26. Decision Support
Supporting Policy, Planning, and Resource Management Decisions in a Climate Change Context

Convening Lead Authors

Richard Moss, Joint Global Change Research Institute, Pacific Northwest National Laboratory, University of Maryland

P. Lynn Scarlett, Resources for the Future

Lead Authors:

Melissa A. Kenney, University of Maryland

Howard Kunreuther, University of Pennsylvania

Robert Lempert, RAND Corporation

Jay Manning, Cascadia Law Group

B. Ken Williams, U.S. Geological Survey

Contributing Authors

James W. Boyd, Resources for the Future

Laurna Kaatz, Denver Water

Lindene Patton, Zurich North America

Key Messages

1. **Creating well-structured, transparent, and collaborative decision processes involving researchers and stakeholders is as important to effective decision-making as having good scientific information and tools. An effective process will better enable decision-makers to apply complex information to decisions, consider uncertainties associated with climate variability and change, assess the wide range of possible human responses, and engage institutions and individuals who are potentially affected.**
2. **Many decision frameworks and tools are available to support and improve decision-making on climate change adaptation and ways to reduce future climate change.**
3. **Steps to improve collaborative decision processes could include training more "science translators" to help bridge science and decision-making; integrating development of decision support tools into fundamental scientific research; improving reward structures and institutional recognition for those who work at the boundary of science and decision-making; increasing support through the USGCRP for research to develop decision support tools; and incorporating assessment of decision support resources for sectors and regions into the ongoing National Climate Assessment (NCA) process.**

Introduction

This chapter introduces decision-making frameworks that are useful for considering choices about climate change adaptation and mitigation. It focuses on the processes that promote sustained interaction between decision-makers and the scientific/technical community. The chapter reviews the state of knowledge and practice at each of the stages of an idealized collaborative decision support process – a process that includes steps such as defining the problem, identifying decision criteria, applying scientific information, evaluating response options, monitoring effectiveness, and revisiting the decision. Because of space limitations, the chapter does not assess specific decision support tools.

Climate conditions are changing (Ch. 2: Our Changing Climate), and historically successful strategies to manage climate-sensitive resources and infrastructure will become less effective over time. Decision-makers must increasingly make choices without full knowledge of the opportunities, risks, and underlying uncertainties. The sensitivity of the climate system to human activities, the extent to which mitigation policies are implemented, and the effects of other demographic, social, ecological, and economic changes on vulnerability also contribute to uncertainty in decision-making (de Chazal and Rounsevell 2009; Holling 2003).

Decision-makers routinely make complex decisions under uncertain conditions; they recognize that even though scientific information may be uncertain, it still provides valuable insights that will lead to better outcomes if incorporated into decision-making. Uncertainties can make decision-making in the context of climate change especially challenging for several reasons, including the rapid pace of changes in physical and human systems, the lags between climate change and observed effects, the high economic and political stakes, the number and diversity of potentially affected stakeholders, the need to incorporate scientific information of varying confidence levels, and value questions that arise (Mattson et al. 2012; NRC 2009). The social, economic, psychological, and political dimensions of these decisions underscore the need for ways, including improved communication of uncertain scientific information, to help decision-makers assess risks and opportunities associated with climate change. These include assisting with identification of climate risks and opportunities in government, business, community, family, and individual decisions.

Decision-makers often find accessing relevant and useful climate information to be a frustrating experience and request assistance with applying the daunting array of information sources and tools (ICATF 2010). Properly framing the issues, understanding the available options, establishing decision criteria, accessing relevant knowledge, and reaching decisions that have a good chance of being implemented are challenging in any case (Beratan and Karl 2012), but integrating scientific understanding of climate risks into specific sectoral and regional applications is daunting. An iterative decision process that incorporates constantly improving scientific information and learning through periodic reviews of decisions over time is helpful in the context of rapid changes in environmental conditions (NRC 2009, 2010c).

For some aspects of decision-making, tools and online information clearinghouses have been both scientifically validated and evaluated by users. Decision frameworks, tools, and processes can help improve decision-making in the context of climate variability and change. However, there are many unanswered questions about effective climate change decision-making that require research, including ways to evaluate the costs and benefits of alternative actions, ways to communicate relative amounts of risk associated with different options, consideration of the role of institutions and governance structures, and development and use of probabilistic forecasts of climate events in specific locations. Communication between scientists, decision-makers, and the public can be difficult and there are barriers to the use of existing tools; improvements in communications related to climate change and associated response options also need more research.

What are the decisions and who are the decision-makers?

There are many scales of decisions related to reducing climate impacts and multiple types of decision-makers. For example, the federal government is engaged in decisions that affect climate policy at the international level, but it also makes regulatory decisions (for example, setting efficiency standards for vehicles) and decisions on how to reduce risks associated with climate change within its own facilities and activities. State and local governments are involved in setting policy about both emissions and adaptation activities in a variety of applications, including land use, renewable portfolio and energy efficiency standards, and investments in resilience to extreme weather events. Many private-sector companies have initiated strategies to respond both to the risks to their investments and the business opportunities associated with preparing for a changing climate. Several non-governmental organizations have been active in supporting decisions that integrate both adaptation and mitigation considerations, often in the context of promoting sustainability within economic sectors, communities, and ecosystems. Finally, individuals make decisions on a daily basis that affect their preparedness for extreme events and the health and welfare of their families (NRC 2010a).

What is decision support?

Decision support refers to “organized efforts to produce, disseminate, and facilitate the use of data and information” to improve decision-making (NRC 2009). It includes processes, decision support tools, and services. Decision support processes are effective when they: 1) build relationships that can support longer-term problem-solving capacity between knowledge producers and users; 2) provide information that users regard as credible, useful, and actionable; and 3) enhance the quality of decisions (NRC 2009). Some examples of products and decision tools include scenarios of the future, assessments of impacts and vulnerability, maps of projected climate impacts, and data management and visualization tools. Decision support activities that facilitate well-structured decision processes can result in consensus about defining the problems to be addressed, objectives and options for consideration, criteria for evaluation, potential opportunities and consequences, and tradeoffs.

Using a Decision-making Framework

Creating well-structured, transparent, and collaborative decision processes involving researchers and stakeholders is as important to effective decision-making as having good scientific information and tools. An effective process will better enable decision-makers to apply complex information to decisions, consider uncertainties associated with climate variability and change, assess the wide range of possible human responses, and engage institutions and individuals who are potentially affected.

The National Research Council has concluded that an "iterative adaptive risk management" framework, in which decisions are adjusted over time to reflect new scientific information and decision-makers learn from experience, is appropriate for decisions about adaptation and ways to reduce future climate change, especially given uncertainties and advances in scientific understanding (NRC 2010a; Willows and Connell 2003). At its heart, iterative adaptive risk management is an approach used daily to make and update decisions, from personal judgments to complex management and policy choices. This process can be more difficult for complex decisions, which is why it is important to put in place institutions that incorporate adaptive management to assure that decisions can be updated as one gains experience and as new scientific information becomes available.

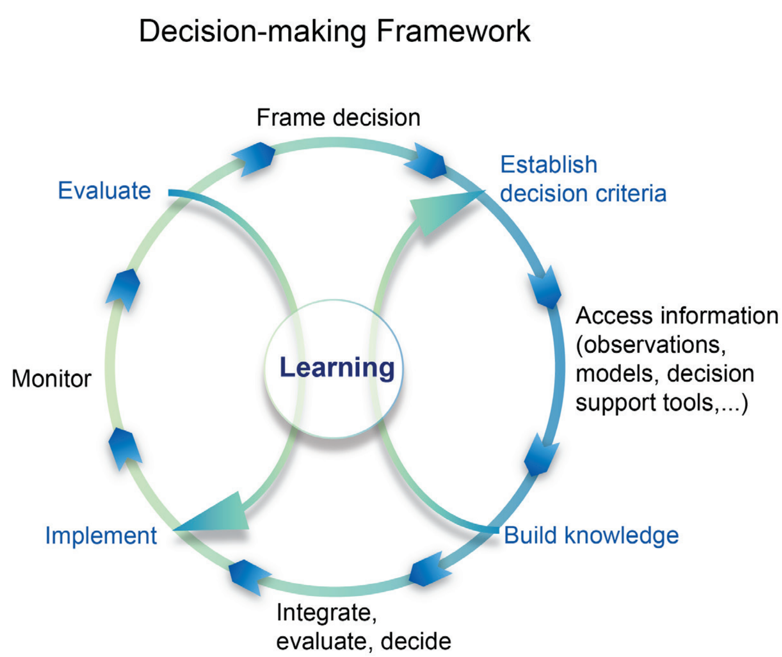

Figure 26.1: Decision-making Framework

Caption: This illustration highlights several stages of a well-structured decision-making process. Adapted from (NRC 2010a; Willows and Connell 2003).

