



RESOURCES
FOR THE FUTURE



SUMMARY REPORT

REFORMING INSTITUTIONS and MANAGING EXTREMES

U.S. Policy Approaches for Adapting to a Changing Climate

Daniel F. Morris, Molly K. Macauley, Raymond J. Kopp, and Richard D. Morgenstern

RESOURCES FOR THE FUTURE

Resources for the Future is an independent, nonpartisan organization that, through its social science research, enables policymakers and stakeholders to make better, more informed decisions about energy, environmental, and natural resource issues. Headquartered in Washington, DC, its research scope comprises programs in nations around the world.

Resources for the Future is pleased to acknowledge the generous support of the Smith Richardson Foundation for this project.

Daniel F. Morris, Center Fellow, Center for Climate and Electricity Policy

Molly K. Macauley, Research Director and Senior Fellow

Raymond J. Kopp, Senior Fellow and Director, Center for Climate and Electricity Policy

Richard D. Morgenstern, Senior Fellow

Resources for the Future
1616 P St. NW
Washington, DC 20036

© 2011, Resources for the Future

Table of CONTENTS

The Challenge Facing Us.....	1
The RFF Domestic Adaptation Project.....	2
What We Mean by “Adaptation”.....	3
The Role of the Federal Government.....	4
What Is Distinctive About This Study.....	6
Key Findings	
Reforming Institutions: Getting Incentives Right.....	13
Reforming Institutions: Improving Regulation and Management.....	19
Providing Information and Managing Extremes.....	29
Conclusions.....	35
Acknowledgements.....	37
References.....	38

The CHALLENGE Facing Us

Since its emergence on the national policy stage two decades ago, climate change has proven to be a tricky legislative challenge. Twenty years of thought and debate on how aggressively and when to mitigate the damage from excess greenhouse gases in the atmosphere through mandatory emissions reductions have seemingly brought the country no closer to a tractable solution. As understanding about climate change impacts matured, mitigation rightly became the focus of policy discussions, while adaptation remained an acknowledged but less immediate issue. For a variety of reasons, adaptation policy is now a growing concern of policymakers at the federal, state, and local levels.

Emphasis on domestic adaptation policy comes at an opportune time, as climate impacts are already manifesting across the country. According to the U.S. Global Change Research Program's 2009 assessment, average temperatures for the United States have increased by 2°F since 1960 (USGCRP 2009). Average precipitation has increased by 5 percent over the past 50 years, and the amount of precipitation falling during the most intense storms has risen by 20 percent over the past century. Similarly, other extreme events like widespread droughts, heat waves, hurricanes, and winter storms have grown more frequent and more intense. Sea levels have crept up across the nation's coasts as arctic ice cover continues to decline.

Even if the growth of greenhouse gas emissions were halted tomorrow, the climate system would continue to change for another 30 to 40 years, meaning that these patterns will continue on their current paths and will grow in strength. Increasingly, advocates and policymakers are beginning to consider mitigation and adaptation policies in concert.

Regardless of any future mitigation program, adaptation will play a fundamental role in protecting people and property from the impacts of climate change. The major question facing the federal government is, What will national adaptation policy look like?

Adaptation is fundamentally different from mitigation in that it cannot be addressed in its entirety in all regions of the country with a stand-alone governance policy. The nation's landscapes and cityscapes will experience both negative and positive impacts from a changing climate, highlighting this particular challenge—there is no single overarching solution that the federal government can craft and administer to effectively address all adaptation issues or problems. If the maxim “all adaptation is local” is true, then it must apply to policy responses as much as it applies to climate impacts.

Despite that fact, the federal government has a large and critical role to play in developing domestic adaptation policy. Municipalities and states are looking to federal agencies for leadership, and federal decisionmakers must steer action in an efficient way—allowing local actors on the ground to properly respond to changing conditions and avoid maladaptations while maintaining structure and coordination at the federal level. The design of national adaptation policy must incorporate many of the concepts important to actual adaptation actions: it must be resilient against failure in the face of extreme climate-related scenarios and, wherever possible, reduce its vulnerability to breakdowns. It must also be flexible enough that it can meet the needs of local actors across the country in a timely manner and allow for major directional shifts as needed if existing policy proves insufficient.



The Obama administration has recognized the need to advance adaptation policy and has made tangible progress. In October 2009, the president established the Interagency Climate Change Adaptation Task Force to develop recommendations for federal responses for both domestic and international adaptation. In its progress report released in October 2010, the task force recommended a set of guiding principles for adaptation generally and policy goals with corresponding actions for the federal government specifically. Some of the guiding principles include adopting integrated approaches, using the best-available science, and applying risk-management methods and ecosystem-based approaches.

THE RFF DOMESTIC ADAPTATION PROJECT

The body of work summarized in this report is not designed to provide a comprehensive plan for national adaptation responses—the range of potential impacts that will require federal action is too large and too uncertain for

a definitive all-encompassing national strategy. Rather, this research highlights specific and tangible examples of possible adaptation actions and policies that address some of the key concerns about adapting to a changing climate. The goal of our study is to provide an outside perspective to federal policymakers and aid them in the determination of adaptation priorities and ways to move forward.

The project unfolded in two phases. Phase One focused on synthesizing current scientific understanding of the effects of a changing climate on six impacts areas identified by the Intergovernmental Panel on Climate Change (IPCC) as critical for adaptation: agriculture, coastal and marine resources, fresh-water resources, infrastructure, public health, and terrestrial ecosystems. In six commissioned RFF reports, experts in these fields tracked the likely impacts of climate change on the continental United States over the next 50 to 100 years and examined strategies that might be employed to cope with and reduce these impacts. Phase Two utilized the findings from the Phase One reports to develop the most compelling and urgent framework through which to look at U.S. climate adaptation policy actions. The result is a series of 16 focused issue briefs that address specific topics for policy decisions. The briefs are primarily intended for use by decisionmakers as they confront the difficult task of effectively adapting the United States to climate change impacts, but may also offer insight and value to scholars and the general public.

This summary report gives a general overview of adaptation as we define it and highlights some of the vexing challenges it presents for effective federal responses. The report also details the specific approach we took to address this complex issue and how our study differs from other efforts to make recommendations for federal adaptation policy. Finally, we summarize our recommendations.

WHAT WE MEAN BY “ADAPTATION”

Climate change adaptation is a complicated and intricate problem that is fundamentally different from mitigation of climate change. It addresses the vulnerability of natural and human systems to changes in the climate, and adaptation policy focuses specifically on reducing the damage from impacts resulting from those changes. In contrast, mitigation policy is designed to avoid impacts by reducing greenhouse gas concentrations that lead to changes in the climate, notably fossil fuel mitigation. In some cases, as with insurance, adaptation and mitigation are interchangeable, as they both refer to the reduction of damages from natural events resulting from climate change. In this report, however, the term *mitigation* refers to efforts to decrease greenhouse gas emissions.

The IPCC defines *adaptation* as “adjustments to reduce vulnerability or enhance resilience in response to observed or expected changes in climate or associated extreme weather events.” Some define adaptation as the cumulative group of changes that individuals, firms, or governments make to reduce damages (or increase the benefits) from climate change (Mendelsohn 2006). Similarly, others argue that adaptation lowers damages from climate change by altering production and consumption decisions to reduce the severity of a potentially bad state of climate (Settle et al. 2007).

Adaptation occurs in multiple systems—including those physical, ecological, and human (Adger et al. 2007)—meaning that many damage-reduction decisions will address one type of climate impact. Adjustments to environmental or social activities, changes in understanding and interpretations of climate risks, and behavior shifts to avoid potential damages or to exploit emerging opportunities all represent possible adaptations to new climatic conditions. Inherent

in these examples are the continuing and sometimes gradual alterations associated with adaptation. More formally, adaptation actions can be either anticipatory (*ex ante*) or reactive (*ex post*), incorporate both private and public initiatives, and respond to variations in temperature or climatic behavior (that is, more gradual climate changes) as well as extreme climatic or weather events.

Embedded within the concept of adaptation are several other important terms. *Adaptive capacity* refers to the extent of the range of options for proactively or reactively reducing society’s vulnerability and increasing resilience to climate variability and change (Moser and Luers 2008). The IPCC defines adaptive capacity as the ability of a system to adjust to climate change and moderate potential damages, to take advantage of opportunities, or to cope with the consequences. More flexible systems will have greater capacity to adapt and will be better suited to handle a changing climate. Adaptive capacity exists within all natural and human systems, yet some will be more adept than others at increasing or buttressing that capacity.

Two additional concepts that are critically important to adaptation fall under the term adaptive capacity: *vulnerability* and *resilience*. Vulnerability is the degree to which a system is susceptible to, and unable to cope with, the negative effects of climate change (Adger et al. 2007). In contrast, resilience is the capacity of a system to absorb disturbances from climate change and reorganize while undergoing change in order to retain essential structures, functions, and feedbacks (Walker et al. 2004). These two terms relate specifically to the anticipated effects of climate change, both extreme events and gradual systematic shifts, and represent important metrics by which successful adaptation actions should be measured. Anticipatory adaptation aims to increase the resilience of natural and human-built systems to climate impacts. At

the same time, that requires some measurement of vulnerability to prioritize actions and areas that are most threatened.

