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ORIGINAL ARTICLE

A comprehensive review of climate adaptation in the United States: more than before, but less than needed

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Abstract We reviewed existing and planned adaptation activities of federal, tribal, state, and local governments and the private sector in the United States (U.S.) to understand what types of adaptation activities are underway across different sectors and scales throughout the country. Primary sources of review included material officially submitted for consideration in the upcoming 2013 U.S. National Climate Assessment and supplemental peer-reviewed and grey literature. Although substantial adaptation planning is occurring in various sectors, levels of government, and the private sector, few measures have been implemented and even fewer have been evaluated. Most adaptation actions to date appear to be incremental changes, not the transformational changes that may be needed in certain cases to adapt to significant changes in climate. While there appear to be no one-size-fits-all adaptations, there

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are similarities in approaches across scales and sectors, including mainstreaming climate considerations into existing policies and plans, and pursuing no- and low-regrets strategies. Despite the positive momentum in recent years, barriers to implementation still impede action in all sectors and across scales. The most significant barriers include lack of funding, policy and institutional constraints, and difficulty in anticipating climate change given the current state of information on change. However, the practice of adaptation can advance through learning by doing, stakeholder engagements (including "listening sessions"), and sharing of best practices. Efforts to advance adaptation across the U.S. and globally will necessitate the reduction or elimination of barriers, the enhancement of information and best practice sharing mechanisms, and the creation of comprehensive adaptation evaluation metrics.

Keywords Adaptation process · Barriers · Climate change · Mainstreaming · Multiple stressors · Stakeholder participation · Successes · Case studies

1 Introduction

Over the past few years, the focus on climate change has transitioned from the question, "Is it changing?" to the equally important question, "Can society manage the unavoidable changes and avoid the unmanageable?" (Bierbaum et al. 2007) Both mitigation and adaptation are needed (McMullen and Jabbour 2009; ORNL 2012a; b; Skaggs et al. 2012). A mitigation only strategy will not work because it is already too late to avoid substantial climate change, and an adaptation only strategy will not work because most adaptation measures become more costly and less effective as the magnitude of changes to which one is trying to adapt gets larger (e.g., Allison et al. 2009; Lenton 2011; McMullen and Jabbour 2009; Meinshausen 2006; NRC 2011; Ramanathan and Feng 2008; SEGCC 2007).

How society responds will be critical. Societies typically react to problems as they occur, and it is reasonable to expect that most adaptation actions will be reactive—i.e., they will follow harmful or beneficial changes in climate and impacts. But anticipation of climate change—taking proactive steps to prepare for future changes in climate—can reduce the harm from climate change and facilitate a more rapid and efficient response to changes as they happen. The climate of the past will not be the climate of the future, and our aging infrastructure and some species cannot tolerate management actions that respond to the climate of the last century. Although there is uncertainty about the exact nature, magnitude,

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and timing of climate changes, this should not be a rationale for inaction or a barrier to adaptation (Kerr 2011; NRC 2010a).

Climate changes affect human health, natural ecosystems, and built environments, and stresses existing social, institutional, and legal arrangements. While a changing climate may create some new opportunities, the pace and magnitude of these changes will make historical planning and management practices insufficient to protect people and property. Building codes and landscaping provisions will need to be updated not only for energy efficiency, but also to protect against disease vectors, reduce susceptibility to heat stress, and improve protection against extreme events. Managing U.S. water resources such as the Great Lakes to address reduced lake levels, managing the Columbia River so that it can adapt to declining snowpack, and managing the Colorado River so that it can deal with drought are examples that involve both national and international issues. Both "bottom up" community planning and "top down" national strategies will be needed to help regions deal with impacts such as increases in electrical brownouts, heat stress, floods, and wildfires. Such a mix of approaches will require Federal, state, and local operational agencies to coordinate as they incorporate climate risks and adaptation planning into their programs.

Although the study of adaptation is nascent compared to the many analyses of policies and practices to reduce emissions, governments at all levels, as well as the private and nongovernmental sectors, are actively examining, and in some cases implementing, options to cope with a changing climate. As such, the objective of this paper is to identify many (but not all) of the specific and cross-cutting efforts at the Federal, regional, state, tribal, and local levels, as well as initiatives in the corporate and nongovernmental sectors, that build resilience to climate change while also highlighting barriers and the research, development, and deployment needs that will help stakeholders across the U.S. rapidly scale up adaptation activities. This paper is not meant to be a critical review of adaptation efforts but a compilation of illustrative adaptation activities happening across sectors and scales in the United States.

1.1 Materials and methods

The sources of materials reviewed for this analysis were documents officially submitted as expressions of interest (Request for Information published July 13, 2011 in 76 FR 41217 and amended in 76 FR 55365 on September 7, 2011) for consideration in the upcoming 2013 U.S. National Climate Assessment (NCA) [a report to the President and the Congress, mandated by the Global Change Research Act of 1990 (GCRA), P.L. 101–606, which evaluates, integrates, and interprets the findings of the U.S. Global Change Research Program's (USGCRP's) research agenda every four years] and approximately 30 external documents from peer-reviewed and grey literature. Adaptation-relevant content in each document was identified and tagged with a set of climate change adaptation-related keywords (e.g., planning; implementation; natural systems; urban; federal, tribal, local and barriers).

Once all NCA submitted material and external documents were reviewed, an analysis of the material by scale, sector, geographic location, and type of adaptation activity (e.g., planning, infrastructure, policy) was conducted. The results were then grouped based on scale of actor (government level, private sector, or nongovernmental). The sector and type of adaptation activity across scales were then analyzed to clarify the context in which adaptation is taking place, including the barriers and the needs of stakeholders at different geographic, spatial, and temporal scales.

The majority of the literature reviewed was published after 2007. A significant number of adaptation activities are not documented, however, particularly those currently being implemented. Therefore, the adaptation activities highlighted in this paper are inherently a snapshot in time and do not represent the full breadth and range of adaptation activities underway throughout the United States.

2 Adaptation activities in the United States

We were able to group adaptation activities into four scales based on actors: Federal government; states; tribal and local/regional governments; and private sector and nongovernmental organizations. The following section profiles some of the adaptation activities happening at these scales.

2.1 Federal government

Federal leadership, guidance, information, and support are vital to planning for and implementing adaptation actions at all scales and in all affected sectors of society (C2ES 2012a; CEQ 2010; 2011b; Smith et al. 2010). Because federal government activities directly influence all stakeholders, the Federal government must continue to work in partnership with local, state, tribal, and regional authorities as it develops adaptation strategies, programs, and policies and implements adaptation actions (CEQ 2011b; National Climate Adaptation Summit Committee 2010). Examples of new federal climate adaptation initiatives and strategies that have been developed in recent years, which will impact stakeholders in other sectors and scales of society, include:

- Executive Order 13514 (E.O.) requiring federal agencies to develop recommendations for strengthening policies and programs to adapt to the impacts of climate change;
- The creation of a U.S. Interagency Climate Change Adaptation Task Force (ICCATF) that led to the development of national principles for adaptation and is leading to crosscutting and government-wide adaptation policies;
- The development of three crosscutting national adaptation strategies focused on integrating Federal, and often state, local and tribal, efforts on adaptation in key sectors: the *National Action Plan: Priorities for Managing Freshwater Resources in a Changing Climate* (ICCATF 2011), the *National Fish, Wildlife and Plants Climate Adaptation Strategy* (forthcoming), and a priority objective on resilience and adaptation in the *National Ocean Policy Implementation Plan* (forthcoming);
- A new decadal National Global Change Research Plan (2012–2021) that identifies the goals of improving basic science, informing decisions, improving assessments, and communicating and educating (USGCRP 2012); and
- The development of several interagency and agency-specific groups focused on adaptation, including a "community of practice" for federal agencies that are developing and implementing adaptation plans; an Adaptation Science Workgroup inside the U.S. Global Change Research Program (USGCRP); and several agency-specific climate change and adaptation task forces.

As shown in Tables 1 and 2, federal actions include coordinated efforts at the White House, regional cross-sector efforts, and agency-specific adaptation plans, as well as support for local-level adaptation planning and action.

Table 1 Examples of U.S. federal interagency actions to promote, implement, and support adaptation at all scales

Entity	Action	Description
White House and Interagency	Established Interagency Climate Change Adaptation Task Force (ICCATF) and issued E.O. 13514, *federal Leadership in Environmental, Energy, and Economic Performance.*	ICCATF is co-chaired by the White House Council on Environmental Quality (CEQ) and Office of Science and Technology Policy (OSTP), along with the National Oceanic and Atmospheric Administration (NOAA), with senior participation from 20+ agencies. E.O. 13514 charged ICCATF with developing recommendations to help prepare for the impacts of climate change, and required federal agencies to "evaluate agency climate-change risks and vulnerabilities to manage the effects of climate change on the agency's operations and mission in both the short and long term."
Interagency Climate Change Adaptation Task Force (ICCATF)	Developed Guiding Principles for federal adaptation efforts and policy goals and recommended actions for the federal government. Guides interagency adaptation planning efforts.	The October 2010 Progress Report of the ICCATF laid out eight principles for federal adaptation efforts and made five key recommendations, including the development of agency adaptation plans and strategies to address key cross-cutting issues such as water management, natural resource management, and the integrating of adaptation actions into existing planning processes.
ICCATF Water Resources Adaptation workgroup	Developed and is leading implementation of the *National Action Plan: Priorities for Managing Freshwater Resources in a Changing Climate.*	The National Action Plan was released in October 2011, and is designed to ensure adequate water supplies and protect water quality, human health, property, and aquatic ecosystems. The workgroup is chaired by the Department of the Interior's (DOI's) U.S. Geological Survey (USGS) and the Environmental Protection Agency (EPA) and coordinated by CEQ.
ICCATF Agency Adaptation Planning Workgroup	Established and coordinates the federal agency adaptation community of practice.	The community of practice provides information and support to federal agencies working to reduce their climate change-related risks and a forum for collaboration and coordination across agencies. Coordinated by EPA.
Steering Committee of the *National Fish, Wildlife, and Plants Climate Adaptation Strategy*	Developed the *National Fish, Wildlife, and Plants Climate Adaptation Strategy.*	Requested by Congress and the ICCATF, this strategy is a collaborative effort of federal, state, and tribal partners to provide a unified approach for reducing the negative impacts of climate change on these resources. The steering committee is chaired by DOI's Fish and Wildlife Service (FWS), NOAA, and the New York Division of Fish, Wildlife, and

Table 1 (continued)

Entity	Action	Description
		Marine Resources (representing State agencies).
National Ocean Council (NOC)	Developed a chapter on adaptation and ocean acidification for the *National Ocean Policy Implementation Plan.*	This was developed in response to the NOC's call to strengthen resiliency of coastal communities and marine and Great Lakes environments and their ability to adapt to climate change impacts and ocean acidification, and the ICCATF's recommendation for a cross-cutting look at ocean and coastal adaptation issues.
U.S. Global Change Research Program (USGCRP)	National Climate Assessment, decadal National Global Change Research Plan (2012–2021), and annual report to Congress	Responsible for the development of the National Climate Assessment (NCA) every 4 years, as mandated by the Global Change Research Act of 1990 (GCRA, P.L. 101–606). Additionally, submits an annual report to Congress called "Our Changing Planet." In April 2012, the USGCRP released a new decadal National Global Change Research Plan with four new strategic goals, including: advance science, inform decisions, conduct sustained assessments, and communicate and educate.
USGCRP's Adaptation Science Workgroup	Identifying critical science information and decision support needs and capabilities in support of adaptation.	Formerly an ICCATF Adaptation Science Workgroup, the Adaptation Science Workgroup was transferred to USGCRP in 2010 as a new program element to improve the federal government's capacity to provide science in support of adaptation decisions at all scales for a diversity of users.