Iterative risk management emphasizes "learning by doing" and continued adaptation to improve outcomes. Often, this process incorporates sustained interaction between decision-makers and the scientific/technical community. An idealized process includes: clearly defining the problem; establishing decision criteria; identifying and incorporating relevant information; evaluating options; and monitoring and revisiting effectiveness.

If the problem identified is to reduce the risks associated with climate change, decision criteria might include minimizing long-term costs and maximizing public safety. The relevant information might involve using scenarios to frame uncertainty in sea level rise and to understand how to translate that information into identifying property and ecosystems at risk.

Options to evaluate could include building levees or expanding coastal wetlands, which can absorb storm surges, including considerations of long- and short-term costs and effectiveness. After the decision is implemented, the effectiveness of the project and management practices can be revisited to ensure that the project continues to protect the community without damaging important habitat.

Scientific and technical information are important at many stages, but decisions about adaptation and ways to reduce future climate change also rest on non-scientific aspects, such as: personal or group values in the affected communities and within the business, government, or institution making the decisions; cultural and organizational characteristics; and other factors. Chapter 28: Adaptation addresses how some of these problems, including those that arise from decentralized decision-making with limited resources, might be addressed in the context of adaptation.

Problem Framing and Establishing Decision Criteria

An initial step in decision-making is to identify the context of the decision and factors that will affect choices – making sure that the questions are posed properly from scientific, decision-maker, and stakeholder (or public) perspectives. An important challenge is identifying the stakeholders in decision-making processes. There are often many categories of stakeholders, including those directly and indirectly affected by the outcomes of decisions as well as the decision-makers themselves, scientists, and elected officials. Other important issues often overlooked but critical to successful decision outcomes are:

- Understanding the goals and values of the participants in the decision process,
- Identifying risk perception and the sense of urgency of the parties involved in the decision,
- Being clear about the time frame of the decision (short- vs. long-term options relative to current and future risk levels) – and when the decision must be reached,
- Acknowledging the scale and degree of controversy associated with the risks and opportunities as well as the alternatives,
- Assessing the distribution of benefits or losses associated with current conditions and the alternatives being considered,
- Recognizing the diverse interests of the participants,
- Recognizing when neutral facilitators or trained science translators are needed to help with analysis, and
- Understanding legal or institutional constraints on options.

Based on the relevant objectives, decision criteria can be established that reflect constraints and values of decision-makers and affected parties. Criteria can be quantitative (for example, obtaining a particular rate of return on investment) or qualitative (for example, maintaining a community's character or culture). Decision framing and establishment of decision criteria can be facilitated using various methods, including brainstorming, community meetings, focus groups, surveys, and problem mapping. A variety of techniques for organizing and weighting information on multiple decision criteria are available, like multi-criteria analysis (Keeney and Raiffa 1993; Linkov and Moberg 2011).

Knowledge Building and Incorporating Scientific Information

Resource management and climate policy decisions often involve complex technical and scientific information. Ongoing conversations among scientists, decision-makers, and the public are often necessary to frame issues and identify, generate, and use relevant information (Scarlett 2010). Much scientific information is highly technical and may not be readily applied by non-experts. Thus, individuals, processes, and organizations that can help structure and sustain communication across different disciplines and communities are needed to effectively apply scientific knowledge in decision processes. Well-designed decision support processes, especially those in which there is a good match between the availability of scientific information and the capacity to use it, can result in more cost-effective outcomes based on relevant information that is perceived as useful and applicable. Unfortunately, the circumstances in which decision-makers, managers, and stakeholders can easily access the information they need in the context of evaluating climate-related risks and opportunities are limited. This leads to the need for assistance in crossing the boundary between science and applications; activities involved in bridging this gap to improve outcomes are often referred to as "boundary processes."

Boundary Processes Linking Decision-Makers and Scientific/Technical Experts

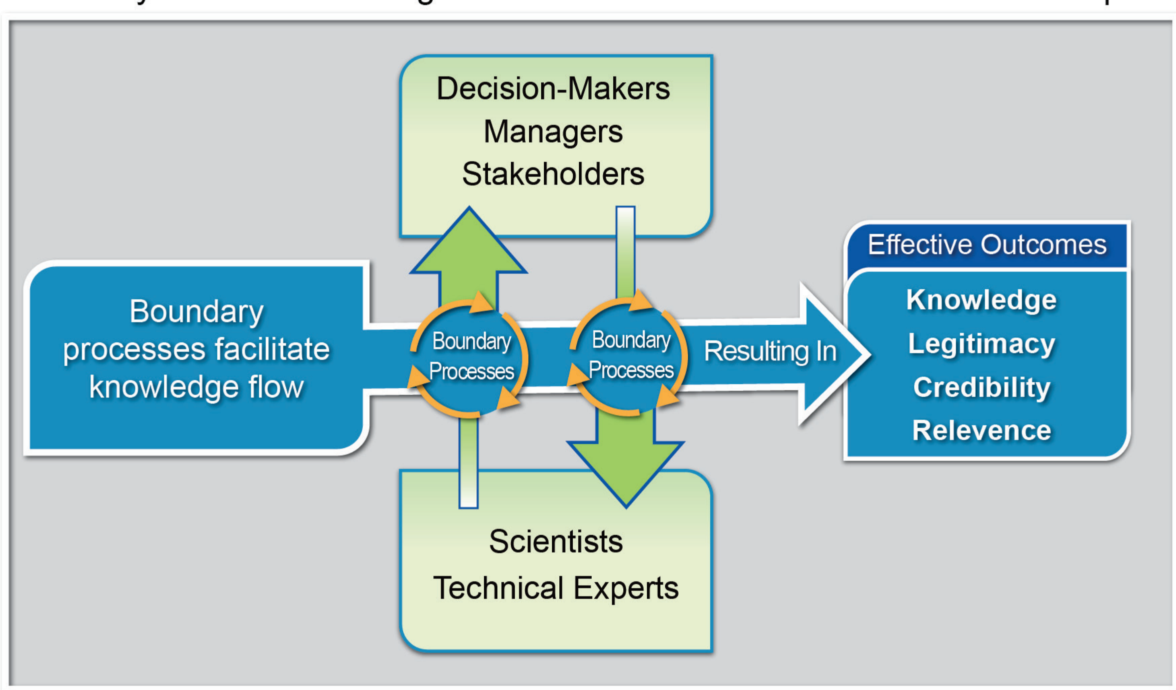

Figure 26.2: Boundary Processes Linking Decision-Makers and Scientific/Technical Experts

Caption: Boundary processes facilitate the flow of information and sharing of knowledge between decision-makers and scientists/technical experts. Processes that bring these groups together and help translate between different areas of expertise can provide substantial benefits. (Figure source: NOAA NCDC)

Regional and Sectoral Applications, Models, and Tools

Many decision support tools apply climate science and other information to specific decisions and issues; several online clearinghouses describe these tools and provide case studies of their use (for example, U.S. Climate Change Science Program (2005); Climate Adaptation Knowledge Exchange (2012), and the Ecosystem Based Management Tools Network (2012)). Typically, these applications integrate observed or modeled data on climate and a resource or system to enable users to evaluate the potential consequences of options for management, investment, and other decisions. These tools apply to many types of decisions that include, for example:

- *Water resources*: making water supply decisions in the context of changes in precipitation, increased temperatures and changes in water quality and water use (Means et al. 2010a; State of Washington 2012; Box 1: Denver Water case study; Ch. 3: Water Resources, especially the "Water Resources Management" section);
- *Infrastructure*: designing and locating energy or transportation facilities in the coastal zone to limit the impacts of sea level rise (See also Ch. 11: Urban Systems, Infrastructure, and Vulnerability and Ch. 10: Water, Energy, and Land Use);
- *Ecosystems and biodiversity*: managing carbon capture and storage, fire, invasive species, ecosystems and ecosystem services (Byrd et al. 2011; Labiosa et al. 2009; USGS 2012a, 2012b, 2012c) (Figure 3);
- *Human health*: providing public health warnings in response to ecosystem changes or degradation, air quality, or temperature issues (See also Ch. 9: Human Health).

Many available and widely applied decision-making tools can be used to support management of climate extremes or seasonal fluctuations of climate. Development of decision support resources focused on decadal or multi-decadal investment decisions is in a relatively early stage but is evolving rapidly and shared through the types of clearinghouses discussed above.