An important aspect of adaptation policy is its relation to mitigation of greenhouse gas emissions. Adaptation and mitigation are not mutually exclusive as investment in one can affect the magnitude of the other (Swart and Raes 2007). In principle, more aggressive mitigation actions will reduce the need for adaptive measures in the future, just as investments in adaptive actions will compensate for mitigation actions not taken (Mendelsohn 2006; Settle et al. 2007). Mitigation and adaptation may not be perfect substitutes, however, depending on increasing climatic variability and discount rates used to estimate immediate action and future damage (Wright and Erickson 2003). Adaptation is fundamentally different from mitigation in the sense that it cannot be addressed in its entirety with a comprehensive stand-alone

government policy such as emissions pricing. The regional and heterogeneous impacts from climate change will require an integrated fabric of many policies. The degree to which adaptation can be addressed as a stand-alone issue or will be embedded in other issues is an important question not clearly answered by the existing literature. Box 1 lists some of the most compelling findings from the adaptation literature that helped inform the research conducted for this study.

THE ROLE OF THE FEDERAL GOVERNMENT

A general assumption that persists is that developed countries like the United States have enough resources and capacity to easily adapt to all but the most extreme impacts of climate change. Some have argued, however, that current governance structures, designed to operate under past climate regimes, will not

BOX 1. IMPORTANT FINDINGS FOR CLIMATE ADAPTATION

- Adaptation will occur naturally in private markets, but it will be suboptimal from a social perspective. Government intervention is necessary to ensure a proper level of adaptation occurs in public and private sectors, though governments must be careful not to remove existing incentives for adaptation through poorly planned and executed policies (Mendelsohn 2006; Fankhauser et al. 1999).
- Ground-level managers will be critical conduits for any adaptation policy application, so they must be well informed and should be involved and consulted with as much as possible (Schilling and Stakhiv 1998).
- As adaptation becomes a more prominent policy issue, adaptive management will also become more prominent and more widely advocated (Arvai et al. 2006; Lempert et al. 2000).
- Information provided by research needs to better incorporate possible climate outcomes that may significantly affect adaptation (such as catastrophic nonlinear events), and research results need to be made easily available and digestible for all levels of resource managers and environmental professionals (Berkhout 2005).
- Many adaptations will be extensions of current practices for coping with extreme events.
- Adaptation efforts are related to risk and vulnerability, in that actions taken to adapt to climate change are meant to reduce the vulnerability of systems that have some risk of a major catastrophic event. Adaptation itself does not influence risk.
- Catastrophic events will set the ceiling for adaptive measures.
- *Ex ante* adaptation is generally more desirable than *ex post* adaptation, whenever it is feasible (Berkhout 2005).

be able to effectively respond to the increasing pressures climate change is likely to deliver (Repetto 2008). Others maintain that the policy focus on mitigation has left institutions ill prepared to adapt (Moser and Luers 2008). The key is mobilizing decisionmakers to make efficient adjustments and design policies that will spur proper adaptation. Though many of these choices will happen at state and local levels, the federal government is best positioned to ensure this happens.

When defining the federal role in domestic adaptation policy, there are a number of important considerations to keep in mind. First, adaptation presents a significant information problem in terms of both impacts and required responses. Current projections of climate impacts are not sophisticated enough to identify where and when events such as prolonged droughts or massive floods will occur or how long they will last. The uncertainties inherent in the historical climate system of the United States will only increase as greenhouse gases continue to accumulate in the atmosphere. Local and state decisionmakers likely do not have the resources necessary to fully understand the uncertainties they face and will need to rely on the research capacity of the federal government to supplement their knowledge. Similarly, as existing climate patterns shift and new patterns emerge, local actors may look to the federal government to give them guidance on what to expect.

A second consideration for federal leadership is the tension between adaptation and long-term capital investments. Climate impacts will stress some large-scale, long-term public infrastructure up to and possibly beyond its current performance limit. As a result, public works projects like levees and dams may become obsolete long before the end of their service lives. Other climate-driven effects may exacerbate undesirable climate impacts or lead to further maladaptations. At the same time, new long-term

investments, from decadal-long drought plans to new seawalls and coastal buffering, will be necessary to develop resilience in different regions of the country. The common thread among all of these issues is that they will require actors to make expensive investments in uncertain conditions that will span long timelines. Markets can play a role in encouraging some anticipatory adaptations, but they will not be able to encourage investment at the scale needed to fully adapt to climate realities. The federal government will have to fill in the gaps wherever possible, either through supporting new or existing markets that develop to address adaptation issues or, in the absence of markets, by direct policy action.

Long-term investment decisions are not the only difficult choices that need to be made. This leads to a third consideration for the role of the federal government in adapting to climate change. Adaptation policies, in some cases, will be extremely contentious, potentially more so than mitigation policies. Similarly, regional concerns that weigh heavily in current mitigation discussions in the United States may be exacerbated by diverse impacts (both positive and negative) across the country. For example, extreme long-term drought in the Southwest or Southeast may lead to water-rationing schemes that generate significant controversy. Also, sea-level rise may eventually overwhelm urban areas such that people will need to relocate and infrastructure will be abandoned. The federal government will likely need to step in and assert its authority when crafting policies to help citizens cope with the most extreme impacts of climate change.

As the government helps people adjust to new climate realities such as massive droughts and encroaching sea levels, issues of justice and equity—the fourth important consideration—will certainly arise. Low-income communities are generally most vulnerable to the impacts of climate change yet

may have the least capacity to adapt. These communities often have fewer opportunities for anticipatory adaptation and may need extra support to carry out reactive adaptation. When designing policy, federal officials should account for the special needs of different communities.

WHAT IS DISTINCTIVE ABOUT THIS STUDY

When the RFF Domestic Adaptation Project was initiated in 2008, there was little discussion about adaptation in the context of domestic action for the United States. While impacts and adaptation in developing countries received a fair amount of research attention, the literature lacked a corresponding level of focus on the United States. Since the inception of our efforts, other groups have attempted to illuminate the role of the federal government in developing adaptation policy, most notably the Pew Center on Global Climate Change (Smith et al. 2010) and the National Academy of Sciences, with its America's Climate Choices reports. Our project differs from other adaptation policy research because we aim to characterize impacts that are most salient and, importantly for policy formation, we make specific policy recommendations to address those impacts. This approach called for the project to unfold in two phases.

During Phase One, we gathered experts and asked them to review and assess the projected physical impacts from climate change and the adaptive capacity of six classes of natural or environmental resources identified as critical to adaptation by the IPCC: agriculture, coastal and marine resources, freshwater resources, infrastructure, public health, and terrestrial ecosystems. Six corresponding RFF reports were produced, spanning the spectrum of expected impacts that will be most important to domestic adaptation policy

responses. Brief synopses of these reports can be found in Box 2, and the full reports can be found at www.rff.org/adaptation.

These scientific assessments provided our research team with a base of understanding from which we could develop creative policy recommendations. In order to make specific recommendations, however, we needed some foundational assumptions for looking at adaptation challenges. From the six reports came three findings that defined the basis for the approach to Phase Two of the project:

1. ***Many climate-related impacts are not new.*** Effects that already manifest throughout the country include freshwater resource scarcity, endangerment of terrestrial and marine species, droughts, variability of agricultural yields, heat waves, and coastal and inland flooding. But these are events that have previously affected different areas of the nation. In addition to these existing problems, climate change will generate two new concerns. The first is completely new types of impacts, such as increased acidification of the oceans from increased CO₂ in the atmosphere. The second concern is types of impacts that have a lower probability of occurring than those previously experienced, but that could be much more extreme in the future. The key insight from this finding is that many communities already have some tools available to begin addressing climate impacts.
2. ***The nation's existing public and private institutions have had mixed success in preparing to deal with existing impacts.*** For example, the public health policy response to heat waves in urban areas and the private agricultural response to shifting agro-ecological zones have so far been quite good. In many areas, however, private and public action has been limited. Vast marine fisheries have collapsed (primarily due to overfishing) because of the absence of effective fishery policies. Freshwater

resources on both sides of the nation are being depleted at unsustainable rates despite a century of water policy development in the western United States. People and infrastructure have long been at risk due to extreme weather events, yet emergency response policies may be inadequate and political institutions have few forward-looking policies to date. This finding indicates that existing public policies and institutions can be improved significantly now and need to be enhanced to address the effects of climate change over time.

3. *Science assessments suggest climate change will lead to a combination of more severe impacts at greater frequency.*

There is still a fair amount of uncertainty about how severe and how frequent, but taken together, those two aspects of climate impacts suggest that the losses to society could, on average, be larger than extreme events seen to date. To effectively cope, communities will need to consider a wider range of responses than was previously necessary. This finding reinforces the need for reform of existing policy and underscores the usefulness of consideration of some wholly new policy approaches to address the probability of extreme and possibly costly events.

These findings presented the research team with the challenge of developing policy recommendations that are specific enough to spur useful federal actions, but flexible enough to provide lessons across a broad range of scenarios. Rather than make suggestions for a comprehensive national adaptation policy, we determined a more valuable approach would be to concentrate on particular issues that represent the spectrum of adaptation concerns policymakers will address in both the short and long terms. As such, we sought out top experts to develop focused policy-relevant issue briefs that clearly establish the adaptation problem and recommend



cogent and realistic policy actions.

