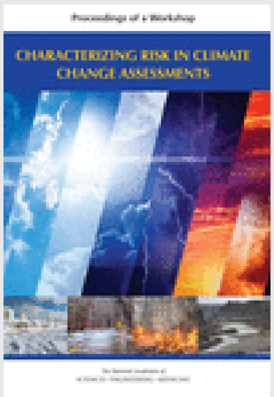

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CHARACTERIZING RISK IN CLIMATE CHANGE ASSESSMENTS

Proceedings of a Workshop

Alexandra Beatty, *Rapporteur*

Board on Environmental Change and Society
Division of Behavioral and Social Sciences and Education

Board on Atmospheric Sciences and Climate
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This Proceedings of a Workshop 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 Academies of Sciences, Engineering, and Medicine. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published proceedings as sound as possible and to ensure that the proceedings meets institutional standards for clarity, objectivity, and responsiveness to the charge. The review comments and draft manuscript remain confidential to protect the integrity of the process.

We thank the following individuals for their review of this proceedings: Paul Fleming, Climate Resiliency Group, Seattle Public Utilities, Seattle, Washington; Robert J. Lempert, Frederick S. Pardee Center for Longer Range Global Policy and the Future Human Condition, RAND Corporation, Santa Monica, California; and Chris Weaver, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Although the reviewers listed above have provided many constructive comments and suggestions, they did not see the final draft of the proceedings before its release. The review of this proceedings was overseen by Cynthia M. Beall, Department of Anthropology, Case Western Reserve University. Appointed by the Academies, she was responsible for making certain that an independent examination of this proceedings was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this Proceedings of a Workshop rests entirely with the rapporteur and the institution.

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1

Introduction

BACKGROUND

The U.S. Global Change Research Program (USGCRP) was established in 1990 to "assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change."[1] A key responsibility for the program is to conduct National Climate Assessments (NCAs) every 4 years.[2] These assessments are intended to inform the nation about "observed changes in climate, the current status of the climate, and anticipated trends for the future." The USGCRP hopes that government entities—from federal agencies to small municipalities, citizens, communities, and businesses—will rely on these assessments of climate-related risks for planning and decision making. The third NCA (NCA3) was published in 2014 and work on the fourth is beginning. The USGCRP provided guidance to the authors of the NCA3 about ways to identify and evaluate key risks. With the fourth NCA (NCA4), the USGCRP hopes to improve its usefulness to decision makers by more clearly addressing the societal risks associated with climate change, rather than primarily cataloging the biophysical effects that have been observed and are projected for the future. The NCA4 will directly address the multiple, interacting factors that influence the risks that changes in climate

[1]See http://www.globalchange.gov/ for more information [April 2016].

[2]For more information about NCA reports, see http://nca2014.globalchange.gov/ [May 2016]. As the third NCA was developed, the USGCRP initiated a plan to expand the program beyond the production of reports every 4 years, to provide sustained, ongoing resources as well. See http://nca2014.globalchange.gov/report/response-strategies/sustained-assessment [May 2016].

pose for people and social systems, and it will take into account the fact that many of these factors are themselves changing over time. The developers hope to provide this information in a way that is accessible, useful, and easy to apply in a wide range of contexts.

The USGCRP, after consultation with the Committee to Advise the U.S. Global Change Research Program of the National Academies of Sciences, Engineering, and Medicine, asked the Academies' Board on Environmental Change and Society to conduct a workshop to explore ways to frame the NCA4 and subsequent NCA reports in terms of risks to society. The workshop was intended to collect experienced views on how to characterize and communicate information about climate-related hazards, risks, and opportunities that will support decision makers in their efforts to reduce greenhouse gas emissions, reduce vulnerability to likely changes in climate, and increase resilience to those changes. The committee's charge is shown in Box 1-1.

The Planning Committee for the Workshop on Methods for Characterizing Risk in Climate Change Assessments was appointed to plan this workshop, which was held March 23-24, 2016. The workshop included experts on (1) the impacts of climate change on physical, biological, and social systems and the associated uncertainties; (2) analysis of vulnerability and resilience to, and consequences of, climate change; (3) tools and approaches reflecting contemporary insights from the risk and decision sciences related to climate change; (4) planning for and managing climate-related risks in various sectors and U.S. regions; and (5) risk communication. The committee's role was limited to planning the workshop, and these proceedings have been prepared by a rapporteur

BOX 1-1
Statement of Task

The committee will organize a public workshop designed to inform the approaches to characterizing and communicating risk within the NCA. The steering committee, in consultation with the sponsor, will identify a series of case examples to use to explore issues such as the following in the context of the NCA report:

- methods, procedures, and terminology for characterizing risks;
- strategies for conveying information about risks;
- ways to enhance the ability to compare risk information across different regions and sectors; and
- research needs and near-term actions required to support and improve the characterization of risk and the effectiveness of communication in future national assessments.

as a factual summary of the presentations and discussions that occurred at the workshop. The views contained in the report are those of individual workshop participants and do not necessarily represent the views of all workshop participants, the planning committee, or the Academies. The workshop agenda and biographical sketches of the committee members and presenters are in Appendixes A and B.

The committee developed a planning document to elaborate the issues it was charged to address and to guide the experts invited to participate in the workshop.[3] The document notes that the NCA4, as well as subsequent reports and the sustained assessments of which they are a part, should be useful to a wide range of decision makers in different geographic places, facing different kinds of decisions, and holding different values. The purpose of the workshop was to help the designers of the NCA identify and implement methods for characterizing the risks of climate change that will help these highly varied users understand the range of environmental, social, and economic risks they face, including what is known about these risks and what is uncertain.

As noted in the planning document, previous NCAs have primarily addressed risk in two ways:

1. by making explicit or implicit statements about the probabilities of future changes in key climate variables, such as temperature or precipitation—for example, by showing ranges of future changes in these variables across multiple climate models and emissions scenarios; and
2. by drawing qualitative, narrative connections (as in the chapter on water and agriculture) among a given climate change, associated biophysical impacts of that climate change, and the socioeconomic systems that may be affected.

The committee asked presenters to address five issues as they considered ways to strengthen the NCA4:

1. approaches for framing climate change risk that can guide chapter authors;
2. challenges of representing the range of biophysical consequences of climate change and their interactions with social and economic changes that matter to decision makers;
3. challenges of representing how development pathways (and the vulnerabilities and capacities they influence) could alter the context for decisions and thereby affect their appropriateness and effectiveness;

[3]The document is available at http://sites.nationalacademies.org/DBASSE/BECS/CurrentProjects/DBASSE_168692 [June 2016]. Many of the workshop presentations and an archived Webcast are also posted at this site.

4. the state of knowledge about the likelihood of risks being realized as impacts across spatial and temporal scales under different assumptions of climate and development, and the degree of confidence in scientific understanding; and
5. available methods and processes for making information about the knowledge and uncertainties understandable, credible, and useful to decision makers.

A NOTE ABOUT TERMS

Some of the terms used frequently in the context of climate change and its effects can be confusing because they have both common and specialized meanings. Below are a few such terms used in these proceedings and definitions that reflect their usage in prior Academies reports:

- Adaptation: Actions taken to limit the damage to people, communities, and infrastructure from events resulting from climate change. Adaptation measures include not only taking protective steps (building sea walls and the like) but also preventing human settlement in vulnerable areas or moving people away from such areas. In some cases, the term also includes compensating people for loss.
- Consequence: The magnitude of damage that would result from a hazard.
- Hazard: A potentially damaging event, such as a fire or flood.
- Impact: An effect of physical climatic events, such as an increase in droughts or wildfires or a rise in sea levels.
- Mitigation: Steps taken to reduce the rate of climate change, for example, using changes in technology and human behavior to reduce emissions of greenhouse gases.
- Probability: The likelihood that a specific event, such as a hazard, will occur within a specified timeframe.
- Resilience: The capacity to anticipate, prepare for, respond to, and recover from a significant hazard or multihazard threats with minimum damage to social well-being, the economy, and the environment.
- Risk: A combination of the magnitude of a potential consequence of a hazard or hazards attributable to climate change and the likelihood that the consequence will occur. Risk may refer to physical, biological, or socioeconomic consequences.
- Vulnerability: The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extreme events. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system

is exposed, its sensitivity (susceptibility to damage from climate-related events), and its adaptive capacity.

OPENING REMARKS

Planning committee chair Joseph Arvai noted in opening the workshop that uncertainty cannot be eliminated from scientific projections but that the NCA4 is an "opportunity to address risk even in a climate of uncertainty." John Holdren of the White House Office of Science and Technology Policy and Thomas Karl of the USGCRP provided an overview of the primary objectives they hoped the workshop would accomplish, which was followed by discussion of some of the most important challenges for the NCA4.

The assessment and characterization of risk, in Holdren's view, should address the needs of those who will use the information: the makers and implementers of policy, firms and businesses, and individuals who make decisions about mitigation and adaptation, as well as voters. Up to now, he suggested, risk has been defined in terms of physical and biological events that can follow from climate change as "the sum over all possible events of probability times consequences." Less attention has been given to the consequences of these events for human well-being, that is, to characterizing the probabilities of their occurrence, as well as the character and quality of the consequences. To prepare for the future, he said, it is critical that people have a much clearer picture of how likely different possible consequences are, understand the strength of the available evidence, and have a realistic understanding of what it will mean for society if "the worst is true."

Many people assume that the uncertainty in climate change projections means it is just as likely that the outcomes could turn out to be favorable as not, Holdren noted. In his view, it is actually the case that "there is a larger chance that things will be worse than we currently expect than better." Because of this gap in understanding of the risks, he said, it is critical that the NCA4 be very clear not only about what is known, but also about how it is known, and that it clearly explains the implications of what is known for mitigation and adaptation. He suggested that the NCA4 could move in this direction by providing the following:

- Disaggregation of information by geographic region and by sectors of economic activity and other influences on human life, such as the water cycle. He said the report should be directly relevant to the needs of many types of users (including makers and implementers of government policy, businesses, and individuals).
- Characterization of vulnerabilities. The report should not only explain how climate will or may change things (e.g., that there is likely to be an increase in stormy weather or a rise in sea level) but also offer specific

information on how those changes will affect people, infrastructure, local weather patterns, and so on.

- Measures of the costs associated with the risks discussed, in dollars and in other terms. The report should compare the costs of taking action to mitigate or adapt to known risks with the costs of taking no action. Drawing reasonable comparisons may require "creative use of yardsticks," Holdren acknowledged.
- Perspectives developed through partnerships across government and the private sector to illuminate specific vulnerabilities and how they work.

Karl focused on what leaders and policy makers need to understand about the risks changes in climate bring, noting that these individuals are a diverse group that includes not only public officials at the local, state, and federal levels, but also decision makers within major corporations, international agencies, and intergovernmental bodies. Recent reports, including *Risky Business: A Climate Risk Assessment for the United States* (Risky Business Project, 2014) and *Climate Change in the United States: Benefits of Global Action* (U.S. Environmental Protection Agency [EPA], 2015), have demonstrated progress in effectively presenting the economic impacts of climate change for a policy audience, Karl noted.

Looking in detail at one example from the 2015 EPA report, which discusses many sectors, Karl noted that it includes a thorough documentation of the cascading impacts of changes in climate on water quality in the coming decades. The authors fed information about expected changes into models for areas related to water supply, such as river flow and water demand, also factoring in weather patterns, and then used those models to work out a water quality index to help readers understand the range of possible impacts and their costs. Other issues are addressed in a similar way.

It is also important, Karl added, to be clear about areas where it is more difficult to outline the potential cascading effects. The interactions among and within complex systems—such as the way energy, agriculture, water, transportation, drought, wildfires, and rising temperatures interact—are difficult to map. But it is these "complex cascades" that bring the greatest potential risks to society, so it is critical that the NCA4 communicate effectively about these risks, in his view.

DISCUSSION

Participants elaborated on several of these opening points. One observed that the frameworks scientists have customarily used to characterize risk do not apply well to climate change. For example, the assumption that the relationships between exposure to a risk factor and response to it are constant over time—which may hold in many situations—is not true for climate. In order to convey the cascading nature of risks, this person suggested, it is important to factor in varying degrees of vulnerability to particular risks. Another participant also called attention to the significant variation in circumstances, vulnerabilities, and risk that face people and systems across geographic regions and sectors.

Nonmonetary measures are needed to help people understand the real risks, a participant noted, and several measures were identified. In the domain of human health, for example, lost life expectancy and days lost to illness and disability can help quantify some effects. It is a big challenge, however, to educate people about how dependent humans are on ecosystems, a participant noted. As the importance of ecosystems to food and water supplies, for example, becomes better understood, measures of how badly ecosystems are being disrupted by climate change will become effective tools.

Another issue raised was that the time trajectories for different elements of the discussion are so different. As one participant noted, three separate timelines are key: the time required for climate science to reduce the uncertainties in risk forecasts, the time it will take for impacts to be felt and for society to identify and execute responses, and the length of time many of the impacts will last. These timelines do not align well, so people may fail to fully understand the consequences of their actions until it is too late to avert those consequences. By one estimate, another participant pointed out, sea-level rise will be as much as 25 meters over the next 10,000 years, even if all greenhouse gas emissions related to human activity stop by the year 2100. In that context, the time it will take to transform the world's energy system may be the most critical timescale. The $25 trillion energy infrastructure, which is currently 80 percent fossil fuel-based, cannot be transformed in a time span shorter than several decades, in that person's view.

2

Characterizing and Communicating Risk

The many complexities of characterizing climate change and communicating clearly about it to diverse audiences were the focus of the first workshop panel. Six presenters provided their perspectives and discussed the implications of their ideas for the fourth National Climate Assessment (NCA4).

CONSEQUENCES OF RISK: A POLICY PERSPECTIVE

Alice Hill of the National Security Council (NSC) opened with a memory of hearing anthropologist Margaret Mead warn during the 1970s of society's carelessness about the environment and the catastrophic results she already foresaw. Despite the body of scientific evidence that has been built in the decades since, Hill observed, "we are not adequately conveying" that the changes that have already taken place are irreversible and that "decisions being made today will really tie the hands of those who come after us." Many policy makers take the issue very seriously, but they face considerable challenges in making the case for taking action, she pointed out.

She spoke in stark terms about the NSC's recognition that climate change is an "urgent and growing threat to homeland security" and mentioned initiatives it has undertaken, such as a flood-management risk standard and a drought resilience strategy. The federal government is also beginning to screen all international development work for its resilience with respect to climate change impacts. She noted that the National Security Strategy[1] also identifies climate change as one of the top risks to the nation, along with weapons of mass destruction, epidemics, and terror attacks.

These efforts are "hard work," Hill commented, because the risks are not widely understood. Her experience speaking with groups—including civil engineers, risk management specialists, infrastructure owners and operators, and policy makers—has shown her that very few have read the previous climate assessments. "This means we are missing the mark," she said. Many people do not see how events and systems at the global, national, and local levels all fit together, she noted, but these connections demonstrate why climate change is relevant to their responsibilities. In her view, the NCA4 is an opportunity to provide information that is as useful to a local policy maker—such as the mayor of a small coastal town who needs to make decisions about spending, planning, and infrastructure—as to a leader making decisions at the national or international level.

Hill identified a few issues to illustrate her point:

- Approximately $96 billion was spent on infrastructure in 2014, but it is not likely that most of the individual investments were screened for climate change resilience.
- Coastal assets have an immediate vulnerability to flooding associated with sea-level rise, as the effects of Hurricane Sandy on parts of the Atlantic coast demonstrated in 2012. Some of the infrastructure affected had been built to withstand a 12-foot storm surge, she noted, but the surges in that storm were higher. Infrastructure failures from the immediate surges had cascading effects on essential sectors, including energy, transportation, and health.
- The Earth is already experiencing increased average temperatures, but the implications of high ambient temperatures for human activity are not fully understood.
- In one case, warming water temperatures have caused the shutdown of a nuclear plant that had relied on lower-temperature water for its cooling towers.
- The Mississippi River, an essential waterway, has in recent years both flooded and had water flow that was too low for barge traffic.
- Internal migration resulting from catastrophic events is already significant and will increase. For example, 237,000 people left New Orleans and other parts of Louisiana after Hurricane Katrina in 2005, which meant an estimated $105 billion loss for the state.

[1]The executive branch of the federal government periodically provides to Congress a summary of national security concerns and strategies for addressing them. See https://www.whitehouse.gov/sites/default/files/docs/2015_national_security_strategy.pdf [May 2016].

Although it is difficult to tie any particular event to climate change, trends can be linked to climate change and it is important to help people understand that the impacts people are experiencing are not isolated events, Hill emphasized. "Impacts in the rest of the world affect us, too," she added. Drought and extreme heat have already caused migration and strained resources. The rise of the terrorist group Boko Haram has been linked to water shortages in western Africa, she noted. Around the world, 100 million people live less than 1 meter above sea level. The U.S. Government Accountability Office lists climate change as a top risk to U.S. assets and to environmental and economic systems.

In short, Hill concluded, it is essential that the NCA4 deliver very clearly the message that changes in the Earth's climate are virtually irreversible in the absence of engineering solutions that do not currently exist, and some will occur even if greenhouse gas emissions are cut entirely today. Despite the fact that the scientific community cannot predict exactly what will happen, she stressed, "we need to talk more about the worst-case scenarios" and make climate forecasts a routine factor in policy decision making.

Participants offered questions and comments that reinforced Hill's messages. One asked whether federal agencies and other government entities have sufficient incentives to work together and with the broader community to deal directly with the policy implications of climate change. Hill answered that progress is iterative. Most policy makers have almost no formal education about climate change, she noted, and they represent a wide range of understanding. If the NCA4 clearly conveys what is at stake, she said, it can spur those who are not yet inspired.

Another noted that infrastructure planning and engineering models are generally designed to withstand the range of extremes in the 100-year historical record, but that using the past 100-year record will no longer provide an adequate basis for planning and design.

There are very few areas of science where it is possible to accurately depict the cascading effects, another noted. Collaborations among engineers, health officials, and others to assess the scenarios that might happen in their sectors can help people move beyond the "scare-mongering" label that can be used to undermine messages about the effects of climate change. Some government agencies may be better structured to operate at local levels than others, a participant noted, and many need guidance on how to do it. The White House has sponsored such exercises, Hill noted, and the United States Climate Resilience Toolkit has been developed for this purpose.[2]

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[2]See https://toolkit.climate.gov/ [May 2016].

HOW LIKELY ARE SIGNIFICANT CONSEQUENCES?

Ben Sanderson of the National Center for Atmospheric Research addressed two questions: "What are the odds we are missing something really catastrophic? And how can science better quantify those odds?" Climate research institutions around the world make decisions about what questions to pursue and how to use computer resources, Sanderson noted, and those decisions influence the potential for assessing risk. Better understanding of the likelihood that extreme outcomes will happen is essential in his view, and he suggested modifications in the types of experiments climate scientists do that could provide a more detailed and realistic picture of such risks.

Climate forecasts are based on computer models that represent the many interacting physical processes that affect climate. Climate models are designed to use physical principles, constrained by past data on the Earth's systems, to produce simulations of future outcomes. They make it possible to test hypotheses about what might happen under varying sets of assumptions regarding specific variables, but the calculations must be "run" multiple times with different inputs (initial conditions and uncertain model parameters) to establish the range of possible outcomes. Thus, climate models can reflect the varying degrees of probability for links in the chain of events that could lead to possible outcomes, but only if they are based on an appropriate experimental design.