Florida Uses a Land-use Planning Tool

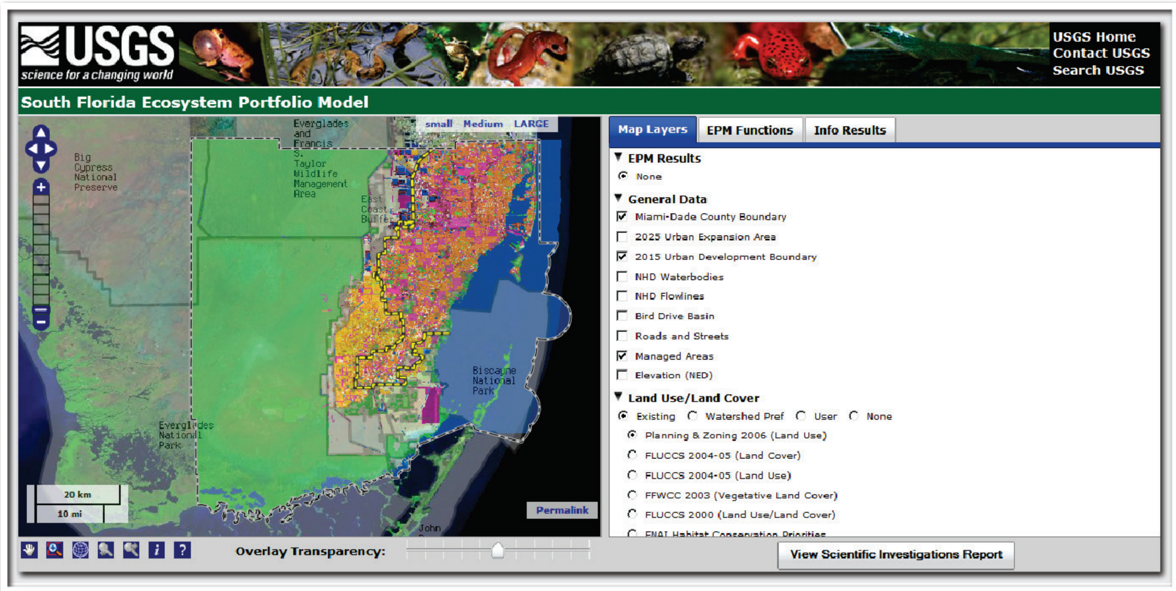

Figure 26.3: Florida Uses a Land-use Planning Tool.

Caption: The South Florida Ecosystem Portfolio Model (EPM) is a regional land-use planning tool that integrates ecological, economic, and social information and places that information in a context that is relevant to decision-makers and stakeholders. The EPM uses a multi-criteria evaluation framework that builds on Geographic Information Systems (GIS) analysis and spatially explicit models that characterize important ecological, economic, and societal consequences of regional land-use/cover change. Image from (USGS 2012).

Box 1: Denver Water Case Study

Climate change is one of the biggest challenges facing the Denver Water system. Due to recent and anticipated effects of climate variability and change on water availability, Denver Water faces the challenge of weighing alternative response strategies and is looking at developing options to help meet more challenging future conditions.

Denver Water is using scenario planning in its long-range planning process (looking out to 2050) to consider a range of plausible future scenarios. This approach contrasts with its traditional approach of planning for a single future based on demand projections, and should better prepare the utility and enhance its ability to adapt to changing and uncertain future conditions.

Denver Water is assessing multiple scenarios based on several potential water system challenges, including climate change, demographic and water use changes, and economic and regulatory changes. The scenario planning strategy includes "robust decision-making," which deliberately focuses on keeping as many future options open as possible while trying to ensure reliability of current supplies.

Scenario planning was chosen as a way to plan for multiple possible futures, given the degree of uncertainty associated with many variables, particularly demographic change and potential changes in precipitation. This method is easy to understand and has gained acceptance across the utility. It is a good complement to more technical, detailed analytical approaches.

The next step for Denver Water is to explore a more technical approach to test their existing plan and identified options against multiple climate change scenarios. Following a modified robust decision-making approach (Hall et al. 2012; Lempert et al. 2003), Denver Water will test and hedge its plan and options until those options demonstrate that they can sufficiently handle a range of projected climate conditions.

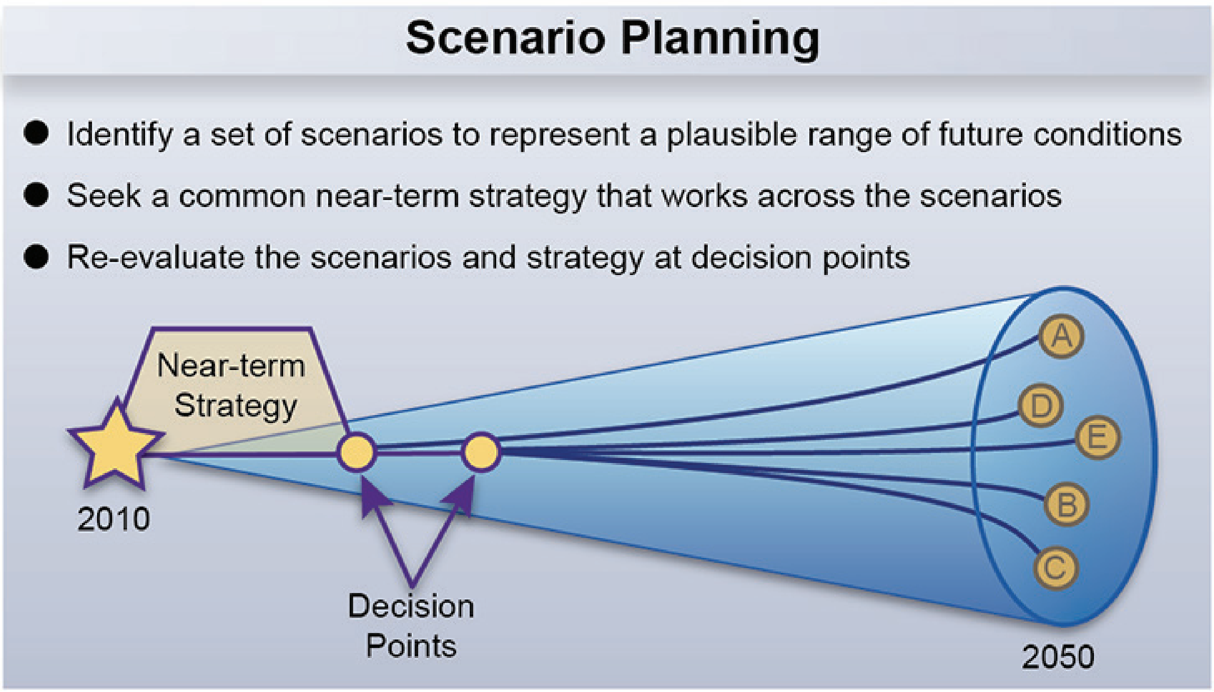

Figure 26.4: Scenario Planning

Caption: Scenario planning is an important component of decision-making. This "cone of uncertainty" is used to depict potential futures in Denver Water's scenario planning exercises. (Adapted from Waage, 2010, courtesy of Denver Water).

-- end box --

Value of Information

A frequently asked question when making complex decisions is: "When does the addition of more information contribute to decision-making so that the benefit of obtaining this information exceeds the expense of collecting and processing it?" In a decision context, the value of information often is defined as the expected additional benefit from additional information, relative to what could be expected without that information (Clemen and Reilly 1999; Williams et al. 2011; Yokota and Thompson 2004). Even though decision-makers often cite a lack of information as a rationale for not making timely decisions, delaying a decision to obtain more information doesn't always lead to different or better decisions (Fisher and Hanemann 1990; Hanemann 1989; Jacobs et al. 2005a; Jacobs et al. 2005b).

Assessing, Perceiving, and Managing Risk

At regional and sectoral levels, a changing and more variable climate generates both risks and opportunities. These positive and negative impacts can be evaluated using multiple criteria methods, valuation of both risks and opportunities, and scenarios. While a full quantitative risk analysis is not always possible or necessary, risk assessment provides a powerful framework for ranking risks and evaluating actions for managing them. The data from these assessments also illuminate how experts and the public can differ in their perception of risk. Understanding both risk assessment and risk perception proves important to managing risks of climate change. Using a risk-based approach is more appropriate for climate change than using cost-benefit analysis, because it incorporates uncertainty in the form of probabilities.