The resulting 16 RFF issue briefs range from critiquing the National Flood Insurance Program to recommending establishment of more responsive property rights for coastal resource use to elucidating the importance of changing risks of extreme events due to climate shifts. The briefs have been organized into three categories—Reforming Institutions: Getting Incentives Right; Reforming Institutions: Improving Regulation and Management; and Providing Information and Managing Extremes—that incorporate the important concepts established by the Phase One findings and highlight the diverse set of actions available to address adaptation. We selected these categories carefully because they broadly incorporate what adaptation research has found so far:

- that markets play a critical role in adaptation, but they can function efficiently only when incentives are correctly defined;
- that public actions are absolutely necessary to help communities adapt, and while current management and regulation structures are not designed to address adaptation,

BOX 2. SUMMARIES OF PHASE I REPORTS

Agriculture—As climate changes, so does the spatial distribution of efficient agricultural production. Impact assessments indicate that the U.S. food supply is not under threat from climate changes because CO₂ fertilization may offset some effects of temperature and precipitation changes, replacing regional losses in more tropical climates with increased production in temperate zones. The net increase in crop yield in the United States does not apply across the board, however, as some crops will benefit more than others. Agricultural productivity in the southern part of the country is likely to drop and be more vulnerable to drought and extreme temperatures, whereas northern areas that receive increased precipitation will become more productive. Livestock production will likely be affected negatively overall as a result of higher summer temperatures. Generally, it appears that most farms are not highly vulnerable to climate change and have the technological capacity to adapt in the near term. The costs of adaptation, however, remain very uncertain, as little to no research has been conducted to estimate them. This should be a priority moving forward to help determine when adaptation makes sense. *See RFF report, Agriculture and the Food System: Adaptation to Climate Change, by John Antle.*

Coastal and Marine Resources—Impacts from climate change on marine and coastal systems include changes to ocean and air temperatures, acidification, increased freshwater runoff, ice loss in the Arctic, sea-level rise, and changes in upwelling and ocean circulation. These effects will combine to stress marine ecosystems on top of existing human-induced stresses, such as overfishing and land-based pollution. Coral reefs are of particular concern because they are already in decline. Coastal and marine impacts will be experienced in different ways and magnitudes across the country. Some communities will be more vulnerable than others, though vulnerability is often directly related to the near-term state of the ecosystem. Coastal land-use is also a critical concern. Emphasis for current uses involving armaments should be on expediting permits for projects that minimize erosion and loss of access. The common pool nature of ocean resources means their adaptive capacity and resilience will be influenced by government action. The most important step the government can take to improve adaptive capacity and resilience is to better define property rights for ocean resources so that users can internalize incentives for maintaining and improving ecosystem function. *See RFF report, An Adaptation Portfolio for the United States Coastal and Marine Environment, by David Kling and James Sanchirico.*

Freshwater Resources—Temperature changes are predicted to increase variability in precipitation extremes across the United States, resulting in historically large floods and prolonged droughts. Water availability for both human uses and ecosystems will become less predictable. Moreover, reduced volumes in rivers and lakes due to increased evaporation may have long-term hydrological consequences as well as implications for water quality. Human and natural systems have the adaptive capacity to respond effectively to flood and droughts, but the frequency and extreme nature of future impacts will push those capacities to their limits. Over the long term, increases in adaptive capacity are the key to adaptation more broadly. Ways to achieve these gains include maintaining biodiversity, protecting source waters for regionally connected watersheds, and removing governance barriers to capacity expansion. Resource managers can correspondingly adjust their practices through stepwise, integrated processes similar to adaptive management practices. Positive and negative examples of regional responses to water scarcity currently exist throughout the nation and can provide useful guidance for future adaptation actions. *See RFF report, Emerging Climate Change Impacts on Freshwater Resources: A Perspective on Transformed Watersheds, by Alan Covich.*

Infrastructure—Climate change impacts will affect public infrastructure, including that related to transportation, energy generation and transmission, water and sewer systems, telecommunications, and coastal defense. Among those sectors, each will experience impacts in different ways, but have some adaptive capacity to deal with impacts, which include damage from extreme events, sea-level rise, water availability, temperature changes, and demand-induced effects like increased electricity consumption. For example, coastal flooding from sea-level rise will likely inflict the most damage on transportation infrastructure, whereas temperature rises will affect the thermal efficiency of electricity generation. Public infrastructure often is long-lived with a regular maintenance schedule, which provides an opportunity to regularly improve adaptive capacity. Some costs of improvement, however, may grow too large to sustain over the long term. Three major implications for policymakers emerge. First, a closer integration of infrastructure planning with land-use planning will help allocate resources more efficiently. Second, innovations in infrastructure technology and updated building standards will expand adaptive capacity. Third, destructive extreme events present a useful opportunity to replace existing infrastructure with more resilient capital. *See RFF report, **Adapting to Climate Change: The Public Policy Response—Public Infrastructure**, by James Neumann and Jason Price.*

Public Health—In relation to public health, climate change is an extremely upstream driver, meaning that impacts are not always directly linked to effects in the health sector. Climate change will not introduce new sources of morbidity and mortality in the United States, but will alter distributions of factors that lead to them. Important impacts include heat stress and heat waves, exacerbation of aeroallergen distribution and allergic diseases, changes in epidemic infectious diseases, and increased ambient air pollution. Heat waves that result in multiple deaths can be more closely correlated to climate change than changes in allergic diseases due to alterations in aeroallergen distributions. As a result, there are varying opinions within the public health community as to what level of urgency should be used to address climate change, though most practitioners agree that primary prevention is needed. Adaptation to some impacts, such as heat waves and infections, will occur through the routine functioning of effective public health systems as long as those systems are in place. Monitoring the distribution of morbidity and mortality resulting from impacts can assist public health officials in ensuring in-place systems are adapting well. *See RFF report, **Adapting to Climate Change: Public Health**, by Jonathan Samet.*

Terrestrial Ecosystems—Terrestrial ecosystems are constrained by the average temperature and precipitation conditions of their environment. As averages shift as a result of climate change, plants and animals will have to adapt while remaining in the same place or migrating outside their current geographic distribution. One of the clearest connections between average climate changes and ecosystem response is the life-cycle timing and early season growth of plants due to earlier spring conditions. As important as changes in averages are, however, changes in extremes may be more critical to ecosystems because high and low temperatures are mortality points for some organisms. Similarly, disturbance events (droughts, floods, and wildfires, for example) can stress ecosystems to the point of altering their basic structure, a situation that may be more prominent under new climate regimes. As a result, native species may struggle while invasive species flourish. Because natural ecosystems receive little active management from humans, options for adaptation actions are limited. Human-facilitated water storage at high altitudes, active removal of invasive species, reduction of nonclimate ecosystem stressors, and assisted connectivity among ecotypes for native species are all possible adaptation opportunities. *See RFF report, **Terrestrial Ecosystem Adaptation**, by Steven Running and L. Scott Mills.*



they can achieve a great deal with some basic reforms; and

- that climate change will result in extreme events that go beyond current experiences and knowledge, so proper adaptation will require better data gathering and more useful information relayed to decisionmakers.

In June 2010, after the completion of these issue briefs, the research team convened participating authors to share their findings with federal officials responsible for formulating policy for climate adaptation. Roughly 30 federal officials from multiple agencies were invited to react to the recommendations. Represented agencies included the Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), the Army Corps of Engineers, the U.S. Department of Agriculture (USDA), the Congressional Budget Office (CBO), and the Department of Energy (DOE). The goal of the

workshop was to both share research findings and get feedback from decisionmakers about their priorities and concerns for adaptation. Based on the officials' reaction to the issue briefs and their experience in their respective agencies, we established six current priorities for federal actors. Adaptation policy recommendations will be most effective if they do the following:

- provide specific guidance for federal rulemaking;
- create connections and synergy with other policy areas;
- address inefficiencies in current federal legislative and regulatory policy;
- supply information and data to enable policymakers to better understand risk and uncertainty;
- embed flexibility and responsiveness into management structures; and
- address equity and social justice concerns.

This list of priorities should guide the short- to medium-term formation of foundational adaptation policy on which the federal government can devise new regulations, authorities, and governance structures. The key findings of this research project apply to all of these concerns in one way or another, and thus represent some of the most advanced thought to date on issues of domestic adaptation in the United States.

The Key Findings section, which follows, further elucidates the theoretical grounding for the three broad categories of issue briefs. It also presents short overviews and key policy insights of the 16 issue briefs, all of which are available for download on the Resources for the Future website (www.rff.org/adaptation). Each summary gives a synopsis of the discussion in the issue brief, highlighting the main themes and important conclusions, and details how the specific recommendations in the issue brief match up with the six policy priorities identified by federal actors.



ISSUE BRIEFS IN THIS CATEGORY:

Encouraging Adaptation to Climate Change: Long-Term Flood Insurance

Howard Kunreuther and Erwann Michel-Kerjan

Adaptation of Agriculture and the Food System to Climate Change: Policy Issues

John Antle

Pre-Positioned Policy as Public Adaptation to Climate Change

Kerry Smith

Ecosystem Services and Climate Adaptation

James Boyd

Key FINDINGS

Reforming Institutions: Getting Incentives Right

Anticipatory *ex ante* adaptation may occur in many sectors of U.S. society, but in order for it to be most effective, market prices need to accurately reflect changes that are occurring in natural and human systems as a result of climate change. Current subsidy and pricing structures were established under climatic conditions that were presumed to remain static into the future. As the climate shifts to new norms, prices need to be flexible enough to reflect new levels of scarcity for certain resources. Indeed, getting incentives right is one of the most immediate and effective ways to encourage efficient adaptation actions. In some cases, the federal government may need to alter subsidies that interfere with private actors making necessary adaptations. In other cases, the federal government may be the one setting the price, and it will need to readjust its current practices. In still other cases, there are no existing effective pricing mechanisms, so it must take the lead in developing them.