Risk is often described in terms of where outcomes might fall on two axes, one for impact and one for likelihood, as shown in Figure 2-1, Sanderson

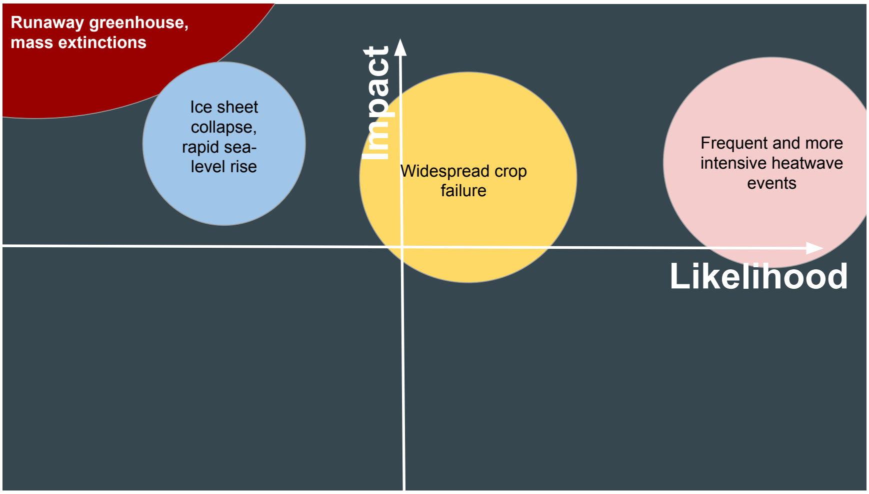

FIGURE 2-1 Visual representation of likelihood and impact of possible climate change outcomes.
SOURCE: Sanderson (2016).

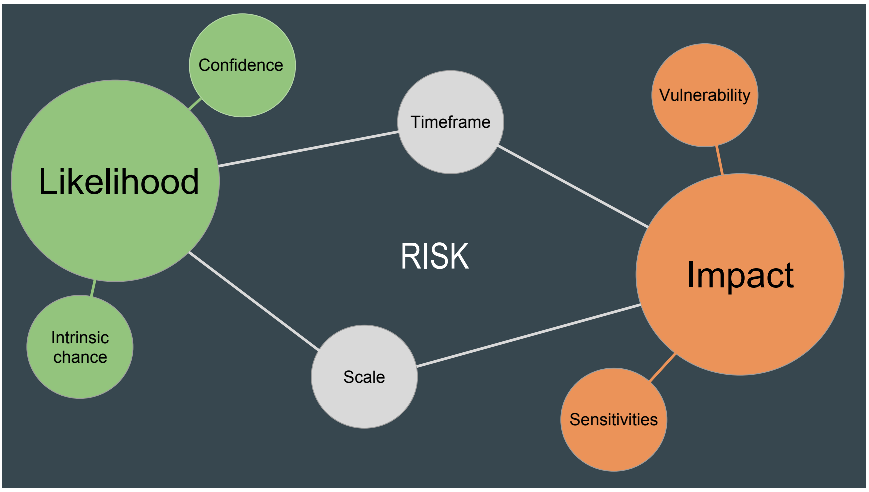

FIGURE 2-2 Alternate depiction of likelihood and impact.
SOURCE: Sanderson (2016).

explained. This figure illustrates that available climate models indicate different degrees of impact and likelihood for different outcomes. For example, frequent and more intense heat waves are an almost certain feature of future climate. Widespread crop failure or ice sheet collapse "can certainly not be ruled out," Sanderson noted, but they are subject to greater model uncertainty.

He noted that multiple models contribute to confidence in the forecast for increasing heat waves. With respect to the likelihood of ice sheet collapse, however, the data on relevant factors (such as the stability of the ice sheets) are less complete. The partial circle in the upper left-hand corner of Figure 2-1 represents climate change feedbacks that would have major effects on a global scale, namely, extremely high greenhouse gas concentrations and mass extinctions. Scientists know little about these feedbacks because the relevant processes are not well represented in the models, which in turn is partly because there is a lack of data on what would be essentially unprecedented effects.

The concept of likelihood can be represented in a more sophisticated way, Sanderson said. Figure 2-2 depicts some other factors that need to be considered. With respect to likelihood, he explained, it is important to distinguish the intrinsic possibility that an event might occur from the confidence with which predictions can be made about it. The diagram also treats risk separately, indicating that it is a product of both the timeframe on which the outcome may occur and the scale of its possible impact (e.g., whether its impacts would be felt locally or on a national or a global scale). Impact itself, he added, is a function of both the vulnerabilities and sensitivity of the systems that may be affected.

Sanderson looked more closely at some specific types of outcomes to illustrate the additional analyses that will be needed to support efforts to prepare for possible risks, turning first to intense heat waves. He discussed the "cascade" of uncertainty, or model of the way in which uncertainty about each of the factors relevant to an outcome will accumulate, to elaborate on what can be said about this risk.

One factor that is uncertain is the choices that humans will make in the future with respect to the use of fossil fuels and other issues, which will determine the levels of greenhouse gas emissions over the coming century. Next in the chain is global climate sensitivity, the degree of increase in global mean temperature that will result from those emissions. Global-level changes affect different regions differently, and those responses introduce another level of uncertainty. There is also a fundamentally irreducible degree of variability in natural phenomena, such as weather, which introduces an additional degree of uncertainty.

Random variability may be the easiest type of uncertainty to account for, Sanderson suggested. If one begins with the assumption that a model is essentially a correct representation of the climate system, then running the model multiple times will eventually allow the range of random variability to become evident and yield a fairly accurate range of outcomes. Other types of uncertainties are more challenging, however. Different models will suggest different responses for particular regions, for example. Climate scientists address this uncertainty using general circulation climate models, a particular type of climate model that calculates atmospheric circulation to represent the behavior of the climate. Researchers look for agreement among such models to assess how likely an outcome is.

However, Sanderson suggested, some of the model agreement may not be as informative as might be hoped. Approximately 40 institutions around the world produce these models, he explained, but many of their models are based on the same design so there are actually far fewer than 40 distinct models. "There is massive overlap," he suggested. It is not difficult to identify cases where two models share significant portions of code and thus can be expected to produce similar outcomes, Sanderson added, so it is possible to eliminate duplicative results from an analysis.

It is also important to realize, Sanderson added, that each group of scientists who run climate models tends, for defensible reasons, to publish a single central estimate, a version of the runs they have produced that minimizes biases and is in their judgment the best simulation they can provide. However, he explained, because each climate center does this, the set of models they collectively produce does not adequately address the "tails" of the distributions, particularly the outcomes that would have the greatest impact on human life. This means, Sanderson suggested, that "we have very little information about a world with high climate sensitivity, even though we cannot confidently rule out such a world." In other words, the existing projections are not adequately bringing the most extreme possible outcomes of climate change to people's attention.

The way to gain more information about extreme scenarios, in Sanderson's view, is to run a model repeatedly and explicitly examine the parameters that contribute to uncertainty, particularly at the tail ends of the distribution. Doing this requires significant computing power and time and is not routinely done, he said. Instead, for many climate centers, the focus is on developing very high-resolution models. However, he observed, these higher-resolution models do not in general yield a more accurate simulation, but rather more detailed pictures of the same information.

These sorts of questions about current modeling practices, Sanderson observed, lead one to wonder about the possibility that "we are underestimating long-term warming." He offered four suggestions for using climate modeling to more directly explore the most extreme possibilities:

1. *Run simulations for longer time spans*. The majority of current models are run on a 100-year timescale. Even current models will show different outcomes for a 300-year timescale than for a 100-year one. For example, by the end of the second century from now, the ability of the ocean to absorb carbon will decrease markedly. "This is not a complex feedback," Sanderson noted, "but it means that the Earth's sensitivity changes as you move into the future."
2. *Incorporate critical carbon cycle feedbacks into current models*. Methane release from permafrost, for example, is not routinely simulated in most models, but this development could increase global sensitivity by as much as 20 or 30 percent.
3. *Sample the parameters that contribute to the uncertainty of models of the tails of the distributions*. In order to gain more precise pictures of extreme scenarios, it is necessary for the models to be run with different plausible combinations of uncertain parameters. This procedure makes it possible to determine in a single model how robust future projections are.
4. *Do not present climate sensitivity as a single number*. Many people assume that when carbon dioxide is doubled, from any starting point, the increase in temperature will correspond in a linear fashion. Various lines of evidence suggest this is not the case, Sanderson argued. The climate is continually evolving, so simplistic, linear projections are incorrect.

Sanderson closed with the conclusion that in order to get a clear picture of the highest risks, "we need to change the types of experiments we are doing."

Participants asked several follow-up questions. One noted the pressure to provide information based on downscaling (a statistical procedure for applying information that is available on a large, e.g., global, scale to make projections for local regions) in order to give people more relevant information about the risks they may face. Downscaling introduces more uncertainties, Sanderson responded. Another noted that incorporating additional parameters into models will be difficult in some cases because adequate data are not available; for example, physics data regarding the behavior of ice sheets are incomplete.

ADDRESSING UNCERTAINTY IN CLIMATE CHANGE ASSESSMENTS

Robert Kopp of Rutgers University described two examples of ways to quantitatively address uncertainties in climate change assessments. One is an econometric analysis of economic risks that uses a framework for producing probability distributions.[3] In the other example, probabilistic sea-level estimates are generated and applied to decisions affected by coastal flood risks.[4] Kopp also discussed the idea of "tipping points" or thresholds in assessing the physical and social systems affected by climate change.

In the first example, Kopp and his colleagues combined econometric approaches to assessing relationships between humans and physical climate using probability distributions for local climate changes. They focused on sectors for which a large body of empirical data exists: agricultural production, health, labor productivity, energy demand, coastal buildings and infrastructure, and crime and civil conflict. They considered key sources of uncertainty, such as emissions, global temperature response, regional changes, socioeconomic responses, and structural uncertainty (i.e., omitted factors or tipping points).

To assess uncertainty in the relationship between emissions and global temperature, they used a simple climate model. To assess uncertainty in regional changes, they developed a framework that used that climate model to develop weights applied to a mixture of global climate models and "model surrogates" that captured tails of climate responses that are not represented in full-complexity climate models.

The researchers used statistical analysis of historical data on local responses to short- and medium-term climatic variability and change. Their objective was to control for the factors that make localities different, in order to isolate what was common in their economic responses to temperature changes. They are developing an open platform to make this procedure widely available: the Distributed Meta-Analysis System[5] is a tool for conducting meta-analyses of climate impact and comparing and aggregating the results. They have used

[3] This work is described in Houser et al. (2015) and Rasmussen et al. (in press).

[4] This work is described in Kopp et al. (2014).

[5] See http://dmas.berkeley.edu/ [May 2016].

this tool to develop probabilistic risk projections based on the assumption that people respond economically to changes in climate as they have in the past, Kopp said.

For example, the models indicate that climate change will have unevenly distributed economic impacts, Kopp noted. Figure 2-3 shows some projections produced by this model for the years 2080 through 2099. Labor productivity is projected to decline almost everywhere in the United States, while violent crime rates will increase, the models show. However, changes in mortality rates and crop yields will be mixed, increasing in some areas and decreasing in others.

Figure 2-4 shows another set of projections produced by the models. This graph depicts the expected increase in the number of years in which extreme heat events will occur, under four different greenhouse gas scenarios. The projections use historical data and calculations of year-to-year variability to show what is likely to happen, depending on the volume of greenhouse gases emitted going forward.

Kopp also summarized an example presented in a second study, in which he and colleagues described a way that local stakeholders can use uncertain projections to support decision making. Kopp and his colleagues combined a variety of evidence—including climate models, physical models of local effects, expert assessments, data on land water storage (water stored in the ground), and historical trend data—to develop probabilistic local sea-level predictions. Kopp noted that users of the projection framework have included the Congressional Budget Office, the state of Delaware, the California Energy Commission, the city of Boston, the New Jersey Climate Adaptation Alliance, and the National Oceanic and Atmospheric Administration.

Kopp said, however, that using these projections to make specific local decisions requires another level of analysis. Decision makers need to consider what responsibilities are potentially affected, the level of acceptable risk in that context, the range of time for which they will plan, and to determine what margin to build in to maintain a constant level of risk. Figure 2-5 shows, for example, that as the projected sea-level rise increases (the x-axis), the expected increase in the frequency of floods of a particular height increases in a nonlinear fashion (the y-axis). The curves represent five different possible degrees of sea-level rise: floods at this location will become three times as likely with the lowest possible sea-level rise and as much as 410 times as likely under the highest projected sea-level rise.

Kopp also noted that it is important to consider risks whose probability may be difficult to assess, because "they may in the end prove to be the most important." The term "tipping point," popularized in a 2000 book of that name by Malcolm Gladwell, generally refers to large changes that result from small changes, are contagious, and occur quickly. The term is often applied to climate

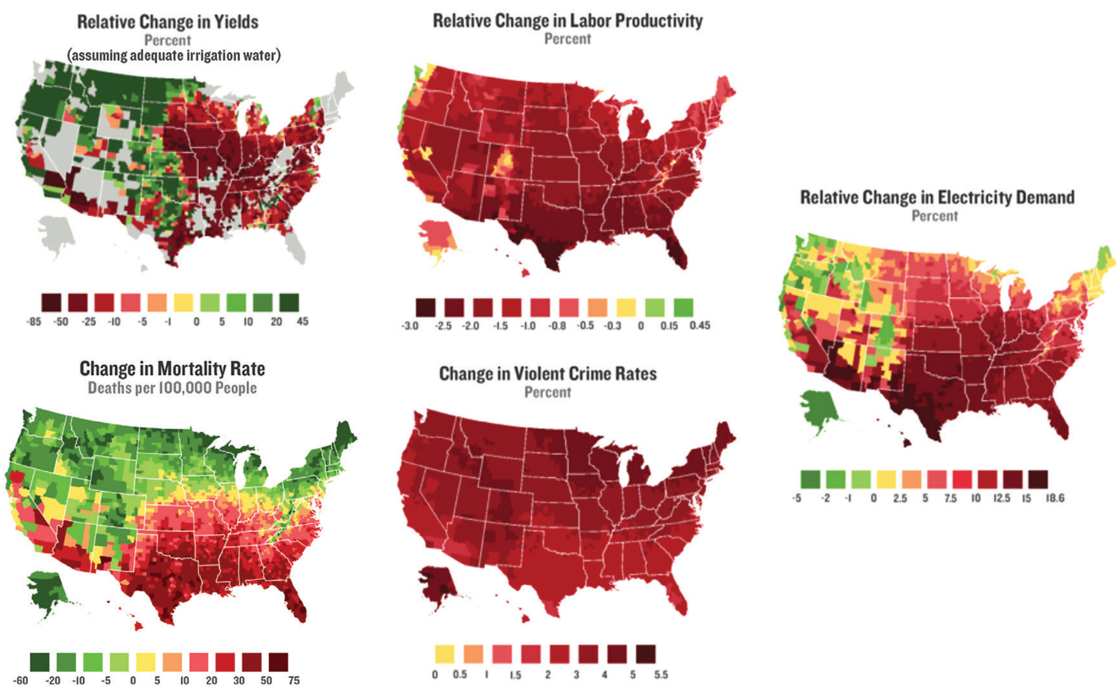

FIGURE 2-3 Projections showing unevenly distributed economic impacts of climate change, 2080-2099.
SOURCE: Houser et al. (2015, Figs. 6.4, 7.5, 8.3, 9.5, and 10.3). These figures are adapted from American Climate Prospectus maps prepared by Climate Prospectus (http://climateprospectus.org/ [August 2016] and reprinted subject to Creative Commons License CC BY-NC 4.0 (http://climateprospectus.org/data/ [August 2016]).

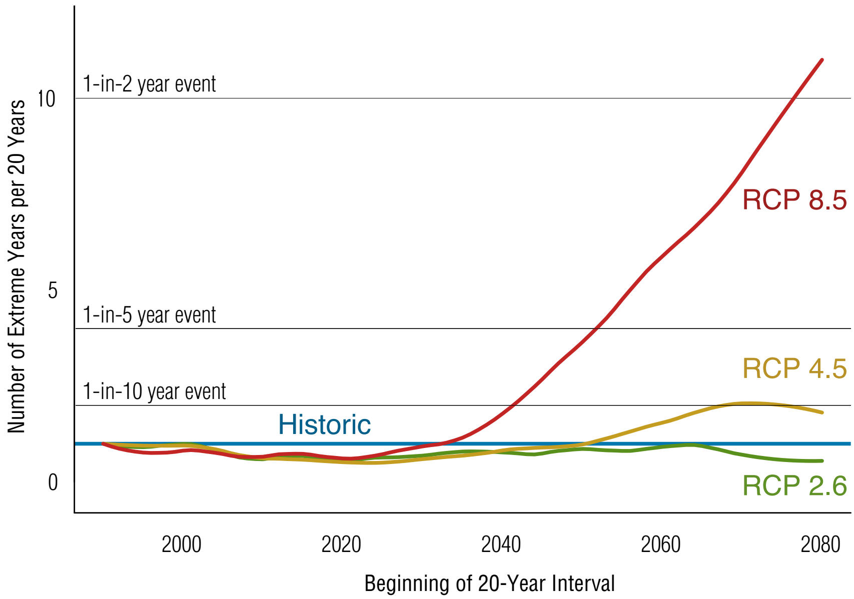

FIGURE 2-4 Historic and projected numbers of extremely fatal hot years, 2000-2080.
NOTES: A 1-in-20 year event assuming current population would result in 25,000 deaths. RCP stands for representative concentration pathways, which are distinct levels of greenhouse gas concentration in the atmosphere that could result in future differing levels of greenhouse gas emissions over time. These pathways are used in climate change modeling.
SOURCE: Houser et al. (2015, Fig. 8.4). From *Economic Risks of Climate Change: An American Prospectus*, by Trevor Houser et al. Copyright © 2015 Columbia University Press. Reprinted with permission.

changes, Kopp noted, but he suggested some modifications to the idea for the climate context.[6]

There are potential tipping points in both physical and social systems, he pointed out. Physical "tipping elements" in a climate context, such as loss of permafrost or ice sheets or dieback of forests, operate on a very long timescale, he explained, in contrast to the much shorter times involved in social tipping points. There may be a long lag between the actions that commit the planet to a climatic change and the full realization of its consequences, making it difficult for people to understand the potentially dramatic consequences of actions they are taking. Thus, understanding how likely it is that the planet may cross a

[6]See Kopp et al. (2016).

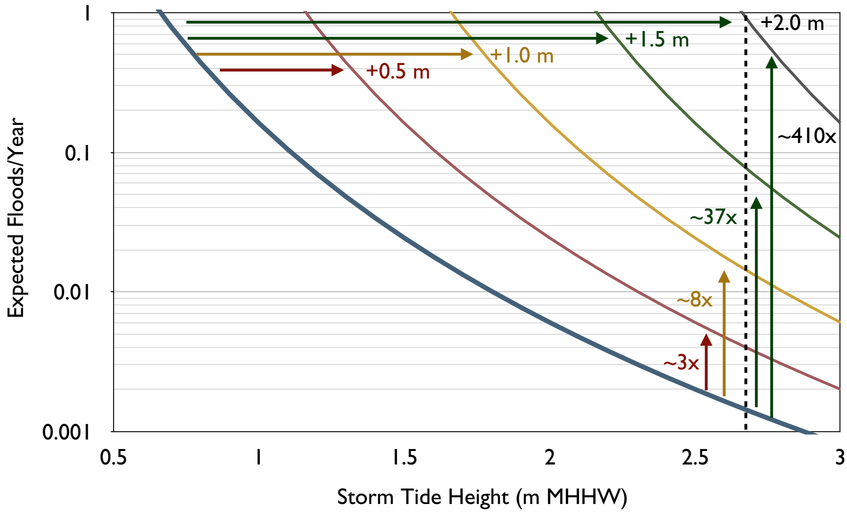

FIGURE 2-5 Expected flood frequency for different projected rises in sea level for the Battery in New York City.
NOTES: Frequency increases labeled are for flood height in Hurricane Sandy. MHHW indicates mean higher high water, the average of the highest high tides per day over a period of time.
SOURCE: Kopp (2016).

critical physical threshold, as well as the potential consequences of doing so, is critical. Physical models can be used to determine the magnitude and timescale of physical changes that may occur, Kopp noted. Empirical models and process models for particular sectors can be used to assess how those physical changes may translate into economic costs.

In closing, Kopp emphasized that many of the consequences of climate tipping points may play out on timescales that are well beyond those typically considered in political and economic decisions—yet these decisions may have vital effects on civilization.