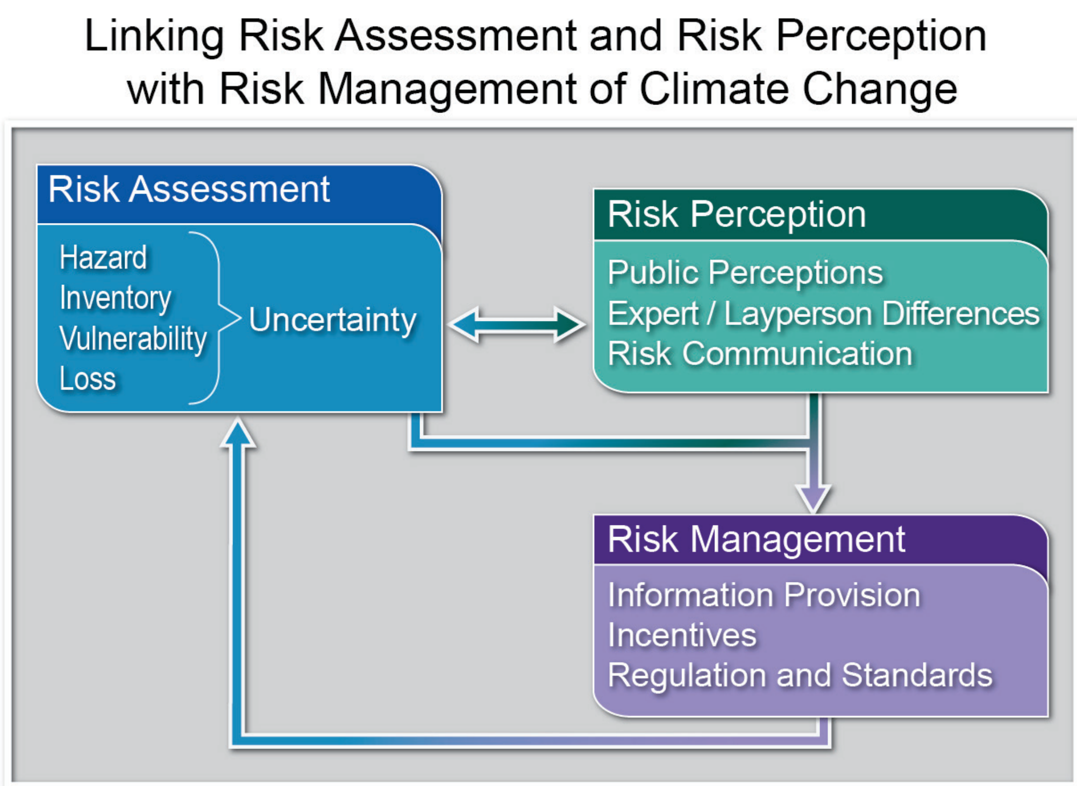

Figure 26.5: Linking Risk Assessment and Risk Perception with Risk Management of Climate Change.

Caption: This figure highlights the importance of incorporating both experts' *assessment* of the climate change risk and general public *perceptions* of this risk in developing risk management strategies. As indicated by the arrows, public perceptions of risk should be considered in expert risk assessment, which ideally helps the public to refine its understanding of the risks. Another crucial factor influencing risk perception is how risk is communicated. As the arrows indicate, risk management strategies should consider expert views and general public views of the risk, which will, in turn, affect the assessment and perception of climate change risk in the future.

Risk Assessment

Risk assessment includes studies that estimate the chances of specific sets of events occurring and/or their potential consequences (Haimes 1998). Experts often provide quantitative information regarding the nature of the climate change risk and the degree of uncertainty surrounding their estimates. Risk assessment focuses on the likelihood of negative consequences but does not exclude the possibility that there may also be beneficial consequences.

There are four basic elements for assessing risk – hazard, inventory, vulnerability, and loss (Grossi and Kunreuther 2005). This generalized approach to risk assessment is useful for a variety of types of decisions. The first element focuses on the risk of a *hazard* as a function of climate change, including interactions of climate effects with other factors. What is the likelihood of specific events occurring, and what is the uncertainty surrounding these estimates? The second element identifies the *inventory* of properties, people, and the environment at risk. To inventory structures, for instance, requires evaluating their location, physical dimensions, and construction quality. To evaluate the hazard and its impacts on inventory, it is useful to construct different climate change scenarios, the likelihood of their occurrence, and the uncertainty surrounding these estimates. Together, the hazard and inventory elements enable calculation of the damage *vulnerability* of the structures, people, and environment at risk.

The vulnerability component enables estimation of the human, property, and environmental *losses* from different climate change scenarios by integrating biophysical information on climate change and other stressors with socioeconomic and environmental information (Turner et al. 2003). These assessments typically involve evaluation of exposure, sensitivity, and adaptive capacity for current and projected conditions. Quantitative indicators are increasingly used to diagnose potential vulnerabilities under different scenarios of socioeconomic and environmental change (Eriksen and Kelly 2007; Moss et al. 2001) and to identify priorities and readiness for adaptation investments (Global Adaptation Institute 2012).

Risk Perception

Risk perception relates to the psychological and emotional factors that affect people's behavior. Social scientists and psychologists have studied people's concerns about risks (Leiserowitz 2010) and found that people view hazards with which they have little personal knowledge and experience as highly risky, and they especially dread them. In the case of unfamiliar technologies with catastrophic potential, such as nuclear power, members of the public often perceive the risks as much higher than experts do (Slovic 2000). The decision process of non-experts with respect to low-probability, high-consequence events differs from experts (Camerer and Kunreuther 1989).

People tend to focus on short time horizons, so future impacts from climate change are not given much weight in actions taken today. This tendency to ignore long-term impacts is one of the reasons that preparations for climate change are less likely to rise to the highest priority among some decision-makers (Kunreuther et al. 2012). This behavior highlights the importance of risk communication. Some of these challenges can be overcome by framing the risk in different ways. One way to convince individuals to pay attention to risk is to adjust the time horizon over which the probability of a loss is measured. For example, people are much more willing to take the risk seriously if they are told that the chance of at least one disaster is greater than 1 in 5 over a 25-year period rather than 1 in 100 in any given year (Weinstein et al. 1996).

Risk Management Strategies

Taking a broad, long-term perspective, risk management in a climate change context requires both mitigation and adaptation strategies (IPCC 2012; The World Bank 2010). In some cases, public agencies, private firms, and individuals already have sufficient incentives, information, and options available to adapt to emerging conditions. These options include ensuring continuity of service or fulfillment of agency responsibilities, addressing procurement or supply chain issues, preserving market share, or holding the line on agency or private-sector production costs. Commercially available mechanisms such as insurance can also play a role in providing protection against losses (Aerts and Botzen 2011). However, in some cases, these incentives and mechanisms are not sufficient, particularly for challenges outside the normal planning horizon of an agency or business. For example, the private sector faces challenges in providing coverage due to the uncertainty of the risks of climate change and liability issues associated with global climate change (Kunreuther and Michel-Kerjan 2007). In these cases, public sector involvement can make this adaptation process more effective. Such policies include public education programs, economic incentives (subsidies and fines), and regulations and standards. Private-public partnerships can be useful for communicating and setting priorities for managing climate change risks (Kunreuther 2002). Criteria for evaluating risk management strategies can include impacts on resource allocation, equity and distributional impacts, ease of implementation, and justification, among others.

Decision-makers' Toolkit

Many decision frameworks and tools are available to support and improve decision-making on climate change adaptation and ways to reduce future climate change.

A number of decision-making tools and processes generated by both the public and private sectors can assist stakeholders and decision-makers in meeting their own objectives, and can clarify where there are value differences or varying tolerances for risk and uncertainty. Several such tools are discussed here.

Comparative Tradeoff Methods

In making decisions, alternative options are often compared against some measure of the objectives. In such cases, approaches such as listing the pros and cons (Hammond et al. 2002), cost-benefit analysis (Boardman et al. 2005), multi-criteria methods (Clemen and Reilly 1999), or robust decision methods (Lempert and Groves 2010; Reeder and Ranger 2011) can be useful (see Box 2: Valuing the effects of different decisions). Multi-criteria methods provide a way to compare options by considering the positive and negative consequences for each of the objectives without having to choose a single valuation method for all the attributes important to decision-makers (Keeney and Raiffa 1993). This approach allows for consequences to be evaluated using criteria most relevant for a given objective (Keeney 2007). The options can then be compared directly, by considering the relative importance of each objective for the particular decision.

Scenarios and Scenario Planning

Scenarios are not predictions, but are a means of gaining insight into the future and how actions may shape it. One approach to building scenarios begins with identifying any changes over time that might occur in climate and socioeconomic factors deemed relevant (for example, population growth and changes in water availability), and then using these projections to help decision-makers rank the desirability of alternative decision options to respond to these changes (Moss et al. 2010). This works well when decision-makers agree on framing and scientific evidence (Morgan et al. 2009; Sarewitz and Pielke Jr 2000). A second approach begins with a specific decision under consideration by a specific community of users and then poses questions relevant to these decisions (for example, "how can we build a vibrant economy in our community in light of uncertainty about population growth and water supply?") to organize information about future climate and socioeconomic conditions.

A relatively new use of scenarios combines quantitative science-based scenarios with "visioning" processes used by communities and organizations to explore desired futures, an approach known as "scenario planning" (Sheppard et al. 2011). This tool has been useful for water managers such as Denver Water, which has also used "robust decision-making" to assess policies that perform well across a wide range of future conditions, in the face of uncertainty and unknown probabilities (see Box 1: Denver Water case study). A variety of scenarios have been developed for the NCA, incorporating many of these approaches (see Ch. 1: Executive Summary).