Material provided in Table is derived from Agency websites

Table 2 Examples of individual U.S. federal agency actions to promote, implement, and support adaptation at multiple scales

Agency	Component	Action	Description
All federal agencies		Developing Adaptation Plans as part of their annual Strategic Sustainability Performance Plans	The 2012 Strategic Sustainability Performance Plans for 50+ federal agencies will contain a specific section on adaptation. Agencies are required to evaluate climate risks and vulnerabilities to manage both short- and long-term effects on missions and operations.
Department of Health and Human Services (HHS)	Centers for Disease Control and Prevention (CDC)	Climate-Ready States and Cities Initiative	Through their first climate change cooperative agreements in 2010, CDC awarded $5.25 million to ten state and local health departments to

Table 2 (continued)

Agency	Component	Action	Description
			assess risks and develop programs to address climate change-related challenges.
Department of Agriculture (USDA)		Integrating climate change objectives into plans and networks.	USDA is using existing networks such as the Cooperative Extension Service, the Natural Resource Conservation Districts, and the Forest Service's Climate Change Resource Center to provide climate services to rural and agricultural stakeholders.
USDA	Forest Service	Developed a *National Roadmap for Responding to Climate Change* and a *Guidebook for Developing Adaptation Options*, among many resources.	The *National Roadmap* was developed in 2010 to identify and long-term actions to reduce climate change risks to the nation's forests and grasslands. The *Guidebook* (developed in 2011) builds on this previous work and provides science-based strategic and tactical approaches to adaptation. Other resources are available on the Forest Service website.
Department of Commerce (DOC)	NOAA	Supports research teams and local communities on adaptation-related issues and develops tools and resources.	Supports research teams such as Regional Integrated Sciences and Assessments (RISAs) to inform resource management, planning, and policy. Established six regional climate centers (RCCs) to better assess and deliver regionally focused climate science and services. Developed the Digital Coast partnership.
Department of Defense (DOD)	U.S. Army Corps of Engineers (USACE)	Developed a USACE climate change adaptation plan, and continues to update guidance for incorporating sea level rise into projects.	The Corps released its climate change adaptation plan in September 2011. The goal of the plan is to reduce vulnerabilities and improve resilience of water resources infrastructure impacted by climate change. The latest update of the guidance on "Incorporating Sea-Level Change Considerations in Civil Works Programs" was released in November 2011.
DOD	Department of the Navy	Developed road maps for adaptation in the Arctic and across the globe.	The Navy Arctic Roadmap (November 2009) promotes maritime security and naval readiness in a changing Arctic. The Climate Change Roadmap (May 2010) examines broader issues of climate change impacts on Navy missions and capabilities globally.
Department of Energy (DOE)		Develops higher spatial and temporal scales of climate projections, and is working to integrate adaptation and climate	Develops community-based, high-resolution (temporal and spatial) models for climate projections and integrated assessment models that increasingly reflect multi-sectoral

Table 2 (continued)

Agency	Component	Action	Description
		considerations into integrated assessments.	processes and interactions, multiple stressors, coupled impacts, and adaptation potential.
DOI	FWS	Developed an FWS climate change strategic plan. Established a network of Landscape Conservation Cooperatives.	The FWS climate change strategy plan (September 2010) establishes a basic framework to help ensure the sustainability of fish, wildlife, plants, and habitats in the face of climate change. In 2009, through Secretarial Order 3289, DOI established a network of 22 Landscape Conservation Cooperatives (LCCs) designed to promote shared conservation goals, approaches, and resource management planning and implementation across the United States, including Alaska, Hawaii, and the Caribbean.
DOI	USGS	Established a network of Climate Science Centers (CSCs).	Operates a National Climate Change and Wildlife Center and eight regional CSCs, which provide scientific information and tools that land, water, wildlife, and cultural resource managers and other stakeholders can apply to anticipate, monitor, and adapt to climate change.
Department of Transportation (DOT)	Federal Highway Administration (FHWA)	Developed Risk Assessment Model for transportation decisions.	DOT worked with five local and state-level transportation authorities to develop a conceptual Risk Assessment Model to help transportation decision-makers identify which assets are: (a) most exposed to the threats from climate change and/or (b) associated with the most serious potential consequences of climate change threats. Completed in November 2011.
DOT		Comprehensive study of climate risks to transportation infrastructure in the Gulf Coast Region, followed by an in-depth study for Mobile, Alabama.	Phase 1 of the study (completed in 2008) assessed the vulnerability of transportation infrastructure to climate change impacts across the Gulf region. Phase 2, expected to be completed in 2013, is focused on Mobile, Alabama. The effort is designed to develop transferable tools that will help transportation planners across the country.
EPA		Developed Climate Ready Estuaries and Climate Ready Water Utilities Working Group. Developed a draft agency water program adaptation strategy.	The Climate Ready Estuaries program works with coastal managers to: (1) assess vulnerabilities; (2) develop and implement adaptation strategies; (3) engage stakeholders; and (4) share lessons learned. The Climate Ready Water Utilities initiative provides

Table 2 (continued)

Agency	Component	Action	Description
			resources and tools to assist the water sector in adapting to climate change. The Draft *National Water Program Strategy: Response to Climate Change* addresses climate change impacts on water resources and EPA's water programs.
NASA		NASA's Climate Adaptation Science Investigator (CASI) Workgroup engages NASA climate models, missions, scientists, and NASA institutional stewards to explore NASA center-specific climate impacts and adaptation strategies.	The team has engaged in a range of activities since CASI's launch in the summer of 2010, including: (1) downscaling center-specific climate hazard information and projections; (2) conducting climate research customized to each Center's needs; (3) building inventories of each Center's existing climate and impact data and research activities; and (4) co-leading adaptation workshops.

Material provided in table is derived from Agency websites

This list contains selected examples of agency work on adaptation and should not be considered all-inclusive

Federal agencies can be particularly instrumental in facilitating climate adaptation by:

- Fostering the stewardship of public resources and maintenance of federal facilities, services, and operations such as defense, emergency management, transportation, and ecosystem conservation in the face of a changing climate (NRC 2010a; Rosenzweig and Horton 2012; Smith et al. 2010);
- Providing usable information and financial support for adaptation (NRC 2010a; Smith et al. 2010);
- Facilitating the dissemination of best practices and supporting a streamlined clearinghouse to share data, resources, and lessons learned (National Climate Adaptation Summit Committee 2010);
- Dealing with and anticipating impacts that cross geopolitical boundaries and supporting flexible regulatory frameworks (NRC 2010a; Smith et al. 2010);
- Ensuring the establishment of federal policies that allow for "flexible" adaptation efforts and that do not lead to unintended consequences (OTA 1993; Smith et al. 2010); and
- Building public awareness (CEQ 2010).

2.2 States

States have become important actors in national climate-related policy efforts, often through the creation of policies and programs that incentivize or inhibit adaptation at other governance scales (Morsch and Bartlett 2011); through the application of pressure on Federal and private entities (Goulder and Stavins 2011); and by serving as laboratories for climate innovation (Feldman and Kahan 2007; Moser 2009). Although many of these actions are not specifically designed to address climate change, they often include climate adaptation components.

Many of the climate-specific adaptation actions at the state level focus on planning. As of early 2012, at least 13 U.S. states have completed climate adaptation plans; one state is in the process of writing its plan; and eight states have made recommendations to create statewide adaptation plans (C2ES 2012b). In addition to formal adaptation plans, numerous states have created sector-specific plans that consider long-term climate change. For example, at least 16 states have biodiversity conservation plans that focus on preparing for long-term changes in climate (AFWA 2011), and states such as North Carolina and South Carolina are actively working to revise their state wildlife strategies to incorporate climate adaptation (Lackstrom et al. 2012).

Strategies identified in state-level adaptation plans generally fall into one of four categories (Feldman and Kahan 2007; Morsch and Bartlett 2011; Moser 2009; NRC 2010a): (1) research and education; (2) promotion and facilitation of existing policies or programs that improve resilience; (3) integration of adaptive measures into current policies or planning processes; and (4) development of new policies or practices that reduce vulnerability (Feldman and Kahan 2007; Morsch and Bartlett 2011; Moser 2009; NRC 2010a).

In addition to planning, some states have created legislation and/or programs that are either directly or indirectly targeted at reducing state-relevant vulnerabilities (Table 3).

Table 3 Examples of U.S. state-level adaptation activities

State	Adaptation action
Alaska (AK)	Alaska Climate Change Impact Mitigation Program provides funds for hazard impact assessments to evaluate climate change-related impacts, such as coastal erosion and thawing permafrost (Immediate Action Work Group 2008).
California (CA)	Building standards that mandate energy and water efficiency savings, advancing both adaptation and mitigatio n; State Adaptation Plan calls for 20 % reduction in per capita water use (EPA 2012).
Florida (FL)	Law supporting dryland landscaping techniques that focus on conserving water (Salkin 2009).
Hawaii (HI)	Water code that calls for integrated management, preservation, and enhancement of natural systems (Marra et al. 2012).
Kentucky (KY)	*Action Plan to Respond to Climate Change in Kentucky: A Strategy of Resilience,* which identifies six goals to protect ecosystems and species in a changing climate.
Louisiana (LA)	*Comprehensive Master Plan for a Sustainable Coast 2012* includes both protection and restoration activities addressing land loss from sea level rise, subsidence, and other factors over the next 50 years (State of Louisiana 2012).
Maine (ME)	The *Maine Sand Dune Rules* require that structures greater than 2,500 square feet be set back at a distance that is calculated based on the future shoreline position and considers two feet of sea level rise over the next 100 years (Grannis 2011).
Maryland (MD)	Passed *Living Shorelines Act* to reduce hardened shorelines throughout the state (Feifel 2010); passed "Building Resilience to Climate Change" policy, which establishes practices and procedures related to facility siting and design, new land investments, habitat restoration, government operations, research and monitoring, resource planning, and advocacy.
Montana (MT)	Maintains a statewide climate change website to help stakeholders access relevant and timely climate information, tools, and resources.
New Mexico (NM)	The Active Water Resource Management program allows for temporary water use changes in real time in case of drought (Propst 2012).
Pennsylvania (PA)	Enacted polices to encourage the use of green infrastructure and ecosystem-based approaches for managing stormwater and flooding (Solecki and Rosenzweig 2012).
Rhode Island (RI)	Requires public agencies considering land use applications to accommodate a 3–5-foot rate of sea level rise.
Texas (TX)	Coordinated response to drought through National Integrated Drought Information System (NIDIS); RISAs [Southern Climate Impacts Planning Program (SCIPP), Climate Assessment for the Southwest (CLIMAS)]; and state and private sector partners through anticipatory planning and preparedness (e.g., implemented in 2011 drought) (SCIPP 2012).

2.3 Local/regional and tribal governments

Most adaptation efforts to date have occurred at local and regional levels (Anguelovski and Carmin 2011; Gregg et al. 2011; Rabe 2009; Wallis 2011; Wheeler 2008). Primary mechanisms that local governments are using to prepare for climate change include land use planning; provisions to protect infrastructure and ecosystems; regulations related to the design and construction of buildings, roads, and bridges; and emergency preparation, response, and recovery (Dierwechter 2010; Grannis 2011; Kahn 2009; Selin and VanDeveer 2007; Solecki and Rosenzweig 2012).

According to a recent survey of 298 U.S. local governments, 59 % indicated they are engaged in some form of adaptation planning (Carmin et al. 2012). Local adaptation planning and actions are unfolding in municipalities of varying sizes and in diverse geographical areas. Communities such as Keene, New Hampshire; New York City, New York; King County, Washington; and Chicago, Illinois are vanguards in the creation of climate adaptation strategies (Binder et al. 2010; Solecki and Rosenzweig 2012). These communities are now implementing their strategies—such as stormwater pipe replacement in Keene, green infrastructure installations in New York City, and green roofs in Chicago (Carter and Fowler 2008; Cruce 2009; Hamin and Gurran 2009; Kessler 2011; Rosenzweig et al. 2011a; Sussman 2009). Regional agencies and aggregations of governments are becoming significant climate adaptation actors (Table 4) (USGS 2012; Wallis 2011).

Tribal governments have also been active in assessing and preparing for the impacts of climate change. For example, adaptation planning in Point Hope, Alaska considered climate impacts and potential actions for issues such as community health (Brubaker et al. 2010). Their plan also noted that while many effects of climate change are negative, there could be positive effects as well, including new food resources and a longer season for securing potable water (ibid). In Newtok, Alaska, the village council is leading a land-acquisition and planning effort to relocate the community, because climate-induced coastal erosion has destroyed essential infrastructure, making the current village site unsafe (Bronen 2011). The Swinomish Indian Tribal Community in Washington State used video storytelling, the tribal newsletter, and alliances built with local organizations to identify and address locally relevant climate concerns (Lamb and Davis 2011; Swinomish Indian Tribal 2010; University of Oregon and USDA 2010). These efforts led to the integration of climate change into decision-making in major sectors of the Swinomish Community, such as education, fisheries, social services, and human health (Lamb and Davis 2011).

Additional examples of local and regional adaptation efforts are listed in Table 4.

There is no one-size-fits-all adaptation solution to the challenges of adapting to the impacts of climate change as solutions will differ depending on context and scale, as well as on the local culture and internal capacity (National Climate Adaptation Summit Committee 2010; Solecki and Rosenzweig 2012).

