city was switched from truck to barge and rail in Staten Island and the Bronx, and similar arrangements are being negotiated for the other boroughs.

On the legislative side, the city council passed in November 2007 codified PlaNYC's goal of reducing citywide greenhouse gas emissions by 30 percent below 2005 levels by 2030. The law further requires the City to reduce carbon emissions by municipal operations at an even faster rate—reaching a 30 percent reduction by 2017. Plans for implementing further reductions include avoided sprawl, clean power, efficient buildings, and sustainable transportation.

In regard to adaptation, three initiatives have been launched: They are an intergovernmental task force to protect vital city infrastructure; the development of site-specific protection strategies with and for vulnerable neighborhoods; and a citywide strategic planning process for climate change adaptation. The intergovernmental task force will work with a technical advisory committee of regional climate experts to develop coordinated climate protection levels for the metropolitan region. At the neighborhood level, two communities have been engaged—Sunset Park in Brooklyn and Broad Channel in Queens. Feedback from these communities will inform a larger program of engagement with 40 particularly vulnerable neighborhoods throughout the city. The goal of the citywide strategic planning process is to update the Federal Emergency Management Administration 100-year floodplain maps.

Challenges

PlaNYC encompasses a broad-ranging and challenging climate change agenda. Due to the short timeframe (less than 8 months) for development, community groups were not engaged fully in discussing the climate change adaptation aspects of the plan. That is being remedied, at least in part, by the vulnerable community adaptation program now under way. On the mitigation side, a sustainability task force at the Metropolitan Transit Authority is providing a continuing forum for climate change discussions in the region, as is a sustainable buildings series presented by the New York Academy of Sciences. These activities highlight the continuing and important role that local and regional organizations can play in engendering stakeholder involvement in the New York metropolitan region in responding to climate change.

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Appendix B

Biographical Sketches of Panel Members and Staff

ROBERT W. CORELL *(Chair)* is the vice president of policy and programs at the H. John Heinz III Center for Science, Economics, and the Environment and a senior policy fellow at the American Meteorological Society. He also cochairs an international planning group that is developing a strategy designed to harness science, technology, and innovation for sustainable development; serves as the chair of the Arctic Climate Impact Assessment; is a senior science advisor to ManyOne.Net; and is chair of the board of the Digital Universe Foundation. Previously, he was a professor and academic administrator at the University of New Hampshire, served as assistant director for geosciences at the National Science Foundation, and led the U.S. Global Change Research Program from 1987 to 2000. An oceanographer and engineer by training, his research focuses on global and regional climate change, related environmental issues, and science to promote understanding of vulnerability and sustainable development. He holds the National Conservation Award for Science from the National Wildlife Federation and the National Lifetime Achievement Award in Science from the National Council for Science and the Environment. He received Ph.D., M.S., and B.S. degrees from the Massachusetts Institute of Technology.

KAI N. LEE *(Vice Chair)* is a program officer in conservation and science at the David and Lucile Packard Foundation and Rosenburg professor of environmental studies, emeritus, at Williams College. He previously taught political science and environmental studies at the University of Washington. He has been a visiting professor, lecturer, or research fellow at the Kyoto Institute of Economic Research, Kyoto University; Stanford

University, the University of California at Berkeley; Trent University, the University of Wisconsin; Memorial University of Newfoundland; and an online education program at the Western Behavioral Sciences Institute. His interests include sustainability science, marine ecosystem management, urban sustainability (provision of ecosystem services and effects on human well-being), sustainable development, the role of learning in environmental policy, and governance. He has an A.B. degree in experimental physics from Columbia College and a Ph.D. degree in experimental physics from Princeton University.

JOSEPH ARVAI is a professor of judgment and decision making in the Department of Community, Agriculture, Recreation, and Resource Studies and the Environmental Science and Policy Program, Michigan State University. He is also an adjunct professor in the Institute for Resources, Environment, and Sustainability at the University of British Columbia and a research scientist with Decision Research in Eugene, Oregon. His research focuses on environmental problems, mainly in terms of designing and testing decision-aiding approaches for risk and resource management, as well as choice and preference behavior more broadly. He frequently leads workshops to improve the decision-making skills of both resource managers and stakeholders, working across Canada, the United States, and internationally as a consultant to government agencies and nonprofit groups. He has a B.Sc. degree in ecology, an M.Sc. degree in oceanography, and a Ph.D. degree in judgment and decision making from the University of British Columbia.