Integrated Assessment Models

Integrated Assessment Models are tools for modeling interactions across climate, environmental, and socioeconomic systems (Patt et al. 2010; Weyant et al. 1996). They typically include representations of climate, economics, energy, and other technology systems, as well as demographic trends and other factors that can be used in uncertainty quantification. They are useful in national and global policy decisions about emissions targets, timetables, and the implications of different technologies for emissions management. These models are now being extended to finer resolutions and smaller scales to support regional decision-making.

Data Management Systems

Information technology systems and data analytics can harness vast data sources, making data more accessible to analysts and more useful for decision-makers. Such technologies allow for rapid scenario building and testing using many different variables so that the physical impacts of climate change can be more immediately and accurately measured (see Box 3: Data management). Similarly, information systems that synthesize data and products, such as the National Integrated Drought Information System (NIDIS) (2007) and the proposed National Climate Assessment Indicator System, (Janetos et al. 2012) can help to support mitigation and adaptation decisions.

Scientific Assessments

Ongoing assessments of the state of knowledge allow for iterative improvements in understanding over time, and the capacity to work directly with decision-makers to understand their needs for information (NRC 2007). A sustained assessment process (see Ch. 30: Sustained Assessment) can be deliberately designed to support the adaptation and mitigation information needs of decision-makers, with ongoing improvements in data quality and utility over time. Such ongoing assessment efforts that support decisions include the development and implementation of an end-to-end climate change indicator system (Janetos et al. 2012)

Box 2. Valuing the Effects of Different Decisions

Understanding costs and benefits of different decisions requires understanding people's preferences and developing ways to measure or "value" outcomes of those decisions relative to preferences. This "valuation" process is used to help rank alternative actions, illuminate tradeoffs, and enlighten public discourse (Keeney and Raiffa 1993). In the context of climate change, the process of measuring the value of different outcomes involves managers, scientists, and stakeholders and a set of methods to help decision-makers evaluate the consequences of climate change decisions (Nordhaus 2007; Stern 2007; Weitzman 2007). Although values are defined differently by different individuals and groups and can involve different metrics – for example, considering monetary versus non-monetary values (Boyd and Wainger 2002; Brown et al. 1995; Gregory et al. 2001), in all cases, valuation is used to assess the relative importance to the public or specific stakeholders of different impacts. Such valuation assessments can be used as inputs into iterative adaptive risk management assessments (which is advocated here because of its ability to robustly address uncertainty) or more traditional cost benefit analyses, if appropriate.

Some impacts ultimately are reflected in changes in the value of activities within the marketplace and in dollars (Mendelsohn 1998; Tol 2009) – for example, the impacts of increased temperatures on commercial crop yields (Cline 2007; Mendelsohn and Dinar 2009; Schlenker et al. 2006). Other valuations use non-economic metrics (Champ et al. 2003; EPA 2000; Freeman 2003; Kopp et al. 1997), such as considering the implications of melting Arctic sea ice on polar bear populations.

Valuation methods can provide input to a range of decision frameworks, including cost-benefit analysis of new or existing regulations (CBO 2009) or government projects (Boyd 2006; PCAST 2011); the implications of land use changes (Banzhaf et al. 2010; Irwin 2002); transportation investments and other planning efforts (Boyd and Banzhaf 2007; McConnell 1992); metrics for ecosystem services; and stakeholder and conflict resolution processes (Van den Belt 2004).

-- end box --

Box 3: Data Management

Decision Support Analysis (DSA), a general category of decision support tool, provides a framework for prioritizing actions in complex or crisis situations. State-of-the-art information technology systems and data analytics can harness vast and disparate data sources, making data more accessible to analysts and more useful for decision-makers. Information technologies that support DSA also make it possible to quickly and accurately measure current and projected physical impacts of climate change. This in turn can enable more effective decision-making, maximize disaster preparedness, and result in decisions that make infrastructure less vulnerable to risks.

With collaborative approaches to gathering and analyzing data, information can be displayed in real time by using both off-the-shelf and customized applications that can be deployed rapidly, either in response to catastrophes or in reaction to newly discovered risks and problems. This increases both the scale and the accessibility of available knowledge to decision-makers, and provides a fuller picture of a given situation as well as the capability to model the short- and long-term impacts of available options.

Recent examples demonstrate the potentially far-reaching effects of integrated, interoperable, data management systems. During the Deepwater Horizon oil spill in the Gulf of Mexico in 2010, the Sierra Nevada Corporation (SNC) created a "knowledge enterprise" system that incorporated data systems and data collection from more than 50 different federal agencies – coordinating, verifying, and centralizing into a single access point models, observations, evaluation of mitigation measures, and assessments of local needs and economic, environmental, and social concerns. This fusion of diverse data enabled decision-makers at national, state, and local levels to organize, sort, and analyze relevant information and ultimately helped to coordinate a comprehensive response. Another example involving Entergy (a regional utility), Swiss Re (a reinsurance company), and the Economics of Climate Adaptation working group integrated natural catastrophe weather models with economic data to predict a range of estimates related to climate change adaptation. This work represents the first comprehensive analysis of climate risks and adaptation economics along the U.S. Gulf Coast (America's Wetland Foundation 2012; Entergy 2012). In a third, a simplified model was developed, with support from the EPA, to look at flooding risks associated with coastal exposure in southern Maine (Gregg 2010; SLAWG 2012). Use of an "open platform" system that allows multiple users to input and access data resulted in spreadsheets, graphs, and 3D imagery displayed on contour maps downscaled to the city and county level for local decision-makers to access.

Technologies exist to solve the kinds of complex problems posed by evaluating, preparing for, and responding to climate-related impacts. The challenge is extending the availability of needed technology and ensuring the accessibility of relevant data, defining quality criteria, and identifying and filling data gaps.

--end box--

Keeping Pace with Scientific Advances

While decision support is not necessarily constrained by a lack of tools, a number of barriers restrict application of existing and emerging science and technology in adaptation and mitigation decisions (NRC 2009, 2010a, 2010d). Recent scientific developments could help to address some of these barriers, but are not yet incorporated into decision support tools (NRC 2006). For example, individual climate models can provide very different scenarios of future climate conditions for a given region, and the divergence of these projections can make it seem impossible to reach a decision. But comparing different models and constructing climate model "ensembles" can highlight areas of agreement across large numbers of models and model runs, and can also be used to develop ranges and other forms of quantification of uncertainty.

However, results from these activities are often difficult for researchers to access, let alone present in formats that could help decision-makers (Slocum et al. 2003)

Improving Decision Processes

Steps to improve collaborative decision processes could include training more "science translators" to help bridge science and decision-making; integrating development of decision support tools into fundamental scientific research; improving reward structures and institutional recognition for those who work at the boundary of science and decision-making; increasing support through the USGCRP for research to develop decision support tools; and incorporating assessment of decision support resources for sectors and regions into the ongoing National Climate Assessment (NCA) process.

The complexity, scope, and scale of climate change science further complicate our ability to apply science to decision-making. The challenges of communicating complex scientific information to decision-makers (including the public) are becoming increasingly clear (Pidgeon and Fischhoff 2011). But the challenges go beyond those of "translation" of complex information. The interface of science and decision-making includes defining and understanding the problem; identifying, generating, and using relevant technical and scientific information and analyses; and adjusting decisions as information and needs evolve. Defining the scope and scale of the relevant climate change problem can raise both scientific and social questions. Answering these questions requires scientific insights. But these questions also involve values and social constructs. This observation suggests the relevance of public engagement with technical experts and decision-makers in framing the problem and defining decision boundaries. It often requires that multiple participants engage in mutual learning and the co-production of relevant knowledge (Lee 1993). Some analysts have emphasized the importance of boundary processes that are collaborative and iterative (Curtin 2002, 2005). Boundary processes include, for example, joint fact finding and collaborative adaptive management, both of which engage scientists, stakeholders, and decision-makers in ongoing dialog about understanding the policy problem and identifying what information and analysis are necessary to evaluate decision options (Karl et al. 2007; McCreary et al. 2001). While use of these kinds of processes is increasing in decision settings involving complex scientific information and multiple, sometimes competing, societal values and goals, analysis of the conditions that contribute to their effectiveness is an emerging area of study (McCreary et al. 2001).

Many authors have noted that the ability to use data and tools has not kept pace with the rate at which new tools are developed. In this context, there is a need for "science translators" who can help decision-makers efficiently access and properly use data and tools that would be helpful in making more informed decisions in the context of climate change (Jacobs et al. 2005a; NRC 1999, 2008, 2009, 2010a, 2010b, 2010c; Snover et al. 2007). The culture of research in the U.S. also perpetuates a belief that basic and applied research need to be kept separate when it has been demonstrated that research motivated by "considerations of use" can also make fundamental advances in scientific understanding and theory (Stokes 1997). The U.S. climate research effort has been strongly encouraged to improve integration of social and ecological sciences and to develop the capacity for decision support to help address the need to effectively incorporate advances in climate science into decision-making (NRC 2011).