2.4 Nongovernmental and private sector

Many nongovernmental entities have been significant actors in the national effort to prepare for climate change by providing assistance that includes planning guidance, implementation tools, contextualized climate information, best practice exchange, and help with bridging the science–policy divide to a wide array of stakeholders (Agrawal 2008; Guston et al. 2000; van Aalst et al. 2008). The Nature Conservancy, for example, established the Canyonlands Research Center in Monticello, Utah to conduct research and develop conservation applications for resource issues in the Colorado Plateau region, focusing on forest-climate

Table 4 Examples of U.S. local/regional and tribal-level adaptation activities

Local/regional government	Adaptation action
Satellite Beach, FL	Collaboration with the Indian River Lagoon National Estuary Program led to the incorporation of sea level rise projections and policies into the city's comprehensive growth management plan (Gregg et al. 2011).
Portland, OR	Updated the city code to require on-site stormwater management for new development and re-development, and provides a downspout disconnection program to help promote on-site stormwater management (EPA 2010b).
Lewes, DE	In partnership with Delaware Sea Grant, ICLEI-Local Governments for Sustainability, the University of Delaware, and state and regional partners, the City of Lewes undertook a stakeholder-driven process to understand how climate adaptation could be integrated into the hazard mitigation planning process. Recommendations for integration and operational changes were adopted by the City Council and are currently being implemented (City of Lewes 2011).
Point Hope, AK	The village of Point Hope, AK created a plan that summarized the effect of climate change on several issues and identified observed changes, health concerns, projected changes, and potential adaptation actions to address each issue (Brubaker et al. 2010).
Groton, CT	Partnered with Federal, state, regional, local, nongovernmental, and academic partners through the EPA's Climate Ready Estuaries program to assess vulnerability to, and devise solutions for, sea level rise (Stults and Pagach 2011).
San Diego Bay, CA	Five municipalities partnered with the port, the airport, and more than 30 organizations with direct interests in the future of the Bay to develop the San Diego Bay Sea Level Rise Adaptation Strategy. The strategy identified key vulnerabilities for the Bay and adaptation actions that can be taken by individual agencies, as well as through regional collaboration (Solecki and Rosenzweig 2012).
Chicago, IL	Through a number of development projects, the city has added 55 acres of permeable surfaces since 2008 and has more than four million square feet of green roofs planned or completed (City of Chicago 2010).
Tulalip Tribes	The Tulalip Tribes in Washington State are using traditional knowledge gleaned from elders, stories, and songs and combining this knowledge with downscaled climate data to inform decision-making (Simmonds 2011).
King County, WA	Created King County Flood Control District in 2007 to address increased impacts from flooding through activities such as maintaining and repairing levees and revetments, acquiring repetitive loss properties, and improving countywide flood warnings (Wolf 2009).
New York City, NY	Through a partnership with the Federal Emergency Management Agency (FEMA), the city is updating FEMA Flood Insurance Rate Maps based on more precise elevation data. The new maps will help stakeholders better understand their current and future flood risks, and allow the city to more effectively plan for climate change (City of New York 2012).
Southeast Florida Climate Compact	Joint commitment among Broward, Miami-Dade, Palm Beach, and Monroe Counties to partner in reducing greenhouse gas emissions and adapting to climate impacts (Southeast Florida Compact 2011).
Haudenosaunee Confederacy	The Haudenosaunee Confederacy is addressing climate impacts by preserving a native food base through seed-banking (Simmonds 2011).
Phoenix, AZ; Boston, MA; Philadelphia, PA; and New York, NY	Climate change impacts are being integrated into public health planning and implementation activities that include creating more community cooling centers and neighborhood watch programs, and reducing the urban heat island effect (EPA 2011; Horton et al. 2012; White-Newsome et al. 2011).
Boulder, CO; New York, NY; and Seattle, WA	Water utilities in these communities are using climate information to assess vulnerability and inform decision-making (EPA 2010b).

Table 4 (continued)

Local/regional government	Adaptation action
Philadelphia, PA	In 2006, the Philadelphia Water Department began a program to develop a green stormwater infrastructure intended to convert more than one-third of the city's impervious land cover to "Greened Acres": green facilities, green streets, green open spaces, green homes, etc., along with stream corridor restoration and preservation (ORNL 2012b).

concerns such as woodland ecosystem restoration, invasive species, and effects of drought on pinyon-juniper woodlands (Vose et al. 2012). The Natural Resources Defense Council (NRDC) collaborated with the California Department of Public Health and Public Health Institute to publish the *Public Health Impacts of Climate Change in California: Community Vulnerability Assessments and Adaptation Strategies* report, which is being used to inform public health preparedness activities in the state (English et al. 2007; NRDC 2012). Table 5 provides examples of the broad types of adaptation efforts and services that nongovernmental actors are providing.

With regard to the private sector, evidence from organizations such as the Carbon Disclosure Project (CDP) and the Securities and Exchange Commission's Climate Change 10-K Disclosure indicate that a growing number of companies are beginning to actively address risks from climate change (CDP 2011). The World Business Council for Sustainable Development and the Center for Climate and Energy Solutions (C2ES) have identified three types of risks driving private sector adaptation efforts, including risks to: core operations, the value chain, and broader changes in the economy and infrastructure (Fig. 1) (PWC 2010; Sussman and Freed 2008; WBCSD 2009). This analysis is supported by responses to the

Table 5 Examples of U.S. nongovernmental adaptation efforts and services

Types of adaptation efforts and services	Examples of organizations providing services*
Adaptation planning assistance, including creation of guides, tools, and templates	Center for Climate Strategies, ICLEI-Local Governments for Sustainability, International Institute for Sustainable Development, The Nature Conservancy, World Resources Institute, World Wildlife Fund, Natural Resources Defense Council
Networking and best practice exchange	C40 Cities Climate Leadership Group, Adaptation Network, Center for Clean Air Policy, ICLEI-Local Governments for Sustainability, Institute for Sustainable Communities, Urban Sustainability Directors Network, World Business Council for Sustainable Development
Climate information providers	Union of Concerned Scientists, Urban Climate Change Research Network, Stockholm Environment Institute–U.S. Center
Policy, legal, and institutional support	Center for Climate and Energy Solutions (formerly Pew Center on Global Climate Change), Georgetown Climate Center
Aggregation of adaptation-pertinent information	Carbon Disclosure Project, Climate Adaptation Knowledge Exchange, Georgetown Climate Center

*This list contains examples of nongovernmental organizations providing the identified services and should not be considered all-inclusive or a validation of actions claimed by the organizations

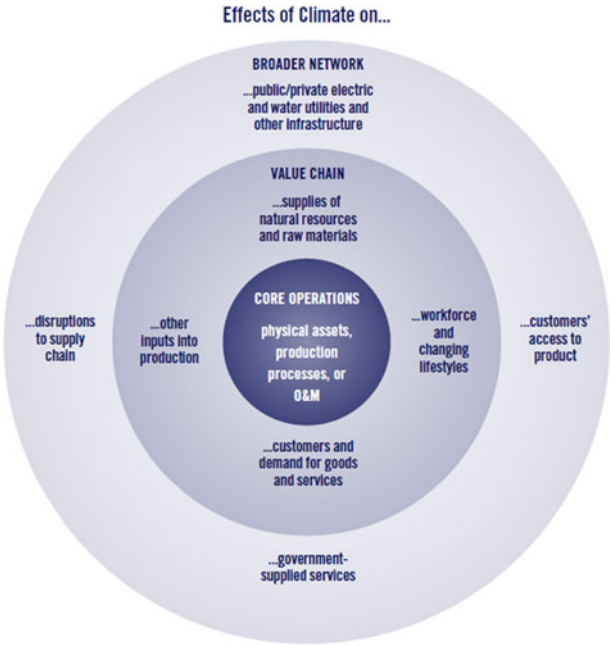

Fig. 1 "Risk Disk" depicts three pathways by which risks posed by climate change can affect business, such as through core operations; value chain; and broader changes in the economy and infrastructure. (Sussman and Freed 2008)

2011 CDP, and suggests that companies are concerned about how changes in climate will impact issues such as feedstock, water supply and quality, infrastructure, core operations, supply chain, and customers' ability to use (and their need for) services (CDP 2011). To address these risks, some companies are working to proactively avoid risk by minimizing the magnitude of impacts, diversifying the sources of risks, and spreading the burden of any future impact through a variety of strategies, including reallocation of financial risks such as through insurance and reinsurance (Table 6) (CDP 2011). For example, the insurance industry has started integrating climate considerations into their rate programs (Ojima et al. 2012) and requiring the insured to adapt to projected changes (McGraw-Hill Construction 2011), although efforts to date have been piecemeal (Culver et al. 2012; GAO 2007).

Some companies are taking action to not only avoid risk, but to explore potential opportunities embodied in a changing climate, such as developing new products and services; developing or expanding existing consulting services; expanding into new operational territories; extending growing seasons and hours of operation; and responding to the potential for increased demand for existing products and services (Agrawala et al. 2011; CDP 2011; Dell and Pasteris 2010; Oxfam America 2009; PWC 2010).

It is difficult to assess the degree to which the private sector is adapting, and whether such adaptations are sufficient to prepare for and minimize future risks from climate change. Many actions that may be spurred by climate change may not be correctly attributed either partially or wholly to climate change. Thus many actions that can be considered to be climate change adaptations by the private sector, such as supply chain diversification, may not be reported as such. Indeed, this may also be true of many public sector actions. Conversely, it is possible that companies (and governments) can claim they are making changes out of a professed concern for the environment or to prepare for climate change when other factors, particularly the cutting of costs or increasing of revenues, are the primary drivers of action.

Table 6 Examples of U.S. private sector actions to adapt to climate risks based on responses to carbon disclosure project

Company	Sector	Climate risk	Examples of actions undertaken
Coca-Cola Company	Consumer Staples	Changes in physical climate parameters; changes in other climate-related developments.	Coca-Cola is working around the world to replenish the water used in finished beverages by participating in locally relevant water projects that support communities and nature. Since 2005, the Coca-Cola system has engaged in more than 320 projects in 86 countries. The range of community projects includes watershed protection; expanding community drinking water and sanitation access; water for productive use, such as agricultural water efficiency; and education and awareness programs. (http://www.thecoca-colacompany.com/citizenship/conservation_partnership.html)
ConAgra Foods, Inc.	Consumer Staples	Company experienced weather-related sourcing challenges, such as delayed tomato harvesting due to unseasonably cool weather and difficulty sourcing other vegetables due to above-normal precipitation.	As part of its business continuity planning, ConAgra Foods has analyzed its supply risk to develop strategic partnerships with suppliers, minimize sole-sourced ingredients, and identify alternate suppliers and contract manufacturers to minimize production disruptions in case of an unexpected disruption in supply. (http://company.conagrafoods.com/phoenix.zhtml?c=202310&p=Policies_Environment)
Constellation Brands	Consumer Staples	Changes in physical climate parameters; changes in other climate-related developments.	Constellation has already taken adaptation actions, particularly in California, where water availability is an issue, to manage or adapt to these risks. Constellation is working with numerous organizations to help fund industry-based research to determine potential climate change impacts on vineyard production.
Munich Re	Reinsurance	Changes in regulation; changes in physical climate parameters; changes in other climate-related developments.	Since 2007, a group-wide climate change strategy covering all aspects of climate change—e.g., weather-related impacts, regulatory impacts, litigation and health risks, etc.—has supported their core corporate strategy. The strategy is based on five pillars: mitigation, adaptation, research, in-house carbon dioxide (CO_2) reduction, and advocacy. (http://www.munichre.com/en/group/focus/climate_change/default.aspx)
Pacific Gas and Electric Company (PG&E)	Utilities	Changes in regulation; changes in physical climate parameters; changes in other climate-related developments.	PG&E's adaptation strategies for potential increased electricity demand include expanded customer energy efficiency and demand response programs and improvements to its electric grid. PG&E is proactively tracking and evaluating the potential impacts of reductions to Sierra Nevada snowpack on its hydroelectric system, and has developed adaptation

Table 6 (continued)

Company	Sector	Climate risk	Examples of actions undertaken
			strategies to minimize them. Strategies include maintaining higher winter carryover reservoir storage levels, reducing conveyance flows in canals and flumes in response to an increased portion of precipitation falling as rain, and reducing discretionary reservoir water releases during the late spring and summer. PG&E is also working with both the U.S. Geological Survey (USGS) and the California Department of Water Resources to begin using the USGS Precipitation-Runoff Modeling System (PRMS) watershed model to help manage reservoirs on watersheds experiencing mountain snowpack loss. (http://www.pge.com/about/environment/commitment/)
SC Johnson & Son, Inc.	Household Products	Changes in physical climate parameters.	SC Johnson is adjusting, through a diversified supplier and global manufacturing base, to the various physical risks imposed by climate change. In March 2009, SC Johnson announced a broad ingredient communication program. The company assesses risks along each ingredient's supply chain to ensure that the company is sourcing from a geographically diverse supplier base. In addition to evaluating product ingredients, SC Johnson has also diversified its operations around the world, allowing it to maintain business continuity in the face of a regional climate-related disruption. (http://www.scjohnson.com/en/commitment/overview.aspx)
Spectra Energy, Inc.	Energy	Changes in regulation; changes in physical climate parameters; changes in other climate-related developments.	Spectra Energy uses a corporate-wide risk analysis framework to ensure the oversight and management of its four major risk categories: financial, strategic, operational, and legal. Physical risks posed by climate change fall within these categories, and the company uses risk management committees to ensure that all material risks are identified, evaluated, and managed prior to financial approvals of major projects. (http://www.spectraenergy.com/Sustainability/)