Participants added a few additional perspectives. One noted that the NCA4 will need to strike the optimal balance between "attempting to produce probability distribution functions for future states" and describing "the scenarios that are most risk-relevant." Another noted her appreciation for Kopp's discussion of cascading consequences but commented that "we are still stove-piping" by focusing on particular sectors. Analyses of risk in particular sectors may disguise the overall risk because it does not address cumulative, interacting effects. She also noted that interdisciplinary collaboration is needed to flesh out what particular risks mean. For example, economists' discussions of the impact of extreme heat do not typically reflect specific understanding of the physiological effects for humans of exposure to extreme heat.

FRAMING RISKS TO IMPROVE COMMUNICATION

The way in which information about climate change risks is framed is central to the way people understand the risks and the decisions they make. Robyn Wilson of the Ohio State University provided perspectives from research in decision and communication science that could help make the NCA4 more engaging and useful.

Some scientists can be uncomfortable with the idea of framing information, Wilson noted, because it might seem to counter the goal of being completely objective. However, any decision about how to present information is a frame, she noted, an "interpretive story line" that communicates why an issue is important to a particular audience and highlights the options or actions that should receive the most attention. A successful frame will pare down technical information so that is it accessible and persuasive to a nontechnical audience.

Researchers who have studied the framing of scientific issues, Wilson noted, have found that a different approach is needed for topics that are controversial than for those that are not. For issues generally accepted by policy makers, it makes sense to focus on highly technical, scientific, and legal information and language because there is no need to attempt to alter policy makers' views. With climate change, however, which many policy makers do not accept as an important issue, effective framing would focus instead on moral considerations and the dramatic risks and costs the scientific information demonstrates. Leaders such as Pope Francis are in a position to address the moral considerations, but the NCA4 is ideal for addressing the risks and costs that can motivate people to act, Wilson noted.

Research also suggests that the risks that are most likely to motivate people are those that are psychologically near to them in space and time. This point highlights the importance of moving beyond abstract data that are not likely to affect people and localities soon. Public health threats, extreme weather events, and economic costs are some of the issues that people see as likely to affect them and their work. Translating the impacts of climate change into economic costs is useful, but many impacts cannot be translated into economic metrics, she added.

Applying these ideas to the NCA4, Wilson explained, suggests several points. While it is important to attempt to support decision making across scales, a single report cannot address every user effectively and provide comprehensive information about every issue. To her, two questions are (1) which risks should the NCA4 present—that is, how should the chapters be framed? and (2) how should those risks be presented—that is, how should the data be framed?

The chapters in the third NCA (NCA3), Wilson noted, varied in their approach because authors were given wide latitude to choose an approach. For the NCA4, she suggested, it is important that all the chapters be focused on decisions people need to make or problems they face and what science can offer to help them think through their options. Linking the science to potential impacts, values, alternatives, and tradeoffs will be most engaging to users. It will also be important to tie information about impacts to possible actions, she added, though scientists sometimes shy away from being prescriptive about how people should use the information they provide. It is possible to focus on the benefits of actions that municipalities, for example, have already taken, and to highlight the probability of particular outcomes, given action as compared with inaction, without making explicit recommendations, she pointed out.

Wilson also had suggestions for framing the data itself. The NCA3 established some guidance for authors, such as

- providing numerical, not just verbal, estimates;
- using standardized likelihood ranges;
- providing a confidence range for conclusions; and
- highlighting low-probability/high-consequence events.

For the NCA4, Wilson suggested, it might be useful to consider three additional practices:

1. presenting expected changes in absolute, not relative, risk terms (e.g., instead of using the phrase “a 50 percent reduction,” describe the change as “a reduction from 10 to 5 percent”);
2. using pictographs to show changes in risk, such as depicting the status quo as compared with ways risk might increase or decrease, depending on human action; and
3. including different temporal frames, for example, noting both the risk that an event will happen in the course of a lifetime and the annual risk.

Wilson offered suggestions for implementing these ideas. In her view, the NCA4 should

Define chapters based on users the authors want to reach, focusing on decisions that members of that audience need to make and problems they face within their regions or sectors. She said the goal for each chapter should be to provide the information those users need most. Wilson has heard the critique that scientists are “very good at answering questions people don’t have,” so it is critical that the chapters not begin with what scientists think is most important or interesting, but on how science can meet the needs of the target audience.

Integrate explicit examples that will support decision making into each chapter, along with links to additional resources. These examples should demonstrate how available science was linked to a local problem and used to make effective decisions.

Require standard representations of the probability of particular impacts relative to some reference point. For example, a table for each chapter that summarizes key impacts and shows the probabilities of certain outcomes under different scenarios could help users put the information in each chapter into context, she suggested.

Provide a clear framework to help authors to frame their material. Wilson cited as an example a graphic used in the development of the chapter on coastlines in the NCA3 as one useful way to guide authors (see Figure 2-6).

Wilson closed with the suggestion that social and behavioral scientists be included as coauthors on chapters. The perspectives they would bring could be invaluable in helping the scientists frame their data.

Participants' questions focused on challenges. One noted that developing tables that summarize probabilities, as Wilson suggested, would be very difficult since the evidence is rarely complete. Another noted that "scientists tend to write for each other" and to be both very precise about the robustness of

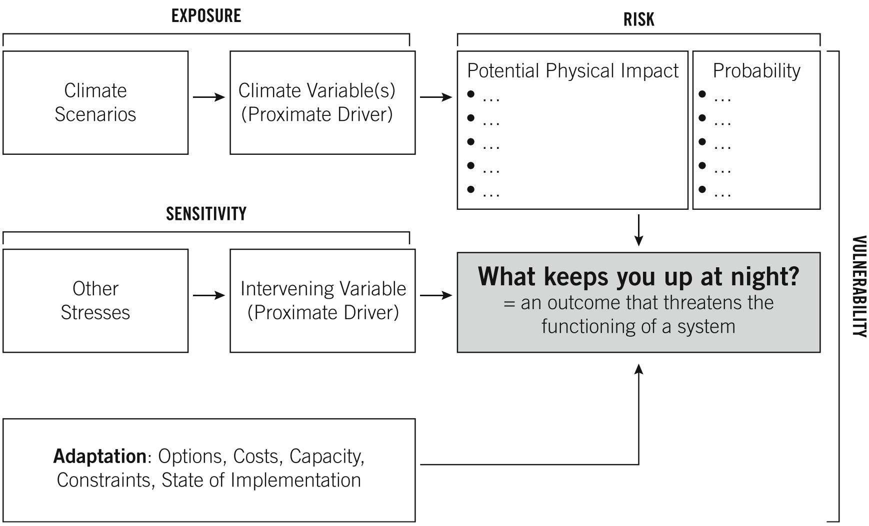

FIGURE 2-6 Guide provided to authors of NCA3 coastal chapter.
SOURCE: Moser and Davidson (2016, Fig. 2). The third National Climate Assessment's coastal chapter: The making of an integrated assessment. *Climatic Change, 135*, 132. Reprinted with permission of Springer.

their evidence, as well as leery about communicating complex or inconclusive results. It would be a big challenge, a participant pointed out, to address this consistently across chapters because of the variation in the knowledge base across the topics.

The participants' comments also included some suggestions. One was to be very explicit in guiding the authors not to write for their peers, but instead to focus on the information that local decision makers, such as ranchers or water or land managers, need. Another was to focus on case studies and on providing probabilities at scales where it is possible to do so. One participant suggested that users would actually be more interested in discussion of possible consequences than probabilities, as long as the NCA4 was clear about the sources of uncertainty. For example, one suggested, the electrical community is very interested in information about the possibility that the frequency of extreme events affecting the power grid, such as ice storms and lightning events, will increase. The existing science may not indicate probabilities but can be very helpful in helping people understand what they need to prepare for and the approximate timeframe. "Scientists need to become more comfortable with uncertainty," that person noted.

CHARACTERIZING TRADEOFFS

Robin Gregory of Decision Research and the University of British Columbia provided some additional ideas from the field of decision research. He reviewed some primary reasons why making decisions about issues affected by climate change is challenging and offered strategies for addressing those challenges.

There are many reasons that policy choices related to climate change are difficult, Gregory pointed out. These decisions involve multiple stakeholders and interests as well as many technical experts, each of whom may view the problems and possible responses very differently. Many levels of decision makers (local, state, and national) can play a part, but it is not always easy for them to coordinate. Climate change decisions engage many dimensions of value, including economic and environmental interests as well as ethical and moral considerations. Yet people often have difficulty engaging in open dialogue about ethical and moral issues, and it can be difficult to distinguish facts from values and opinions, he said.

There are also many possible responses to any climate-related problem, Gregory noted, including attempts at both mitigation and adaptation, but the numerous alternatives can complicate and confuse the issue. In many cases, the probabilities of possible consequences to be averted are uncertain, and that can lead to a lack of trust in scientists and other experts. Many decisions interact with others and present multiple tradeoffs to consider, which can make it difficult to decide where to focus attention and effort. All of these complications can lead to apathy, Gregory noted. He focused on several challenges the complexities of climate change present for which decision science offers guidance:

Articulating clear objectives for climate-related policies. People have difficulty identifying clear objectives when the available options are not familiar to them, Gregory noted, and that is often the case in climate-related policy discussions. Vague objectives are a poor basis for decisions so it is important to define precisely the values to be pursued through different policy alternatives using measures of their performance.

Unfortunately, there are no ready measures for many of the concerns and goals that people value, Gregory added. Social concerns such as community identity or family ties, psychological states such as anxiety or happiness, environmental concerns such as the health and resilience of an ecosystem or species, and cultural concerns such as for a sacred site or traditional practice—all may be very important to people though they cannot easily be quantified. One solution, Gregory suggested, is to identify objectives related to these concerns for which measures can be identified. For example, proxy or constructed measures related to physical or psychological health, economic opportunity, livability of a community, aesthetics, and the like, can represent some of the local knowledge, community values, and other intangibles that people value.

Defining the consequences of changes in climate. Predicting the specific consequences of climate change is challenging, and different people have different views of which potential consequences are important and why. Scientists may be frustrated because they provide good scientific data that are ignored by decision makers. Decision makers may be frustrated because they are asked to consider so many conflicting factors that no one is ever happy with their solutions. Structured techniques for making decisions can help, Gregory explained. These techniques might include using diagrams to explore means and ends or identifying priorities for different objectives using decision trees, profiles of risk tolerance, or surveys of what people value.

Thinking both slowly and quickly. Quick thinking, sometimes known as System 1 thinking,[7] happens automatically and with little effort. It is based on associations, recent experiences, and simplified judgment rules. Deliberative thinking, or System 2 thinking, is slower and involves weighing and balancing different ideas and considering strategies or justifications for options. Tension between these types of thinking influences how both experts and nonexperts generate and evaluate alternatives. Thus, it is useful to make room for both in dialogues about climate policy choices, Gregory suggested. Intuitions and emotions associated with System 1 thinking can provide valuable insights into people's priorities, he explained, but need to be combined with deliberation, analysis and reasoning, and other aspects of System 2 thinking.

[7]See Kahneman (2011).

Making choices that relate to multiple values. Climate change policy choices may have impacts in very diverse areas of life. Thus, making optimal decisions may require considering economic, environmental, social, cultural, political, and other values, Gregory noted. People have difficulty making multi-attribute choices that involve numerous values, he added. Asking group members to identify and compare their priorities is one strategy for helping them make choices. Another is to support them in analysis of the options in terms of the values that are most important to them. Table 2-1 shows a consequence table, one way to organize thinking about a situation in which there are multiple objectives and possible alternatives; the "alternatives" column is blank because the user generates the possibilities.

Grappling with scientific uncertainty. Uncertainty is a serious challenge, Gregory noted, which arose in almost every session of the workshop. The complexities of climate models and the results of studies are difficult to communicate in clear, simple terms. Scientists want to be clear about the degree of certainty of their projections, but more attention should be paid to how that uncertainty is framed, in Gregory's view. Stakeholders who are not scientists can easily lose faith in science when the messages sound either overconfident or too murky to be the basis for action. There are varied methods for presenting probabilities, Gregory noted, and for communicating about adaptive management options. However, people tend to reinterpret information about uncertainties to align with what they already know or believe about the issue.

Integrating risks and benefits. Every climate change policy decision involves balancing risks and benefits, in Gregory's view. Ideally, decision makers would be provided with clear information about the benefits, costs, and risks of possible actions. However, Gregory explained, research suggests that this is not so simple. People tend to have preferences and emotional responses

TABLE 2-1 Consequence Table for Climate Change Adaptation in a Rural Coastal Community

Objective	Attribute	Measures	Alternatives
Minimize Management Costs	Cost	Dollars	
Maintain Environmental Health	Productivity of salmon	Biomass (kg.)	
Maintain Cultural Traditions	Continuity of ceremonies	Constructed scale 1-4	
Improve Human Health	Number of doctor visits	Number of visits	

SOURCE: Gregory et al. (2016a).

that influence the way they perceive options. For example, one study has shown that people tend to rate technology toward which they are favorably disposed as more beneficial and less risky, but to do the opposite in thinking about technology they fear or dislike, as shown in Figure 2-7.

Tradeoffs that involve moral considerations are particularly difficult, Gregory added, and in his view conventional approaches to addressing them have not been effective. Large-scale opinion polls are often superficial, he believes. Town hall meetings often veer off topic, and it can be difficult to distill consensus messages from them. Interviews or small-group meetings involving key stakeholders necessarily involve very small numbers of people, he observed. Information presented in adversarial forums (including legal courts) is often biased or inaccurate. More promising are techniques for combining interviews and small-group discussions with large-scale surveys, deliberative polling, and surveys that allow decision makers to learn about participants' decision pathways and reasoning.

A decision pathways approach, Gregory explained, allows participants to explore the links between scientific information and other values using a set of common-sense questions. This approach can be used to[8]

- situate the decision in its social and policy context;
- identify specific policy objectives;
- identify possible alternative actions;
- compare the benefits, costs, and risks of each alternative;
- reflect on key tradeoffs; and
- reconcile differences and summarize the results for policy makers.

If there are gaps in information, or participants who are misinformed about the science, tutorials can be used to address those issues so the process can proceed on the basis of a common understanding of the essential facts.

Gregory closed by emphasizing that there are many promising ideas for dealing with climate change, but policy makers and others are often impeded in implementing them because of confusion about choices that involve multiple dimensions of value. Nonexperts are often uncertain about the consequences of decisions and may lack trust in both scientists and government officials. They also may be frustrated that their concerns appear to be ignored by decision makers. Thus the aims of communication should be to guide people in better understanding both the scientific information and their own values and to help decision makers design policy alternatives that are responsive to stakeholders' concerns. To do this, "we must learn to listen to what people are telling us

[8] See Gregory et al. (2016b).

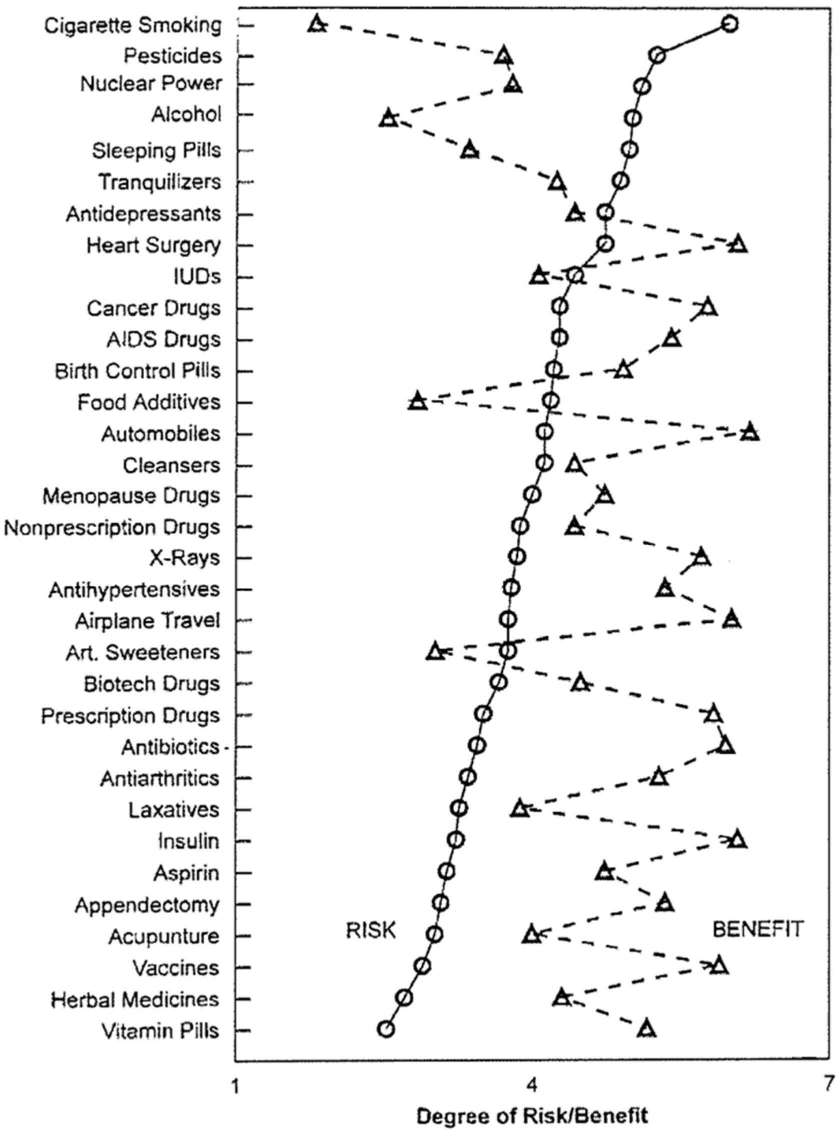

FIGURE 2-7 Perceived risk and benefit ratings.
NOTE: Triangles and circles represent survey respondents' perceived ratings of risks and benefits.
SOURCE: Slovic et al. (1991, Fig. 3). Reprinted with permission of the Canadian Public Health Association.

and establish an improved contract for deliberation: you talk, we listen," he concluded.

A FRAMEWORK FOR DECISION MAKING UNDER UNCERTAINTY

The decisions that need to be made in the near term are critical building blocks for the broader, longer-term changes needed to fully address climate change, Inês Azevedo of Carnegie Mellon University explained. She described a strategy for making the kinds of decisions that can and should be made immediately to "start de-carbonizing the economy." She listed several studies that illustrate how the climate science community can assess the potential benefits to health, the environment, and climate of different possible interventions in the U.S. energy system.[9]

Concern about climate and the environment raises countless challenging questions, Azevedo noted. "We know we need to increase reliance on renewable energy sources," she noted, "but where can we get the largest benefits?" It is important to know whether it helps the environment more to increase reliance on solar power in California or in Pennsylvania, or whether an electric car brings more benefits than a hybrid does. In which parts of the country will actions such as introducing more stringent building codes, increasing the availability of solar and wind power, or providing more storage in the electrical grid have the most benefit?

What is important to realize, Azevedo noted, is that all of these questions are related. Any intervention in the energy system may reduce or increase emissions, so answering challenging questions is easier if potential benefits and costs can be monetized.

Energy services are responsible for the majority of carbon dioxide (CO_2) emissions in the United States, she explained. The infrastructure for producing power in the United States is aging and very carbon-intensive. Different regions of the country rely on different mixes of energy sources and use energy in different ways, she added, and their emissions also vary significantly, as Figure 2-8 shows. That is one reason why the effects of interventions will be different in different locations. Another is that the monetized damage caused by criteria air pollutants[10] varies, for example, from as little as $1,000 per ton of sulfur dioxide to as much as $15,000 per ton. Thus, potential benefits will depend on the type of fuel generation that would be displaced by an intervention and other factors. Furthermore, relying on average annual emissions data by region will not be adequate for accurately calculating costs and benefits, Azevedo

[9]Siler-Evans et al. (2012, 2013), Hittinger and Azevedo (2015), Tamayao et al. (2015), Gilbraith et al. (2014).

[10]Criteria air pollutants are the six air pollutants that are most common in the United States: carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter, and sulfur dioxide.