Here, we have tried to identify opportunities for the federal government to incorporate incentives correctly in areas where maladaptation may occur under current conditions. The findings in this category range from recommendations to revise the nation's approach to flood protection pricing to reducing existing distortions in the prices of electricity, water, and agricultural commodities (including crop price supports and trade policy). Getting incentives right provides a host of benefits that can enable government, resource managers, and consumers to become more resilient in adapting to climate change. Findings include recommendations for the following:

- Revise the National Flood Insurance Program to create long-term policies.
- Tie long-term flood insurance policies to *properties*, not persons.
- Price flood insurance to reflect risk.
- Improve and refine pricing policies for “substitute” resources (that is, resources that will be called upon to offset—“substitute for”—changes in climate, such as electricity for cooling and water for periods of reduced precipitation).
- Encourage dynamic pricing (including time of day and seasonal) of electricity and water.
- Reduce agricultural subsidies and reform trade policy to enhance capacity of the agricultural sector to respond flexibly to climate-induced environmental and economic change.
- Expand and enhance payments for ecosystem services to include co-benefits (for instance, forest watershed protection as well as forest carbon sequestration).
- Amend natural resource damage-assessment protocols to include option value lost in resource degradation.

ENCOURAGING ADAPTATION TO CLIMATE CHANGE: Long-Term Flood Insurance

The evidence on increasing losses from disasters, notably floods and hurricanes, indicates that the current structure of the National Flood Insurance Program (NFIP) is not adequate to cover truly catastrophic floods. It is also somewhat limited in achieving its twin objectives of reducing property losses from future disasters and providing protection to those who suffer severe water damage for a simple reason: many property owners do not invest in risk-reduction measures voluntarily and, in fact, cancel their flood insurance coverage if they haven't suffered a loss for several years. Congress and the administration should revise the NFIP, which covers more than \$1.2 trillion of assets today.

Key Recommendations for Revising the National Flood Insurance Program

Note: The recommendations below are correlated with the priorities listed in the Building Effective Adaptation Policies section at the bottom of this page.

Create multiyear (long-term) flood insurance tied to property (via the length of mortgage) versus the standard one-year policy tied to the property owner. (1, 3, 5)

Ensure that premiums reflect actual risk. (3, 4)

- This will signal property owners about the hazards they face and encourage them to engage in cost-effective mitigation efforts.

Provide public funding to assist existing low-income homeowners currently living in flood-prone areas. (6)

- This will help balance large premium increases when premiums reflect actual risk.

BUILDING EFFECTIVE ADAPTATION POLICIES

RFF worked with representatives from EPA, NOAA, NASA, the Army Corps of Engineers, USDA, CBO, and DOE throughout this process. This group determined that in order to be effective, adaptation policy should do the following:

1. Provide specific guidance for federal rulemaking.
2. Create connections and synergy with other policy areas.
3. Address inefficiencies in current federal legislative and regulatory policy.
4. Supply information and data to enable policymakers to better understand risk and uncertainty.
5. Embed flexibility and responsiveness into management structures.
6. Address equity and social justice concerns.

For more information, see *Encouraging Adaptation to Climate Change: Long-Term Flood Insurance*, an RFF Issue Brief by Howard Kunreuther and Erwann Michel-Kerjan, at www.rff.org/adaptation.

ADAPTATION OF AGRICULTURE and the Food System to Climate Change

Despite substantial research on the effects of a changing climate, relatively few studies have considered the likely costs of adaptation to agriculture and its related sectors. Initiatives that improve this limited understanding will be essential to effective policy development. Based on what we do know, several steps can be taken, including improving existing waste-management and confined-livestock practices and developing climate-resistant crops and livestock.

Key Recommendations for Adapting Agriculture and the Food System

Note: The recommendations below are correlated with the priorities listed in the Building Effective Adaptation Policies section at the bottom of this page.

Increase the stock of knowledge regarding the costs of adaptation in the agricultural sector.

- Estimate agriculture-specific impacts and costs. (3, 4)
- Determine climate impacts on pest and disease management. (4)
- Research adaptation practice effects on ecosystem services. (2, 3, 4)
- Provide public information on long-term climate trends. (1, 2, 3, 4)
- Assess implications of energy and offset policies on the food system. (2, 4)

Improve existing agricultural practices.

- Implement better waste-management and confined-livestock techniques. (2)
- Develop climate-resistant crops and livestock. (3, 5)

BUILDING EFFECTIVE ADAPTATION POLICIES

RFF worked with representatives from EPA, NOAA, NASA, the Army Corps of Engineers, USDA, CBO, and DOE throughout this process. This group determined that in order to be effective, adaptation policy should do the following:

1. Provide specific guidance for federal rulemaking.
2. Create connections and synergy with other policy areas.
3. Address inefficiencies in current federal legislative and regulatory policy.
4. Supply information and data to enable policymakers to better understand risk and uncertainty.
5. Embed flexibility and responsiveness into management structures.
6. Address equity and social justice concerns.

For more information, see *Adaptation of Agriculture and the Food System to Climate Change: Policy Issues*, an RFF Issue Brief by John Antle, at www.rff.org/adaptation.

PUBLIC ADAPTATION TO CLIMATE CHANGE: Pre-Positioned Policy for Effective Responses

Inherent uncertainty concerning the magnitude of impacts on natural resources from climate change makes losses in the supply of service flows inevitable. Demand management of services such as water and electricity will be necessary. “Pre-positioned policies” —policies already developed and embraced politically in advance of environmental events—will be required for an effective response. An example is policies that adjust water prices to accurately reflect scarcity and encourage rationing in times of severe drought. When households, businesses, and governments understand their access to natural resources services will suffer when services are most stressed, they will undertake adaptation actions in advance to limit losses. Flexible pricing strategies and information provision are the two most important categories of pre-positioned policies.

Key Recommendations to Help Design Pre-Positioned, Incentive-Based Adaptation Policies for Resource Use and Investments

Note: The recommendations below are correlated with the priorities listed in the Building Effective Adaptation Policies section at the bottom of this page.

Adopt flexible pricing strategies.

- Institute real-time pricing for electricity for cooling and water, which are substitutes for climate services. (1, 3, 4, 5)
- Use rationing schemes and innovative pricing to enhance use of complementary goods and services to climate goods and services (outdoor recreation, for example). (1, 2, 5)
- Tie prices to varying conditions in different areas, over time, and predictable environmental conditions. (5, 6)
- Design price structures dynamically to adjust to extreme climatic conditions. (1, 5)

Provide information so that businesses and households can respond.

- Develop public information programs to account for the scale of desired action and to consider potential free riders. (4, 5, 6)

BUILDING EFFECTIVE ADAPTATION POLICIES

RFF worked with representatives from EPA, NOAA, NASA, the Army Corps of Engineers, USDA, CBO, and DOE throughout this process. This group determined that in order to be effective, adaptation policy should do the following:

1. Provide specific guidance for federal rulemaking.
2. Create connections and synergy with other policy areas.
3. Address inefficiencies in current federal legislative and regulatory policy.
4. Supply information and data to enable policymakers to better understand risk and uncertainty.
5. Embed flexibility and responsiveness into management structures.
6. Address equity and social justice concerns.

For more information, see *Pre-Positioned Policy as Public Adaptation to Climate Change*, an RFF Issue Brief by Kerry Smith at www.rff.org/adaptation.

ECOSYSTEM SERVICES and Climate Adaptation

Preservation and management of natural wealth—including clean air; clean, plentiful water; productive soils; and a diversity of plant and animal species—are important even in the absence of climate change, but are hampered by imperfect knowledge that links altered environmental conditions to changes in the quantity and/or quality of the services provided by natural systems. Climate change poses new challenges because it is likely to further degrade natural resources. Adapting to climate change will require protecting and managing natural wealth to reduce damages that may be irreversible.

Key Recommendations to Facilitate Protection and Adaptation of Ecological Goods and Services

Note: The recommendations below are correlated with the priorities listed in the Building Effective Adaptation Policies section at the bottom of this page.

Increase investment in evidence-based ecology to focus on the relationship between environmental stressors and the effects on ecological goods and services. (1, 4)

Manage the resilience of ecosystems through hedging strategies. (3)

- This can be done by protecting refuges and investing in restoration and management of natural systems.

Acknowledge the economic option value associated with ecological protection. (4, 5)

- There is value in protecting ecosystems from climate impacts and delaying irreversible damage until uncertainties about the costs of environmental damages are resolved.

Invest in a diversified portfolio of natural resources and systems. (2, 3, 5)

- A diversified portfolio should consider what is being directly consumed, what produces those consumed goods, and changes in demand for the goods.

BUILDING EFFECTIVE ADAPTATION POLICIES

RFF worked with representatives from EPA, NOAA, NASA, the Army Corps of Engineers, USDA, CBO, and DOE throughout this process. This group determined that in order to be effective, adaptation policy should do the following:

1. Provide specific guidance for federal rulemaking.
2. Create connections and synergy with other policy areas.
3. Address inefficiencies in current federal legislative and regulatory policy.
4. Supply information and data to enable policymakers to better understand risk and uncertainty.
5. Embed flexibility and responsiveness into management structures.
6. Address equity and social justice concerns.

For more information, see *Ecosystem Services and Climate Adaptation*, an RFF Issue Brief by James Boyd, at www.rff.org/adaptation.