3 Adaptation process

General patterns in adaptation processes are only beginning to emerge, with similarities discernible across sectors, systems, and scales (Anguelovski and Carmin 2011; Dell and Pasteris 2010; Means et al. 2010). Figure 2 depicts a generalized and iterative adaptation

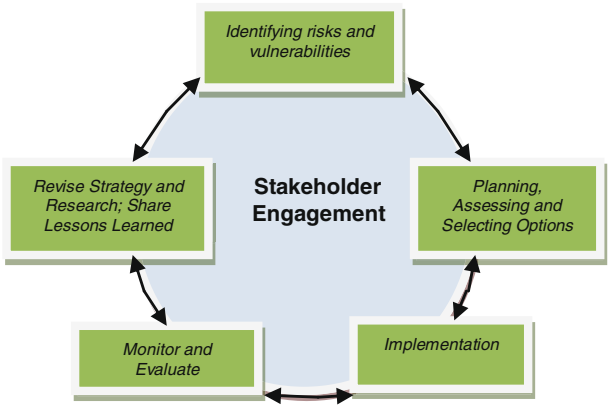

Fig. 2 Generalized adaptation process adapted from America's climate choices

process. This is not a step-wise or linear process, as various stages of the adaptation process can occur simultaneously or in an order different from that presented; some steps can be omitted completely. More detail about each phase in this process is provided below.

3.1 Identifying and understanding risk, vulnerabilities, and opportunities

Most adaptation actions are currently in the initial phase, with many actors focusing on identifying the relevant climate risks and conducting current and future risk and vulnerability assessments of their assets and resources (Carmin et al. 2012; Glick et al. 2011; Ingram et al. 2012; Lackstrom et al. 2012; NRC 2010a; Rowland et al. 2011; USGS 2012; West et al. 2009). In 2011, out of 298 U.S. municipalities surveyed, only 13% had completed vulnerability or risk assessments—but 42% expected to complete an assessment in the future (Carmin et al. 2012). At least 21 state fish and wildlife agencies are undertaking climate vulnerability assessments, or have recently completed an assessment of a particular species, habitat, or both (AFWA 2011).

Multiple qualitative and quantitative methods are used to understand climate vulnerability, including case studies and analogue analyses, scenario analyses, sensitivity analyses, peer information sharing, monitoring of key species, and information sharing among peers (Barrett et al. 2011; EPA 2011; Ford et al. 2010; Fussel 2007; Hulme and Dessai 2008; NPS 2010). Participatory research and "on the ground" efforts in places such as New York City, Boston, Flagstaff, Interior Alaska, and in the Swinomish Tribe demonstrate the importance of starting with the identification of existing vulnerabilities (City of Flagstaff 2012; Lamb and Davis 2011; McNeeley and Shulski 2011; Rosenzweig et al. 2011b). Relevant historical and future climate data are often then used to conduct a risk and/or vulnerability analysis; such efforts have been used in the water utility (Berry et al. 2011), land and ecosystems management (Glick et al. 2011; Heller and Zavaleta 2009; NPS 2010; USGS 2012), and government sectors (Pahl-Wostl et al. 2011; Wheeler 2008).

3.2 Planning, assessing, and selecting options

Once risks and vulnerabilities are understood, the next stage typically involves identifying, evaluating, and selecting options for response to existing and future changes in climate (NPS 2010). Decision support planning methods and associated tools help to identify flexible and

context-relevant adaptation activities for implementation (Means et al. 2010; NRC 2010a). Participatory approaches enable the design of adaptation processes with context-specific information (Fazey et al. 2010; Few et al. 2007; Preston et al. 2011; Smit and Wandel 2006), often by having community stakeholders and governing institutions work collectively to define the problem and identify adaptation strategies that are robust, while incorporating stakeholder values (Brunner 2005; Preston et al. 2011; Stern and Fineberg 1996; World Bank 2008). Moreover, regional collaboration has emerged in places such as San Francisco Bay, San Diego Bay, Southeast Florida, Chesapeake Bay, and the Intermountain West, where stakeholders are coming together to address issues of regional concern (e.g., sea level rise, water distribution, transportation systems). In this way they are defining common strategies to reduce potential threats, identifying metrics for tracking purposes, and often creating governance structures to help navigate political challenges (ICLEI 2012; Moser and Ekstrom 2010; Pyke et al. 2011; Southeast Florida Compact Counties 2011).

Common approaches to adaptation planning include "mainstreaming" or integrating climate adaptation into existing environmental, climate, or sustainability frameworks or sector-based plans (e.g., hazard mitigation, ecosystem conservation, water management, risk contingency planning, public health, environmental management, energy and national security) or developing standalone adaptation plans (ASTHO 2012; Culver et al. 2012; Horton et al. 2012; Lackstrom et al. 2012). Grand Rapids, Michigan; New York City, New York; and Keene, New Hampshire are examples of communities in which adaptation was integrated into broader climate, sustainability, and/or master plans (City of Grand Rapids 2011; City of Keene 2010; NYC 2011).

Activities underway in the Water Utility Climate Alliance (WUCA) and statewide coastal zone management offices are leading to the integration of future weather and climate considerations into water and coastal zone management planning (Culver et al. 2012; Means et al. 2010). The Navajo Nation; the City of Lewes, Delaware; and the State of Idaho have integrated climate adaptation concerns into their drought contingency, hazard mitigation, and State Wildlife Action planning processes, respectively (AFWA 2011; Delaware Sea Grant College Program et al. 2011; Navajo Nation Department of Water Resources 2003; USGS 2012). Additionally, a number of discrete adaptation plans, or plans with a focus on adaptation, have been released, such as the forthcoming *National Fish, Wildlife, and Plants Climate Adaptation Strategy* (National Fish, Wildlife, and Plants Climate Adaptation Strategy Partnership 2012); the City of Chicago Climate Adaptation Plan (City of Chicago 2008); and the *National Action Plan: Priorities for Managing Freshwater Resources in a Changing Climate* (CEQ 2011a).

The selection of options appropriate for building resilience to climate impacts depends on the socio-political and environmental context in which these decisions are made. Uncertainty about the timing and magnitude of climate change poses challenges to making such choices (NRC 2008), and many frameworks, tools, and approaches have emerged to help decision-makers make decisions in the face of this uncertainty (Kareiva 2008). Many of these, however, are specific to particular localities or resources, are not easy to use, and require sophisticated knowledge of climate change (Federspiel 2012; Hammill and Tanner 2011). In general, these approaches seek options that allow reversibility, preserve future options, can resist a variety of impacts, and are flexible, such that mid-course adjustments are possible (OTA 1993; Wilby and Vaughan 2011). Among these approaches are Robust Decision Making (RDM), Iterative Risk Management (IRM), Adaptive Management or Co-Management, Portfolio Management, and Scenario Planning (Gregg et al. 2011; Groves and Lempert 2006; Kareiva 2008; Lee 1993; Lempert et al. 2006; Moore et al. 2012; Moser 2012; NPS 2010; NRC 2004; Williams and Brown 2012).

3.3 Implementation

Because adaptation activities in the United States are relatively new, there is little peer-reviewed literature on adaptation actions or evaluation of their successes and failures (Ford et al. 2011; Ingram et al. 2012; Moser 2009; NRC 2010a). Much of the documentation that does exist is in "grey" literature, such as government reports and planning documents; agency "white" or background papers; and "expressions of interest" reports officially submitted as part of the upcoming NCA process. These documents indicate that adaptation actions are being implemented for a variety of reasons—often with an aim toward reducing current vulnerabilities to hazards or extreme weather events. For example, forest thinning and fuel treatments can reduce fire risks in national forests. Similarly, diversifying material sourcing in the private sector can reduce the risk of supply chain disruption (CDP 2011; Vose et al. 2012). Additionally, an increasing movement toward mainstreaming climate adaptation concerns into existing processes means that discerning unique climate adaptation activities will be a challenge (Dovers and Hezri 2010; Lackstrom et al. 2012). An example of local adaptation implementation is Seattle Public Utilities' RainWatch—an early warning precipitation forecasting tool used for drainage operations (CEQ 2011a) (more examples can be found in Fig. 3).

3.4 Monitoring and evaluation

There is little literature evaluating the effectiveness of adaptation actions (Means et al. 2010; Preston et al. 2011; Solecki and Rosenzweig 2012; Vose et al. 2012). Evaluation and monitoring efforts to date have focused on the creation of process-based rather than outcome-based indicators (Culver et al. 2012; Preston et al. 2011). The Forest Service Performance Scorecard (USDA, Forest Service) and the City of Portland Oregon and Multnomah County Climate Action Plan both use indicators to gauge progress in the planning and implementation of adaptation actions (Vose et al. 2012; City of Portland and Multnomah County 2009). Some adaptation indicators currently being tracked are the percentage of building permits issued in current and future FEMA coastal flood zones, trends of weather-related emergency/disaster losses, and the number of days with telecommunication outages related to weather (Jacob, et al. 2010).

In addition, a number of efforts are underway to create indicators related to climate adaptation (USCGRP, 2012). The National Climate Assessment Development Advisory Committee (NCADAC) Indicators Working Group is currently working to develop indicators that will aid in identifying effective climate adaptation and mitigation activities (Janetos et al. 2012). EPA is also working to develop indicators of resilience, specifically in the urban setting (EPA 2010a; Federspiel 2012). Both of these efforts anticipate the pilot testing of draft indicators in mid-2013.

3.5 Revise strategies/processes and information sharing

Uncertainty about the future climate, as well as about population growth, economic development, response strategies, and other social and demographic issues, can stymie climate adaptation activity (McCollum et al. 2011; Moore et al. 2012; USGS 2012). Through iterative processes, however, stakeholders can regularly evaluate the appropriateness of planned and implemented activities and revise them as new information becomes available (EPA 2011; NPS 2010; NRC, 2010a). Additionally, the sharing of best practices and lessons learned is crucial in advancing understanding and uptake of climate adaptation activity (Lackstrom et al. 2012; Preston et al. 2011).

Established information-sharing networks such as the World Business Council on Sustainable Development, ICLEI-Local Governments for Sustainability, WUCA, and regional climate initiatives are the types of networks that have supported stakeholder adaptation activity to date (Means et al. 2010; WBCSD 2009). Facilitating and encouraging networking will be instrumental in ensuring that lessons learned and best practices are shared in a manner that will foster the scaling up of climate adaptation activity.

The following map and table highlight some adaptation activities taking place in different geographical regions and scales in the United States (Fig. 3). The map is not intended to be a comprehensive compilation of adaptation activities throughout the country, but is illustrative of the types of activities taking place.