Implementation

The implementation phase of a well-structured decision process involves an ongoing cycle of setting goals, taking action, learning from experience, and monitoring to evaluate the consequences of undertaking specific actions. This cycle offers the potential for policy and outcome improvement through time. Ongoing evaluation can focus on how the system responds to the decision, leading to better future decisions, as well as on how different stakeholders respond, resulting in improvements in future decision-making processes. The need for social and technical learning to inform decision-making is likely to increase in the face of pressures on social and resource systems from climate change. However, the relative effectiveness of monitoring and assessment in producing social and technical learning depends on the nature of the problem, the amount and kind of uncertainty and risk associated with climate change, and the design of the monitoring and evaluation efforts.

Improving Decision Support

As they adjust to observed differences in climate and plan for uncertain future changes, decision-makers will face significant challenges because of uncertainties, a wide range of options, and the potentially extensive effects on numerous groups of stakeholders. Creating a well-structured, transparent, and inclusive decision process is vital and does not depend on additional scientific information.

However, there are a number of areas where scientific knowledge needs to be expanded or tools further developed to take advantage of existing insight, including:

- A comprehensive analysis of the state of decision support for adaptation and mitigation, including processes, tools, use, and successes/challenges, would be useful.
- Currently, the costs and benefits of non-market ecosystem goods and services (Boyd and Banzhaf 2007; EPA 2009; Heal 2000; Millennium Ecosystem Assessment 2005; NRC 2005) affected by mitigation and adaptation are inadequately understood, particularly those that have an impact over longer time scales.
- Improvements in risk management require closing the gap between expert and public understanding of risk, and building the institutions needed for managing persistent risks over the long term.
- Probabilistic forecasts or other information regarding consequential climate extremes/events have the potential to be very useful for decision-makers, if confidence in such forecasts can be improved.
- Improved communication among scientists, decision-makers, and the public regarding levels of scientific confidence and uncertainty in the context of specific decisions would be very useful in supporting risk management strategies.
- Currently, processes that effectively link scientists with decision-makers and the public in resource management settings are inadequate, and criteria to evaluate their effectiveness are not well-developed.

Traceable Accounts

Chapter 26: Decision Support

Key Message Process: During March-June 2012, the author team engaged in multiple technical discussions via teleconference (6 telecons) and email, and in a day-long in-person meeting (April 27, 2012 in Washington, DC). Authors reviewed over 50 technical inputs provided by the public and a wide variety of technical and scholarly literature related to decision support, including reports from the National Research Council that provided recent syntheses of the field [America's Climate Choices series, especially the report *Informing an effective response to climate change (NRC 2010a)*; *Informing Decisions in a Changing Climate* (NRC 2009)]. During the in-person meeting, authors reflected on the body of work informing the chapter and drafted a number of candidate critical messages that could be derived from the literature. Following the meeting, authors ranked these messages and engaged in expert deliberation via teleconference and email discussions in order to agree on a small number of key messages for the chapter.

Key message #1/3	**Creating well-structured, transparent, and collaborative decision processes involving researchers and stakeholders is as important to effective decision-making as having good scientific information and tools. An effective process will better enable decision-makers to apply complex information to decisions, consider uncertainties associated with climate variability and change, assess the wide range of possible human responses, and engage institutions and individuals who are potentially affected.**
Description of evidence base	Decisions about investment in adaptation and mitigation measures occur in the context of uncertainty and high political and economic stakes, complicating the evaluation of information and its application in decision-making (NRC 2009, 2010a). Decisions involve both scientific information and values—for example, how much risk is acceptable and what priorities and preferences are addressed (Mattson et al. 2012). At least as important as access to decision support tools is the creation of a well-structured and transparent decision process that involves affected parties in problem framing, establishing decision criteria, fact finding, deliberation, and reaching conclusions (Beratan and Karl 2012; NRC 2010a; Willows and Connell 2003). These aspects of decision-making are often overlooked by those who focus more on scientific inputs and tools, but given the high stakes and remaining uncertainties, they are crucial for effective decision-making on adaptation and mitigation. This message emphasizes that making a decision is more than picking the right tool and adopting its outcome. It is a process that should involve stakeholders, managers, and decision-makers to articulate and frame the decision, develop options, consider consequences (positive and negative), evaluate tradeoffs, make a decision, implement, evaluate, learn, and reassess (Beratan and Karl 2012; NRC 2010a). Often times having an inclusive, transparent decision process increases buy-in, regardless of whether a particular stakeholder's preferred option is chosen (NRC 2009).
New information and remaining uncertainties	N/A
Assessment of confidence based on evidence	N/A

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Chapter 26: Decision Support

Key Message Process: See key message #1.

Key message #2/3	**Many decision frameworks and tools are available to support and improve decision-making on climate change adaptation and ways to reduce future climate change.**
Description of evidence base	Many of these tools are developed to support adaptive management in specific sectors or for specific issues and include: risk assessments; GIS-based analysis products; targeted projections for high consequence events such as fires, floods, or droughts; vulnerability assessments; integrated assessment models; decision calendars; scenarios and scenario planning; and others (NRC 2009, 2010a; U.S. Climate Change Science Program 2005). Many of these tools have been validated scientifically and evaluated from the perspective of users. They are described in the sector or regional chapters of the assessment. In addition, a variety of clearing houses and data management systems provide access to decision support information and tools (for example, Climate Adaptation Knowledge Exchange ; Ecosystem Based Management Tools Network 2012). There are many tools, some of which we discuss in the chapter, that are currently being used to make decisions that include a consideration of climate change and variability, or the impacts or vulnerabilities that would result from such changes.
New information and remaining uncertainties	N/A
Assessment of confidence based on evidence	N/A

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Chapter 26: Decision Support

Key Message Process: See key message #1.

Key message #3/3	**Steps to improve collaborative decision processes could include training more "science translators" to help bridge science and decision-making; integrating development of decision support tools into fundamental scientific research; improving reward structures and institutional recognition for those who work at the boundary of science and decision-making; increasing support through the USGCRP for research to develop decision support tools; and incorporating assessment of decision support resources for sectors and regions into the ongoing National Climate Assessment (NCA) process.**
Description of evidence base	There are many challenges in communicating complex scientific information to decision makers and the public (Pidgeon and Fischhoff 2011), and while "translation" of complex information is one issue, there are many others. Defining the scope and scale of the relevant climate change problem can raise both scientific and social questions, which require both scientific insights and consideration of values and social constructs, and that participants engage in mutual learning and the co-production of relevant knowledge (Lee 1993). Boundary processes that are collaborative and iterative (Curtin 2002, 2005), such as joint fact finding and collaborative adaptive management, foster ongoing dialogue and increasing understanding of policy problems and information and analysis necessary to evaluate decision options (Karl et al. 2007; McCreary et al. 2001). Analysis of the conditions that contribute to their effectiveness is an emerging area of study (McCreary et al. 2001). A large body of literature notes that the ability to use data and tools has not kept pace with the rate at which new tools are developed, pointing to a need for "science translators" who can help decision-makers efficiently access and properly use data and tools that would be helpful in making more informed decisions in the context of climate change (Jacobs et al. 2005a; NRC 1999, 2008, 2009, 2010a, 2010b, 2010c; Snover et al. 2007). The U.S. climate research effort has been strongly encouraged to improve integration of social and ecological sciences and to develop the capacity for decision support to help address the need to effectively incorporate advances in climate science into decision making (NRC 2011).
New information and remaining uncertainties	N/A
Assessment of confidence based on evidence	N/A

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

References

Aerts, J.C.J.H. and W.J.W. Botzen, 2011: Climate change impacts on pricing long-term flood insurance: A comprehensive study for the Netherlands. *Global Environmental Change*, **21,** 1045-1060

America's Wetland Foundation, cited 2012. [Available online at http://americaswetland.com]

Banzhaf, H.S., W.E. Oates, and J.N. Sanchirico, 2010: Success and design of local referenda for land conservation. *Journal of Policy Analysis and Management*, **29,** 769-798

Beratan, K.K. and H.A. Karl, 2012: Managing the science-policy interface in a complex and contentious world. *Restoring Lands-Coordinating Science, Politics and Action***,** 183-216

Boardman, A.E., D.H. Greenberg, A.R. Vining, and D.L. Weimer, 2005: Cost-benefit analysis: concepts and practice

Boyd, J. and L. Wainger, 2002: Landscape indicators of ecosystem service benefits. *American Journal of Agricultural Economics*, **84,** 1371-1378

Boyd, J. and S. Banzhaf, 2007: What are ecosystem services? The need for standardized environmental accounting units. *Ecological Economics*, **63,** 616-626

Boyd, J.W., 2006: The Non-Market Benefits of Nature: What Should Be Counted in Green GDP? *Discussion Papers*

Brown, T.C., G.L. Peterson, and B.E. Tonn, 1995: The values jury to aid natural resource decisions. *Land Economics*, **71,** 250-260

Byrd, K.B., J.R. Kreitler, and W.B. Labiosa: Tools and Methods for Evaluating and Refining Alternative Futures for Coastal Ecosystem Management—the Puget Sound Ecosystem Portfolio Model: U.S. Geological Survey Open-File Report 2011–1279, 47 p. U.S. Geological Survey. [Available online at http://pubs.usgs.gov/of/2011/1279/]

Camerer, C.F. and H. Kunreuther, 1989: Decision processes for low probability events: Policy implications. *Journal of Policy Analysis and Management*, **8,** 565-592

CBO, 2009: The Economic Effects of Legislation to Reduce Greenhouse-Gas Emissions (Washington: CBO, September).