GARRY D. BREWER is Frederick K. Weyerhaeuser professor of resource policy and management at Yale School of Management. Previously at Yale, he held the Frederick K. Weyerhaeuser and Edwin W. Davis chairs in the School of Management and in the School of Forestry and Environmental Studies. He was director of the university's Institution for Social and Policy Studies. He is a policy scientist who began at the RAND Corporation, where he was a senior staff member of the social science department. He has also held positions at the University of Michigan as a dean and as a professor in the School of Natural Resources and Environment, a professor in the business school, and as the founding director of the Erb Sustainability Institute. Later he was a professor in the Energy and Resources Group at the University of California at Berkeley. He was appointed by His Majesty the King of Sweden to be the King Carl XVI Gustaf professor of environmental sciences at the Royal Institute of Technology. He is a member of the Royal Swedish Academy and the World Academy of Art and Science. He has an M.S. degree from San Diego State University and a Ph.D. degree from Yale University.

JENNIFER F. BREWER *(Program Officer)* was a staff member at the National Research Council, working with the Committee on the Human Dimensions of Global Change. She is now an assistant scientist in the Institute for Coastal Science and Policy and an assistant professor in the Department of Geography, both at East Carolina University. Her recent research investigates models of environmental governance in fisheries management, including common property, market-based, and spatial approaches. She has worked with governments, nongovernmental organizations, and private industry in marine policy and international voluntary service. She was a John A. Knauss Sea Grant fellow of the National Oceanic and Atmospheric Administration in the U.S. House of Representatives. She holds a B.A. degree from the University of Michigan, an M.S. degree in marine policy from the University of Maine, and a Ph.D. degree in human geography from Clark University.

CHARLES (CHIP) G. GROAT is interim dean at the Jackson School of Geosciences at the University of Texas at Austin. Previously, he held several positions at the University of Texas at El Paso, including associate vice president for research and sponsor projects, director of the Center for Environmental Resource Management, director of the Environmental Science and Engineering Ph.D. Program, and a professor of geological sciences. He has worked directly for many years in geological studies, energy and minerals resource assessment, groundwater occurrence and protection, geomorphic processes and landform evolution in desert areas, and coastal studies. He previously served as director of the U.S. Geological Survey of the U.S. Department of the Interior, executive director at the Center for Coastal, Energy, and Environmental Resources at Louisiana State University, executive director for the American Geological Institute, and assistant to the secretary of the Louisiana Department of Natural Resources, where he administered the Coastal Zone Management Program and the Coastal Protection Program. He has a Ph.D. in geology from the University of Texas at Austin.

MARTHA KREBS is deputy director for research and development at the Public Interest Energy Research Program of the California Energy Commission. The division is responsible for the Public Interest Energy Research Program, which conducts research to develop environmentally sound, reliable, and affordable electricity and natural gas services and products. Previously, she was president of Science Strategies, an analysis and consulting firm that works with public and private organizations to identify critical issues and opportunities in science and technology. Before establishing Science Strategies, she was an associate vice chancellor for research at the University of California at Los Angeles and founding director of the

California NanoSystems Institute. Earlier, she was a senior fellow at the Institute for Defense Analysis, where she led studies in R&D management, planning, and budgeting. She is a member of Phi Beta Kappa, a fellow of the American Physical Society, the American Association for the Advancement of Science, and the Association of Women in Science. She is also a trustee of the Institute for Defense Analyses. She received her B.A. and Ph.D. degrees in physics from the Catholic University of America.

ROBERT LEMPERT is a senior scientist at the RAND Corporation and a professor at and director of RAND's Frederick S. Pardee Center for Longer Range Global Policy and the Future Human Condition. His research focuses on decision making under uncertainty, with an emphasis on climate change, energy, and the environment. Currently, he is working with a number of natural resource agencies in their efforts to include climate change in their long-range plans. He is a coauthor of *Shaping the Next One Hundred Years: New Methods for Quantitative, Longer-Term Policy Analysis*. He is a fellow of the American Physical Society and a member of the Council on Foreign Relations. He holds a B.A.S. degree in physics and political science from Stanford University and a Ph.D. degree in physics from Harvard University.