Adaptation Activity

1. The State of Hawaii Office of Planning, in cooperation with university, private, state, and Federal scientists and others, has drafted a framework for climate change adaptation that identifies sectors affected by climate change, and outlines a process for coordinated statewide adaptation planning. (Adapting to Climate Change: A Planning Guide for State Coastal Managers, NOAA (NOAA 2012), (http://coastalmanagement.noaa.gov/climate/docs/adaptationguide.pdf)
2. One of the priorities of the Hawaii State Plan is preserving water sources through conservation of the forests, as indicated in their "Rain Follows The Forest" report. (http://hawaii.gov/dlnr/chair/pio/nr/2011/The-Rain-Follows-the-Forest.pdf)
3. New England Federal Partners is a multi-agency group formed to support the needs of the states, tribes, and communities of the New England Region and to facilitate and enable informed decision-making on issues pertaining to coastal and marine spatial planning, climate mitigation, and climate adaptation throughout the region. (http://www.epa.gov/region1/eco/energy/adaptation-efforts-epane.html)
4. The City of Philadelphia is greening their combined sewer infrastructure to protect rivers, reduce greenhouse gas emissions, improve air quality, and enhance adaptation to a changing climate (http://www.phillywatersheds.org/ltcpu/)
5. The City of Keene, NH replaced culverts with larger ones that were designed to withstand projected increases in precipitation and population demand. (City of Keene 2010) (http://www.ci.keene.nh.us/sites/default/files/CMPprint-final-1027-fullversion_2.pdf)
6. New York City has created a Green Infrastructure Plan and is committed to goals that include the construction of enough green infrastructure throughout the city to manage 10 % of the runoff from impervious surfaces by 2030. (http://www.nyc.gov/html/dep/html/stormwater/nyc_green_infrastructure_plan.shtml)
7. The City of Lewes, DE undertook an intensive stakeholder process to integrate climate change into the city's updated hazard mitigation plan. (http://www.ci.lewes.de.us/Hazard-Mitigation-Climate-Adaptation-Action-Plan/)
8. Local governments and tribes throughout Alaska, such as those in Homer, are planting native vegetation and changing the coastal surface, moving inland or away from rivers, and building riprap walls, groins, or seawalls. (http://www.cakex.org/virtual-library/2555)
9. Villages are physically being relocated because of climate impacts such as sea level rise and erosion; these include Newtok, Shishmaref, Kivalina, and dozens of other villages. (http://www.commerce.state.ak.us/dca/planning/npg/Newtok_Planning_Group.htm)
10. The City of Cedar Falls recently passed legislation that includes a new floodplain ordinance that expands zoning restrictions from the 100-year floodplain to the 500-year floodplain, because this expanded floodplain zone better reflects the flood risks experienced by the city during the 2008 floods. (http://www.epa.gov/dced/pdf/iowa_climate_adaptation_report.pdf)
11. In January 2011, the Michigan Department of Community Health (MDCH) released the *Michigan Climate and Health Adaptation Plan*, which has a goal of "preparing the Public Health System in Michigan to address the public health consequences of climate change in a coordinated manner." In September 2010, MDCH received 3 years' funding to implement this plan as part of the Climate-Ready States and Cities Initiative of CDC. (http://www.michigan.gov/documents/mdch/MDCH_climate_change_strategicPlan_final_1-24-2011__343856_7.pdf)

12. The City of Chicago was one of the first cities to officially integrate climate adaptation into a citywide Climate Adaptation Plan. Since its release, a number of strategies have been implemented to help the city manage heat, protect forests, and enhance green design, such as their work on green roofs. (http://www.chicagoclimateaction.org/pages/adaptation/11.php)
13. The City of Grand Rapids, MI recently released a Sustainability Plan that integrates future climate projections to ensure that the economic, environmental, and social strategies embraced are appropriate for today as well as the future. (http://grcity.us/enterprise-services/officeofenergyandsustainability/Pages/default.aspx/)
14. Tulsa, OK has a three-pronged approach to reducing flooding and managing stormwater: (1) prevent new problems by looking ahead and avoiding future downstream problems from new development (e.g., requiring on-site stormwater detention); (2) correct existing problems and learn from disasters to reduce future disasters (e.g., through watershed management and the acquisition and relocation of buildings in flood-prone areas); and (3) act to enhance the safety, environment, and quality of life of the community through public awareness, an increase in stormwater quality, and emergency management. (http://www.smartcommunities.ncat.org/articles/rooftop/program.shtml)
15. Firewise Communities USA is a nationwide program of the National Fire Protection Association and is co-sponsored by USDA Forest Service, DOI, and the National Association of State Foresters. According to the Texas Forest Service, there are more than 20 recognized Texas Firewise Communities. The Texas Forest Service works closely with communities to help them to reach Firewise Community status and offers a variety of awareness, educational, informational, and capacity-building efforts, such as *Texas Wildscapes*, a program that assists in choosing less fire-friendly plants. (http://texasforestservice.tamu.edu/main/article.aspx?id=1602)
16. After the heavy rainfall events of 2004 that resulted in significant erosion on his farms, Dan Gillespie, a farmer with NRCS in Norfolk, NE, began experimenting with adding cover crops to the no-till process. It worked so well in reducing erosion and increasing crop yields that he is now sharing his experience with other farmers (http://www.lenrd.org/projects-programs/; http://www.notill.org/; personal communication, L Carter, June 1, 2012)
17. Point Reyes National Seashore is preparing for climate change by creating a more resilient ecosystem through restoring connectivity of fresh and salt-water ecosystems for anadromous fish passage by removing two dams that are barriers to water flow and fish migration, thus restoring ecological continuity. (http://www.cakex.org/case-studies/1083)
18. Western Adaptation Alliance is a group of 10 cities in four states in the Intermountain West that share lessons learned in adaptation planning, develop strategic thinking that can be applied to specific community plans, and join together to generate funds to support capacity building, adaptation planning, and vulnerability assessment. (http://sustainablecommunitiesleadershipacademy.org/workshops/regional-western-adaptation-alliance)
19. Navajo Nation used information on likely changes in future climate to help inform their drought contingency plan. (Navajo Nation Department of Water Resources 2003) (http://www.frontiernet.net/~nndwr_wmb/PDF/drought/drghtcon_plan2003_final.pdf)
20. California Department of Health and the Natural Resources Defense Council collaborated to create the *Public Health Impacts of Climate Change in California: Community Vulnerability Assessment and Adaptation Strategies* report, which is being used to inform public health preparedness activities in the State. (http://www.ehib.org/papers/Heat_Vulnerability_2007.pdf) (English et al. 2007)
21. State of Idaho successfully integrated climate adaptation into the State's Wildlife Management Plan. (USGS 2012) (http://fishandgame.idaho.gov/public/wildlife/cwcs/)
22. The Rising Tides Competition was held in 2009 by the San Francisco Bay Conservation and Development Commission to elicit ideas for how the Bay could respond to sea level rise. (http://www.risingtidescompetition.com/risingtides/Home.html)
23. The Olympic National Forest and Olympic National Park were sites of case studies looking at how to adapt management of Federal lands to climate change. Sensitivity assessments, review of management activities and constraints, and adaptation workshops in the areas of hydrology and roads, fish, vegetation, and wildlife were all components of the case study process. (http://www.fs.fed.us/pnw/pubs/pnw_gtr844.pdf)
24. King County Flood Control District was reformed to merge multiple flood management zones into a single county entity for funding and policy oversight for projects and programs—partly in anticipation of increased stormwater flows due to climate change. (http://www.nerrs.noaa.gov/doc/pdf/training/strategies_king_county.pdf)
25. The Water Utilities Climate Alliance has been working with member water utilities to ensure that future weather and climate considerations are integrated into short- and long-term water management planning. (Culver et al. 2012) (http://www.wucaonline.org/html/)

26. Seattle's RainWatch program uses an early warning precipitation forecasting tool to help inform decisions about issues such as drainage operations. (CEQ 2011a) (http://www.atmos.washington.edu/SPU/)
27. City of Portland and Multnomah County created a Climate Action Plan that includes indicators to help them gauge progress in planning and implementing adaptation actions. (City of Portland and Multnomah County 2009) (http://www.portlandoregon.gov/bps/article/268612)
28. In 2010, the State of Louisiana launched a $10 million program to assist communities that had been impacted by Hurricanes Gustav and Ike in becoming more resilient to future environmental problems. 29 communities from around the State were awarded resiliency development funds. The Coastal Sustainability Studio at Louisiana State University started working in 2012 with all 29 funded communities, as well as many that did not receive funds, to develop peer-learning networks, develop best practices, build capacity to implement plans, and develop planning tools and a user-inspired and useful website to increase community resiliency in the State. (http://lra.louisiana.gov/index.cfm?md=newsroom&tmp=detail&articleID=608 and http://resiliency.lsu.edu/)
29. FWS and The Nature Conservancy are cooperating in a pilot adaptation project to address erosion and salt water intrusion, among other issues, in the Alligator River Refuge. This project incorporates multiple agencies, native knowledge, community involvement, local economics, and technical precision. (http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/northcarolina/afield-spring-2011.pdf)
30. North and South Carolina are actively working to revise their state wildlife strategies to include climate adaptation. (Lackstrom et al. 2012)
31. The Southeast Florida Climate Compact is a collaboration of the four southernmost counties in Florida (Monroe, Broward, Palm Springs, and Miami-Dade) focusing on enhancing regional resilience to climate change and reducing regional greenhouse gas emissions. (Southeast Florida Compact 2011) (http://www.southeastfloridaclimatecompact.org/documents/DraftRCAP.pdf)

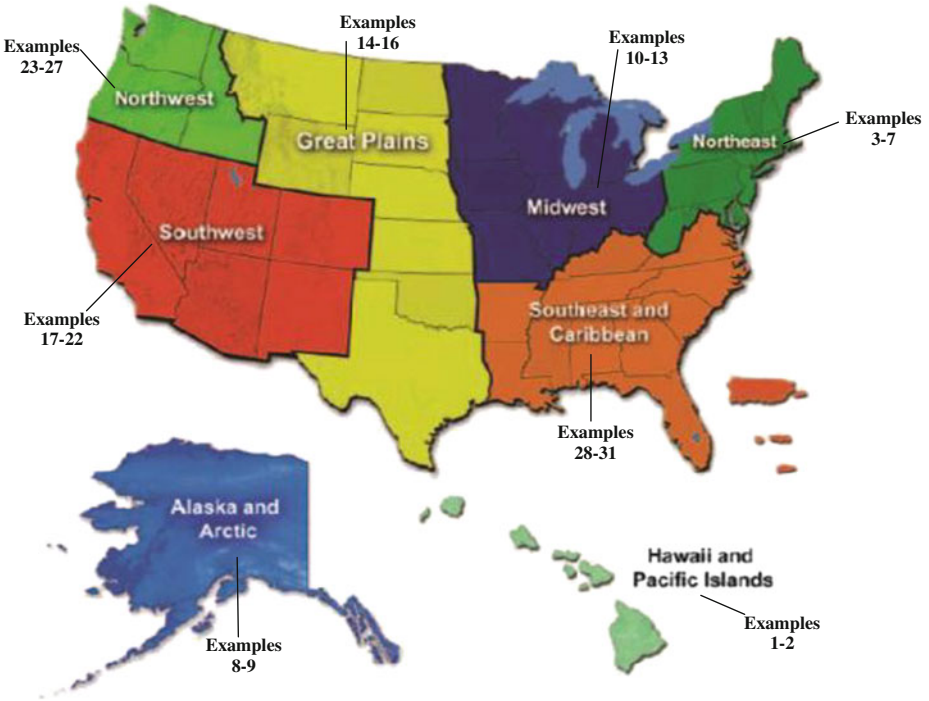

Fig. 3 Illustrations of adaptation activities overlaid on geographical regions of the upcoming 2013 U.S. National Climate Assessment

4 Barriers to adaptation

Despite emerging recognition of the necessity of climate change adaptation, many barriers still impede efforts to build local, regional, and national-level resilience. Barriers are obstacles that can delay, divert, or temporarily block the adaptation process (Ekstrom et al. 2011), and include difficulties in using climate change projections for decision-making; lack of resources to begin and sustain adaptation efforts; fragmentation of decision-making; institutional constraints; lack of leadership; and divergent risk perceptions/cultures and values (Table 7). Additionally, an array of barriers, such as uncertainty about future costs and benefits, high costs of action, and institutional constraints, are impeding transformational adaptations, which may be necessary for long-term adaptation (Kates et al. 2012). The barriers described here are distinguished from physical or ecological limits to adaptation, such as physiological tolerance of species to changing climatic conditions that cannot be overcome (except with technology or some other physical intervention) (Adger et al. 2007; Gregg et al. 2011; McIlgorm et al. 2010; USGS 2012).