Champ, P.A., K.J. Boyle, and T.C. Brown, 2003: A Primer on Nonmarket Valuation. The economics of non-market goods and resources

Clemen, R.T. and T. Reilly, 1999: *Making hard decisions with DecisionTools Suite.* Duxbury.

Climate Adaptation Knowledge Exchange, cited 2012. [Available online at www.cakex.org]

Cline, W.R., 2007: *Global warming and agriculture: Impact estimates by country.* Peterson Institute.

Curtin, C.G., 2002: Integration of Science and Community ‐ Based Conservation in the Mexico/US Borderlands. *Conservation Biology*, **16,** 880-886

——, 2005: Linking complexity, conservation, and culture in the Mexico/US Borderlands. *Borderlands***,** 235-258 de Chazal, J. and M.D.A. Rounsevell, 2009: Land-use and climate change within assessments of biodiversity change: A review. *Global Environmental Change*, **19,** 306-315

Ecosystem Based Management Tools Network, cited 2012. [Available online at www.ebmtools.org]

Entergy. [Available online at http://entergy.com/gulfcoastadaptation]

EPA, 2000: Guidelines for preparing economic analyses. EPA 240-R-00-003. U. S. E. P. Agency, Ed., U.S. Environmental Protection Agency.

——, 2009: Valuing the Protection of Ecological Systems and Services: A Report of the EPA Science Advisory Board. EPA-SAB-09-012

Eriksen, S.H. and P.M. Kelly, 2007: Developing credible vulnerability indicators for climate adaptation policy assessment. *Mitigation and Adaptation Strategies for Global Change*, **12,** 495-524 doi: 10.1007/s11027-006-3460-6, [Available online at http://dx.doi.org/10.1007/s11027-006-3460-6]

Fisher, A.C. and W.M. Hanemann, 1990: Option value: theory and measurement. *European Review of Agricultural Economics*, **17,** 167-180

Freeman, A.M., 2003: *The measurement of environmental and resource values: theory and methods.* RFF Press.

Global Adaptation Institute: Global Adaptation Index. [Available online at http://index.gain.org/]

Gregg, R.M., cited 2010: Munincipal Adaptations to Create Resilient Beach Communities in Southern Maine: The Coastal Hazard Resiliency Tools Project [Case Study on a Project of the Southern Maine Regional Planning Commission and Maine Geological Survey] Product of EcoAdapt's State of Adaptation Program. Southern Main Regional Planning Commission. [Available online at http://www.cakex.org/case-studies/2779]

Gregory, R., T. McDaniels, and D. Fields, 2001: Decision aiding, not dispute resolution: creating insights through structured environmental decisions. *Journal of Policy Analysis and Management*, **20,** 415-432

Grossi, P. and H. Kunreuther, 2005: *Catastrophe modeling: A new approach to managing risk.* Springer.

Haimes, Y., 1998: *Risk modeling, assessment, and management.* Wiley.

Hall, J.W., R.J. Lempert, K. Keller, A. Hackbarth, C. Mijere, and D.J. McInerney, 2012: Robust Climate Policies Under Uncertainty: A Comparison of Robust Decision Making and Info‐Gap Methods. *Risk Analysis*, **32,** 1657-1672, in press doi: 10.1111/j.1539-6924.2012.01802.x

Hammond, J.S., R.L. Keeney, and H. Raiffa, 2002: *Smart choices: a practical guide to making better life decisions.* Broadway.

Hanemann, W.M., 1989: Information and the concept of option value. *Journal of Environmental Economics and Management*, **16,** 23-37

Heal, G., 2000: Valuing ecosystem services. *Ecosystems*, **3,** 24-30

Holling, C.S., 2003: Introduction. *Navigating social-ecological systems: building resilience for complexity and change*, F. Berkes, J. Colding, and C. Folke, Eds., Cambridge Univ Pr

ICATF, 2010: Progress Report of the Interagency Climate Adapatation Task Force

IPCC, 2012: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation–A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. C. Field, and Coauthors, Eds., Cambridge University Press, .

Irwin, E.G., 2002: The effects of open space on residential property values. *Land Economics*, **78,** 465-480

Jacobs, K., G. Garfin, and M. Lenart, 2005a: More than just talk: Connecting science and decisionmaking. *Environment: Science and Policy for Sustainable Development*, **47,** 6-21

Jacobs, K.L., G.M. Garfin, and B.J. Morehouse, 2005b: Climate Science and Drought Planning: The Arizona Experience. *JAWRA Journal of the American Water Resources Association*, **41,** 437-446

Janetos, A.C., R.S. Chen, D. Arndt, and M.A. Kenney, 2012: National Climate Assessment Indicators: Background, Development, and Examples. A Technical Input to the 2013 National Climate Assessment Report. [Available online at http://downloads.usgcrp.gov/NCA/Activities/NCA-Indicators-Technical-Input-Report-FINAL--3-1-12.pdf]

Karl, H.A., L.E. Susskind, and K.H. Wallace, 2007: A Dialogue, Not a Diatribe: Effective Integration of Science and Policy Through Joint Fact Finding. *Environment: Science and Policy for Sustainable Development*, **49,** 20-34

Keeney, R., 2007: Developing Objectives and Attributes. *Advances in decision analysis: from foundations to applications*, W. Edwards, R. F. Miles, and D. Von Winterfeldt, Eds., Cambridge Univ Pr, pp 104-128

Keeney, R.L. and H. Raiffa, 1993: *Decisions with multiple objectives: Preferences and value tradeoffs.* Cambridge Univ Pr.

Kopp, R.J., W.W. Pommerehne, and N. Schwarz, 1997: *Determining the value of non-marketed goods: economics, psychological, and policy relevant aspects of contingent valuation methods.* Vol. 10, Springer.

Kunreuther, H., 2002: Risk Analysis and Risk Management in an Uncertain World. *Risk Analysis*, **22,** 655-664

Kunreuther, H., R.J. Meyer, and E. Michel-Kerjan, 2012: Overcoming Decision Biases to Reduce Losses from Natural Catastrophes. *Behavioral Foundations of Policy*, **in press**

Kunreuther, H.C. and E.O. Michel-Kerjan, 2007: Climate change, insurability of large-scale disasters and the emerging liability challenge

Labiosa, W.B., R. Bernknopf, P. Hearn, D. Hogan, D. Strong, L. Pearlstine, A.M. Mathie, A.M. Wein, K. Gillen, and S. Wachter: The South Florida Ecosystem Portfolio Model—A Map-Based Multicriteria Ecological, Economic, and Community Land-Use Planning Tool: US Geological

Survey Scientific Investigations Report 2009-5181, 41 p. [Available online at http://pubs.usgs.gov/sir/2009/5181/sir2009-5181.pdf]

Lee, K., 1993: Compass and Gyroscope: Integrating Science and Politics for the Environment. Island Press.

Leiserowitz, A., 2010: Climate change risk perceptions and behavior in the United States. Climate change science and policy. Washington, DC: Island Press.

Lempert, R.J. and D.G. Groves, 2010: Identifying and evaluating robust adaptive policy responses to climate change for water management agencies in the American west. *Technological Forecasting and Social Change*, **77,** 960-974

Lempert, R.J., S.W. Popper, and S.C. Bankes, 2003: *Shaping the next one hundred years: New methods for quantitative, long-term policy analysis.* Rand Corporation.

Linkov, I. and E. Moberg, 2011: *Multi-criteria decision analysis: environmental applications and case studies.* Vol. 1, CRC Press.