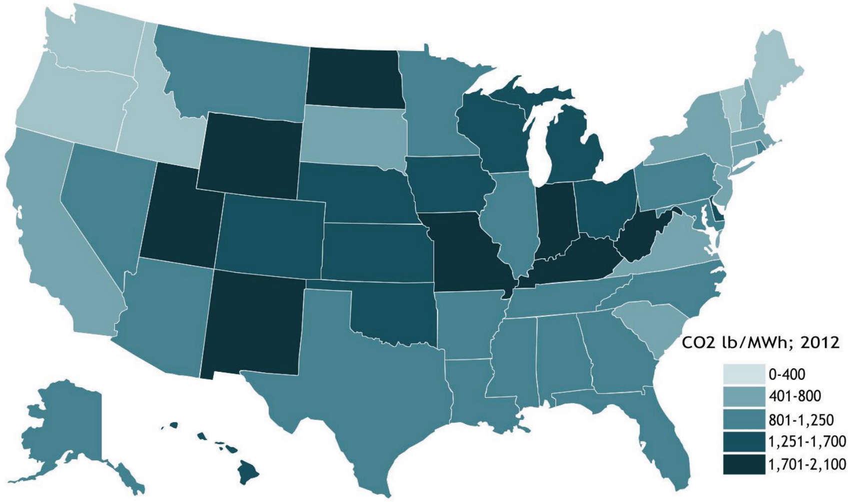

FIGURE 2-8 State-by-state CO_2 emissions.
NOTE: Map shows emissions per megawatt-hour of power produced, adjusted for size of state.
SOURCE: Ceres (2014).

explained, because of the temporal variations in energy usage (by 24-hour cycle as well as season).

What is needed, Azevedo explained, is to analyze the following with respect to any possible intervention: the temporal profile (usage patterns across time), its match with the power generation it might displace, and the monetized value of that displacement. Azevedo and her colleagues conducted this analysis for five interventions: conversion to either wind or solar power, increasing the energy storage capacity in the electrical grid, increasing use of electrified vehicles, strengthening building codes, and making lighting strategies more efficient. They used hourly data on emissions of sulfur dioxide and nitrogen oxides for every power plant that uses fossil fuels, which is collected by the Environmental Protection Agency. With these data they were able to derive actual or simulated information about the effects of interventions on an hourly basis. They could estimate savings in CO_2 emissions as well as additional benefits from reducing other pollutants and the monetized value of those reductions.

With this sort of information, Azevedo explained, they focused on three measures of performance for the interventions:

1. energy production;
2. climate benefits from reductions in carbon dioxide emissions; and

3. health and environmental benefits from reductions in sulfur dioxide, nitrogen dioxide, and particulate matter.

Azevedo and her colleagues were able to characterize the environmental and health benefits of wind and solar power using hourly data for thousands of power plants across the country by estimating the amount and type of power that would be displaced and calculating the benefits of that displacement. As one might expect, Azevedo explained, the results for solar power show that the locations that can provide the largest electricity output using solar panels are not the ones that can benefit the most. That is, a solar panel in Ohio will produce about 30 percent less energy than a panel in Arizona but will provide 17 times more health and environmental benefits than the Arizona panel because it will displace electricity that would otherwise have been produced by burning coal. In many cases, the comparative analysis will be different depending on whether the top-priority outcome is health outcomes or other benefits, Azevedo noted.

The story is a bit different for wind power. In that case, the locations that provide the largest electricity output using wind power are the ones that can realize the greatest reductions in CO_2 emissions, but not reductions in other air pollutants. This is because wind turbines located in the Midwest are most effective at displacing CO_2 emissions because that region has excellent wind resources and also has relied heavily on coal-fired generators. Thus, for example, a wind turbine in West Virginia displaces 27 times more CO_2 emissions than a turbine in California because of West Virginia's heavy reliance on coal.

Azevedo briefly described how this type of analysis could be used to assess the impact on CO_2 emissions of widespread conversion to battery-powered electric or hybrid vehicles. Variation in these vehicles' designs is one complicating factor, she noted, so the researchers focused on the Nissan Leaf and the Toyota Prius. Effects on emissions also depend on where and when an electric car is charged, because the time of the day and the type of fuel that supplies the electricity must be considered. Here also, they found the results differed by region.

"A major transition in our energy system is needed," Azevedo said in closing. Even the most immediate decisions will have long-lasting effects, so it will be critical to determine which strategies will provide the optimal results. To do that, she said, it will be important to consider both greenhouse gases and criteria air pollutants and to examine patterns in behavior and across time and location that will influence the effects of all interventions.

Participants' comments focused on specific applications of this analysis. One pointed out that this type of analysis could help the authors of the NCA4 identify useful regional case studies to include. Another asked how Azevedo's analysis might apply to interventions designed to reduce the grid's reliance on fossil fuels, rather than adding renewable sources. Azevedo noted that she and her colleagues had examined projections of power plant retirements currently under way and assumptions about the effects of those, but that additional modeling might be useful to better understand that type of policy intervention. Another wondered whether the analysis could integrate additional sources of complexity, such as the varied nature of the power grid in any one region and impacts that changes in climate will have in a particular region. For example, the participant noted that during droughts in California, limitations in hydropower capacity can cause an increase in reliance on natural gas. Azevedo noted that the analysis is designed to identify optimal potential benefits across the country. California, which has already made significant moves toward use of renewables, will show lower incremental benefits, but that should be interpreted as a sign of progress the state has already made, she explained. She and her colleagues have worked to incorporate the complexity of the grids and other complexities into their model, she noted.

3

Cases: Methods and Approaches for Risk Assessment and Communication

The chapters in previous editions of the National Climate Assessment (NCA) were organized around region- and sector-based topics, including the Southwest; coastal regions of the United States; and the interactions among energy, water, and land use.[1] For the workshop, three panels of experts were asked to consider how the authors of the chapters on those three topics for the NCA4 might take into account the ideas about characterizing and communicating discussed in the workshop. The panelists, many of whom had contributed to the development of prior NCAs, were asked to address ways to make risk information useful for the decision makers most interested in their particular topics and improve the treatment of consequences, uncertainties, and tradeoffs.

THE U.S. SOUTHWEST

The Southwest has already begun looking across sectors and using scientific information in making policy decisions, noted moderator Kristie Ebi of the University of Washington. Gregg Garfin of the University of Arizona, Bradley Udall of Colorado State University, and Jonathan Overpeck of the University of Arizona provided their perspectives on how the NCA4 can be most helpful to that region.

Garfin offered recommendations for the process of developing the NCA4, based on his experience contributing to the development of the NCA3. He

[1] For a complete list of the chapters of the NCA3, see http://www.globalchange.gov/sites/globalchange/files/NCA3_Highlights_LowRes-small-FINAL_posting.pdf [May 2016].

noted that the objectives for the NCA4, described in the planning document for the workshop, are ambitious. The document indicated that users hope the NCA4 will be, among other things, accessible, useful for decision making, easy to understand, focused on individual hazards, clear about the consequences of particular choices, accurate, and useful for making comparisons and assessing tradeoffs. Garfin said he doubts that the NCA4 can achieve all of these objectives given expected constraints in time. “If we focus on individual hazards,” for example, “we will need to reframe the NCA.” It will not be possible to address comparisons and possible consequences of alternatives at the scale of the NCA regions, he explained. This could be done using individual case studies that have a narrower focus, which he believes would be useful. Garfin offered three broad suggestions for the writing of the NCA4: developing a culture of risk assessment, providing more author support, and taking users’ perspectives as a starting point.

With respect to his first suggestion, Garfin said that the NCA4 writing teams should be given instructions on how to frame risk, and he suggested several strategies for making the characterization of risk a high priority in the chapters. Integrated teams that work together beginning at the technical input phase could bring in diverse perspectives, and guidance to the stakeholder workshops for each chapter would sharpen the messages about risk. He also suggested forming teams of research evaluators, including members of the research and practitioner communities, to build the authors’ understanding of ways to characterize risk. Another possibility is to have multiple author teams, which would be charged with working separately on vulnerability and impact, risk and uncertainty, and expert assessments. Garfin also suggested that risk-based analyses developed through the sustained climate assessment process could be used in the NCA4.[2]

Second, authors will need more time to do their work than they had for the NCA3, Garfin observed, as well as guidance on methods for evaluating the importance of a topic and characterizing vulnerability and risk in ways that are consistent, even if imperfect. This guidance should not just be a suggestion, he added, because consistency across the document is critical. The authors will need more research that provides risk-based assessments, particularly research that takes into account nonclimate factors to produce assessments of adaptive capacity.

Third, Garfin offered several possibilities for making sure the document meets the needs of those who will use it, including involving end users in the author teams and asking them to define the thresholds they use in making decisions. He recommended that models be used as a basis for discussion rather than for prediction. He advocated holding user workshops focused on risks and producing graphics and scenarios defined by users’ interests to help NCA

[2]For more on this idea, Garfin referred participants to Buizer et al. (2015).

authors understand the specific challenges users face in addressing uncertainty and community values and thus help them in communicating about risk.

Garfin discussed a few communication strategies that he thought successfully addressed users' needs. One was a graphic used in the NCA3, shown in Figure 3-1, which he said may have generated more positive feedback than any other graphic included in the NCA3's Southwest chapter.

Another was a planning tool he developed with a colleague to guide the people of the Southwest in thinking about climate change impacts for their region, including drought, decreased reliability of the water supply, heat waves, increased energy demand, and strain on the power grid. The influence diagram in Figure 3-2 depicts connections among events and the responses of different stakeholders. A third strategy is scenario planning that guides people in conceptualizing the possible outcomes of different options.

Tools such as these cannot be used effectively at a regional scale, Garfin emphasized, but they are useful in case studies for localities. Another example he showed, a tool developed by the U.S. Department of Agriculture Forest Service, allows users to incorporate evidence about wildfire hazards in a region with expert judgment about the risks to high-value resource areas. The Forest Service surveyed users about their experiences using decision-support tools. Many of the users reported that the tools were useful, citing reasons such as the clarity and transparency they can bring to the decision process, help they

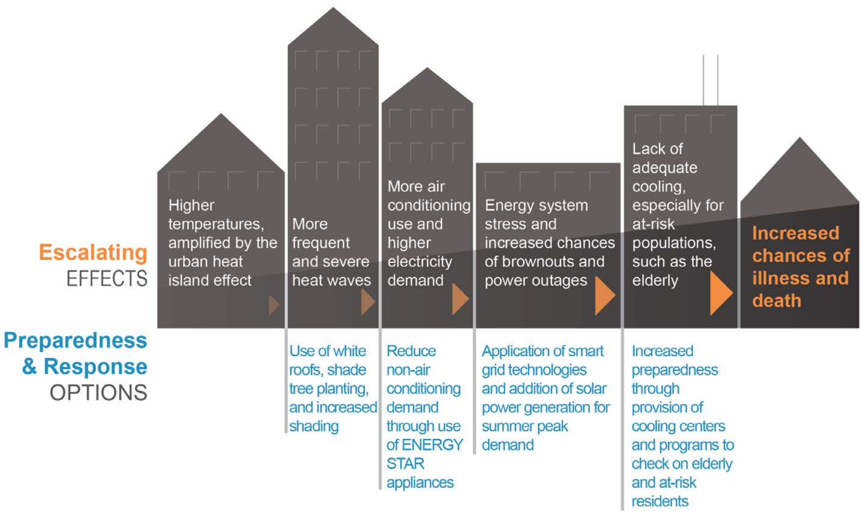

FIGURE 3-1 Urban heat and public health graphic used in the third National Climate Assessment (NCA3).
SOURCE: Garfin et al. (2014, Fig. 20.6).

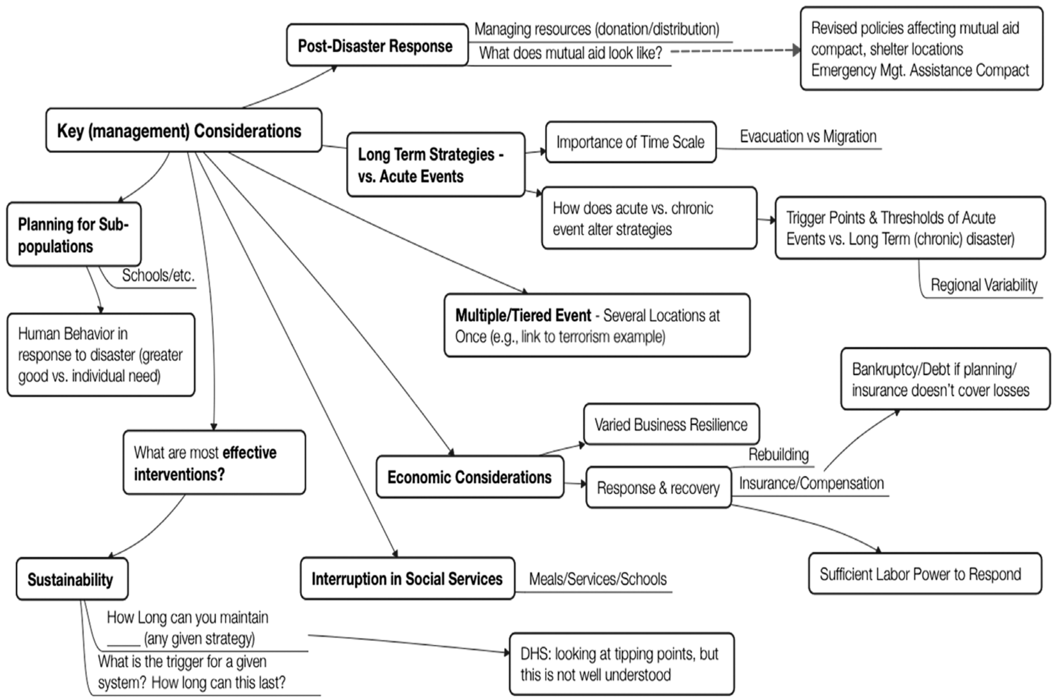

FIGURE 3-2 Influence graph for climate change impact in the Southwest.
SOURCE: Garfin et al. (2016, Fig. 3). Conceptual diagram (or "influence diagram") showing potential cascades of impacts from the combination of drought, reduced water resources, and power outage in the Southwestern United States. Figure by Ben McMahan (University of Arizona) in Garfin et al. (2016).

provide in addressing conflict or controversy, and protection they can offer against litigation.

Overpeck suggested that "getting the risks right" will be a key issue for the Southwest chapter. He began with a description of the region, which is defined by the Colorado River Basin and includes seven states.[3] This fast-growing region contains many large cities and many Native American nations and is also home to a significant volume of agricultural production. The Colorado River, which supplies the two largest reservoirs in the United States, is the primary water source for the entire region. Changes that affect the river's flow will affect virtually everyone in the region, which has a population of between 30 and 50 million, Overpeck emphasized.

Recent projections for the river's flow have conflicted, Overpeck noted. One recent report, from the Bureau of Reclamation, suggests that flow from snowpack runoff will remain approximately consistent through the 2070s. However, this report differs from a large body of research suggesting that river flows will decrease by 5 to 45 percent by mid-century. A look at recent data, Overpeck noted, shows a significant downward trend in flow over the past century, exacerbated by major droughts in the 1950s and the current drought, which began in the 2000s.

Drought can be caused by low precipitation, Overpeck noted, but the Colorado River Basin is experiencing a new type of drought, caused by warming temperatures. This is "a whole new ball game," known as "hot" drought (meaning drought caused by global warming), Overpeck explained. "It's going to get hotter" in the Colorado River Basin according to all models, he added. The only questions are how much it will warm and how decision makers should respond.

The risks projected by models are "worth betting on," Overpeck suggested, when

- they are consistent with theory,
- they are consistent with ongoing change already observed,
- they are consistent across most models, and
- the physics of the projected change is consistent with both model results and observations.

All of these criteria hold true for model-based projections about warming in the region, Overpeck explained. Despite the Bureau of Reclamation report, he said, recent research he conducted with colleagues shows that warming alone will result in flow declines of 6.5 percent (± 3.5%) for each degree centigrade of average warming. The past 16 years of drought have resulted in an average 16 percent loss in flow, and they estimate that as much as 10 percent of that loss is the result of temperature increases. By mid-century, depending on emissions

[3]The seven states are Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming.

levels, the median decline is expected to be 26 percent. The declines could be as high as 50 percent or more by the end of the century under the highest emissions scenarios.

The Bureau of Reclamation indicates that temperature increase will be offset by increases in precipitation, Overpeck noted. But, he said, models project a range of possible effects on precipitation in the region, again depending on emissions levels. The Colorado River Basin could get a little wetter or a little drier, or stay about the same. Given those findings, he suggested, placing a lot of hope in the possibility of precipitation increase seems unwise. The most recent report from the Intergovernmental Panel on Climate Change (IPCC) also found that there is substantial uncertainty in projections for storm tracks that could bring increased precipitation to the Southwest.

Moreover, said Overpeck, even if "you're going to bet" that the mean precipitation levels will go up, "you also have to bet against the risk of multidecadal drought." But estimates he and his colleagues developed, based on the paleo-climate record, project a 10 to 15 percent chance of a 35-year drought in the second half of the 21st century. In other words, even if average precipitation goes up, it is likely that the region will see multidecade periods when the Colorado River's flow is below normal by 15 percent or more. The extreme end of the projection is that there may be temperature-driven reductions of 50 percent or more in the river's flow.

The standard approach in the climate science community, Overpeck concluded, is to rely on averages across multiple models. To really give stakeholders what they need, in his view, it is necessary to take apart the components of the evidence base. A simple number can be quite misleading, and the stakeholders are well equipped to understand a more sophisticated analysis of the areas of uncertainty.

Udall turned the discussion beyond the Southwest to the broader risks to society. He cited a 2015 essay by Naomi Oreskes in which she chided the scientific community for being too scared of making a mistake.[4] Though scientists are often accused of exaggerating the risk of climate change, Oreskes argued that they should be more emphatic. Scientists tend to be cautious in presenting their findings, the essay argued, which means they are too willing to risk Type 2, or "Trojan horse," errors (missing a major risk) and too reluctant to risk Type 1, or "cry wolf," errors.

Almost every week, Udall commented, new research is published showing "eye-opening climate risks." Recent examples addressed increases in ice melting, sea-level rise, and superstorms; significant drying of the Southwest; and projections for multimillennial consequences of 21st-century policies. To illus-

[4]This essay, "Playing Dumb on Climate Change," appeared in *The New York Times*, January 3, 2015. Available: http://www.nytimes.com/2015/01/04/opinion/sunday/playing-dumb-on-climate-change.html?_r=0 [September 2016].

trate the growing awareness of long-term impacts, Udall showed graphs from a 2016 study, shown in Figure 3-3, which examined the effects of CO_2 emissions on a 30,000-year scale. The top set of trend lines shows the persistence of CO_2 in the atmosphere under a range of human-caused emission scenarios. The middle set of lines shows the effects of that CO_2 on temperatures under the same range of scenarios, and the bottom set shows the rate at which CO_2 levels will change depending on how quickly humans stop burning carbon. According to Udall, the study suggests the effects on temperatures are much longer lasting than changes in emissions or even changes in CO_2 concentrations.

Looking at the NCA3 report, Udall noted all that was accomplished but also called attention to gaps that he believes should be addressed for the NCA4.

Framing of Risks. Risks in the sectors and regions were not adequately emphasized in the NCA3, Udall noted, but perhaps more important is that the report offers "next to nothing" about the unique nature of the existential risks to society. These risks are "really different from any kinds of risks humans have faced," he pointed out, and the report did not get that level of seriousness across. The report generally frames risks on a 100-year timeframe, which in his view is too short. It is like "driving at 100 mph and providing information only on the next mile," he noted. It is not the case that there is greater uncertainty associated with projections for all of the longer-term consequences, he added; indeed, "when people see the irreversibility, they wake up." The design of the NCA3, which provided short, stand-alone chapters on each topic, made it very difficult to accurately frame the risks, Udall added. The authors were not given clear guidelines for handling risk consistently across topics or examples of effective ways to convey risk information.

Mitigation. The NCA3 says "next to nothing" about mitigation, Udall observed, noting that "we've been too skittish." Scientists have been cautious about overstepping the line between describing their findings and conclusions and making recommendations, he said, but mitigation is "the most critical form of risk management we have."