Table 7 Summary of adaptation barriers

Barrier	Specific examples	References
Climate change information and decision- making	Uncertainty about future climate impacts	NRC 2010b; National Climate Adaptation Summit Committee 2010; Hauser and Jadin 2012; NRC National Research Council 2010a; Dilling and Lemos 2011; Barsugli et al. 2012; NRC 2007; OTA 1993; Vose et al. 2012; Horton et al. 2012; Culver et al. 2012; Winkler et al. 2012; McCollum et al. 2011; Lackstrom et al. 2012; Brunner and Nordgren 2012; USGS 2012; Lebow et al. 2012; Needham et al. 2012; Mitchell 2010; White-Newsome et al. 2011; Larsen et al. 2011; Fowler and Wilby 2007; Kerr 2011; Schramm 2012; Marra et al. 2012; Carmin et al. 2012; Kareiva 2008; USGS 2012; McNie 2007
	Disconnect between information providers and information users	
	Fragmented, complex, and often confusing information	
	Lack of climate education for professionals and the public	
	Lack of usability and accessibility of existing information	
Lack of resources to begin and sustain adaptation efforts	Lack of financial resources	Brugger and Crimmins 2011; Needham et al. 2012; Schramm 2012; Marra et al. 2012; Simmonds 2011; Carmin et al. 2012; Gregg et al. 2011; Ingram et al. 2012; Lackstrom et al. 2012; Brunner and Nordgren 2012; Garfin et al. 2012; Mittal 2009; USGS 2012
	Limited staffing capacity	
Fragmentation of decision- making	Lack of coordination within and across agencies, private companies, and nongovernmental organizations	Winkler et al. 2012; Simmonds 2011; Lebow et al. 2012; Horton et al. 2012; National Climate Adaptation Summit Committee 2010; USGS 2012; NRC 2009; OTA 1993; Clark and Levin 2010

Table 7 (continued)

Barrier	Specific examples	References
	Uncoordinated and fragmented research efforts	
	Disjointed climate-related information	
	Fragmented ecosystem and jurisdictional boundaries	
Institutional constraints	Lack of institutional flexibility	Nelson et al. 2007; Lee 1993; Folke 2006; NRC 2004; Garfin et al. 2012; Adger et al. 2009; McNeeley 2012; Brugger and Crimmins 2011; Simmonds 2011; USGS 2012; Marra et al. 2012; NRC 2010a; Gregg et al. 2011; CDP 2011; Vose et al. 2012; Moser and Ekstrom 2012; Carpenter and Brock 2008; Craig 2008
	Rigid laws and regulations	
	No legal mandate to act	
	Use of historical data to inform future decisions	
	Restrictive management procedures	
	Lack of operational control or influence	
Lack of Leadership	Lack of political leadership	Moser 2012b; Smith et al. 2009; Brugger and Crimmins 2011; Schramm 2012; Smith et al. 2010; Ding et al. 2011; Leiserowitz et al. 2012; Moser and Ekstrom 2012
	Rigid and entrenched political structures	
	Polarization	
Divergent risk perceptions, cultures, and values	Conflicting values/risk perceptions	Verweij et al. 2006; Kahan et al. 2007; Kahan et al. 2011; Adger et al. 2009; Renn 2011; van Aalst et al. 2008; Doria et al. 2009; Renn et al. 2011; Lackstrom et al. 2012; Leiserowitz 2006; McNeeley 2012; Simmonds 2011; NRC 2009; Ding et al. 2011; Gifford 2011; Weber and Stern 2011
	Little integration of local knowledge, context, and needs with traditional scientific information	
	Cultural taboos and conflict with cultural beliefs	
	Resistance to change due to issues such as risk perception	

4.1 Climate change information and decision-making

Uncertainty about how the climate will change (not whether it will change), combined with complicated data sets on climate, diffuse sources of information on adaptation, and the difficulty of making decisions in light of uncertainty, are often barriers to adaptation decision-making (Hauser and Jadin 2012; Kareiva 2008; National Climate Adaptation Summit Committee 2010; NRC, 2010a, b; Kerr 2011). Examples of information that would

help to inform decision-making, but currently do not exist or are difficult to obtain or assemble, include:

- **Projections:** Regular and updated projections of climate change and impacts at appropriate spatial and temporal scales to inform planning horizons (Barsugli et al. 2012);
- **Options:** Portfolios of adaptation options that can help to build adaptive capacity and resilience despite remaining uncertainties (Kareiva 2008);
- **Cost, Benefit, and Effectiveness Analysis:** Detail on the relative costs, benefits, and effectiveness of sustainable adaptation options—including, in some cases, no action;
- **Adaptive Capacity:** Information on how enhancing adaptive capacity can address multiple other stresses, such as pollution and habitat fragmentation (IPCC 2007; NRC National Research Council 2007; OTA 1993; USGCRP 2009);
- **Adaptation–Mitigation Interface:** Information on how choices for adaptation options may interact with mitigation actions;
- **Limits:** Limits to adaptation (Adger et al. 2009); and
- **Metrics of Success:** An evaluation framework with supporting metrics to gauge adaptation success or failure (Culver et al. 2012; Horton et al. 2012; McCollum et al. 2011; USCGRP, 2012; USGS 2012; Vose et al. 2012; Winkler et al. 2012).

An important aspect of the first item (projections) is the lack of knowledge among stakeholders about where to find scientifically sound information that can be translated into understandable and useful formats to support communication and policy-making (Brunner and Nordgren 2012; Hauser and Jadin 2012; Lackstrom et al. 2012; Lebow et al. 2012; Lemos and Rood 2010; McNie 2007; Mitchell 2010; Needham et al. 2012).

The inability to access information and apply it in the right context can also be a significant hurdle (National Climate Adaptation Summit Committee 2010; Needham et al. 2012; NRC, 2010b). The complex nature of the climate system, combined with uncertainty about future climate impacts, is often a stumbling block to effective communication of climate risks, adaptation needs, and decision-making on climate change adaptation (Fowler and Wilby 2007; Kerr 2011; Larsen et al. 2011; White-Newsome et al. 2011). Many professionals working in public health, engineering, planning, and natural resource management are not formally trained on climate change, which limits their ability to communicate about and use climate information in decision-making (ASTHO 2012; Carmin et al. 2012; Marra et al. 2012; National Climate Adaptation Summit Committee 2010; NRC, 2010b; Schramm 2012). Similarly, many scientists do not conduct research to answer questions posed by users of climate information (Dilling and Lemos 2011; McNie 2007). Decision-makers and scientists must collaborate to ensure that timely answers can be found to key adaptation questions.

4.2 Lack of resources to begin and sustain adaptation efforts

Many stakeholders lack the financial resources and staff to successfully identify, implement, monitor, and maintain adaptation efforts (Brugger and Crimmins 2011; Carmin et al. 2012; Marra et al. 2012; Needham et al. 2012; Schramm 2012; Simmonds 2011). Very few resource managers, municipalities, states, and regional councils of governments have dedicated funds for adaptation; the funding that is available is often a one-time influx of capital rather than a sustained source of revenue (e.g., the American Recovery and Reinvestment Act and the Partnership for Sustainable Communities program administered jointly by HUD, DOT, and EPA) (Carmin et al. 2012; Ingram et al. 2012; Lackstrom et al. 2012).

The lack of comprehensive, coordinated, and sustained multi-year funding continues to impede stakeholders' ability to advance climate adaptation planning, implementation, and evaluation (Brunner and Nordgren 2012; Garfin et al. 2012; Mittal 2009). Without additional funding, current budgetary constraints and competing priorities will continue to be significant barriers to adaptation activity (Gregg et al. 2011; Needham et al. 2012; USGS 2012).

4.3 Fragmentation of decision-making

Many government agencies and businesses may have some responsibility for a given resource, with different regulations and incentives motivating its management and use. Adaptations to climate change are being inhibited by fragmentation of responsibilities; a lack of coordination at the federal, private, and nongovernmental levels; and the proliferation of often duplicative and sometimes contradictory adaptation data, tools, and resources (Horton et al. 2012; Lebow et al. 2012; National Climate Adaptation Summit Committee 2010; Simmonds 2011; Winkler et al. 2012). Fragmentation of jurisdictional control is also a critical barrier to building the resilience of systems that cross jurisdictional boundaries (e.g., transportation systems, ecosystems) (NRC 2009; OTA 1993; USGS 2012).

Beyond the policy environment, fragmentation among research efforts and data production from the physical and social sciences (Clark and Levin 2010) has led to many stakeholders feeling overwhelmed by the amount and complexity of available information (Horton et al. 2012).

4.4 Institutional constraints

Preparing for climate change requires flexible systems and approaches, such as adaptive management, (Folke 2006; Lee 1993; Nelson et al. 2007; NRC 2004). However, many existing institutional structures, such as accepted rules for water infrastructure planning, inherently lack the flexibility to allow for effective responses to a dynamic and changing climate (Adger et al. 2009; Garfin et al. 2012; McNeeley 2012). Existing regulations and laws often have rigid structures, or are based on principles of a non-changing climate (stationarity) that can inhibit the use of flexible strategies needed to prepare for climate change (Brugger and Crimmins 2011; Garfin et al. 2012; Simmonds 2011; USGS 2012). This includes the lack of clear, legal mandates to consider climate conditions and impacts when making decisions (Gregg et al. 2011; Marra et al. 2012; NRC, 2010a). Restrictive management procedures in systems such as biodiversity conservation and emergency management can also prevent the advancement of adaptation activity (USGS 2012). Other barriers to current adaptation efforts stem from past decisions, institutions, or infrastructure (Carpenter and Brock 2008; Moser and Ekstrom 2012).

A lack of influence, legal or management authority, or operational control over systems and sectors likely to be vulnerable to climate change can also impede action and inhibit responsiveness (CDP 2011; Craig 2008; Vose et al. 2012). For example, a frequently flooded road within a municipality may be under state or federal control, which limits the local community's ability to implement adaptation actions. This is also the case when a river or stream is under state authority, but cuts through private, tribal, or Federal lands.

4.5 Lack of leadership or champions

Strong political leadership and the creation of champions for adaptation are frequently noted as a reason that many adaptation efforts have been successful (Moser and Ekstrom 2012;

Smith et al. 2009). A lack of political leadership and entrenched political structures, however, can be barriers to advancing resilience-building approaches (Brugger and Crimmins 2011; Schramm 2012). Adaptation processes and policies adopted through Executive Order by one Administration but not incorporated into legislation can be reversed by successors (Smith et al. 2010). Moreover, even as the scientific evidence for climate change becomes more robust and certain, evidence from public polls on climate change indicate political polarization (Ding et al. 2011; Leiserowitz et al. 2012).

4.6 Divergent risk perceptions, cultures, and values

Because of different and sometimes conflicting individual and group cultures, values, and experiences, there are many divergent perceptions about the risk of climate change impacts (Kahan et al. 2007; Leiserowitz 2006; Verweij et al. 2006). This can lead to polarization and gridlock surrounding decisions about how to prepare for long-term climate variability and change. Some think climate adaptation and mitigation are top priorities, and others do not (Adger et al. 2009; Kahan et al. 2011; Renn 2011). It is critical to move beyond this gridlock and create collaborative and inclusive processes for implementing climate adaptation (Doria et al. 2009; Renn et al. 2011; van Aalst et al. 2008; Verweij et al. 2006). Currently, a dearth of experience integrating local knowledge and needs with traditional scientific information has impeded adaptation activity and capacity building in many parts of the nation (Lackstrom et al. 2012; McNeeley 2012). Cultural taboos, resistance to change, and psychological barriers are also be impediments to climate action (Ding et al. 2011; Gifford 2011; NRC 2009; Simmonds 2011; Weber and Stern 2011).

5 Overcoming barriers

A number of actors across sectors and regions are organizing to collectively overcome barriers and adapt to climate change. This section profiles four examples of adaptation in the Colorado River Basin, in the Northwoods of Wisconsin, on Cape Cod Massachusetts, and through the National Integrated Drought Information System (NIDIS). These examples were selected because of their explicit attempts to lessen or overcome the barriers presented in the previous section and their ability to bridge multiple spatial and temporal scales.

5.1 Illustrative case one: adaptive governance in the Colorado River Basin

The Colorado River supplies water and valuable ecosystem services to 33 million people, and is highly vulnerable to climate change because of decreases in mountain snowpack and water availability, increased competition among water users, fires, drought, invasive species, and extended extreme heat events, among other threats (Cayan et al. 2010; Christensen and Lettenmaier 2007; Garfin et al. 2012; Hidalgo et al. 2009; Pierce et al. 2008; Seager and Vecchi 2010). The 1922 Colorado River Compact, which allocates water among seven U.S. states and Mexico, was agreed upon in a particularly wet time period (Gray et al. 2011; Woodhouse et al. 2006); thus the river water is already over-allocated for current conditions. Given the likelihood of having less water because of climate change, resource managers and government leaders are increasingly recognizing that water must be managed with flexibility to respond to the projected impacts and the range of possible future climates (Brown 2010; Garfin et al. 2012). Multiple actors across all scales of governance (i.e., tribal, local, state, federal), nongovernmental

organizations, and the private sector are organizing and working together to address these concerns and the relation between climate and other stresses in the basin.

The Western Governors' Association (WGA) spearheaded adaptation efforts to enable Federal, state, tribal, local, and private sector partners to address a range of issues, including climate change (WGA 2006; 2008; 2010). For example, the Western Federal Agency Support Team (WestFAST), which was established in 2008, created a partnership between the Western States Water Council (WSWC) and 11 Federal agencies with water management responsibilities in the western United States. The agencies created a work plan in 2011 to address three key areas: (1) climate change; (2) water availability, water use, and water reuse; and (3) water quality. To date they have produced the WestFAST Water-Climate Change Program Inventory, the Federal Agency Summary, and a Water Availability Studies Inventory (http://www.westgov.org/wswc/WestFAST.htm).