ISSUE BRIEFS IN THIS CATEGORY:

Better-Defined Rights and Responsibilities in Marine Adaptation Policy

James N. Sanchirico

Adaptation to Climate Change: Revisiting Infrastructure Norms

James Neumann

A Legal Framework for Climate Adaptation Assessment

Daniel Farber

Adaptation to Climate Change in Public Lands Management

Joel Smith and William Travis

Adaptations to Sustain High-Quality Freshwater Supplies in Response to Climate Change

Alan Covich

Public Health: Adapting to Climate Change

Jonathan Samet

Climate Adaptation and Watershed Transboundary Governance Institutions

Marc Landy

Key FINDINGS

Reforming Institutions: Improving Regulation and Management

The United States' legacy of regulation and management of environmental issues and natural resources in the 20th century is impressive and has served as a blueprint for regulations in many other nations. Despite past successes, current regulations and management regimes were established under what were assumed to be static climatic conditions, and they have a mixed record of effectively addressing environmental and natural resource problems. Climate change impacts will present daunting new challenges to the nation's governance and rules structures, some of which are already producing suboptimal results. There are, however, opportunities for policymakers to take action to enhance the ability of management and regulation structures to respond to climate change as well as increase their robustness against eventual impacts.

Adapting to a changing climate is often thought to be local, in that most actions, such as protecting coastal shorelines or sheltering persons during hurricanes, are executed by subnational governments. Yet the federal government can take many steps to improve management efforts and expand the capacity for local governments to act, particularly by coordinating efforts across jurisdictions, and employing innovative options to improve national regulations and management systems for resources such as water and lands, as well as public goods like infrastructure and public health. For example, federal steps could do the following:

- Effectively assign property rights for marine and coastal resources in advance of climate effects.
- Establish ocean governance practices through planning and allocating “use rights.”
- Adopt an “asset management” approach for maintenance of public infrastructure.
- Adjust tax policy to improve treatment of depreciating physical capital and investment in climate-hardy infrastructure.
- Reform soil and water conservation policy to increase flexibility to respond to climate change by improving the ability to adapt land use and respond to extreme events.
- Coordinate regional efforts to cooperate in managing land (such as protecting wildlife corridors).
- Establish and implement a public health heat-warning system.
- Improve infectious disease surveillance systems to detect “signature” diseases associated with a changing climate.
- Form state and federal institutions for transboundary governance of watersheds.
- Enhance coordination of federal and state agencies for long-term planning for water scarcity (for example, by providing deep reservoir storage).
- Update and modernize monitoring of reservoir storage capacity.

Better-Defined Rights and Responsibilities in MARINE RESOURCE MANAGEMENT

Invasive species, overfishing, and the loss of coastal wetlands are some of the factors that weaken marine ecosystems' robustness against climate change. Policies that simultaneously improve the economic and ecological health of our oceans and coasts can increase resilience and better the ability of coastal communities and species to adapt to a changing environment. Two key elements to marine adaptation policy are better-defined rights and responsibilities and more comprehensive governance.

Key Recommendations for Successful Marine and Coastal Resources Adaptation Policies

Note: The recommendations below are correlated with the priorities listed in the Building Effective Adaptation Policies section at the bottom of this page.

Establish better-defined rights and responsibilities for commercial and recreational fisheries.

- Give owners flexibility to choose scale, location, and methods of operation. (3, 5)
- Implement rights-based programs now; they will adapt over time with changing environmental, social, and economic conditions. (2, 3, 5, 6)
- Rights-based programs may generate funds for additional climate research. (3, 4)

Establish an adaptive ocean governance framework that includes comprehensive planning, allocation of dominant use zones and user rights within the zones, and ecological standards. (1, 2, 3, 5, 6)

- Create an ownership ethic that fosters a long-term conservation perspective; rewards innovation; and permits contract negotiations, trades, and cooperative regimes to address use conflicts in marine environments.
- Species adaptations will help sustain existing economic opportunities, and users with an ownership ethic will be in a better position to adapt and prosper from such opportunities.

BUILDING EFFECTIVE ADAPTATION POLICIES

RFF worked with representatives from EPA, NOAA, NASA, the Army Corps of Engineers, USDA, CBO, and DOE throughout this process. This group determined that in order to be effective, adaptation policy should do the following:

1. Provide specific guidance for federal rulemaking.
2. Create connections and synergy with other policy areas.
3. Address inefficiencies in current federal legislative and regulatory policy.
4. Supply information and data to enable policymakers to better understand risk and uncertainty.
5. Embed flexibility and responsiveness into management structures.
6. Address equity and social justice concerns.

For more information, see *Better-Defined Rights and Responsibilities in Marine Adaptation Policy*, an RFF Issue Brief by James N. Sanchirico, at www.rff.org/adaptation.

Adaptation to Climate Change: REVISITING INFRASTRUCTURE NORMS

U.S. infrastructure has enormous value, both directly as a capital asset and indirectly as an essential element contributing to a productive economy. Climate change presents various threats to infrastructure assets, from damage or destruction from extreme events to coastal flooding and effects of higher temperatures on operating costs. However, policy reforms that better prepare public infrastructure for the stresses of climate change, such as improved systems for sharing relevant data, proper use of uncertainty models, and efforts to better link infrastructure planners and climate scientists can mitigate some of these threats. Because of the significant federal role and investment in highways and transportation infrastructure, the best opportunity for federal government to take effective adaptation action is in the transportation sector.

Key Recommendations for Successful Adaptation Policy for Infrastructure

Note: The recommendations below are correlated with the priorities listed in the Building Effective Adaptation Policies section at the bottom of this page.

Adopt a formal asset management approach to public infrastructure maintenance. (1, 3, 5)

- Give more consideration to how climate changes will affect capital investment and maintenance cycles.
- This could yield immediate benefits and provide a framework for incorporating future climate change impacts.

Map major capital infrastructure against locations that are most vulnerable to climate stress, and use the information to guide investment in public infrastructure. (3, 4, 5)

- Actively publicize these results to signal to the private sector the expectations and limits of where infrastructure investment will be federally supported.

Update design standards to ensure that future infrastructure is more resilient to climate change and extreme events. (3, 5)

- This not only will improve the resiliency of structures built in high-risk areas, but also can spur innovation in materials science, engineering, and construction.

BUILDING EFFECTIVE ADAPTATION POLICIES

RFF worked with representatives from EPA, NOAA, NASA, the Army Corps of Engineers, USDA, CBO, and DOE throughout this process. This group determined that in order to be effective, adaptation policy should do the following:

1. Provide specific guidance for federal rulemaking.
2. Create connections and synergy with other policy areas.
3. Address inefficiencies in current federal legislative and regulatory policy.
4. Supply information and data to enable policymakers to better understand risk and uncertainty.
5. Embed flexibility and responsiveness into management structures.
6. Address equity and social justice concerns.

For more information, see *Adaptation to Climate Change: Revisiting Infrastructure Norms*, an RFF Issue Brief by James Neumann, at www.rff.org/adaptation.

A LEGAL FRAMEWORK for Climate Adaptation Assessment

To help guide federal agencies in planning for adaptation, Congress should adopt a National Adaptation Planning Act (NAPA). A model can be found in the National Environmental Policy Act (NEPA), which mandates the preparation of environmental impact statements (EISs). Whereas an EIS focuses on how agency actions affect the environment, adaptation planning would focus on how environmental changes will affect agency missions and how to mitigate potential harm. However, NAPA would go beyond the basic EIS requirements in key ways, as described below.

Key Recommendations for Implementing a National Adaptation Planning Act (NAPA)

Note: The recommendations below are correlated with the priorities listed in the Building Effective Adaptation Policies section at the bottom of this page.

Complete a climate adaptation statement whenever climate change may affect a federal action, program, or activity. (1, 2, 3, 4, 5)

- This would begin by inventorying major projects, activities, or lands under each agency's jurisdiction that may be significantly affected by climate change. (1, 3, 4)

Archive climate adaptation statements in a searchable, online database to improve access to and accuracy of information. (3, 4, 5)

- The statements should require periodic follow-up to determine the accuracy of predictions and incorporate updates (such as recent events and public concern). (4, 5, 6)
- Statements should be linked to a geographic information system (GIS) so that adaptation efforts in particular geographic areas can be easily tracked.

Clearly identify uncertainties regarding climate impacts, including disagreements between models, areas of scientific disagreement, and gaps in necessary data. (1, 3, 4)

- Rather than planning only for the scenario it considers most likely, an agency would consider a range of possibilities.

BUILDING EFFECTIVE ADAPTATION POLICIES

RFF worked with representatives from EPA, NOAA, NASA, the Army Corps of Engineers, USDA, CBO, and DOE throughout this process. This group determined that in order to be effective, adaptation policy should do the following:

1. Provide specific guidance for federal rulemaking.
2. Create connections and synergy with other policy areas.
3. Address inefficiencies in current federal legislative and regulatory policy.
4. Supply information and data to enable policymakers to better understand risk and uncertainty.
5. Embed flexibility and responsiveness into management structures.
6. Address equity and social justice concerns.

For more information, see *A Legal Framework for Climate Adaptation Assessment*, an RFF Issue Brief by Daniel Farber, at www.rff.org/adaptation.

Adaptation to Climate Change in PUBLIC LANDS MANAGEMENT

Climate change can significantly alter federal public lands, creating grasslands out of forests and causing species to migrate to other areas. These changes have serious implications for federal public lands that are managed for specific uses. Additionally, the division of lands management among different agencies—the U.S. Forest Service (USFS), the National Park Service (NPS), the Bureau of Land Management (BLM), and the U.S. Fish and Wildlife Service (FWS)—creates additional challenges to efficiently addressing the effects of climate change. These agencies will need a process for creating the flexibility needed to adapt to a changing climate.