Return Periods (estimates of likelihood). Risk is often discussed in terms of how likely an event has been in the past, Udall noted, but "backward-looking return periods provide no useful guidance for the future." Udall used a study of temperature and precipitation in California to illustrate how the trend for both has moved consistently in the drier and hotter direction. As Figure 3-4 shows, the years since 2000 (circled) were on average much drier and hotter than earlier years. In other words, the frequency of anomalous high heat and low precipitation periods has increased relative to the mean for the years 1901 to 2000. It is important to recognize that relying on data about past trends can lead to a false sense of security, Udall explained, but there are few useful metrics to replace comparisons with data from the past.

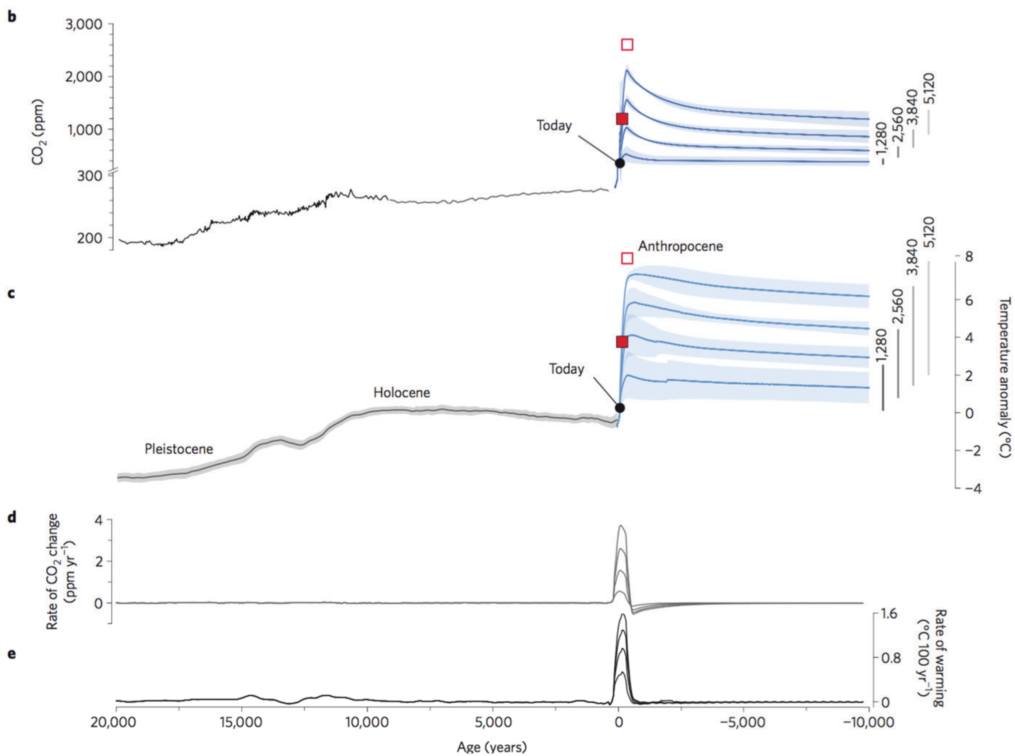

FIGURE 3-3 Effects of CO_2 emissions on a 30,000-year timescale.
SOURCE: Clark et al. (2016, Fig. 1b-e). Reprinted by permission of Macmillan Publishers Ltd: [Nature Climate Change] Clark et al., Copyright © 2016.

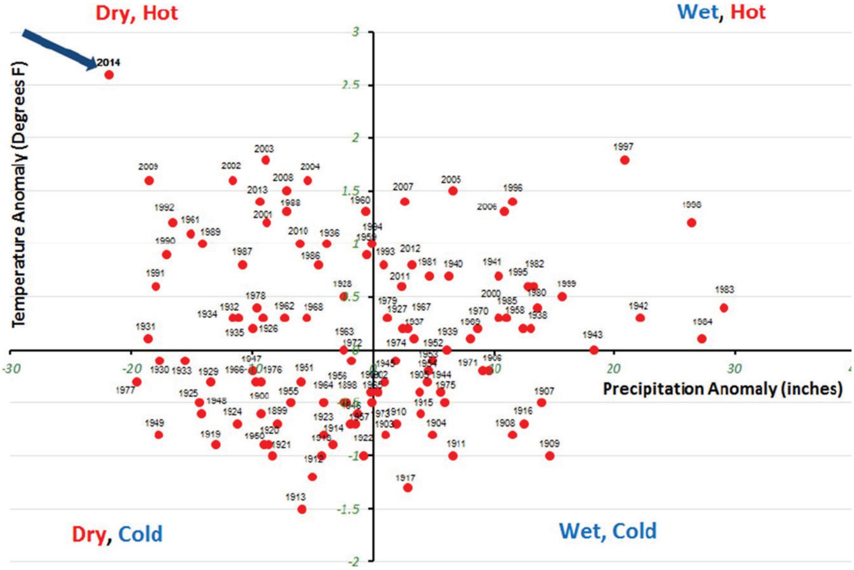

FIGURE 3-4 Anomalous heat and temperature events in California, 1901-2000.
SOURCE: Mann and Gleick (2015, Fig. 1).

Context. The NCA3 did not provide clear enough "anchors to help users understand the significance of temperature and precipitation changes," Udall stated. Members of the public may compare daily temperatures and rates of precipitation with projections. For example, 10 percent might sound like a small change in temperature or precipitation, but its impacts would be very significant.

"We are playing dumb on climate change," Udall concluded. The NCA3 did not portray the unique, irreversible nature of the risks. "Why isn't it possible," Udall wondered, "to say that burning carbon is risky?" It is critical to convey to people that continuing on the current path means "very large risks to civilization as we know it." There are economically viable paths to a carbon-free world, but these must be pursued immediately and "with unparalleled vigor" to prevent dangerous changes to the climate, he argued. He closed with the thought that perhaps the most important challenge to climate scientists is to continue repeating these messages until they are heard.

The question-and-answer session allowed participants to highlight what they believed was most important for the development of the NCA4. With regard to characterizing risk, participants had several suggestions. One suggested identifying a set of variables to address in every chapter, such as effects on human health and forest health, biodiversity, and ecosystem services (such as crop pollination, water supply, etc.). If these could be discussed in plain language, they would help "cut across" regional and sectoral differences and illustrate everyday consequences. Another suggested focusing on unprecedented events as a way of demonstrating the potential magnitude of the effects of changes that may sound small. Showing users how past shifts of only a few degrees in mean temperature have led to the development of ice sheets and their subsequent melting in a specific place, such as Ohio, can make the significance of changes occurring now more real. A third suggested that profiles of sets of scenarios, based on a range of assumptions that lead to alternate futures, provide a very useful way to portray risk and the range of possible outcomes.

Several participants emphasized the value of case studies that allow decision makers to focus on specifics and see how their own concerns can be addressed. However, others commented that identifying suitable case studies is very challenging and that it is important to use them strategically to highlight important ideas and to make clear why they are important. What has been missing is analysis from the social sciences that explicitly examines what different possible future scenarios will look like.

Several participants offered comments about the expertise authors should bring and ways to better weave in the perspectives of end users of the climate assessments. One noted that many scientists are uncomfortable with venturing beyond their specific areas of expertise and with offering their judgments about what should be done about their findings. Another noted that "there are *no* experts on climate change" because climate scientists tend to focus on their own relatively narrow areas. "No one is paying attention to big, cross-sector effects," this person suggested. Using broader expert panels that include decision makers at different levels and including nonscientists on author teams are two ways these participants suggested to both bolster the scientists' confidence in speaking beyond their areas of expertise and make sure that users' practical concerns are carefully considered.

COASTAL REGIONS

Margaret Davidson of the National Oceanic and Atmospheric Administration (NOAA), Robin Gregory of the University of British Columbia, and independent consultant Susanne Moser offered their perspectives on how the NCA4 can best address coastal regions.

Davidson drew on her experience with the NCA3, noting that the assessment was the first to include a chapter focused explicitly on coastal issues. There are many challenges posed by rising sea levels and related changes, she noted, but she argued that the greatest is the need for changes in behavior "at a very fine scale." The infrastructure located along the U.S. coastline is managed at a local and regional level, she noted. Decisions about planning and zoning that have critical long-term impacts are made at those levels.

The individuals who make these decisions, she added, bring different levels of experience and perspectives to their jobs. Regional water resource managers, she observed, tend to have a very sophisticated understanding of risk management, but the local officials who respond to flooding, for example, are less likely to think on a national scale or in long timeframes.

These observations highlight the importance of considering the needs of the audience in framing the coastal chapter of the NCA4. The NCA3 included regional assessments and local case studies, which in Davidson's view were far more useful than the national assessments. The case studies in the NCA3 were arranged on a national map to make it easy for people to identify the ones most relevant to their own challenges.

Davidson also stressed the importance of using language that is accessible to audience groups. Within the climate science community, she noted, "we all kind of understand what we mean by risk and uncertainty, but most people don't know or care." The developers of the NCA3 coastal chapter brought together groups of experts that included policy makers as well as representatives from the segments of the coastal sector the authors hoped to address. These groups reviewed both the substance of the material the authors were developing for the chapter and also the ways they were shaping the presentation. Davidson noted that the case studies required a significant investment in Website maintenance and that the group meetings were expensive.

"We are sometimes dumb about how we frame and present important communication," Davidson observed—and slow to learn. For decades, she noted, the National Weather Service reported storm surges in terms of the number of feet storm water rose above the high-water mark. "People don't have time to search for what that means when a storm is approaching," Davidson noted. Now surges are reported in terms of feet above ground level, which is "much easier to understand."

The most urgent challenges in coastal regions will be to elevate and harden critical infrastructure and to relocate noncritical infrastructure, Davidson observed. This challenge will require innovative thinking about financing and other nonscientific issues, so technical input on these issues will be key to the usefulness of the NCA4 coastal chapter.

Gregory focused on strategies for addressing the many perspectives people bring to climate change-related issues. A stakeholder once told him, "science is interesting to people but it's a very poor entry point into climate change issues." What people are interested in, he added, is what will happen in their lives. Gregory used three projects he is currently working on to illustrate approaches for helping people make difficult choices that relate to climate change.

The first project involves safety issues for a bitumen pipeline. Gregory found that the experts involved were focused on such science issues as temperature, precipitation, sea-level rise, and storm surges. The residents in the local community were focused on the salmon fishing industry and other impacts on their lives: their own jobs and place in society. It took structured dialogue, Gregory explained, to provide an opportunity for both sets of concerns to be expressed. The dialogue sparked community members' interest in the relevance of information from scientific modeling and engaged the interest of industry and government representatives in the observations and concerns of local residents.

A second project, involving port security in a large city in the Northwest, presented a similar challenge. There, experts had tried hard to convince the personnel managing the port to consider planning for climate change impacts that are low probability but could have very serious consequences. The port officials were less worried, Gregory explained, about the possible consequences of those impacts than in the political consequences of the spending required to prepare for them. They were concerned that if the worst-case scenarios did not occur, they would be blamed for spending tax revenue to build in unnecessary protection. Dialogue was needed to help the two groups communicate their concerns, identify the objectives they shared, and identify responsive management alternatives.

The third project is an ongoing review of the possibility of listing the Pacific walrus, which is native to waters off the coast of Alaska, as an endangered species. This issue also has involved different perspectives among stakeholder groups. The science community—including engineers, biologists, and others—is focused on the factors influencing the growth and abundance of the species. Members of the local indigenous communities are more focused on how the walrus harvest might be affected if this species was listed as threatened or endangered because walrus hunting is both a vital tradition in the region and a critical source of food. Community members are concerned that an agency such as the Fish and Wildlife Service might place limits on hunting.

Gregory explained that in cases in which stakeholders hold different perspectives, a structured decision-making process can help people to set aside their positions and establish a common basis for dialogue by identifying objectives and considering new sources and types of information. Once the discussion gets going, he added, participants become very interested in others' opinions and want to learn more about their knowledge and points of view. "People started to let perspectives they hadn't considered in," Gregory commented, and often their own views started to change in turn.

These conversations require time and skillful leadership, Gregory noted. It is very difficult to get people to think about issues that are upsetting and difficult, and climate change impacts are generally "dismal." It is also difficult to get people to integrate diverse kinds of information and dimensions of values. "Experts are as prone to judgmental biases as members of the public," he commented. This means that expert judgment elicitation, an element that many workshop presenters recommended for the NCA4, is both essential and quite challenging. It is important to be sure the group addresses key areas of uncertainty. But identifying those and structuring precise questions for the group to address is just the start—the experts might still really disagree.

Effective dialogue and public communication about climate change issues is the responsibility of the climate science community and decision makers, Gregory added. “It is our job to make ourselves intelligible,” he said. This can be done by focusing on the concerns of the people who need to be reached and engaging them on their own terms.

Gregory had specific recommendations for the NCA4. With respect to the case studies, he recommended using very brief text boxes that highlight what is most important about each example—illustrating how it made a difference in mitigation or adaptation by changing people’s minds. The short text could include links to a much longer description and other resources, but it should not be just a “nifty example.” More generally, he recommended reviewing the objectives that guided the NCA3 and how they might differ from those for the NCA4. “Who do we want to reach? What do we want to convey?” he asked. “Will it be a presentation tool or a tool for engaging in dialogue?”

Moser began by noting that the coastal chapter in the NCA3 was a very good knowledge assessment that reflected well what was known when it was released. Despite its quality, however, she believes that “we should not repeat it unchanged.” The probability that sea levels will rise and have significant impacts is 1, she pointed out. The only questions are how quickly and how much the sea will rise. The United States has never overprepared for coastal disasters, and it is unlikely to overprepare for changes that are already certain to occur. She proposed an approach for the NCA4 that would more directly address this challenge.

The coastal chapter of the NCA3 provided a frame for thinking about climate change risks, following the guidance the authors were given on vulnerability framing and confidence assessment. It did not provide estimates of confidence. She explained that the author team for the coastal chapter began with the question “what keeps you up at night?” to identify which outcome most threatens the system. They considered climate variables, potential physical impacts, and probabilities in identifying scenarios and other factors that affect coastlines. Some systems are more sensitive because of other stresses and their relative capacity to respond to stress, she noted. The authors tried to work through all of these factors to assess overall vulnerability. The interdisciplinary team worked well in identifying the most important things that could happen, she explained.

However, they were not able to provide risk probabilities, and Moser argued that this is actually a good thing. Quantifying the risk of “wicked problems” is a “dead end,” she said. The state of the science on sea-level rise is such that it is extremely difficult to quantify defensible estimates of probabilities, she explained, and that is not likely to change soon. Moreover, it is impossible, she explained, to develop a national picture of all the outcomes

BOX 3-1
Assessing Adaptation Pathways:
Steps in Characterizing the Adaptive Response Space

1. **Identify areas for "protection"**
   Identify areas able to generate/attract the necessary funds for in situ adaptation.
2. **Determine assessment criteria**
   Establish normative criteria beyond benefit-cost ratio, involving a range of experts (science, economists, security, ethics, systems, etc.) and stakeholders.
3. **Prioritize based on urgency**
   Compare level of existing protection to level of needed protection. Assess time it would take to build needed protection. Rank must-protect areas by the time available to build the necessary/desired protection before it is needed.
4. **Assess pros and cons of in situ adaptation**
   Describe pros and cons of in situ adaptation and how the integration of "green" infrastructure and other social/economic measures would affect outcomes. Propose "best practice" approaches for in situ adaptation.
5. **Assess options for "accommodation"**
   For lower-priority protection areas and for not-to-be-protected areas, describe and assess all approaches for "accommodation." Establish normative criteria beyond benefit/cost ratio and provide "best practices" lists of approaches for accommodation (living with sea-level rise).

that matter across the United States in a way that is sensitive to context and also accounts for critical interacting factors. Thus, the characterization of risk is a subjective judgment at best. The risks of climate change are not like other problems society has faced, she stressed. They involve multiple, conflicting demands and do not lend themselves to simple, linear solutions. Furthermore, she believes that it is extremely unlikely that the NCA4—a government report that will be released by the administration of a new president—will be able to convey messages about risk so clearly that its audiences interpret them in the ways the authors intend.

The NCA4 should not be an effort to improve on what the NCA3 did, or simply "fail better," she argued, but a chance to find a better approach. Projections regarding sea-level rise will remain conditional, she noted. There are no studies that effectively integrate even the most important of the factors that will affect outcomes. Most planners and members of the general public are not in a position to understand complex risk assessments. Political expediency will likely affect the reception of the NCA4, yet the difficulty of responding will become

6. **Determine time to abandonment**
   For most-likely-to-be-abandoned areas, assess time remaining before occupancy becomes untenable to establish a reasonable timeline. Consider sea-level rise and socioeconomic, cultural, environmental factors in this determination. Then rank to-be-abandoned areas by time available and level of needed assistance.
7. **Assess status, options, challenges, and best practices**
   For areas to be relocated, synthesize status, challenges, attempted/available solutions, and status of unresolved issues. Assess needs of receiving communities. Review and assess international experience on best practices, comprehensive "relocation" programs.
8. **Assess social acceptability**
   Synthesize literature on status and conditions of social acceptability of full range of adaptation options and pathways. Consider all factors that affect acceptability (e.g., sense of place/place identity, ecological, economic, political, cultural).
9. **Assess governance adequacy**
   Consider governance, not just government. Describe/assess governance approaches. Identify "best practice" examples and innovative approaches from the United States and around the world.
10. **Synthesis and research needs**
   Conclude with assessment of the level of challenge the nation is facing. Assess confidence in the state of knowledge. Identify research needs to better inform adaptation pathways.

SOURCE: Moser (2016).

exponentially greater moving forward because of the physical changes already in process.

"We are running out of time" to provide the information people need to make forward-looking adaptation decisions, she said. Instead of characterizing risk, she suggested, it would be better to characterize the possible responses and pathways that will be required in a difficult future or ways to make society more resilient. The starting point should be neither risks nor the decisions that need to be made, but the problems that will need to be solved, along with an assessment of how long decision makers have to solve them. The goal would be to give decision makers what they need to solve their problems. Moser provided a list of 10 steps for the approach she proposes: a process in which scientists, practitioner experts, and stakeholders are guided through a deliberative process that allows all to share their knowledge and identify the most workable pathways forward for different contexts (see Box 3-1).

In closing, Moser noted that even the most carefully prepared risk assessments and characterizations are not fit for the purposes of a national assessment. The objective for the NCA4 should be to help policy makers focus on, prioritize, and assess problem-solving strategies for the challenges that are sure to come. Instead of simply communicating how bad the situation is, she argued, the NCA4 can change the public discourse into a problem-solving conversation about coastal risks and adaptation.

During the discussion period, participants focused on their reactions to the suggestions for the NCA4 put forward by the presenters. Some comments addressed practical ways to use the ideas; others speculated about their conceptual implications.

Several participants suggested ways that the sorts of processes described by Gregory and Moser could be used in the context of NCA4. The NCA already includes discussion of adaptation, mitigation, and decision support, one noted, and there is wide agreement that these are expected to be strengthened in the NCA4. Because the NCA4 is a national document, however, one noted, it would not be possible to build in the processes suggested for every sector and region. It would be possible to use a few case studies to demonstrate how it could be done and provide supports and resources that people could use to try these approaches in their own contexts. One noted that the ongoing, sustained assessment, as distinct from the reports produced every 2 years,[5] could provide a mechanism for engagement and partnership, which could contribute both to the development of the NCA reports and to building capacity.

Several participants questioned the sharp distinction Moser had made between risk assessment and the focus on resilience preparation that she described. One noted that executing her 10 steps would require risk analysis as part of the process for identifying priorities. Another questioned whether many in the climate science community would oppose her approach on the grounds that it is "too alarmist" and that it may be too early to shift so much focus to adaptation. Communication about risks has been helping to move public discussion toward mitigation and has helped people to recognize that it is still possible to forestall the worst sea-level rise. On the other hand, several participants agreed that focusing not on the risk of climate change but on the risk of failing to deal with it could be very valuable in "shaking people loose."

ENERGY-LAND-WATER INTERACTIONS

Peter Gleick of the Pacific Institute, Paul Fleming of Seattle Public Utilities, and Joseph Arvai of the University of Michigan offered their perspectives on risk characterization in the context of the nexus among water, energy, and land. The NCA3 described the nexus this way:

[5]See http://nca2014.globalchange.gov/report/response-strategies/sustained-assessment [May 2016].