MACK McFARLAND is a principal scientist of environmental programs at DuPont Fluoroproducts, with primary responsibilities for coordination of research programs and assessment and interpretation of scientific information on stratospheric ozone depletion and global climate change. During mid-1990s he was on loan for 2 years to the Atmosphere Unit of the United Nations Environment Programme and for 1 year to the Intergovernmental Panel on Climate Change Working Group II Technical Support Unit. At DuPont, he has received a C&P Flagship Award, an Environmental Respect Award, and an Environmental Excellence Award, and he is also a recipient of an individual Climate Protection Award by the U.S. Environmental Protection Agency for his contributions in providing understandable and reliable information to decision makers. He received a B.S. degree in chemistry from the University of Texas at Austin and a Ph.D. degree in chemical physics from the University of Colorado.

SUSANNE C. MOSER is director and principal researcher of Susanne Moser Research and Consulting and associate researcher at the University of California, Santa Cruz, Institute of Marine Sciences. Previously, she was a research scientist at the Institute for the Study of Society and Environment at the National Center for Atmospheric Research in Boulder, Colorado. She has also served as staff scientist at the Union of Concerned Scientists, a visiting assistant professor at Clark University, and a fellow in the Global

Environmental Assessment Project at Harvard University. Her research interests include the impacts of global environmental change, especially in the coastal, public health, and forest sectors; societal responses to environmental hazards in the face of uncertainty; the use of science to support policy and decision making; and the effective communication of climate change to facilitate social change. Her current work focuses on developing adaptation strategies to climate change at local and state levels, identifying ways to promote community resilience, and building decision support systems. She is a fellow of the Aldo Leopold and Donella Meadows Leadership Programs. She received a diploma in applied physical geography from the University of Trier in Germany and M.A. and Ph.D. degrees in geography from Clark University.

JONATHAN A. PATZ is professor of environmental studies and population health sciences at the Center for Sustainability and the Global Environment. He also holds appointments with the Nelson Institute for Environmental Studies and the Department of Population Health Sciences, all at the University of Wisconsin-Madison, and he is an affiliated scientist with the National Center on Atmospheric Research. Formerly, he directed the Program on Health Effects of Global Environmental Health Sciences at the Bloomberg School of Public Health at Johns Hopkins University. His research activities are focused on the effects of climate change on heat waves, air pollution and water- and vector-borne diseases, and the link between deforestation and resurgent diseases in the Amazon. He was cochair for the U.S. National Assessment on Climate Variability and Change Health Sector Expert Panel and convening lead author for the United Nations/World Bank Millennium Ecosystem Assessment. He has an M.D. degree from Case Western University and a M.P.H. degree from Johns Hopkins University.

CYNTHIA E. ROSENZWEIG is a senior research scientist at the National Aeronautics and Space Administration Goddard Institute for Space Studies, where she is the leader of the Climate Impacts Group. The mission of the group is to investigate the interactions of climate with systems and sectors important to ecological and human well-being. She is currently cochairing the New York City Panel on Climate Change. She also holds adjunct appointments as a senior research scientist at the Columbia University Earth Institute and at Barnard College. Her research focuses on the impacts of environmental change, including increasing carbon dioxide, global warming, and El Niño, on regional, national, and global scales. She received an M.S. degree in soils and crops from Rutgers University and a Ph.D. degree in plant, soil, and environmental sciences from the University of Massachusetts.

HARVEY RUVIN is the elected county clerk for Miami-Dade County, with responsibility for 1,400 employees and a $65 million budget. In a long career in public service, he has been mayor of the City of North Bay Village and served five consecutive 4-year terms on the Metro Dade County Commission. As president of the National Association of Counties, he has chaired task forces on immigration, environment and energy, and liability insurance. He is a past chair and current member of the Urban Consortium of Public Technology, the technology arm of the National League of Cities; the National Association of Counties; and the International City/County Management Association. His main interest is in seeking to apply emerging technologies to local government needs. In 1990 he helped form the International Council for Local Environmental Initiatives, which started the Cities for Climate Protection initiative and has reduced greenhouse gases in 14 communities around the world. He was recently appointed cochair of the 25-member Miami–Dade County Climate Change Adaptation Task Force, which has committees focused on science, intergovernmental affairs, natural systems adaptation, built environment/property/infrastructure, greenhouse gas reduction, and economic/social/health. He has also served on advisory panels to Presidents Ford, Carter, Reagan, Bush, and Clinton covering such topics as energy and sustainability. He holds an engineering degree from the University of Florida and a J.D. degree from the University of Miami.