Key Recommendations for Incorporating Climate Change into Public Lands Management

Note: The recommendations below are correlated with the priorities listed in the Building Effective Adaptation Policies section at the bottom of this page.

Short-term policy recommendations

- Exhibit strong, consistent leadership by identifying lead agencies for adaptation actions. (1, 3)
- Conduct vulnerability assessments and incorporate climate change considerations into agency and cross-agency strategic planning. (1, 2, 3, 4)
- Develop monitoring systems and richer information sources to help decisionmaking. (3, 4, 5)
- Institute regional public-private partnerships to address climate change at various scales. (2, 3)
- Fully implement adaptive and ecosystems management, examining outdated management practices and integrating climate change into decisionmaking. (1, 3, 5)
- Create a multi-agency system of coordinated climate research programs and expertise. (4)
- Expand experimental adaptation strategies and tactics on public lands. (1, 3, 5)

Long-term policy recommendations

- Revise legislation to allow for more unified management of federal lands. (1, 2, 5)
- Explore federal government organizational changes to promote more integrated planning. (1, 4)
 - Integrate land management within the Department of the Interior and create a Department of Natural Resources. (1, 2, 3)

BUILDING EFFECTIVE ADAPTATION POLICIES

RFF worked with representatives from EPA, NOAA, NASA, the Army Corps of Engineers, USDA, CBO, and DOE throughout this process. This group determined that in order to be effective, adaptation policy should do the following:

1. Provide specific guidance for federal rulemaking.
2. Create connections and synergy with other policy areas.
3. Address inefficiencies in current federal legislative and regulatory policy.
4. Supply information and data to enable policymakers to better understand risk and uncertainty.
5. Embed flexibility and responsiveness into management structures.
6. Address equity and social justice concerns.

For more information, see *Adaptation to Climate Change in Public Lands Management*, an RFF Issue Brief by Joel Smith and William Travis, at www.rff.org/adaptation.

Adaptations to SUSTAIN HIGH-QUALITY FRESHWATER SUPPLIES in Response to Climate Change

Climate change will affect the availability and quality of freshwater. Current methods to provide sustainable water supplies during droughts, floods, and hurricanes may not be effective under new circumstances. Innovative policy approaches and improved information sharing are needed to help create solutions to limited water supplies.

Key Recommendations for Sustaining High-Quality Freshwater Supplies

Note: The recommendations below are correlated with the priorities listed in the Building Effective Adaptation Policies section at the bottom of this page.

Increase redundancy in water systems for more resilience during shortages. (2, 5)

Integrate various data sources to improve communication regarding changes in climate and water supplies. (2, 4)

- Improve satellite observation and atmospheric modeling to enhance public alert systems. (3, 4, 5, 6)

Increase protected floodplains, green roofs, water gardens, and other infrastructure to slow runoff and reduce erosion during floods. (2, 5)

- Separate stormflow runoff systems from sewage treatment systems to increase water quality during floods. (2, 5)

Evaluate and upgrade water storage and treatment infrastructure. (1, 5)

Lower the risk of catastrophic losses by revising the National Flood Insurance Program to consider the full costs of floods. (1, 2, 3)

Promote innovation and best practices by developing public-private partnerships and conducting regional comparisons of responses to extreme events. (2, 4)

BUILDING EFFECTIVE ADAPTATION POLICIES

RFF worked with representatives from EPA, NOAA, NASA, the Army Corps of Engineers, USDA, CBO, and DOE throughout this process. This group determined that in order to be effective, adaptation policy should do the following:

1. Provide specific guidance for federal rulemaking.
2. Create connections and synergy with other policy areas.
3. Address inefficiencies in current federal legislative and regulatory policy.
4. Supply information and data to enable policymakers to better understand risk and uncertainty.
5. Embed flexibility and responsiveness into management structures.
6. Address equity and social justice concerns.

For more information, see *Adaptations to Sustain High-Quality Freshwater Supplies in Response to Climate Change*, an RFF Issue Brief by Alan Covich, at www.rff.org/adaptation.

PUBLIC HEALTH: Adapting to Climate Change

While climate change does not create new health problems, it can worsen known problems (such as heat exposure and aeroallergen distribution) and change patterns of infectious diseases (such as those caused by insects). In fact, these impacts are already being felt to some degree. Existing public health surveillance systems in the United States are sufficiently comprehensive and sensitive to detect potential effects of climate change on health, including infectious disease surveillance systems. Consequently, policy recommendations related to climate change and public health reflect the need to sustain and refine current measures to maintain their sensitivity to climate change.

Key Recommendations for Reinforcing Public Health Systems

Note: The recommendations below are correlated with the priorities listed in the Building Effective Adaptation Policies section at the bottom of this page.

Ensure that systems to track public health can detect the effects of climate change on health. (2, 5, 6)

- This requires analyzing data, reviewing findings, taking action when needed, and monitoring for consequences.

Ensure that infectious disease surveillance systems can detect “signature” diseases related to climate change. (1, 4, 6)

Establish heat warning systems and increase public awareness of heat exposure consequences. (4, 6)

Build awareness of climate change effects on health among medical practitioners. (1, 4, 6)

- Clinicians are critical to tracking public health and will be better prepared if they are alerted to the potential health consequences of climate change.

Educate medical practitioners and patients about climate changes that may affect asthma and other allergies. (4)

BUILDING EFFECTIVE ADAPTATION POLICIES

RFF worked with representatives from EPA, NOAA, NASA, the Army Corps of Engineers, USDA, CBO, and DOE throughout this process. This group determined that in order to be effective, adaptation policy should do the following:

1. Provide specific guidance for federal rulemaking.
2. Create connections and synergy with other policy areas.
3. Address inefficiencies in current federal legislative and regulatory policy.
4. Supply information and data to enable policymakers to better understand risk and uncertainty.
5. Embed flexibility and responsiveness into management structures.
6. Address equity and social justice concerns.

For more information, see *Public Health: Adapting to Climate Change*, an RFF Issue Brief by Jonathan Samet, at www.rff.org/adaptation.

Climate Adaptation and WATERSHED TRANSBOUNDARY GOVERNANCE Institutions

Many of the problems associated with adaptation to climate change involve water quantity (too much or too little) or water quality (polluted or clean). These issues are difficult to manage using conventional governing institutions because they involve watersheds that spill over state and local borders. This makes it impossible to govern watersheds on a state-by-state basis, so federal agencies play a critical role in water quantity and quality issues. To ensure an effective and unified approach to watershed management, the federal government should encourage the creation of state-federal Watershed Transboundary Governing Institutions (Watershed TGIs).

Key Recommendations for the Formation of State-Federal Watershed TGIs

Note: The recommendations below are correlated with the priorities listed in the Building Effective Adaptation Policies section at the bottom of this page.

Give state-federal Watershed TGIs regulatory authority over specified major watersheds. (1, 2, 3, 5)

- Clearly defined and established authority for all parties has a direct effect on the level of performance.

Appoint state governors to serve as official representatives on Watershed TGIs to ensure political accountability. (5)

Grant Watershed TGIs the authority to execute their own specific projects. (1, 2, 3, 5)

- This will provide the flexibility for the Watershed TGI to function more like a planning agency than merely an authority with veto power over projects.

Ensure a single federal perspective is represented by the federal representative to the Watershed TGIs. (1, 5)

- The lack of a unified federal voice can impede successful policy integration.

BUILDING EFFECTIVE ADAPTATION POLICIES

RFF worked with representatives from EPA, NOAA, NASA, the Army Corps of Engineers, USDA, CBO, and DOE throughout this process. This group determined that in order to be effective, adaptation policy should do the following:

1. Provide specific guidance for federal rulemaking.
2. Create connections and synergy with other policy areas.
3. Address inefficiencies in current federal legislative and regulatory policy.
4. Supply information and data to enable policymakers to better understand risk and uncertainty.
5. Embed flexibility and responsiveness into management structures.
6. Address equity and social justice concerns.

For more information, see *Climate Adaptation and Watershed Transboundary Governance Institutions*, an RFF Issue Brief by Marc Landy, at www.rff.org/adaptation.



ISSUE BRIEFS IN THIS CATEGORY:

Climate Adaptation Policy: The Role and Value of Information

Molly Macauley

Climate Adaptation and Federal Megadisaster Policy: Lessons from Katrina

Marc Landy

Adapting to Extreme Events: Managing Fat Tails

Carolyn Kousky and Roger Cooke

Climate Dependencies and Risk Management: Microcorrelations and Tail Dependence

Roger Cooke and Carolyn Kousky

Promoting Innovative Climate Adaptation through Federalism

Winston Harrington

Key FINDINGS

Providing Information and Managing Extremes

Climate change presents such a vexing challenge for human societies because it will change the baseline conditions under which we have flourished. As the climate baseline shifts, events that were once considered extreme and rare will occur with greater frequency and stronger intensity. As a result, formerly reliable buffers against severe events like hurricanes, floods, and droughts will become less effective. Similarly, historical benchmarks will no longer provide useful guidance for at-risk communities to adjust to new climate paradigms. The need is clear for new and better information that can help decisionmakers steer resources toward their most effective use, and that need will only grow with time.