> Energy production, land use, and water resources are linked in complex ways. Electric utilities and energy companies compete with farmers and ranchers for water rights in some parts of the country. Land-use planners need to consider the interactive impacts of strained water supplies on cities, agriculture, and ecological needs. Across the country, these intertwined sectors will witness increased stresses due to climate changes that are projected to reduce water quality and quantity in many regions and change heating and cooling electricity demand, among other impacts. (Melillo et al., 2014, p. 43)

Gleick offered both general and water- and energy-related recommendations for the NCA4. He began with the observation that the NCA has made great strides since the first report was published in 2000. He reminded the group that the NCA cannot do everything, given its charge and limited resources. He suggested that it should focus less on reducing the uncertainty of projections and more on reducing the risks of climate change. But, he added, social and political issues come into play when the goal is to reduce risk, and those are much harder for the NCA to integrate. If the focus is reducing risk, he added, it will be important to pay more attention to the events that have low probability but the highest potential consequences, as many presenters had suggested.

He also stressed the importance of being clear about "how we know what we know," and also "the implications of what we know" for adaptation and mitigation. He recommended that the NCA4 be explicit about issues such as what makes a sector vulnerable to expected changes and how to compare the cost of mitigation and adaptation to the cost of doing nothing. In the United States and around the world, governments and the private sector are already spending a fair amount of money adapting to climate change, "whether we call it that or not," he observed. There has been no accounting of which expenses are climate related and how much is being spent. These costs are not included in discussions about risks.

Turning to water, Gleick went on, there are many points to consider. Issues include the availability of water, water quality, and links to human health. Risk assessments that do not look across sectors will miss critical issues such as these, he pointed out. For example, it used to be uncommon to consider the links between water and energy systems, but it takes a tremendous amount of water to drive the energy system that society has chosen to build—and it also takes a tremendous amount of energy to deliver clean water.

It is very likely that climate change will require significant changes in the operation of the energy and water sectors, Gleick noted. For example, some reservoirs in California are operated based on hand-drawn rule curves that use data on past snowpack runoff: these are no longer a sound basis for planning because of the loss of snowpack, Gleick noted. "We're not dealing with that," he suggested. Similarly, because of uncertainty about the range of outcomes for coastal aquifers and waterways, necessary steps are not being taken. It would help water managers and other planners, he added, if they had clear information about which water and energy issues are climate-sensitive and therefore require new thinking about what to anticipate.

Like other presenters, Gleick emphasized the importance of planning for high-impact outcomes of uncertain probability, such as ecosystem collapse, dam and reservoir failures, species die-off, and political disputes about water. People do not understand where the thresholds are, he noted, and equity and environmental justice issues also need attention.

Gleick acknowledged that the past NCAs may not have been as widely read as they should be. One important step to increase readership is to involve the groups most vulnerable to climate change in developing the report, both to learn more explicitly about what their needs are and also to reach broader communities through them. As examples, these groups include water utility managers, managers of highly energy-dependent operations, forest fire agency managers, reservoir and ski-resort managers, coastal regulatory planners, and infectious disease specialists.

Gleick's closing point was that the NCA cannot accomplish every goal that people may have for it. Improved clarity on the role it should play and the primary audience it should address would help sharpen its focus. His opinion is that if it can make a strong case in identifying the next steps that society needs to take to address risks, it could do a better job at motivating government at all levels, professional societies, and the private sector to act.

Fleming focused on the framing of risk in the NCA3 water chapter. He noted that the document discussed the observed and projected physical changes in the water cycle in the context of systems and management responses. The chapter also addressed the cascading implications of those changes for resource management, adaptation, and institutional responses. The authors also discussed specific impacts of the physical changes. They considered variation by season and geographic region and looked at specific outcomes such as changes in soil moisture or snowpack. The authors did not, however, articulate a clear probability and risk framework for these issues. Fleming suggested that the scientific basis for doing that was not complete at the time so that developing such a framework would have been beyond the authors' charge.

Looking forward to the NCA4, Fleming wondered whether risk characterization is "the end or the means" to other objectives. Acknowledging Gleick's point that the NCA4's primary purpose is to motivate people to take actions that increase resilience, he suggested that the focus should shift to risks that are most likely to do that. Public health threats, extreme weather, and economic costs are some of the issues that are "near to people in time and space" and most likely to move them to action, he noted. Issues such as these can be communicated to people in a qualitative way—the detailed risk and probability assessments that are difficult for some topics may not always be necessary, he suggested.

Fleming agreed with earlier speakers that identifying the audiences for the NCA is key because it cannot meet the needs of every possible user. He said he suspects, for example, that very few people have used the NCA for a specific vulnerability assessment because it is not detailed enough by region and sector. Seattle Public Utilities, he noted, commissions its own detailed vulnerability assessment. However, Fleming noted that he has used the NCA "as a buttress to support organizational changes" he advocated, such as a new management strategy for drainage and wastewater. The NCA text about new challenges and opportunities that cannot be addressed with existing practices, and the reasons why relying on historical data is no longer tenable, were extremely helpful to him in making the case for proposed changes.

Fleming also believes that the NCA4 presents an opportunity to establish new links between the report itself, which is a statutory obligation that comes with a specific charge, and the sustained assessment process that is just getting under way. The sustained assessment can be an incubator for innovation, particularly for some of the new ideas presented earlier in the workshop, and it should be "ramped up" and better supported, he suggested.

Decisions that are climate sensitive are being made daily, Fleming concluded, and they relate to essential services. Yet, he said, decision makers are to a large extent "flying blind" and "building for yesterday's climate." Advances that can be useful for these decisions are "eminently doable," he added. Not all of the changes needed are expensive, he said, and that message can help users become more comfortable with building climate resilience into their planning.

Arvai also used a look back at the NCA3 as the basis for suggestions to the developers of the NCA4. The NCA3 was very effective in characterizing human use of energy, land, and water as an interactive system, he commented. This was an important contribution, in his view, but the next step is to move from what people need to know about this system to addressing what they need to know about how to manage the risks that will affect it. The focus in his view should not be on describing problems but on providing guidance for decision makers, from the part-time mayor of a coastal town to those making the large-scale decisions that affect complex systems and large numbers of people. "This is an opening that is begging to be filled" and could significantly increase the audience for the NCA4, he said.

Decision making, Arvai added, should no longer be framed as "doing something versus doing nothing." This framing "sounds like an ultimatum, not a decision," and most people respond negatively to ultimatums. Instead, he suggested, the report could guide users to think through the range of options available in managing the energy, land, and water systems.

The previous NCA reports, though available online, have been primarily text-based, he added. The next round, he pointed out, is an opportunity to make this resource far more interactive, which would be especially useful in addressing a dynamic, interactive system such as that of land, energy, and water.

If an online version allowed users to modify parameters to see how a system would respond over time to different impacts, under different assumptions and constraints, it could be far more useful to decision makers. Links to other work—such as the Marian Koshland Science Museum's Earth Lab,[6] which allows users to use information about climate risk and energy systems to make decisions and see their outcomes—would expand the possibilities. The NCA4 will need to do more than nudge people forward, Arvai said. The decisions its users will make will be extremely challenging and have potentially major impacts.

Another key objective for the NCA4, in Arvai's view, would be to more directly address social inequities in the way the impacts of climate change will be experienced. Previous NCAs have addressed issues of vulnerability in a fairly abstract way, he noted, but populations who are already disadvantaged are likely to be disproportionately affected by many of the disruptions related to changes in climate. The recent problems with lead in the water of Flint, Michigan, though not climate related, illustrate how careless decision making can have dire consequences, he said. This issue also highlights the importance of integrating other systems into the decision-making framework, he added. Social and economic factors of many kinds will play a critical role in supporting decision makers, determining what decisions are made and how they are implemented, and shaping the way communities and the nation respond to climate changes.

Finally, Arvai concluded, the NCA4 clearly has a vital contribution to make, but obstacles may limit its impact. Political pressure, particularly under leadership that does not accept the science of climate change, could undermine it. Its development relies heavily on the work of volunteers who have many other commitments. There is a clear need, he concluded, to put the climate assessment program on a more secure and sustained footing.

Richard Moss offered some comments to begin the general discussion. He highlighted the vital importance of the interacting water, energy, and land systems, noting that changes in them can potentially affect numerous vital services and cause social disruption. Given the range of stakeholders and interests involved in these systems, he noted, the challenge of coordinating them is potentially daunting. It is difficult to imagine a set of institutions that could accomplish that, he suggested, so coordination may need to remain informal. However, decision making in this arena is "tremendously complicated" in his view, and it is very difficult for leaders, civil servants, and others to look beyond their own complex responsibilities to consider interactions beyond their sector.

The NCA3 provided what Moss described as "categorical decision-making examples" that illustrate the direct possible outcomes of some actions. The report also did weave in the potential effects of mitigation. However, he added,

[6]See https://www.koshland-science-museum.org/ [May 2016].

there are many challenges in integrating data across agencies, which often use incompatible platforms or analytic tools. New modeling and analytic work will be needed to make it easier to look at problems that cross the land, water, and energy sectors. One approach he suggested is to begin with a decision-analytic approach: taking specific cases and identifying what is needed to model them. Another is to build sets of models that address different scales. A very high level of detail may be needed to examine regional or sectoral contexts closely, he suggested, whereas integrated assessment models could explore the greater complexity that comes into play on a larger scale.

The water, energy, and land systems offer an excellent opportunity to address the technical and other challenges of thinking through the effects of climate change on a complex, dynamic, and interactive system. It is important to remember, he concluded, that global climate changes ultimately all involve connections across sectors. The NCA4 is an opportunity to support civil servants and others who must operate in a political system and face big challenges in bringing scientific knowledge to bear on decision making.

General discussion focused on strategies for meeting the needs of NCA users. One participant noted that the purpose of the NCA has changed. It was originally designed to inform decision makers and the public about climate change risks, this person noted, but much progress has now been made in doing that. As the goal shifts to supporting people in responding to those risks, new writing teams and strategies are needed. Another noted that there is little evidence about how previous NCAs have been used and how users have responded to them, and recommended that mechanisms for collecting feedback be among the interactive features built into the NCA4.

A few participants offered examples and comments to illustrate some of the obstacles that may constrain users from changing standard practices in response to the messages in the NCA. In one case, a group of utilities in the Northwest was offered models for assessing their energy use and the likely results with specific changes designed to limit their emissions of greenhouse gases. Few took up the models, the participant noted, because the utilities have little institutional pressure to consider limiting emissions as an explicit goal. Had the other potential benefits of making the changes been highlighted and monetized, or other incentives such as taxes been integrated, he suggested, the utility managers might have found more leeway to respond. Another participant stressed the importance of using examples in the NCA4, but also the need to distill from them the most important elements that make them useful.

Several other participants stressed the value of the NCA4 for helping to foster a political environment in which facility operators and other decision makers see less risk in changing practices on the basis of new information about climate-related changes. People are likely to be blamed if they change a traditional protocol that has an unexpected result, one noted. Establishing procedures for collective decision making, in which multiple stakeholders influence the choices and share in responsibility for the outcomes, is another way to support those making changes. Another participant observed that many of the changes designed to reduce emissions may have other valuable social benefits—related to human health and the economy, for example—and that highlighting those also fosters a safe environment for action.

4

Strategies for the Fourth National Climate Assessment

The closing sessions of the workshop offered an opportunity for wide-ranging discussion of how the fourth National Climate Assessment (NCA4) might best assess and convey the risks of climate change and meet the needs of users. Jeremy Martinich of the U.S. Environmental Protection Agency (EPA) discussed recent EPA work that has an explicit focus on the benefits of taking actions that reduce greenhouse gas emissions and that might serve as a model for achieving some of the goals for the NCA4. The floor was then opened for general discussion, and the workshop concluded with final thoughts from members of the committee, two users of the NCA, and the executive director of the U.S. Global Change Research Program (USGCRP).

AN EPA APPROACH TO ASSESSMENT OF RISKS AND BENEFITS

The EPA has a long history of analyzing the impacts of environmental damage and pollution and their costs, Martinich noted. In 2015, the agency released a report from its Climate Change Impacts and Risk Analysis Project (CIRA), *Climate Change in the United States: Benefits of Global Action* (U.S. Environmental Protection Agency, 2015), which described the risks of inaction and the benefits, in terms of damages avoided, of global action to reduce greenhouse gas emissions.

The report drew on the work of multiple teams who developed models designed to estimate physical and economic impacts of climate change across multiple sectors, including human health, infrastructure, and water resources. It used a consistent set of data on socioeconomic variables, emissions, and climate to quantify impacts. By doing so, Martinich suggested, the report provided a more integrated look at the benefits of climate action in the United States than other available assessments have.

Table 4-1 shows the sectors and impacts covered in the 2015 report. Martinich noted that many other important physical effects and economic damages associated with climate change were not included in the report, so its estimates cover only a portion of the total benefits of reducing greenhouse gas emissions.

The report makes a strong quantitative case for the benefits of both mitigation and adaptation, Martinich said, and he presented its key findings:

- Global action on climate change limits costly damages in the United States. Across sectors, global greenhouse gas mitigation is projected to prevent or substantially reduce adverse impacts in the United States in this century compared to a future without emission reductions.
- Global action on climate change reduces the frequency of extreme weather events and associated impacts. Global greenhouse gas reductions are projected to substantially reduce the frequency of extreme temperature and precipitation events by the end of the century.
- Global action now leads to greater benefits over time. For a majority of sectors, the benefits to the United States of greenhouse gas mitigation are projected to be even greater by the end of the century compared with the next few decades.
- Adaptation can reduce damages and overall costs in certain sectors. Though actions to prepare for climate change incur costs, they can be very effective in reducing certain impacts and will be necessary in addition to greenhouse gas mitigation.
- Impacts are not equally distributed. Some regions are more vulnerable than others and therefore will experience greater impacts.

Martinich used the example of air quality to illustrate the kind of analysis the report provides for each sector covered. If traditional air pollutant emissions remain constant and no action is taken to mitigate greenhouse gas emissions, he explained, air quality is likely to worsen across much of the United States, particularly in the East, Midwest, and South. Densely populated areas are expected to be particularly affected by ozone levels. Figure 4-1 shows projections for ozone and fine particulate matter in the two top maps. The bottom two maps show the levels projected if greenhouse gas emissions are mitigated. The report describes some of the health benefits of the mitigation, including the prevention of 13,000 premature deaths annually by 2050 and 57,000 premature deaths by 2100. The economic benefits of preventing those premature deaths are estimated at $160 billion in 2050 and $930 billion in 2100.

Following that report, EPA is working on the next phase of the project

TABLE 4-1 Sectors and Impacts Covered in 2015 CIRA Report

Health	Infrastructure	Electricity	Water Resources	Agriculture and Forestry	Ecosystems
Air Quality	Bridges	Electricity demand	Inland flooding	Crop and forest yields	Coral reefs
Extreme Temperature	Roads	Electricity supply	Drought	Market impacts	Shellfish
Labor	Urban drainage		Water supply and demand		Freshwater fish
Water Quality	Coastal property				Wildfire Carbon storage

NOTE: CIRA, Climate Change Impacts and Risk Analysis Project.
SOURCE: Martinich (2016).

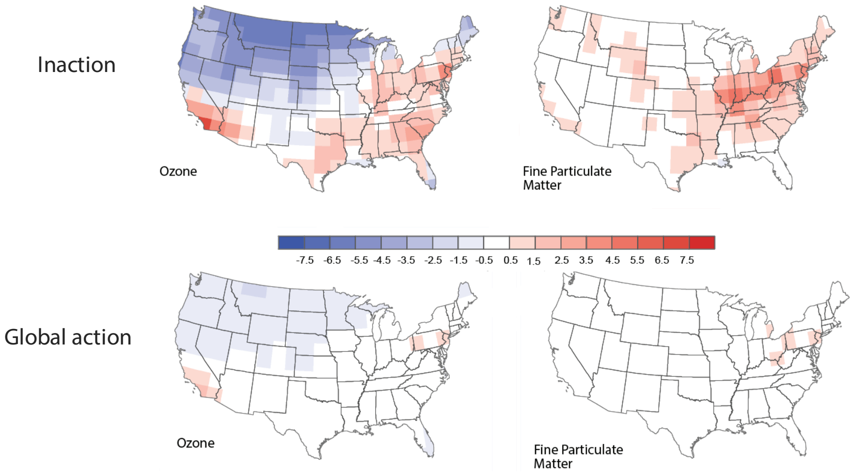

FIGURE 4-1 Projected impacts on air pollution in 2100 under two scenarios.
NOTES: Maps show estimated change in annual-average, ground-level hourly concentrations from 2000 to 2100. Numbers for the shaded bar indicate change in annual-average ground-level hourly ozone and fine particulate matter from 2000 to 2100 under two scenarios.
SOURCE: U.S. Environmental Protection Agency (2015, pp. 24-25).

with an eye to providing analysis that will be useful for the NCA4, Martinich explained. The EPA is pilot-testing an approach for analyzing coordinated impacts. The sectoral models developed for the 2015 report will be used to conduct new simulations that can assess scenarios and climate projections being recommended for inclusion in the NCA4. A new technical report will document and describe the methods and results for each of the regions covered in the NCA4, he added. To do this, the new report will map the sectors to be included in the next version of CIRA to the sectors analyzed in the NCA.

CIRA is not the only project working on the challenge of impact analysis, Martinich noted. However, it does provide a source of recent, peer-reviewed estimates of risks avoided and economic damages that NCA4 authors can use. The next phase of CIRA work will test how the results of a coordinated impacts exercise using scenarios and projections could support further development of the NCA. In the longer term, Martinich hopes, the concept of a coordinated impacts modeling will become a credible and feasible way to incorporate analysis of avoided risk and the value of impacts into future NCAs.

KEY IDEAS FOR FUTURE ASSESSMENTS

The primary goal for the workshop, as moderator Richard Moss reminded the group, was to support the development of the NCA4, as well as future reports and the sustained assessment process, by identifying promising approaches for:

- characterizing the risks and clearly framing them in terms of their implications for people and systems,
- conveying clear and accurate information about those risks in ways that are useful and accessible, and
- identifying the connections across sectors and regions that are critical for understanding risks.

Moss offered his ideas about each of these goals to initiate a general discussion, and Joseph Arvai also offered a summary of key points he took away from the workshop as they related to the goals for the NCA4. Participants offered comments and questions that also highlighted the importance of ideas that came up during the workshop. This section summarizes the primary points from the discussion that were relevant to each of the three workshop goals. It closes with a synthesis of suggestions that individual workshop participants offered regarding the structure of the NCA4 and the process for developing it.

Characterizing Risks

A primary challenge in characterizing the risks of climate change, many participants noted, is to articulate the magnitude of the potential consequences. The scientific community, one noted, "excels at assessing probabilities but falls short on consequences." Many participants commented that insufficient attention is paid to the tail ends of the distributions in climate models, which represent the scenarios that may be least likely to occur but have the most dire implications for humans. The likelihood of these most serious outcomes occurring cannot be determined precisely far in advance because they depend on choices people have yet to make and also on many interacting, cascading, and cumulative factors yet in the future. For this reason, climate scientists have been reluctant to focus on these "worst-case scenarios," but these are the things that "keep people up at night," many participants noted.

One key goal for the NCA4, numerous participants suggested, is to continue the effort to help people understand that climate change is a different kind of challenge for society and for risk assessment experts. This means, numerous participants argued, that it is time to help nonspecialists understand that it will not be possible to develop substantially greater confidence in estimates of the probability of these long-term outcomes. Hazards of serious magnitude for which estimates of likelihood are uncertain are no less serious because of such uncertainty.

The importance of being clear about "how we know what we know" was raised several times. Some participants argued that people may ignore information about climate change because of confusion between outcomes that scientists agree are of great magnitude, although the probability that they will occur is low, and possible outcomes about which scientists have little knowledge. One participant suggested that it might make sense to develop a separate chapter that directly addresses the issues associated with assessing and communicating risk, rather than relying on a consistent presentation across chapters to convey the messages.