SOROOSH SOROOSHIAN is distinguished professor of civil and environmental engineering and of earth system science at the University of California at Irvine. His research focuses on surface hydrology, primarily in the area of rainfall-runoff modeling. He has devoted much of his work to model identification and calibration issues and has developed special estimation criteria to account for the uncertainties of calibration data. Other research interests include the application of remote sensing data for characterization of hydrologic parameters and fluxes and the implication of climate variability and change in water resources. He also consults on problems related to surface hydrology and flood forecasting. He is a member of the National Academy of Engineering. He has a B.S. degree in mechanical engineering from California Polytechnic State University, an M.S. degree in operations research, and a Ph.D. degree in engineering from the University of California at Los Angeles.

PAUL C. STERN *(Study Director)* is a senior program officer at the National Research Council and director of its standing Committee on the Human Dimensions of Global Change. His research interests include the determinants of environmentally significant behavior, particularly at the individual level; participatory processes for informing environmental decision making; and the governance of environmental resources and risks. He is coauthor of the textbook *Environmental Problems and Human Behavior* (2nd ed., 2002) and coeditor of numerous National Research Council publications. He coauthored (with Paul Dietz and Elinor Ostrom) the 2003 *Science* article "The Struggle to Govern the Commons," which won the 2005 Sustainability Science Award from the Ecological Society of America. He is a fellow of the American Association for the Advancement of Science and the American Psychological Association. He holds a B.A. degree from Amherst College and M.A. and Ph.D. degrees from Clark University, all in psychology.

RICHARD THOMAS is the senior vice president and chief underwriting officer for the Commercial Insurance Group of American International Group (AIG). He has held a number of positions at AIG, including president of its Risk Management's Industry Specialties Group and overseer of its planning and implementation of Y2K strategies for casualty underwriting worldwide. Previously, he worked with Aetna Life & Casualty, The Hartford Group, INA/CIGNA, and Reliance Insurance Companies. He serves on the M-200, an association of risk managers of multinational corporations, and on the Board of the Workers' Compensation Research Institute, which he has also chaired. He also serves on advisory boards for the Risk Management and Decision Processes Center of the Wharton School at the University of Pennsylvania, the Center for Terrorism Risk Management Policy of the RAND Corporation, and the College of Mathematics and Physical Sciences at the University of Maryland. He has advised the U.S. Treasury Department on insurance issues related to the Resource Conservation and Recovery and "Superfund" Acts, and he has testified before the U.S. Senate Commerce Committee on insurance programs for large construction projects. He holds a B.A. degree from Hiram College.

KATHLEEN J. TIERNEY is professor of sociology and director of natural hazards research and applications at the University of Colorado. Previously, she was professor of sociology and director of the disaster research center at the University of Delaware. With more than 25 years of experience in the disaster field, she has been involved in research on the social aspects and impacts of major earthquakes in California and Japan, floods in the Midwest, Hurricanes Hugo and Andrew, and many other natural and technological disaster events. Since September 2001 she has been directing a study on the organizational and community response in New York following the terrorist attack on the World Trade Center. She has a Ph.D. degree in sociology from the Ohio State University.

Appendix C

Workshop Participants

Keck Building
Washington, DC
March 4–5, 2008

Jeffrey Andresen, Department of Geography, Michigan State University
Hannah Campbell, Climate Program Office, NOAA
Nell Codner, National Ocean Service, Office of Coast Surveys, NOAA
Margaret Davidson, Coastal Services Centers, NOAA
Kirsten Dow, Department of Geography, University of South Carolina
Rebecca Feldman, Climate Program Office, NOAA
John Kostyack, Wildlife Conservation and Global Warming, National Wildlife Federation
Jeremy Martinich, Climate Change Division, U.S. Environmental Protection Agency
Claudia Nierenberg, Climate Program Office, NOAA
Eric Toman, Climate Program Office, NOAA
Lisa Vaughan, SARP Coastal Project, NOAA

Arnold and Mabel Beckman Center
Irvine, CA
May 12–13, 2008

John Andrew, California Department of Water Resources, Sacramento, CA
Tony Brunello, Climate Change and Energy, California Resources Agency, Sacramento, CA
Susan Craig, Arizona Department of Water Resources
Bart Croes, Research Division, California Air Resources Board
Gregg Garfin, Institute for the Study of Planet Earth, University of Arizona
Amy Luers, Environmental Predict and Prevent, Google
Elizabeth McNie, Center for Science and Technology Policy Research, University of Colorado, Boulder

Steve Murawski, Scientific Programs, NOAA
Roger Pulwarty, CIRES Climate Diagnostics Center, NOAA, Boulder, CO
Bradley Udall, University of Colorado, Western Water Assessment, NOAA Earth Science Research Laboratory, University of Colorado, Boulder