The supply of information, including that required to enable the public to anticipate extreme events, has long been a role of government. Climate scientists at present collect massive amounts of data to model and measure the physical properties of Earth's climate. But which of these data are most useful for preparing the nation to adapt to a changing climate, including extreme events? What is the federal role in anticipating the possibility of abrupt climate change? When better data are available, how can the federal government help utilize them to assist in preparation? Here, recommendations are wide-ranging and include the following:

- Enhance use of climate data and climate science to improve understanding of micro-correlations and tail dependencies induced by climate change. These correlations have implications for the ability of the global insurance industry to diversify its portfolio of insured risks.
- Use principles of the “economics of information” to identify what information is worth federal investment to acquire, as budgets for information collection and dissemination are limited.
- Consider design of an early warning system for extreme climate events, perhaps on the timescales of geologic hazard warning protocols.
- Identify the “weakest link” among those who need to receive and act on information—whether the local emergency responder or the Federal Emergency Management Agency (FEMA).
- Improve the length of lead time in providing El Niño–Southern Oscillation (ENSO) forecasts.
- More tightly couple U.S. investment in global climate observing systems to the policy relevance of data obtained from these systems.
- Improve coordination of all federal agencies with responsibilities for responding to “megadisasters” in the event of large-scale damages and loss of life.
- Require federal agencies to design recovery plans for disaster response.
- Propose and fund a presidential-level, inter-agency national recovery plan.

Climate Adaptation Policy: THE ROLE AND VALUE OF INFORMATION

One of the federal government's largest roles in climate adaptation is the supply of information, and because information is not costless, identifying and prioritizing that of the highest value is critical. Perfect information, however, may not be worth the cost of acquisition, and furthermore, it may be less useful if responsive action would have little impact or if the costs of inaction are small. The nation has made a large investment in climate science and data collection and now must shape this knowledge into useful information relevant to local, regional, and state decisionmaking. Of particular importance is greater study of indicators of possible abrupt climate change, defined by the National Research Council as large-scale and persistent changes in the climate system that take place over a few decades or less and cause significant disruptions in human and natural systems.

Key Recommendations for Assessing, Valuing, and Using Climate Information for Adaptation Activities

Note: The recommendations below are correlated with the priorities listed in the Building Effective Adaptation Policies section at the bottom of this page.

Adopt guiding principles for valuing and prioritizing information and data collection and analysis. (1, 2, 3, 5)

Link the nearly 50 climate variables (that scientists have already identified as essential for understanding climate) more closely to help solve the problems of adaptation. (1, 2)

Increase information gathering at spatial scale relevant to regional, state, and local decisions. (1, 4, 5)

Use understanding of Earth systems to identify climate-induced, financially relevant microcorrelations. (3, 4, 5)

Investigate what information is necessary to identify early indicators of climate tipping points. (3, 4, 5, 6)

BUILDING EFFECTIVE ADAPTATION POLICIES

RFF worked with representatives from EPA, NOAA, NASA, the Army Corps of Engineers, USDA, CBO, and DOE throughout this process. This group determined that in order to be effective, adaptation policy should do the following:

1. Provide specific guidance for federal rulemaking.
2. Create connections and synergy with other policy areas.
3. Address inefficiencies in current federal legislative and regulatory policy.
4. Supply information and data to enable policymakers to better understand risk and uncertainty.
5. Embed flexibility and responsiveness into management structures.
6. Address equity and social justice concerns.

For more information, see *Climate Adaptation Policy: The Role and Value of Information*, an RFF Issue Brief by Molly K. Macauley, at www.rff.org/adaptation.

Climate Adaptation and FEDERAL MEGADISASTER POLICY

Determining who is in charge and accountable in the event of a massive natural disaster, including severe storms and other events possibly linked with climate change, is a consistent, fundamental problem. Red tape, unclear lines of responsibility and authority, and a host of other barriers too often impede the delivery of immediate emergency aid as well as long-term delivery of recovery services. One way to address this issue is for Congress to provide the president with authority to appoint an “officer in charge” (OIC) to oversee and manage the federal government’s response to a megadisaster immediately after it occurs. A dedicated leader in the aftermath of a natural disaster could wield authority to orchestrate a response campaign and help integrate and adapt existing institutional policies to emergency situations.

Key Recommendations for Federal Megadisaster Management with an Officer in Charge (OIC)

Note: The recommendations below are correlated with the priorities listed in the Building Effective Adaptation Policies section at the bottom of this page.

The OIC coordinates federal response efforts. (1, 2, 3, 5)

- This will address some inefficiencies with coordinating multiple agencies.

The OIC convenes relevant state and local officials and leads recovery planning effort. (2, 3, 5)

The OIC manages a dedicated budget of at least \$100 million. (5)

- This authority includes transferring federal officials to temporary posts if needed.

The OIC assesses the need for and, if necessary, proposes a national recovery plan to the president. (1, 3, 5)

BUILDING EFFECTIVE ADAPTATION POLICIES

RFF worked with representatives from EPA, NOAA, NASA, the Army Corps of Engineers, USDA, CBO, and DOE throughout this process. This group determined that in order to be effective, adaptation policy should do the following:

1. Provide specific guidance for federal rulemaking.
2. Create connections and synergy with other policy areas.
3. Address inefficiencies in current federal legislative and regulatory policy.
4. Supply information and data to enable policymakers to better understand risk and uncertainty.
5. Embed flexibility and responsiveness into management structures.
6. Address equity and social justice concerns.

For more information, see *Climate Adaptation and Federal Megadisaster Policy: Lessons from Katrina*, an RFF Issue Brief by Marc Landy, at www.rff.org/adaptation.

Adapting to Extreme Events: MANAGING “FAT TAILS”

Damages from natural disasters fueled by climate change may be “fat tailed,” meaning that future disasters that are at least as bad as the largest experienced to date may be orders of magnitude greater than those that have already occurred. For example, the most costly hurricane to hit the United States was Hurricane Katrina, which caused more than \$100 billion in damages. The second-costliest was Hurricane Andrew, which the National Oceanic and Atmospheric Administration (NOAA) estimates caused \$35.6 billion in damages. The frightening implication of fat tails is that the next hurricane we observe that is *at least as bad* as Katrina could be much, much worse.

Damages from natural disasters are the result of not just the severity of the hazard (such as wind speeds in hurricanes), but also the housing and other development that affected communities have undertaken. Additionally, increased development in hazardous areas and underinvestment in protection have caused the economic damages from natural disasters to rise in inflation-adjusted terms, and extreme events may become increasingly expensive to insure. Insurance-linked securities and tax-deferred catastrophe reserves could enhance the affordability and availability of private insurance. A more robust response to fat-tailed damage distributions is to reduce damages through cost-effective mitigation measures. Mitigation provides public as well as private benefits, and government could speed adoption through a variety of policy incentives.

Key Recommendations for Adapting to Extreme Events and Managing Fat Tails

Note: The recommendations below are correlated with the priorities listed in the Building Effective Adaptation Policies section at the bottom of this page.

Utilize insurance-linked securities and tax-deferred catastrophe reserves to cover disaster losses. (1, 3, 5)

Employ risk-based rates in the National Flood Insurance Program. (2, 3, 5)

Reduce damages through cost-effective mitigation measures. (5)

BUILDING EFFECTIVE ADAPTATION POLICIES

RFF worked with representatives from EPA, NOAA, NASA, the Army Corps of Engineers, USDA, CBO, and DOE throughout this process. This group determined that in order to be effective, adaptation policy should do the following:

1. Provide specific guidance for federal rulemaking.
2. Create connections and synergy with other policy areas.
3. Address inefficiencies in current federal legislative and regulatory policy.
4. Supply information and data to enable policymakers to better understand risk and uncertainty.
5. Embed flexibility and responsiveness into management structures.
6. Address equity and social justice concerns.

For more information, see *Adapting to Extreme Events: Managing Fat Tails*, an RFF Issue Brief by Carolyn Kousky and Roger Cooke, at www.rff.org/adaptation.

Climate Dependencies and Risk Management: MICROCORRELATIONS and TAIL DEPENDENCE

Microcorrelations are tiny correlations among variables (such as insurance policies, mortgages, and bonds) that are easily overlooked but can undermine traditional diversification strategies. For instance, weather-related events in widely separated parts of the world could be correlated through the intricacies of global climate patterns. Also not widely recognized is a link among events, known as tail dependence, which refers to the tendency of dependence between variables to concentrate in the extreme values (the “tails” of distributions, when represented graphically); more simply, this means that bad things often happen together. Hurricane Katrina provided a salient example of this effect—lines of insurance that are usually independent all experienced large losses, including cargo, inland marine and recreational watercraft, floating casinos, onshore energy, automobile, workers’ compensation, and health and life insurance.

Microcorrelations and tail dependence are generally not well understood or appreciated by risk managers and policymakers, and failure to take these interdependencies into account can lead to undercapitalization in insurance markets and unintended risk-taking in other sectors. Better understanding of these effects can lead to actions that may separate some interdependencies (for example, the design and installation of water and gas lines to be more resilient against extreme events) and give rise to novel approaches to managing risk from climate change.

Key Recommendations to Manage Risk Related to Microcorrelations and Tail Dependence

Note: The recommendations below are correlated with the priorities listed in the Building Effective Adaptation Policies section at the bottom of this page.

Adopt mitigation strategies that target tail dependencies and avoid undercapitalization and unintended risk-taking. (2, 5)

Invest in research to identify climate-induced shifts in microcorrelation and tail-dependence patterns. (4, 5)

BUILDING EFFECTIVE ADAPTATION POLICIES

RFF worked with representatives from EPA, NOAA, NASA, the Army Corps of Engineers, USDA, CBO, and DOE throughout this process. This group determined that in order to be effective, adaptation policy should do the following:

1. Provide specific guidance for federal rulemaking.
2. Create connections and synergy with other policy areas.
3. Address inefficiencies in current federal legislative and regulatory policy.
4. Supply information and data to enable policymakers to better understand risk and uncertainty.
5. Embed flexibility and responsiveness into management structures.
6. Address equity and social justice concerns.