In that regard, several participants suggested that the focus of the NCA4 should shift from characterizing risks to supporting decision makers in addressing the risks productively so as to reduce vulnerability. Climate change is a "threat to national security," a participant pointed out, citing the presentation by Alice Hill, yet "decisions are not being made on that basis." Despite uncertainty about the likelihood of the most dire possible consequences, much is known about major changes to the Earth's climate that will persist for millennia even if human beings stop emitting carbon today. Given that reality, several participants urged that the NCA4 communicate clearly about which changes are already inevitable and which can be precluded if human beings take action to mitigate the risks.

The worst unintended consequences for human life, participants pointed out, will result from mismatches in timescales. That is, the risk is greatest for those areas where the time remaining before it will be too late to mitigate a risk is far shorter than the timeframe within which the negative outcome will be apparent. It is critical to prioritize the risks that need attention based on careful consideration of timescales, a participant urged.

Several participants noted that in characterizing the risks of climate change, it is also important to be clear about what the risks mean for humans. People tend to understand and pay attention to risks that may affect them personally, and the NCA4 could be very useful in helping users to better understand the ways in which they are vulnerable to climate change. Marked inequities in vulnerability are already evident and are only likely to grow more extreme, several participants noted. It is important, in their view, that the NCA4 clearly articulate the particular risks to groups who lack the economic resources and political power to protect themselves. Reducing vulnerability is likely to be a more useful theme for the NCA4 than mitigating climate change processes because it is more concrete and immediate, several participants observed.

Conveying Risk Information

The way in which information about climate change risks could be conveyed in the NCA4 depends on the document's goals and the nature of the audiences it is intended to reach, most participants agreed. In different ways, many participants suggested that the primary goal should be to get Americans to think seriously about how they can reduce their vulnerability to climate change by making decisions that help them adapt to changes already under way and help mitigate future changes. The challenge for the NCA4, one suggested, is to frame the risk in a way that is "empowering, not paralyzing." "Many people don't want to talk about this," noted another person, and a key contribution for the NCA4 would be to help create an environment in which information about climate change is accepted and understood.

Much discussion focused on identifying possible audiences for the NCA4 and understanding their needs. Some participants suggested that the NCA can now move on from cataloging impacts and assessing the state of the scientific literature and can build on that base to address new kinds of users, such as officials and managers at many levels who need to understand the vulnerabilities of the sectors and regions in which they live and work in order to make sound decisions. The NCA4, many emphasized, should be designed to support its users, whether they are politicians, government officials from the local to the federal level, utility managers, engineers or architects, or other kinds of decision makers.

Numerous participants emphasized the importance of understanding how audience groups might use the NCA4. Many urged that the development process allow multiple ways for users to be engaged in identifying the questions with which they need help. Means of engaging stakeholders, including adding them to author teams, convening work sessions across regions, and involving them as reviewers and consultants, should all be considered, these participants suggested. Only by hearing from these groups will the NCA4 authors be able to provide information that is relevant in different sectors and across regions, some suggested.

Case studies were identified as a particularly valuable way to reach users by numerous participants. Specific cases make challenges vivid and allow users to work through specific sets of decisions and their implications. Most important, case studies are an ideal basis for helping users work through the application of the information the NCA4 provides to their own circumstances and challenges. A typology for selecting examples might help the authors use them consistently across chapters, one person suggested.

Many participants emphasized the importance of the NCA4 as a support for decision making and problem solving. Users can be guided in considering explicit tradeoffs, such as those between the demands of different sectors, between the goals of adaptation and mitigation, between budgetary priorities, and between the competing needs of different stakeholders. The NCA4 needs to "find a way to structure the examples as good exemplars," while making clear that they are not an exhaustive list and do not provide conclusive solutions, one noted.

No matter which case studies and other material are included in the NCA4, several participants noted, it cannot address the needs of every user or cover every important topic. One suggested that a key contribution would be to weave the perspectives of social science into the framing of ways to reduce vulnerability. Collateral benefits of actions intended to reduce greenhouse gas emissions—for human and environmental health and the economy in particular—are important for multiple reasons.

Identifying Connections across Sectors and Regions

Several participants emphasized that risks that involve multiple regions or sectors are particularly important. It is in cross-sector and cross-region issues that "you see the really wicked problems," one participant commented, because multiple stakeholders are involved and because interacting and cascading effects are most evident.

It can be difficult to integrate information across sectors and regions, several noted. Multiple types of decisions are involved. The impacts of climate change manifest themselves differently depending on the geographic region, and the impacts affect sectors differently. Sectors and the government agencies that are concerned with them in many cases collect different kinds of data and use incompatible data systems. Multiple institutions are involved in cross-sector and cross-region challenges. Duplication of effort and unintentional negative consequences can easily occur, one participant observed.

Because multiple stakeholders are involved, several participants noted, these are the situations in which engagement is most critical. The NCA4 can be useful by helping to identify uniform metrics for calculating risk, a participant suggested, particularly nonmonetary metrics that are needed to assess many critical risks.

Participants also noted the importance of looking outside U.S. borders as the NCA4 authors collect case studies and best-practice information. Canada and Mexico share ecosystems and other resources with the United States and are stakeholders in many of the same climate-related challenges. Moreover, another noted, the United States is not necessarily the leader in innovation in many areas and much can be learned from international examples.

Suggestions for the NCA4

Participants offered several suggestions to the USGCRP focused primarily on ways to sustain the assessment process and to make the NCA4 as useful as possible.

A number of reasons for strengthening the sustained component of the NCA—which operates continuously while the reports are released every 4 years—were put forward. The developers of the NCA4 are being given a serious and difficult charge, several participants noted, and are being pressed to do it quickly and "on the cheap." If the political environment should become less open to discussion of climate change, the mission of the NCA will become more difficult, another commented. Updated scientific information is continuously available and should be folded into the guidance to users to the extent possible.

Several participants recommended that the NCA be made much more interactive. The first three NCA reports consist primarily of text that could be printed, even if most people gain access to the reports through the USGCRP Website. Some suggested further augmenting the text in the future by expanding the Website to add more links to other resources, tools to support decision-making, case studies, and background research.

The sustained assessment process that supplements the printed documents, several participants noted, can also build user engagement and support cross-sectoral discussions. This process can support ongoing dialogue about the status of knowledge and the possibilities for action as they evolve. Expanding options to support individual users in their own decision making might also be easier in a web format, a participant suggested. In any case, he recommended that the NCA4 draw on the research literature regarding decision making to provide explicit guidance to users.

CLOSING THOUGHTS

The final workshop session featured comments from committee members Baruch Fischhoff and Chris Weaver and two users of the National Climate Assessments, Margaret Davidson of the National Oceanic and Atmospheric Administration and Paul Fleming of Seattle Public Utilities. These panelists were asked both to offer immediate suggestions for the NCA4 and to suggest longer-term objectives for the future of the NCA. The workshop closed with reflections from USGCRP Executive Director Michael Kuperberg on the workshop's messages to the developers of the NCA4.

Fischhoff provided a social science perspective on the challenges of risk communication. Reports going back to the 1970s have described these challenges in the context of risks to the environment, Fischhoff noted. Table 4-2 lists some of those reports. For example, a 1975 report on nuclear reactor safety and a 1981 report comparing the risks of different methods of generating electricity both assessed risks and candidly addressed key challenges in communicating about risks. What these and other reports make clear, Fischhoff explained, is that risk analysis inevitably involves definitions of valued outcomes that reflect particular ethical or political interests. Such definitions should be controversial, he suggested, if their implications are not buried in analytic

TABLE 4-2 Reports Addressing Environmental Risks

Year	Title	Author
1975	*Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants*	U.S. Nuclear Regulatory Commission
1980	*Environmental and Societal Consequences of a Possible CO_2-Induced Climate Change: A Research Agenda*	R. Revell, E. Boulding, C.F. Cooper, L. Lave, S.H. Schneider, and S. Wittwer
1981	*Assessing Environmental Risks of Energy*	P.H. Gleick and J.P. Holdren
1996	*Understanding Risk: Informing Decisions in a Democratic Society*	National Research Council
1999	*Toward Environmental Justice: Research, Education, and Health Policy Needs*	Institute of Medicine
2011	*Communicating Risks and Benefits: An Evidence-Based User's Guide*	B. Fischhoff, N.T. Brewer, and J.S. Downs (Eds.)
2011	*Intelligence Analysis for Tomorrow: Advances from the Behavioral and Social Sciences*	National Research Council
2013	*The Science of Science Communication*	B. Fischhoff and D.A. Scheufele
2015	*The Realities of Risk-Cost-Benefit Analysis*	B. Fischhoff

SOURCE: Fischhoff (2016).

language. Identifying definitions of relevant values that are acceptable to all stakeholders, he added, requires open deliberation (Fischhoff, 2015).

Past reports have also clearly shown, Fischhoff continued, that climate science requires collaboration among disciplines. An early illustration of the benefits of collaboration was a project of the U.S. Department of Energy and the American Association for the Advancement of Science, which began in the 1970s to examine the possible consequences of a CO_2-induced change in climate (American Association for the Advancement of Science, 1980). The project report addressed a very wide range of possible effects, with chapters on oceans, the less-managed (by humans) biosphere, and the managed biosphere, he noted. It also addressed social and institutional responses, as well as economic and geopolitical consequences. Few climate projects since have matched that one in terms of involvement of the social sciences, Fischhoff noted. He pointed out that text from that report could have been written today. It warned that the impacts of climate change will not be distributed uniformly, highlighting potential economic and social effects. The report noted—35 years ago—that despite some uncertainties in predictions, corrective action is needed and that "because of the varied geophysical, biological, and societal effects that may result from CO_2 buildup, the problem calls for an unprecedented interdisciplinary research effort" (American Association for the Advancement of Science, 1980, p. 6).

Communication is also addressed by many other early reports that drew on social science. For example, a 1999 Institute of Medicine report on environmental justice laid out principles to guide communication, Fischhoff noted:

- *Improve the science base*. More research is needed to identify and verify environmental etiologies of disease and to develop and validate improved research methods.
- *Involve the affected populations*. Citizens from the affected population in communities of concern should be actively recruited to participate in the design and execution of research.
- *Communicate the findings to all stakeholders*. Researchers should have open, two-way communication with communities of concern regarding the conduct and results of their research activities. (Institute of Medicine, 1999, p. 7)

Although these older reports identified issues that still require attention today, Fischhoff noted, progress has been made. The NCA reports are readable, accessible, easily available, and relevant. There is an increasing public demand for the evidence, he said, because the NCA has been committed to making it relevant to people's immediate concerns. There are also some examples of collaborative work to point to, he added, that demonstrate mutual respect among disciplines.

Despite this progress, however, there are "threats to the enterprise" in Fischhoff's view. One is that there is "still more supply than demand for" the work of the social, behavioral, and decision sciences in climate contexts. Although there has been an enormous growth in basic research in these fields that is applicable to climate change and risk, little of it has made its way into practice. He also said he worries that the supply of research from these fields is not secure—many of the social science researchers who focus on climate issues are not in departments dedicated to their own disciplines. Moreover, there is no secure pipeline for developing and supporting these researchers, he added. As a result, Fischhoff suggested, "there isn't a cadre of people ready to make the 'last-mile' connections," that is, to make clear the precise relevance of climate science findings to people's lives and concerns. When these connections are not clear, climate change messages can be skewed by "misplaced precision or imprecision," he added. In many cases detailed analysis is available for issues that may be less important than others for which such analysis has not been done. The importance of the issue should drive the analysis, he said.

Fischhoff closed with three suggestions for the future:

1. *Provide more pilot studies that model how to apply what has long been known by social scientists.* People learn best from examples they can attempt to copy and adapt.
2. *Obtain a "seal of approval" for communications about climate change.* For example, the seal might indicate that authors have clearly presented the state of the science and their best guesses at its implications.[1]
3. *Adopt a standard approach to characterizing risk at a high level for broad audiences*. Detailed analysis may not necessarily follow this standard, but effective communication about complex issues could guide users in understanding what is most relevant and where key decisions lie.

Fischhoff noted that one way to structure such a communication was developed by the U.S. Food and Drug Administration (U.S. Department of Health and Human Services and U.S. Food and Drug Administration, 2009). That model guides users in identifying factors relevant to product approval decisions: analysis of a condition, treatment options, benefits, risks, and risk management. For each factor, users were guided to identify evidence and uncertainties, and then their conclusions and reasons for them. The process does not dictate the decisions, Fischhoff emphasized, but helps users to structure their thinking about key factors, clearly distinguishing between scientific issues and other factors.

Davidson focused on practical approaches to getting around the political sensitivities that often surround discussion of climate change. There is little practical difference between disaster mitigation and climate change adaptation for issues that pose immediate threats, she noted, such as flood, drought, and wildfire. In cases where the timescales are not important because the threats are imminent, she explained, there is no need to talk about climate: the actions people need to take are the same no matter how the problem is framed. The disaster community, she added, has made progress in developing an integrated and systematic approach to measuring losses and damages associated with extreme events.

The NCA, she argued, should provide a framework for regional engagement and assessment that is relevant to the risks people face today. Involving stakeholders in the process will be important to framing the risks not only from a scientific perspective, but in terms of threats to people's daily lives. A process that involves both experts and nonexperts, she noted, will shape what is measured and how, and "help people come to an understanding of risk and what they value." Citizen science—research to which volunteer nonscientists contrib-

[1]Fischhoff referred participants to Fischhoff, Brewer, and Downs (2011) for more about this point.

ute by collecting and reporting data—is an important, and underused, tool for building engagement with and understanding of risk, she added. Aquariums and science centers provide another avenue for engaging the public and could do much more in this area than they have, in her view.

Weaver began with the question, "What is the value of the NCA?" The NCA3, he suggested, was "somewhat uneasily perched between two goals." One was to build public awareness that climate change is occurring and will have diverse effects that will touch everyone. The other was to provide meaningful guidance for decision making. He believes it was more effective at the first of these goals and that new thinking will be required to make the NCA4 more effective at the second. An NCA4 that is aimed at supporting decision making, he added, may also be an even stronger tool for raising public awareness of risk.

The NCA "can't support every decision or be all things to all users," he noted. Every context is unique and requires its own detailed analysis. He suggested some ways that a national document could address this challenge.

Weaver suggested that in the past the NCA has not been especially explicit about the sorts of decisions that need to be made in a particular context. The NCA4 could be designed to point the way toward the kinds of analysis that will be needed to support decisions. Given the wide range of decisions that could be relevant, Weaver suggested, the developers could begin by identifying which types of decisions and decision makers the report could best serve. The developers might also consider which decision-making frameworks to address, he added. For example, tools often used to support decision making, such as benefit-cost analysis, are based on underlying assumptions that may not hold for future climate change scenarios about which there is considerable uncertainty. It would also be useful for the NCA4 to identify which types of hazards to include, he added. The report might focus on either reversible or irreversible hazards, for example, or those for which a critical threshold is approaching.

Identifying the upper boundary of risk might be the most important task the NCA4 could undertake, Weaver suggested. Many of the presenters had pointed out that too little attention has been paid to the low-probability but highest-consequence scenarios, he noted. Identifying those scenarios and providing tools for thinking about how decisions made today can influence them is a critical responsibility for the NCA4 in his view. This responsibility points to the importance of including analyses of the consequences that come with those outcomes. For example, the report could assess the consequences of a particular worst-case scenario across a number of sectors and then explore the kinds of responses that could mitigate them. The organizing principle could be to systematically identify the specific questions to be asked in different sectors and regions about the implications of these scenarios and provide guidance about the kinds of detailed analysis needed to address them. One could think of this as a kind of "risk stress test," he suggested.

Weaver concluded by observing that the process of constructing the NCAs has taught the community a lot. It is clear that making sure stakeholders are integrally involved is essential, particularly if the NCA4 is to focus on support for decision making. He said past experience also indicates that formal guidance to authors is much less useful than active facilitation, especially when the goal is to create a new kind of document. He also noted that consensus is not always essential in an NCA and that clarity about differences could be more useful than unanimity. Looking beyond the NCA4 to the future of the climate assessment program, Weaver suggested, the focus should be not only on assessing and characterizing risks, but also on "assessing our ability to respond to risks" and explicitly focusing on solutions.

Fleming began by noting that the NCA reports are not only required by statute, but also have been very valuable to federal agencies and other users. The sustained assessment just getting under way is technically not required but in his view is essential. While it is not yet clear what the sustained assessment will look like or what its scope will be, it should provide a venue for a greater degree of creativity than can be realized within confines of a report. These two components together—the sustained assessment and the 4-year reports—he suggested, will allow the NCA program to continue to meet the needs of those users who have long relied on it while also dramatically enhancing its relevance to new kinds of users. These paired platforms provide the opportunity to launch multiple ideas that may take different directions, he added.

Fleming endorsed the idea that the NCA4 should focus on responses and solutions. There are many examples of well-founded and robust approaches that the authors can draw on, and sustained engagement with multiple stakeholders and experts will help the report's authors identify the most relevant and useful ones, he said. Case studies that make the "last-mile connections" mentioned by previous speaker Fischhoff, and that also illustrate how decision makers can respond, will be key, Fleming added.

A key contribution that this sort of report can make, in Fleming's view, will be to help reveal the sensitivity of many sorts of decisions to climate issues. The political and cultural environment is still not uniformly favorable to conversation that includes climate change, and clear examples that highlight the implications of decisions can help to make that environment more open. "Many parties would welcome partnering on that," Fleming concluded.

The workshop closed with Kuperberg's reflections on the many ideas presented at the workshop and how the USGCRP might take advantage of them in strengthening the NCA program. Communicating about climate risk to a range of audiences will always be both important and challenging, he said, and it is a challenge that will need to be revisited repeatedly. He said he appreciated the advice and reflections of the workshop participants in support of what he views as a vital effort for the USGCRP.

Kuperberg began with a few broad points. He reminded the group of the language in the Global Change Research Act that describes the purpose of the Global Change Research Program, which is not only to provide scientific information, but also to assist the nation and world to understand, assess, predict, and respond to human-induced climate change. "The 'assist' part of the charge" is one that he and his colleagues take seriously, he stressed. The program's work begins with fundamental research and ends with providing education and guidance, and he looks forward to "building the full range of that effort."

Kuperberg also noted that he does not see the NCA reports and the sustained assessment process as in competition, in the way that some participants had suggested. The mechanisms for the sustained process are still new, he noted, but the USGCRP is "very much committed" to it. The NCA4 will be an important product of the sustained assessment process, he noted, but not an end goal—the primary goal is to build the capacity to continue on multiple fronts.

Kuperberg highlighted some of the points from the workshop that he said he hopes will influence the development of the NCA4:

- Characterizing and modeling cascading hazards and also dealing with the risks and uncertainties associated with them are challenging.
- Engaging authors from outside the traditional disciplines, including experts from the social sciences, will be key.
- Focusing on regional issues and needs is important. The developers of the NCA4 plan to work closely with the existing regional science organizations of the USGCRP member agencies because they provide strong bases of knowledge and experience. Kuperberg noted, though, that many issues overlap because a region might be defined and understood in various ways, such as by ecological or geological boundaries. Natural systems ignore geopolitical boundaries, Kuperberg commented, but decision makers must operate within them.
- Kuperberg suggested that the USGCRP might use a risk-based framework for identifying case studies that would be most useful, given that such studies could not be provided for every possible case. A storyline approach could make such information more inspiring and useful.
- Clear discussion of the timelines on which changes will occur and on which different sorts of responses can be accomplished and take effect will be very useful.
- The basic science is foundational. The USGCRP must keep advancing fundamental climate science and continue to feed it into the reports and other elements of the sustained assessment.
- Models are often tuned to the average condition, which could allow users to overlook some important features, such as low-probability but high-impact conditions (the tails of the distributions).

- The assessment program has practical limitations. One strategy for expanding the program's reach is to work with institutions that have constituencies of their own and can help to transmit the findings from the NCA. The USGCRP is piloting public-private partnerships focused on resilience and preparation that can take advantage of existing relationships.
- Consensus is important, Kuperberg noted, but he also stressed the importance of characterizing the range of possibilities (e.g., the tails). This is part of helping users to understand probabilities and projections.
- There will always be room for improvement in communication, but Kuperberg said he took note of the challenge to reach out to new groups.