The WSWC and the USACE produced the Western States Watershed Study (WSWS), which demonstrated how Federal agencies could work collaboratively with western states on planning activities (USACE 2009). In 2009, the WGA also adopted a policy resolution titled "Supporting the Integration of Climate Change Adaptation Science in the West" that created a Climate Adaptation Work Group composed of western state experts in air quality, forest management, water resources, and wildlife management. Other important adaptation actions were the SECURE Water Act in 2009, the Reclamation Colorado River Basin water supply and demand study, and the creation of NIDIS to support stakeholders in coping with drought (Hayes and Pulwarty 2012 [in press]; Reclamation 2011a, b).

5.2 Illustrative case two: climate change adaptation in forests

Northern Wisconsin's climate has warmed over the past 50 years, and windstorms, wildfires, insect outbreaks, and floods are projected to become more frequent in this century (Swanston et al. 2011). The resulting impacts on forests, combined with fragmented and complex forest ownership, create management challenges that extend across ownership boundaries, creating the need for a multi-stakeholder planning process (Joyce et al. 2009; Miles 2010; WDNR 2009; 2010).

To address these concerns, the Northern Institute of Applied Climate Science, the USDA's Forest Service, and many other partners initiated the Climate Change Response Framework to incorporate scientific research on climate change impacts into on-the-ground management. Originally developed as a pilot project for all-lands conservation in northern Wisconsin, it has expanded to cover three ecological regions [Northwoods (Fig. 4), Central Hardwoods, and Central Appalachians] across eight states in the Midwest and Northeast. The Framework uses a collaborative and iterative approach to provide information and resources to forest owners and managers across a variety of private and public organizations. Several products were developed through the Framework in northern Wisconsin:

1. Vulnerability and mitigation assessments summarized the observed and projected changes in the northern Wisconsin climate; projected changes in forest composition and carbon stocks across a range of potential climates; and assessed related vulnerabilities of forest ecosystems in northern Wisconsin (Swanston et al. 2011).
2. *Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers* (Swanston and Janowiak 2012) was developed to help managers identify management tactics that facilitate adaptation. A "menu" of adaptation strategies and approaches for planning, implementing, and monitoring adaptation activities was synthesized into an adaptation workbook from a broad set of literature, and refined based on feedback from regional scientists and managers (Butler et al. 2011; Janowiak et al. 2012).

Fig. 4 Northwoods climate change response framework region

3. A series of adaptation demonstrations was initiated to showcase ground-level implementation. The Framework and adaptation workbook provide a common process shared by diverse landowners, and a formal network that supports cross-boundary discussion about different management objectives, ecosystems, and associated adaptation tactics.

From the beginning, the Framework has taken an adaptive management approach in its adaptation planning and projects. Lessons learned include:

- Define the purpose and scope of the Framework and its components early, but allow for refinement to take advantage of new opportunities;
- Begin projects with a synthesis of existing information to avoid duplicating efforts;
- Plan for the extra time necessary to implement true collaboration;
- Carefully match the skills, commitment, and capacity of people and organizations to project tasks;
- Maintain an atmosphere of trust, positivity, and sense of adventure, rather than dwelling on failures;
- Acknowledge and work with uncertainty, rather than submit to "uncertainty paralysis";
- Recognize the necessity of effective communication among people with different goals, disciplinary backgrounds, vocabulary, and perspectives on uncertainty;
- Integrate the ecological and socioeconomic dimensions early by emphasizing the many ways that communities value and depend on forests; and
- Use technology to increase efficiency of internal communication and collaboration, as well as outreach.

The Framework brings scientists and land managers together to assess the vulnerability of ecosystems based on scientific information and experience in order to plan adaptation actions that meet management goals. On-the-ground implementation has just begun, and an increased focus on demonstrations, monitoring, and evaluation will inform future adaptation efforts.

5.3 Illustrative case three: transportation, land use, and climate change: integrating climate adaptation and mitigation in Cape Cod, Massachusetts

Cape Cod, Massachusetts, a region of scenic beauty and environmental significance, is currently affected by sea level rise, coastal erosion, and localized flooding—impacts that are likely to be exacerbated by climate change (Volpe National Transportation Systems 2011a;

b). To address these concerns and help meet the state's greenhouse gas (GHG) reduction target (25% reduction based on 1990 levels by 2020), the DOT's Volpe Center worked with Federal, regional, state, and local stakeholders to integrate climate change into existing and future transportation, land use, coastal zone, and hazard mitigation planning through an initiative called the Transportation, Land Use, and Climate Change Pilot Project (Commonwealth of Massachusetts 2004; Volpe National Transportation Systems Center 2011a).

The process was initiated through an expert elicitation held in mid-2010 to identify areas on Cape Cod that are or could potentially be vulnerable to sea level rise, flooding, and erosion. The Volpe Center then used a geographic information system (GIS) software tool to develop and evaluate a series of transportation and land use scenarios for the Cape under future development projections (Esri 2011; Volpe National Transportation Systems Center 2011b). All scenarios were evaluated against a series of criteria that included: (1) reduction in vehicle miles traveled (VMT); (2) reduced GHG emissions; (3) reduction in transportation energy use; (4) preservation of natural/existing ecosystems; (5) reduction in percentage of new population in areas identified as vulnerable to climate change impacts; and (6) increased regional accessibility to transportation (Volpe National Transportation Systems 2011a).

Once the preliminary scenarios were developed, a workshop was convened in which community and transportation planners, environmental managers, and Cape Cod National Seashore stakeholders selected areas for new development and transit improvements to accommodate new growth, while meeting the goals of reduced GHG emissions, increased resilience to climate change, and the conservation of natural systems (Volpe National Transportation Systems 2011b). Through interactive visualization tools, participants were able to see, in real time, the impacts of their siting decisions, allowing them to evaluate synergies and potential tradeoffs of their choices and to highlight areas where conflict could or already does exist, such as density enhancement in areas already or likely to be vulnerable to climate change (APA 2011). As a result, the stakeholders developed a refined transportation and land use scenario that will support the region's long-range transportation planning, as well as other local, regional, and state plans.

This updated scenario identifies strategies that have climate adaptation and mitigation value, helping to ensure that the region simultaneously reduces its GHG footprint while building resilience to existing and future changes in climate (Volpe National Transportation Systems 2011a; b). The overall success of the pilot project stemmed from the intensive stakeholder interaction at each phase of the project (design, implementation, and evaluation).

5.4 Illustrative case four: the national integrated drought information system

NIDIS (National Integrated Drought Information System), originally proposed by the WGA and established by Congress in 2006 (Public Law 109–4003) (Hayes and Pulwarty 2012 [in press]), is a Federally created entity that improves the nation's capacity to proactively manage drought-related risks across sectors, regions, and jurisdictions. It was created by Congress to "enable the Nation to move from a reactive to a more proactive approach to managing drought risks and impacts." NIDIS has successfully brought together government partners and research organizations to advance a warning system for drought-sensitive areas.

The creation of NIDIS involved many years of development and coordination among federal, state, local, regional, and tribal partners, with the help of Governors' associations and Senate and congressional leaders. NIDIS provides: (1) drought early warning information systems with regional detail concerning onset and severity; (2) a web-based portal (www.drought.gov); (3) coordination of federal research in support of and use of these

systems; and (4) leveraging of existing partnerships and of forecasting and assessment programs. NIDIS currently supports work on water supply and demand, wildfire risk assessment and management, and agriculture. Regional drought early warning system pilot projects have been established to illustrate the benefits of improved knowledge management, improved use of existing and new information products, and coordination and capacity development for early warning systems. These prototype systems are in the Upper Colorado Basin, the Apalachicola-Chattahoochee-Flint River Basin in the Southeast, the Four Corners region in the Southwest, and the State of California. The NIDIS Outlook in the Upper Colorado Basin early warning system, for example, is conducted weekly, and now draws in a variety of users from Federal agencies, water resource management, and the recreation industry.

The Western Governors' Association, the U.S. Congress, and others formally acknowledge that NIDIS provides a successful example of achieving effective Federal–state partnerships by engaging both leadership and the public, and by establishing an authoritative basis for integrating monitoring and research to support risk management. Some of NIDIS' keys to success include:

- *Usable Technology and Information for Decision Support*: The U.S. Drought Monitor map, which integrates multiple indicators and indices from many data sources, was developed before NIDIS was established and has become a useful visual decision support tool for monitoring and characterizing drought onset, severity, and persistence. NIDIS has engaged regional and local experts in refining the regional details of this national product and in "ground truthing" maps via email discussions and webinars.
- *Financial Assistance*: Federal funding was NOAA-allocated specifically for NIDIS, but leveraged in kind by other agencies and partners.
- *Institutional/Partnerships*: Effective collaborations, partnerships, and coordination with NOAA, WGA, USDA, DOI, and USGS, as well as local, regional, state, and tribal partners and with the National Drought Mitigation Center at the University of Nebraska–Lincoln, have led to multi-institutional interest.
- *Institutional/Policy*: The NIDIS Act was oriented toward the improvement of coordination across Federal agencies and with regional organizations, universities, and states. It focused on the application of technology, including the Internet, and on impact assessments for decision support. A key aspect of NIDIS is the development of ongoing regional outlook forums based on the above information to build awareness of the drought hazard and to embed information in planning and practice (in partnership with the National Drought Mitigation Center, the Regional Integrated Sciences and Assessments (RISAs), and other research-based boundary organizations) to reduce risks and impacts associated with drought (see Fig. 5).
- *Leadership and Champions*: There was leadership at all levels over more than two decades (1990s and 2000s) to establish the NIDIS Act, including political (WGA, Southern Governors' Association, National Governors Association, U.S. Senators, and congressmen); scientific (Wilhite, Pulwarty, Verdin); and federal agency leadership (NOAA, USDA, DOI).
- *Risk Perceptions*: Whereas drought had been considered primarily a western issue in previous decades, drought is now regularly impacting the southern, southeastern, and northeastern parts of the country, and response strategies are needed. Because of the 2012 drought, more than 63 % of the area in the contiguous U.S. was classified by the end of July as experiencing moderate to exceptional drought, and more than 3,200 heat records were broken in June 2012 alone (NOAA 2012; Schwalm et al. 2012).

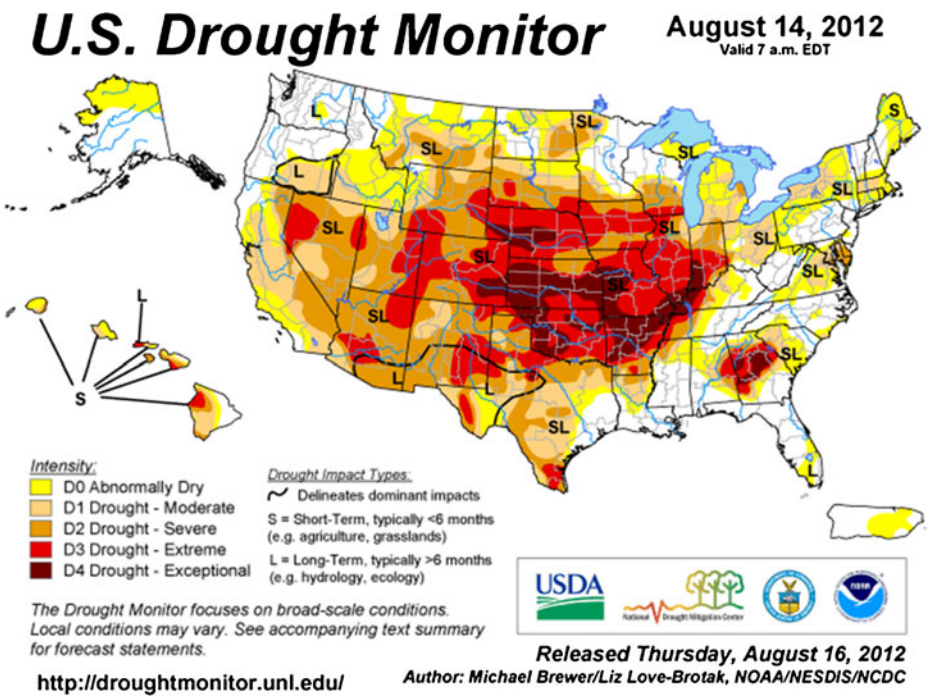

Fig. 5 U.S. drought monitor map accessed on August 20, 2012. http://droughtmonitor.unl.edu

6 Research and development needs in support of adaptation

Adaptation to climate change is in an emerging stage and will therefore benefit from more research. This section draws on the information gleaned from our analysis, but it is not meant to be a comprehensive research agenda on adaptation. It does not identify the many research needs that are specific to individual sectors and regions, such as development of heat- and drought-resistant varieties of crops, appropriate management of reservoirs under increased uncertainty about future conditions, strategies for managing coastal resources, the effectiveness of corridors for species migration, and ecosystem-based adaptation. Some of these sector- and region-specific adaptation needs are mentioned in the sector-specific chapters of the upcoming 2013 NCA. The focus of this section is instead on some high-level actions that the federal government can enable.