For more information, see *Climate Dependencies and Risk Management: Microcorrelations and Tail Dependence*, an RFF Issue Brief by Roger Cooke and Carolyn Kousky, at www.rff.org/adaptation.

Promoting Innovative Climate Adaptation through FEDERALISM

There is still much to be learned about adaptation policy, including what will work, how to best implement it, and what will have the greatest impact. Fortunately, there is a growing abundance of policy ideas as more researchers and entrepreneurs turn their attention to adaptation. Similarly, states, counties, and cities have long served as experimental laboratories for testing policy ideas before their broader, nationwide adoption. A federal program of generous and competitive grants can encourage state and local governments—and perhaps other organizations—to adopt and implement innovative experimental policy ideas in a real-world environment.

Key Recommendations to Encourage Adaptation Innovation through a Federal Grant Program

Note: The recommendations below are correlated with the priorities listed in the Building Effective Adaptation Policies section at the bottom of this page.

Establish a Policy Grants Division within the U.S. Global Change Research Program. (1, 2)

- The Policy Grants Division will manage the grant program, which will invite state and local government agencies to submit proposals for funds to implement actual policy demonstration projects.

Use a competitive grants evaluation process. (1, 5)

- Proposals will be judged on their contribution to practical knowledge, their implementation feasibility, their relevance to other states and localities, and their budget.

Build an independent and well-qualified review panel. (1, 5)

- Safeguards would need to be established to shield the program from political influence.

Conduct independent evaluations of policies after implementation. (1, 4, 5)

BUILDING EFFECTIVE ADAPTATION POLICIES

RFF worked with representatives from EPA, NOAA, NASA, the Army Corps of Engineers, USDA, CBO, and DOE throughout this process. This group determined that in order to be effective, adaptation policy should do the following:

1. Provide specific guidance for federal rulemaking.
2. Create connections and synergy with other policy areas.
3. Address inefficiencies in current federal legislative and regulatory policy.
4. Supply information and data to enable policymakers to better understand risk and uncertainty.
5. Embed flexibility and responsiveness into management structures.
6. Address equity and social justice concerns.

For more information, see *Promoting Innovative Climate Adaptation through Federalism*, an RFF Issue Brief by Winston Harrington, at www.rff.org/adaptation.

CONCLUSIONS

Adapting to the impacts of climate change is going to be a long-term process that will involve diverse sets of stakeholders and institutions. Adaptation is not simply a matter of responding to crises as they develop, but will require a wholesale shift of existing regulations and governance systems to more accurately reflect new climate realities. It is not a simple problem, nor are the solutions as clear as some argue they are for mitigation. Yet adaptation is not an impossible problem. Indeed, significant adaptive capacity exists within the current structures of the federal government to catalyze useful adaptation measures at national, state, and local levels. This potential needs to be harnessed, however, if the United States is going to adapt effectively. The recommendations made in this report are an attempt to highlight some salient opportunities for timely adaptation actions. They are first steps on the path to engendering more resilience and robustness against climate change in the structure and actions of the federal government, as well as allowing it to provide the proper support to state and local governments.

Many of these recommended actions are ones that can not only gird the ability of people in the United States to respond to climate impacts, but also shine a light on existing inefficiencies embedded in regulations and management regimes. Several are “no-regrets” actions that have added value with regard to their potential for efficient adaptation. Moreover, steps taken now may allow the federal government to learn important lessons in implementation and from mistakes at a time when the impacts of climate change are muted and risks are lower than in the future. As such, we hope that federal decisionmakers will seriously consider the insightful and



salient findings highlighted throughout this summary report. The challenges of climate change adaptation are great, but the United States now has the opportunity to address them effectively and vigorously to the benefit of all its citizens.

ACKNOWLEDGEMENTS

We gratefully acknowledge the financial support of the Smith Richardson Foundation, which supported our effort at a time in the nation's history when climate adaptation was taking a back seat to a flurry of efforts to mitigate greenhouse gas emissions. We are additionally grateful for the foundation's willingness to allow us academic freedom in the conduct of the study. Responsibility for errors and opinions in this summary report rests solely with its authors.

This report draws liberally from experts who wrote studies for both phases of this project. Phase One consisted of summaries of the state of scientific understanding of the effects of climate change on infrastructure, freshwater, marine resources, terrestrial ecosystems, agriculture, and public health. Authors of these studies were as follows:

John M. Antle, Oregon State University
Alan P. Covich, University of Georgia
David Kling, University of California, Davis
L. Scott Mills, University of Montana
James Neumann, Industrial Economics, Inc.
Jason C. Price, Industrial Economics, Inc.
Steven W. Running, University of Montana
Jonathan Samet, University of Southern California
James N. Sanchirico, University of California, Davis

Phase Two consisted of policy recommendations described within issue briefs on topics of reforming institutions and getting prices right, improving regulation and management, and providing information and managing extremes. Authors of the issue briefs were as follows:

John M. Antle, Oregon State University
James Boyd, Resources for the Future
Roger Cooke, Resources for the Future
Alan P. Covich, University of Georgia
Daniel A. Farber, University of California, Berkeley
Winston Harrington, Resources for the Future
Carolyn Kousky, Resources for the Future
Howard Kunreuther, University of Pennsylvania
Marc Landy, Boston College
Molly K. Macauley, Resources for the Future
Erwann Michel-Kerjan, University of Pennsylvania
James Neumann, Industrial Economics, Inc.
Jonathan Samet, University of Southern California
James N. Sanchirico, University of California, Davis
Joel B. Smith, Stratus Consulting
V. Kerry Smith, Arizona State University
William R. Travis, University of Colorado, Boulder

Almost 40 experts from federal agencies and nongovernmental organizations provided comments and interpretations on our work during two workshops held in October 2008 and June 2010. We are grateful to them for their insights and critiques.

We also thank Winston Harrington for his intellectual insight during the drafting of the summary report, as well as Adrienne Foerster, Felicia Day, Shannon Wulf, and Peter Nelson for their editorial expertise; Ellen A. Walter for her design expertise; and Tiffany Clements for her technical Web-based expertise.

REFERENCES

- Adger, W.N., S. Agrawala, M.M.Q. Mirza, C. Conde, K. O'Brien, J. Pulhin, R. Pulwarty, B. Smit, and K. Takahashi. 2007. Assessment of Adaptation Practices, Options, Constraints and Capacity. In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson. Cambridge: Cambridge University Press, 717–743.
- Arvai, J., G. Bridge, N. Dolsak, R. Franzese, T. Koontz, A. Luginbuhl, P. Robbins, K. Richards, K.S. Korfmacher, B. Sohngen, et al. 2006. Adaptive Management of the Global Climate Problem: Bridging the Gap between Climate Research and Climate Policy. *Climatic Change* 78(1): 217–225.
- Berkhout, Frans. 2005. Rationales for adaptation in EU climate change policies. *Climate Policy* 5: 377–391.
- Fankhauser, S., J. Smith, and R. Tol. 1999. Weathering climate change: some simple rules to guide adaptation decisions. *Ecological Economics* 30: 67–78.
- Lempert, Robert J., Michael E. Schlesinger, Steven C. Bankes, and Natalia G. Andronova. 2000. The Impact of Variability on Near-Term Climate-Change Policy Choices and the Value of Information. *Climatic Change* 45(1): 129–161.
- Mendelsohn, Robert. 2006. The Role of Markets and Governments in Helping Society Adapt to a Changing Climate. *Climatic Change* 78(1): 203–215.
- Moser, Susanne C., and Amy Lynd Luers. 2008. Managing climate risks in California: the need to engage resource managers for successful adaptation to change. *Climatic Change* 87(1): 309–322.
- Repetto, Robert, 2008. The Climate Crisis and the Adaptation Myth. Working paper 13. New Haven, CT: Yale School of Forestry and Environmental Studies.
- Schilling, K., and E. Stakhiv. 1998. Global Change and Water Resource Management. *Water Resource Update* 112: 1–5.
- Settle, Chad, Jason F. Shogren, and Sally Kane. 2007. Assessing mitigation-adaptation scenarios for reducing catastrophic climate risk. *Climatic Change* 83(4): 443–456.
- Smith, J.B., J.M. Vogel, T.L. Cruce, S. Seidel, and H.A. Holsinger. 2010. Adapting to Climate Change: A Call for Federal Leadership. Arlington, VA: Pew Center on Global Climate Change.
- Swart, Rob, and Frank Raes. 2007. Making integration of adaptation and mitigation work: mainstreaming into sustainable development policies? *Climate Policy* 7: 288–303.
- United States Global Change Research Program (USGCRP). 2009. *Global Climate Change Impacts in the United States*, edited by Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson. New York: Cambridge University Press.
- Walker, B., C.S. Holling, S.R. Carpenter, and A. Kinzig. 2004. Resilience, Adaptability and Transformability in Social-Ecological Systems. *Ecology and Society* 9(2): 5
- Wright, Evelyn L., and Jon D. Erickson. 2003. Incorporating Catastrophes into Integrated Assessment: Science, Impacts, and Adaptation. *Climatic Change* 57(3): 265–286.



RESOURCES
FOR THE FUTURE

1616 P St. NW • Washington, DC 20036-1400

WWW.RFF.ORG