Kuperberg closed by noting that the U.S. government relies on the information provided by the NCA in making decisions and setting policies in many domains, for anything from the EPA's Clean Power Plan[2] to its Endangerment Finding,[3] to setting guidelines for federal buildings managed by the General Services Administration. These decisions have far-reaching effects and can also provide examples that may be influential. He repeated his appreciation for the contributions of all the participants in this vital work.

[2]See https://www.epa.gov/cleanpowerplan/clean-power-plan-existing-power-plants [June 2016].
[3]See https://www3.epa.gov/climatechange/endangerment [June 2016].

References

American Association for the Advancement of Science. (1980). *Environmental and Societal Consequences of a Possible CO_2-Induced Climate Change: A Research Agenda.* Volume 1. Washington, DC: Author. Available: http://www.osti.gov/scitech/servlets/purl/6728173 [June 2016].

Azevedo, I. (2016). *A Framework for Climate Change Decision Making Under Uncertainty.* Presentation at Methods for Characterizing Risk in Climate Change Assessments: A Workshop for the U.S. Global Change Research Program, March 23-24, National Academy of Sciences, Washington, DC. Available: http://sites.nationalacademies.org/dbasse/becs/DBASSE_171811 [June 2016].

Buizer, J.L., Dow, K., Black, M.E., Jacobs, K.L., Waple, A., Moss, R.H., Moser, S., Luers, A., Gustafson, D.I., Richmond, T.C., Hays, S.L., and Field, C.B. (2015). Building a sustained climate assessment process. *Climatic Change, 135,* 23-37. doi: 10.1007/s10584-015-1501-4.

Ceres. (2014). *New Report Shows Decline in Carbon Dioxide and Other Pollutants from U.S. Power Plants, but State and Power Company Emissions Vary Widely.* Press release, May 28. Available: http://www.ceres.org/press/press-releases/new-report-shows-decline-in-carbon-dioxide-and-other-pollutants-from-u.s.-power-plants-but-state-and-power-company-emissions-vary-widely [June 2016].

Clark, P.U., Shakun, J.D., Marcott, S.A., Mix, A.C., Eby, M., Kulp, S., Levermann, A., Milne, G.A., Pfister, P.L., Santer, B.D., Schrag, D.P., Solomon, S., Stocker, T.F., Strauss, B.H., Weaver, A.J., Winkelmann, R., Archer, D., Bard, E., Golder, A., Lambeck, K., Pierrehumbert, R.T., and Plattner, G. (2016). Consequences of twenty-first-century policy for multi-millennial climate and sea-level change. *Nature Climate Change, 6*, 360-369. Available: http://www.nature.com/nclimate/journal/v6/n4/full/nclimate2923.html [June 2016].

Fischhoff, B. (2016). *Things We've Known, Accomplished, Need to Fear, and Might Do.* Presentation at Methods for Characterizing Risk in Climate Change Assessments: A Workshop for the U.S. Global Change Research Program, March 23-24, National Academy of Sciences, Washington, DC. Available: http://sites.nationalacademies.org/dbasse/becs/DBASSE_171819 [June 2016].

Fischhoff, B. (2015). The realities of risk-cost-benefit analysis. *Science*, *350*(6260), aaa6516. Available: http://dx.doi.org/10.1126/science.aaa6516 [June 2016].

Fischhoff, B., Brewer, N., and Downs, J.S. (Eds.). (2011). *Communicating Risks and Benefits: An Evidence-based User's Guide*. Washington, DC: U.S. Food and Drug Administration. Available: http://www.fda.gov/AboutFDA/ReportsManualsForms/Reports/ucm268078.htm [June 2016].

Garfin, G.M. (2016). *Methods and Approaches for Risk-Based Assessment and Communication: Climate Change and the U.S. Southwest.* Presentation at Methods for Characterizing Risk in Climate Change Assessments: A Workshop for the U.S. Global Change Research Program, March 23-24, National Academy of Sciences, Washington, DC. Available: http://sites.nationalacademies.org/dbasse/becs/DBASSE_171812 [June 2016].

Garfin, G.M., Franco, G., Blanco, H., Comrie, A., Gonzalez, P., Piechota, T., Smyth, R., and Waskom, R. (2014). Southwest. In J.M. Melillo, T.C. Richmond, and G.W. Yohe (Eds.), *Climate Change Impacts in the United States: The Third National Climate Assessment* (Ch. 20, pp. 462-486). Washington, DC: U.S. Global Change Research Program. doi: 10.7930/J08G8HMN.

Garfin, G.M., Leroy, S., McMahan, B., Black, M., and Roh, B. (2016). *Preparing for High-Consequence, Low-Probability Events: Heat, Water and Energy in the Southwest.* Report to U.S. Bureau of Reclamation. Tucson: Institute of Environment, University of Arizona. Available: http://environment.arizona.edu/sites/default/files/High-Low_Report_FINAL.pdf [June 2016].

Gilbraith, N., Azevedo, I.L., and Jaramillo, P. (2014). Regional energy and GHG savings from building codes across the United States. *Environmental Science and Technology, 48*(24), 14121-14130.

Gregory, R., Dieckmann, N., and Satterfield, T. (2016a). *Characterizing Risk-Based Trade-Offs to Support Climate Change Decisions.* Presentation at Methods for Characterizing Risk in Climate Change Assessments: A Workshop for the U.S. Global Change Research Program, March 23-24, National Academy of Sciences, Washington, DC. Available: http://sites.nationalacademies.org/dbasse/becs/DBASSE_171813 [June 2016].

Gregory, R., Satterfield, T., and Hasell, A. (2016b). Using decision-pathway surveys to inform climate engineering policy choices. *Proceedings of the National Academy of Sciences of the United States of America, 113*(3), 560-565. Available: http://www.pnas.org/content/113/3/560.full.pdf [June 2016].

Hittinger, E., and Azevedo, I.L. (2015). Bulk energy storage increases U.S. electricity system emissions. *Environmental Science and Technology*, *49*(5), 3203-3210.

Houser, T., Hsiang, S., Kopp, R., and Larsen, K. (2015). *Economic Risks of Climate Change: An American Prospectus*. New York: Columbia University Press.

Institute of Medicine. (1999). *Toward Environmental Justice: Research, Education, and Health Policy Needs.* Washington, DC: National Academy Press. doi:10.17226/6034.

Kahneman, D. (2011). *Thinking, Fast and Slow.* New York: Farrar, Straus and Giroux.

Kopp, R.E. (2016). *Treatment of Uncertainty in Climate Change Risk Assessments.* Presentation at Methods for Characterizing Risk in Climate Change Assessments: A Workshop for the U.S. Global Change Research Program, March 23-24, National Academy of Sciences, Washington, DC. Available: http://sites.nationalacademies.org/dbasse/becs/DBASSE_171814 [June 2016].

Kopp, R.E., Horton, R.M., Little, C.M., Mitrovica, J.X., Oppenheimer, M., Rasmussen, D.J., Strauss, B.H., and Tebaldi, C. (2014). Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. *Earth's Future, 2*, 383-406. doi:10.1002/2014EF000239.

Kopp, R.E., Shwom, R., Wagner, G., and Yuan, J. (2016). *Tipping Elements and Climate-Economic Shocks: Pathways toward Integrated Assessment.* Available: http://arxiv.org/abs/1603.00850 [June 2016].

Mann, M.E., and Gleick, P.H. (2015). Climate change and California drought in the 21st century. *Proceedings of the National Academy of Sciences, 112*(13), 3858-3859. doi: 10.1073/pnas.1503667112.

Martinich, J. (2016). *Climate Change in the United States: Benefits of Global Action.* Presentation at Methods for Characterizing Risk in Climate Change Assessments: A Workshop for the U.S. Global Change Research Program, March 23-24, National Academy of Sciences, Washington, DC. Available: http://sites.nationalacademies.org/dbasse/becs/DBASSE_171815 [June 2016].

Melillo, J.M., Richmond, T.C., and Yohe, G.W. (Eds.). (2014). *Highlights of Climate Change Impacts in the United States: The Third National Climate Assessment.* Washington, DC: U.S. Global Change Research Program. Available: http://www.globalchange.gov/sites/globalchange/files/NCA3_Highlights_LowRes-small-FINAL_posting.pdf [June 2016].

Moser, S.C. (2016). *Assessing Coastal Risks in Future National Climate Assessments.* Presentation at Methods for Characterizing Risk in Climate Change Assessments: A Workshop for the U.S. Global Change Research Program, March 23-24, National Academy of Sciences, Washington, DC. Available: http://sites.nationalacademies.org/dbasse/becs/DBASSE_171816 [June 2016].

Moser, S.C., and Davidson, M.A. (2016). The third national climate assessment's coastal chapter: The making of an integrated assessment. *Climatic Change 135*, 127-141. Available: http://link.springer.com/article/10.1007%2Fs10584-015-1512-1 [June 2016].

Overpeck, J.T. (2016). *Climate Change and the U.S. Southwest: Are We Getting the Risks Right?* Presentation at Methods for Characterizing Risk in Climate Change Assessments: A Workshop for the U.S. Global Change Research Program, March 23-24, National Academy of Sciences, Washington, DC. Available: http://sites.nationalacademies.org/dbasse/becs/DBASSE_171816 [June 2016].

Rasmussen, D.J., Meinshausen, M., and Kopp, R.E. (in press). Probability-weighted ensembles of U.S. county-level climate projections for climate risk analysis. *Journal of Applied Meteorology and Climatology.* Available: http://dx.doi.org/10.1175/JAMC-D-15-0302.1.

Risky Business Project. (2014). *Risky Business: A Climate Risk Assessment for the United States*. Available: http://riskybusiness.org/site/assets/uploads/2015/09/RiskyBusiness_Report_WEB_09_08_14.pdf [June 2016].

Sanderson, B. (2016). *Risk: Likelihood of Significant Consequences.* Presentation at Methods for Characterizing Risk in Climate Change Assessments: A Workshop for the U.S. Global Change Research Program, March 23-24, National Academy of Sciences, Washington, DC. Available: http://sites.nationalacademies.org/dbasse/becs/DBASSE_171817 [June 2016].

Siler-Evans, K., Azevedo, I.L., and Morgan, M.G. (2012). Marginal emissions factors for the U.S. electricity system. *Environmental Science and Technology, 46*(9), 4742-4748.

Siler-Evans, K., Azevedo, I.L., Morgan, M.G., and Apt, J. (2013). Regional variations in the health, environmental, and climate benefits from wind and solar generation. *Proceedings of the National Academy of Sciences*, *110*(29), 11768-11773.

Slovic, P., Kraus, N.N., Lappe, H., and Major, M. (1991). Risk perception of prescription drugs: Report on a survey in Canada. *Canadian Journal of Public Health, 32*, S15-S20.

Tamayao, M., Michalek, J., Hendrickson, C., and Azevedo I.L., (2015). Regional variability and uncertainty of electric vehicle life cycle CO_2 emissions across the United States. *Environmental Science and Technology, 49*(14), 8844-8855.

Udall, B. (2016). *Climate Change and the U.S. Southwest.* Presentation at Methods for Characterizing Risk in Climate Change Assessments: A Workshop for the U.S. Global Change Research Program, March 23-24, National Academy of Sciences, Washington, DC. Available: http://sites.nationalacademies.org/dbasse/becs/DBASSE_171816 [June 2016].

U.S. Department of Health and Human Services and U.S. Food and Drug Administration. (2009). *FDA's Strategic Plan for Risk Communication*. Available: http://www.fda.gov/AboutFDA/ReportsManualsForms/Reports/ucm183673.htm [June 2016].

U.S. Environmental Protection Agency. (2015). *Climate Change in the United States: Benefits of Global Action*. EPA 430-R-15-001. Washington, DC: Author. Available: https://www.epa.gov/sites/production/files/2015-06/documents/cirareport.pdf [June 2016].

Weaver, C. (2016). *Comments from Organizing Committee Member Chris Weaver.* Presentation at Methods for Characterizing Risk in Climate Change Assessments: A Workshop for the U.S. Global Change Research Program, March 23-24, National Academy of Sciences, Washington, DC. Available: http://sites.nationalacademies.org/dbasse/becs/DBASSE_171821 [June 2016].

Wilson, R.S. (2016). *Framing Climate Change Risk to Enhance Effective Communication.* Presentation at Methods for Characterizing Risk in Climate Change Assessments: A Workshop for the U.S. Global Change Research Program, March 23-24, National Academy of Sciences, Washington, DC. Available: http://sites.nationalacademies.org/dbasse/becs/DBASSE_171818 [June 2016].

Appendix A

Workshop Agenda

Methods for Characterizing Risk in Climate Change Assessments:
A Workshop for the U.S. Global Change Research Program

The National Academy of Sciences Building-Room 120
2101 Constitution Avenue, NW
Washington, DC 20418
March 23-24, 2016

Purpose of this meeting: The U.S. Global Change Research Program (USGCRP), in response to its legislative mandate, conducts periodic National Climate Assessments to inform the nation about observed changes in climate, the current status of the climate, and anticipated trends for the future. The Program has conducted three such assessments and intends to develop a sustained assessment process. This workshop is designed to address a key issue for NCAs: providing information about climate-related hazards, risks, and opportunities in formats that are understandable, credible, and useful to decision makers in their efforts to reduce greenhouse gas emissions and to reduce vulnerability and increase resilience to climate change in the regions or sectors for which they are responsible.

AGENDA

March 23

8:30 am **Welcome, introductions, workshop background, and objectives**

Richard Moss, Chair, Board on Environmental Change and Society

Joseph Arvai, University of Michigan, Workshop Planning Committee Chair

8:40 am **The objectives for, and desired impact of, the workshop**

John P. Holdren, White House Office of Science and Technology Policy

Thomas Karl, USGCRP

9:10 am **Panel on issues, methods, and approaches for characterizing and communicating risk in climate change assessments** (see planning document)

Introductory Remarks: *Joseph Arvai, University of Michigan, Workshop Planning Committee Chair*

9:15 am 1. Risk: Consequences to consider in climate change assessments

Alice Hill, National Security Council

9:45 am 2. Risk: Likelihoods of significant consequences

Ben Sanderson, National Center for Atmospheric Research

10:15 am Break

10:30 am 3. Risk: Treatment of uncertainty in climate change assessments

Robert Kopp, Rutgers University

11:00 am 4. Framing climate change risks to enhance effective communication

Robyn Wilson, Ohio State University

11:30 am 5. Characterizing risk-based tradeoffs to support climate change decisions

Robin Gregory, University of British Columbia

12:00 pm 6. A framework for climate change decision making under uncertainty

Inês Azevedo, Carnegie Mellon University

12:30 pm Lunch

1:30 pm **Case-focused panels: Methods and approaches for risk-based assessment and communication**

Each panel will consider, in the context of one of the chapters in the NCA, how the chapter could be written to take into account the risk issues and methods raised in the earlier discussion. Speakers will be asked to address issues of characterizing risks (consequences, likelihoods, and uncertainties), process issues in making risk information useful for decisions, and informing tradeoffs among risks to be reduced. Moderators will help guide the discussion and offer summative comments.

Panel 1: Climate Change and the U.S. Southwest
NCA3 Chapter 20—Southwest

Moderator: Kristie Ebi, University of Washington

Gregg Garfin, University of Arizona
Bradley Udall, Colorado State University
Jonathan Overpeck, University of Arizona

3:00 pm Break

3:15 pm **Panel 2: Impacts of Climate Change on Coastal Regions**
NCA3 Chapter 25—Coasts

Moderator: Claudia Tebaldi, National Center for Atmospheric Research

Robin Gregory, University of British Columbia
Susanne Moser, Independent Consultant
Margaret Davidson, National Oceanic and Atmospheric Administration

4:45 pm Concluding comments by moderators

5:00 pm Adjourn

March 24

8:30 am **Welcome, Recap of Day 1, and Plan for Day 2**

Joseph Arvai, University of Michigan, Workshop Planning Committee Chair

8:45 am **Panel 3: Energy-Land-Water Interactions**
NCA3 Chapter 10—Energy, Water, and Land

Moderator: Robyn Wilson, Ohio State University

Peter Gleick, Pacific Institute
Paul Fleming, Seattle Public Utilities
Joseph Arvai, University of Michigan, Workshop Planning Committee Chair

10:15 am Break

10:30 am **An EPA Approach to Assessment: *"Climate Change in the United States"***

Moderator: Chris Weaver, U.S. Environmental Protection Agency

Jeremy Martinich, U.S. Environmental Protection Agency

10:45 am **General Discussion: Key Risk-Related Topics for the National Climate Assessments**

Moderator: Richard Moss, Joint Global Change Research Institute

Key Topics:

1. Best Practices for Characterizing Risks
2. Best Processes for Conveying Risk Information
3. Approaches to Comparing Risk Information Across Sectors or Regions

4. Research Needs and Additional Issues to Be Considered in National Assessments

12:15 pm Lunch

1:00 pm **Closing Panel: *One Small Step Takeaways for NCA4* and *One Giant Leap Takeaways for NCA5+***

Moderator: Joseph Arvai, University of Michigan, Workshop Planning Committee Chair

1. Comments from organizing committee members: *Baruch Fischhoff, Carnegie Mellon University; Chris Weaver, U.S. Environmental Protection Agency*
2. Comments from users of the NCA: *Paul Fleming, Seattle Public Utilities; Margaret Davidson, National Oceanic and Atmospheric Administration (by phone)*
3. Comments from the USGCRP perspective: *Michael Kuperberg, USGCRP*
4. General discussion

2:30 pm Adjourn

Appendix B

Biographical Sketches of Committee Members and Presenters

Joseph Arvai (*Planning Committee Chair*) is the Max McGraw professor of sustainable enterprise in the School of Natural Resources and Environment and the Ross School of Business at the University of Michigan. He is also the director of the Frederick A. and Barbara M. Erb Institute for Global Sustainable Enterprise at the University of Michigan, senior researcher at the Decision Science Research Institute in Eugene, Oregon, and adjunct professor at Carnegie Mellon University. His research has two main areas of emphasis: advancing an understanding of how people process information and make decisions and developing and testing decision-aiding tools and approaches across a wide range of environmental, social, and economic contexts. His work also focuses on choices made by people individually and when working in groups. He has an M.Sc. in oceanography and a Ph.D. in decision sciences from the University of British Columbia.

Inês Azevedo is associate professor of engineering and public policy and codirector of the Center for Climate and Energy Decision Making at Carnegie Mellon University. Her research interests lie at the intersection of environmental, technical, and economic issues, such as how to address the challenge of climate change and to move toward a more sustainable energy system. She has been looking at how energy systems are likely to be shaped in the future, which requires comprehensive knowledge of technologies that can address future energy needs and the decision-making process followed by different agents in the economy. She has also been working on assessing how specific policies will shape future energy systems. She has a Ph.D. in engineering and public policy from Carnegie Mellon University.

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Peter Gleick (*Planning Committee Member*) cofounded and leads the Pacific Institute in Oakland, California. His work has redefined water from the realm of engineers to the world of social justice, sustainability, human rights, and integrated thinking. He developed the first analysis of climate change impacts on water resources and the earliest comprehensive work on water and conflict and defined basic human needs for water and the human right to water. He pioneered the concept of the "soft path for water," developed the idea of "peak water," and has written about the need for a "local water movement." He has a B.S. from Yale University and an M.S. and a Ph.D. from the University of California, Berkeley.

Robin Gregory is senior researcher with Decision Research and adjunct professor at the University of British Columbia (UBC), Institute for Resources, Environment and Sustainability. He works on applied problems of stakeholder consultation, environmental and risk management, value elicitation, decision making under uncertainty, community and indigenous health assessment, and negotiated decision making. Using methods drawn from decision analysis, behavioral psychology, applied ecology and negotiation analysis, his research and applied work emphasizes collaborative decision-aiding approaches that help participants to understand their own and others' responses to the consequences of actions characterized by multiple dimensions, substantial uncertainty, and often controversy. In such cases, tough choices need to be made across different options; the use of structured decision methods can serve as the basis for generating and evaluating better and more broadly accepted alternatives. Robin has written and consulted extensively on the subject of informing public policy choices and is lead author of the book, *Structured Decision Making: A Practical*

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