6.1 Research on the policy-making process (i.e., governance and institutions)

As noted above, a key barrier to climate adaptation and to resource management in general is the fragmentation at different levels of government (federal, state, and local); at geographic boundaries (e.g., ecosystems or watersheds crossing international borders, borders between states, and borders between municipalities); and in various sectors (e.g., different departments and agencies within the same government having overlapping or competing authorities) (Craig 2008; Kates et al. 2012). Research is needed on how to reduce this barrier by, for example, fostering coordination and better communication and sharing of knowledge among fragmented governing structures and stakeholders.

Understanding the dynamics of governance and institutional structures (including the influences of multiple and sometimes conflicting risk perceptions, cultures, values, and ideas about how to govern the economy and environment) is critical to adaptation concerning complex environmental resource problems such as climate change (Lemos and Agrawal 2006; Verweij et al. 2006). Ongoing research that supports, sustains, and identifies criteria for best practices for building governance and institutional capacity to anticipate and respond to climate change is imperative (Bierbaum et al. 2007; Kareiva 2008). It should focus on identifying climate-sensitive laws, policies, and regulations that support climate-related activities (Lackstrom et al. 2012; Moser and Ekstrom 2012).

One important consideration of the policy-making process is that rigid laws, regulations, and institutions can sometimes encourage maladaptive behaviors in particular locations (Carpenter and Brock 2008; Easterling et al. 2004; Kates et al. 2012). Because adaptation is inherently place- and time-specific, a detailed understanding of institutional interworkings and dynamics is critical to moving adaptation strategies forward. Information gathered from areas outside of the traditional climate studies can be researched for relevance to various adaptation processes (Dovers and Hezri 2010; Skaggs et al. 2012).

Research is also needed to better understand how certain underrepresented and highly vulnerable groups (e.g., tribes, inner city poor, rural communities) can be supported in reducing vulnerability and building adaptive capacity (Dow et al. 2006; Intertribal Climate Change Working Group 2009; Kates et al. 2006; Thomas and Twyman 2006). Research on policy processes, governance, and institutions in the United States to date has been understudied and underappreciated (Eakin and Patt 2011).

6.2 Research on organizing and delivering usable climate change information

One of the challenges to adaptation often cited by decision-makers is the lack of clear information about the rate and magnitude of climate change. Research investigating the types of information users want and the creation of appropriate delivery mechanisms are needed. To be usable, scientific information must be relevant to users (Lemos and Rood 2010). To best understand the needs and context of decision-makers, researchers will need to involve and engage decision-makers in clarifying how decision-making processes unfold and how scientific and other information to support, enable, and empower decision-making is used in these proceses (Hulme and Dessai 2008). The participation and engagement of stakeholders in the development of questions for research agendas and project implementation are important, as this creates a two-way conversation about what is needed and possible.

The research could examine, for example, how to make relevant monitoring data and climate change information accessible, as well as how to update it regularly, in a federally supported clearinghouse. It will be important to create a "translational" capacity—i.e., to enable users to combine data sets to evaluate how climate change, in concert with other multiple stresses, may change desired options. Having the further capability of linking local users to regional and federal tools to support adaptation decision-making, evaluation, and monitoring would advance the collection of best practices. A map of existing federal science, capabilities, and services in support of adaptation could begin to provide a useful information system for users (CEQ 2010; 2011b; National Climate Adaptation Summit Committee 2010; USGS 2012).

One of the challenges for adaptation is the complexity of information on climate change. Some decision-makers find that climate model projections are too coarse and look too far

into the future and that they address average conditions rather than variability, and may be about variables that are not useful (Lemos and Rood 2010). General Circulation Model (GCM) output, for example, is often considered to have too coarse a resolution, and different GCMs can yield very different projections. Climate model output can be used to project changing growing season average temperatures, but this may be less useful than dates of first and last frost, or the timing and extent of extreme rainfall events. The matter is further complicated by the lack of a single institution providing climate change information.

Research should address the types of information that need to be made available, as well as the methods for transmitting such information in a way that can best support understanding of climate change risks and opportunities and facilitate decision-making.

6.3 Research on decision-making in light of uncertainty

Climate change adaptation involves making decisions about an uncertain future climate, as well as other future conditions, that can extend for many decades (Moore et al. 2012). Even if information on projected trends were accessible and clearly understood, there would remain uncertainty about exactly how much the climate will change, where it will change, how key variables such as precipitation will change, and how society will react to these changes. This is added to the uncertainty about important future socioeconomic conditions, such as population, income, settlement patterns, global competition, changing human preferences, and technology and innovation (Lemos and Rood 2010). There is research on decision-making approaches that account for uncertainty (Lempert and Groves 2010; Means et al. 2010), which is useful for making decisions in light of complexity and changing conditions (Moore et al. 2012; NRC 2004; Renn 2008). Additional research is needed, however, on the role and efficacy of inclusive and iterative risk management approaches in climate change adaptation, including how various risk perceptions influence behavior in these decision-making processes (Aven and Renn 2009; Aven et al. 2011; Jones and Preston 2011; Kahan et al. 2011; NRC 2010a; b; Renn 2011; Renn et al. 2011; van Aalst et al. 2008).

6.4 Research on methods to incorporate adaptation

Adapting to climate change requires altering the planning for, and management of, our natural and built systems (ORNL 2012b; USGS 2012). Research on how measures that promote adaptation to climate change can be built into existing institutions, networks, and agencies, rather than creating a brand new set of institutions, is needed. Our regulations, laws, and agency missions should be reevaluated with climate change in mind. For example, flood plain maps could be required to take projected climate change (e.g., sea level, storm surge, rainfall intensity, and flood volumes) into account. Building codes may need to be updated to handle more extreme weather impacts, and multi-hazard mitigation planning may need to be revised to allow future climate projections, not historical climate conditions, to inform decision-making.

Climate change is occurring within the context of other environmental and socioeconomic stresses. Given that the adaptation options chosen will have both short- and long-term consequences, and may affect sectors and regions differently, it is important to develop evaluation criteria to measure outcomes and learn to characterize successful adaptation. As the adaptation process itself must be adaptive, continued evaluation and revision of adaptive strategies will be needed (National Climate Adaptation Summit Committee 2010; PCAST President's Council of Advisors on Science and Technology 2011).

6.5 Other research and development needs

In addition to the aforementioned research and development needs, a series of needs that cross across sector, scale, and geography emerged during analysis. Many of these cross-cutting needs include:

- **Costs and Benefits of Adaptation.** There is uncertainty about the costs of different adaptation options, as well as the costs of inaction (i.e., benefits of adaptation). This includes analysis of the costs of traditional grey adaptation (i.e., for hard infrastructure) versus green approaches to adaptation (Ingram et al. 2012; Lebow et al. 2012; Sussman et al. 2012; USGS 2012; Winkler et al. 2012).
- **Best Adaptation Practices.** Research could define and apply criteria that are useful to decision-makers to evaluate adaptation options. The research could involve a comprehensive assessment of adaptation options that are effective under changing climate conditions and are affordable and feasible. It should also examine conditions that affect relative costs and benefits (Doria et al. 2009; Sussman et al. 2012; Ackerman et al. 2009).
- **Adaptation and Mitigation Interface.** Many mitigation measures affect adaptation, and many adaptation measures have consequences for mitigation. The literature on this topic, however, is limited. Among the topics to be explored through research are the growing and competing demands for land, water, and energy, and how mitigation actions could affect adaptation options, and vice versa (Bloetscher et al. 2011; Ingram et al. 2012; ORNL 2012a; Skaggs et al. 2012).
- **Climate Adaptation Science.** While major advancements have taken place, there remains a need for basic and applied research on climate adaptation science to help inform decision-making.
- **Critical Thresholds.** Research is needed to identify critical thresholds beyond which social and/or ecological systems are unable to adapt to climate change. This should include analyzing historical and geological records to develop models of "breakpoints" (NAST 2000; National Climate Adaptation Summit Committee 2010).
- **Extreme Events.** Research is needed on preparedness for and response to extreme events, such as droughts, floods, intense storms, and heat waves, to protect people, ecosystems, and infrastructure. Increased attention must be paid to how the "tails" of the distribution may change as climate change proceeds, and how that affects adaptation actions (IPCC 2012; Kates et al. 2012).

7 Conclusions

Our main conclusions are:

1. Substantial adaptation planning is occurring in public and private sectors and at all levels of government, however, few measures have been implemented and those that have appear to be incremental changes.
2. Barriers to implementation of adaptation action include lack of funding, policy and legal impediments, and difficulty in anticipating climate-related changes at local scales.
3. There is no one-size fits all adaptation, but there are similarities in approaches across regions and sectors. Sharing best practices, learning by doing, and iterative and collaborative processes including stakeholder involvement, can help support progress.

4. Climate change adaptation actions often fulfill other societal goals, such as sustainable development, disaster risk reduction, or improvements in quality of life, and can therefore be readily incorporated into existing decision-making processes.
5. Vulnerability to climate change is exacerbated by other stresses such as pollution and habitat fragmentation. Adaptation to multiple stresses requires assessment of the composite threats as well as tradeoffs amongst costs, benefits, and risks of available options.
6. The effectiveness of climate change adaptation has seldom been evaluated, because actions have only recently been initiated, and comprehensive evaluation metrics do not yet exist.

Adaptation to climate change is in a nascent stage, but is happening at all levels of government, as well as in the private and non-profit sectors. Yet there is a long way to go. Adaptation will require not only the protection of existing livelihoods and land and water uses, but in some cases the enabling of changes in livelihoods and land and water uses. The federal government is beginning to develop the institutions and practices necessary to address adaptation. A number of states have developed adaptation plans, but most have not. Many local governments have developed adaptation plans or engaged in adaptation activities, but many others have not. Among the important barriers to adaptation that governments must address are lack of financial and staff resources, lack of access to useful information about climate change, difficulty in making decisions under uncertainty, and fragmentation of policies, authorities, and information.

A key federal role in adaptation is enhancing the adaptive capacity of regions and sectors. This could include reviewing existing laws and regulations to ensure that they enable proactive as well as efficient reactive adaptation to climate change; funding pilot projects; providing usable information, including disseminating best practices; and helping to develop tools to evaluate successful adaptation.

Protecting people, infrastructure, and ecosystems in a changing climate will require the updating of current best practices for adaptation and disaster preparedness and response. A streamlined national clearinghouse for current best practices is needed, and existing small networks of scientists and stakeholders could be linked (National Climate Adaptation Summit Committee 2010; NRC, 2010b). Building blocks could include the existing USDA Extension Services, the Sea Grant Programs, the NOAA Regional Climate Centers (RCCs) and RISAs, the DOI Landscape Conservation Cooperatives (LCCs), and new regional Climate Science Centers (CSCs).

The authority to undertake necessary changes varies among levels of government, but the need to identify and implement these changes at the appropriate scale is nationwide. The federal government owns 30% of U.S. land, and state governments own large tracts of land. Land-use planning, however, is generally carried out at the local government level. The challenge is to ensure that existing institutions, agencies, and networks identify the potential threats posed by climate change, and move forward with appropriate transparent and collaborative processes to develop and implement effective adaptation plans and measures. The Federal government can help facilitate this systematically and thoughtfully, and with adequate provision of relevant information, resources, and funding.

Key information gaps remain. Decision support tools need to be further developed and evaluated for usefulness and usability. For example, rules for managing Great Lakes levels, reservoir levels, and dam dredging times will need revision; surveillance for disease outbreaks and extreme events such as floods, droughts, and heat waves needs to be heightened; and new tools to characterize “breakpoints” in management and infrastructure must be developed and shared.

As identified in the research section, basic and applied research is needed on climate adaptation science (e.g., management of the resources of an acidifying ocean, the effectiveness of migration corridors in preserving ecosystem integrity and services) and how to effectively manage transformations of social or natural systems. Similarly, regional analyses of climate change impacts need to be conducted and refined. No one lives in the "global average temperature," and climate change impacts will occur in concert with existing regional conditions; thus continually updating and sustaining regional assessments will be important. Stakeholders must be included from the outset to define the key questions to be answered and to identify feasible options for coping with climate change that address regionally specific needs. Regional vulnerability mapping and regional listening forums will be key to determining which impacts are of greatest concern for different regions and in ensuring the development of effective response strategies. A short- and long-term research agenda must also be developed that will provide timely answers for decision-makers. New research foci on adaptation, decision support, and education and outreach will be important in providing useful, usable, and understandable information in a timely fashion.

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