Mattson, D., H. Karl, and S. Clark, 2012: Values in Natural Resource Management and Policy. *Restoring Lands-Coordinating Science, Politics and Action***,** 239-259

McConnell, K.E., 1992: On-site time in the demand for recreation. *American Journal of Agricultural Economics*, **74,** 918-925

McCreary, S., J. Gamman, and B. Brooks, 2001: Refining and Testing Joint FactFinding for Environmental Dispute Resolution: Ten Years of Success. *Mediation Quarterly*, **18,** 4

Means, E., M. Laugier, J. Daw, L. Kaatz, and M. Waage, 2010a: Decision support planning methods: Incorporating climate change uncertainties into water planning. [Available online at http://www.wucaonline.org/assets/pdf/pubs_whitepaper_012110.pdf]

Mendelsohn, R., and James Neumann, 1998: *The Market Impact of Climate Change on the US Economy.* Cambridge University Press.

Mendelsohn, R.O. and A. Dinar, 2009: *Climate change and agriculture: an economic analysis of global impacts, adaptation and distributional effects.* Edward Elgar Publishing.

Millennium Ecosystem Assessment, 2005: Ecosystems and human well-being: synthesis. Island Press Washington (DC).

Morgan, M.G., H. Dowlatabadi, M. Henrion, D. Keith, R. Lempert, S. McBride, M. Small, and T. Wilbanks, 2009: Best practice approaches for characterizing, communicating and incorporating scientific uncertainty in climate decision making, 96 pp

Moss, R.H., A.L. Brenkert, and E.L. Malone, 2001: Vulnerability to Climate Change. A Quantitative Approach. *Prepared for the US Department of Energy*, [Available online at http://www.globalchange.umd.edu]

Moss, R.H., J.A. Edmonds, K.A. Hibbard, M.R. Manning, S.K. Rose, D.P. van Vuuren, T.R. Carter, S. Emori, M. Kainuma, and T. Kram, 2010: The next generation of scenarios for climate change research and assessment. *Nature*, **463,** 747-756

National Integrated Drought Information System: National Integrated Drought Information System Implementation Plan: A Pathway for National Resilience. [Available online at http://www.drought.gov/portal/server.pt/community/what_is_nidis/207]

Nordhaus, W.D., 2007: A review of the Stern Review on the economics of climate change. *Journal of Economic Literature*, American Economic Association, 686-702.

NRC, 1999: Making Climate Forecasts Matter

——, 2005: Valuing ecosystem services: toward better environmental decision making

——, 2006: Linking Knowledge with Action for Sustainable Development: The Role of Program Management - Summary of a Workshop

——, 2007: Analysis of Global Change Assessments: Lessons Learned. [Available online at http://www.nap.edu/catalog.php?record_id=11868.]

——, 2008: Research and Networks for Decision Support in the NOAA Sectoral Applications Research Program

——, 2009: Informing Decisions in a Changing Climate. [Available online at http://www.nap.edu/openbook.php?record_id=12626&page=R1]

——, 2010a: Informing an Effective Response to Climate Change

——, 2010b: Advancing the Science of Climate Change

——, 2010c: Adapting to the Impacts of Climate Change

——, 2010d: Facilitating Climate Change Responses: A Report of Two Workshops on Insights from the Social and Behavioral Sciences

——, 2011: A Review of the U.S. Global Change Research Program's Strategic Plan

Patt, A.G., D.P. van Vuuren, F. Berkhout, A. Aaheim, A.F. Hof, M. Isaac, and R. Mechler, 2010: Adaptation in integrated assessment modeling: where do we stand? *Climatic Change*, **99,** 383-402

PCAST, 2011: Report to the President: Sustainability Environmental Capital: Protecting Society and the Economy: Washington, D.C., President's Council of Advisors on Science and Technology, Executive Office of the President

Pidgeon, N. and B. Fischhoff, 2011: The role of social and decision sciences in communicating uncertain climate risks. *Nature Climate Change*, **1,** 35-41

Reeder, T. and N. Ranger, cited 2011: "How do you adapt in an uncertain world?: lessons from the Thames Estuary 2100 project", *World Resources Report,* Washington, D.C. [Available online at http://www.worldresourcesreport.org/files/wrr/papers/wrr_reeder_and_ranger_uncertainty.pdf]

Sarewitz, D. and R.A. Pielke Jr, 2000: Breaking the global-warming gridlock. *The Atlantic Monthly*, **286,** 55-64

Scarlett, L., 2010: Climate change effects: the intersection of science, policy, and resource management in the USA. *Journal of the North American Benthological Society*, **29,** 892-903

Schlenker, W., W.M. Hanemann, and A.C. Fisher, 2006: The impact of global warming on US agriculture: an econometric analysis of optimal growing conditions. *Review of Economics and Statistics*, **88,** 113-125

Sheppard, S.R.J., A. Shaw, D. Flanders, S. Burch, A. Wiek, J. Carmichael, J. Robinson, and S. Cohen, 2011: Future visioning of local climate change: a framework for community engagement and planning with scenarios and visualisation. *Futures*, **43,** 400-412

SLAWG, cited 2012: Sea Level Adaptation Working Group for Saco Bay. [Available online at http://www.smrpc.org/Sea%20Level%20Adaptation/Sea%20Level%20Adaptation%20Working%20Group%20Page.htm]

Slocum, T.A., D.C. Cliburn, J.J. Feddema, and J.R. Miller, 2003: Evaluating the usability of a tool for visualizing the uncertainty of the future global water balance. *Cartography and Geographic Information Science*, **30,** 299-317

Slovic, P.E., 2000: *The perception of risk.* Earthscan Publications.

Snover, A.K., L. Binder, J. Lopez, E. Willmott, J. Kay, D. Howell, and J. Simmonds, 2007: *Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments.* ICLEI.

State of Washington, 2012: Preparing for a changing climate: Washington state's integrated climate response strategy. Chapter 7: Water resources.

Stern, N., 2007: *The Economics of Climate Change: The Stern Review.* Cambridge University Press.

Stokes, D.E., 1997: *Pasteur's Quadrant: Basic Science and Technological Innovation.* Brookings Inst Press.

The World Bank, 2010: Economics of Adaptation to Climate Change: Social Synthesis Report. The International Bank for Reconstruction and Development

Tol, R.S.J., 2009: The economic effects of climate change. *The Journal of Economic Perspectives*, **23,** 29-51

Turner, B.L., R.E. Kasperson, P.A. Matson, J.J. McCarthy, R.W. Corell, L. Christensen, N. Eckley, J.X. Kasperson, A. Luers, M.L. Martello, C. Polsky, A. Pulsipher, and A. Schiller, 2003: A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences*, **100,** 8074-8079 doi: 10.1073/pnas.1231335100, [Available online at http://www.pnas.org/content/100/14/8074.abstract

http://www.pnas.org/content/100/14/8074.full.pdf]

U.S. Climate Change Science Program: U.S. Climate Change Science Program Workshop: Climate Science in Support of Decision Making,. U.S. Climate Chante Science Program. [Available online at http://www.climatescience.gov/workshop2005]

USGS, cited 2012: South Florida Ecosystem Portfolio Model. [Available online at http://lcat.usgs.gov/sflorida/sflorida.html]

——, cited 2012a: The Puget Sound Ecosystem Portfolio Model. U.S Geological Survey. [Available online at http://geography.wr.usgs.gov/pugetSound/index.html]

——, cited 2012b: Santa Cruz Watershed Ecosystem Portfolio Model. U.S. Geological Survey. [Available online at http://geography.wr.usgs.gov/science/ecoSevicesSCWatershed.html]

——, cited 2012c: South Florida Ecosystem Portfolio Model. U.S. Geological Survey. [Available online at http://lcat.usgs.gov/sflorida/sflorida.html]

Van den Belt, M., 2004: *Mediated modeling: a system dynamics approach to environmental consensus building.* Island press.

Waage, M., 2010: Nonstationary Water Planning: A Review of Promising New Methods. *Workshop on Nonstationarity, Hydrologic Frequency Analysis, and Water Management*, Denver Water and Water Utitliy Climate Alliance.

Weinstein, N.D., K. Kolb, and B.D. Goldstein, 1996: Using time intervals between expected events to communicate risk magnitudes. *Risk Analysis*, **16,** 305-308

Weitzman, M.L., 2007: A review of the Stern Review on the economics of climate change. *Journal of Economic Literature*, **45,** 703-724

Weyant, J., O. Davidson, H. Dowlabathi, J. Edmonds, M. Grubb, E. Parson, R. Richels, J. Rotmans, P. Shukla, and R. Tol, 1996: *Integrated assessment of climate change: an overview and comparison of approaches and results.* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Williams, B.K., M.J. Eaton, and D.R. Breininger, 2011: Adaptive resource management and the value of information. *Ecological Modelling*

Willows, R.I. and R.K. Connell, 2003: Climate adaptation: Risk, uncertainty and decision-making.UKCIP Technical Report

Yokota, F. and K.M. Thompson, 2004: Value of information literature analysis: a review of applications in health risk management. *Medical Decision Making*, **24,** 287-298