Recommendations for Future Work

Through the creation of this report on global climate change impacts in the United States, several important but unresolved research issues of importance for decision making were identified. Below, we summarize five high-priority research recommendations that would greatly reduce current gaps in our understanding and responding to climate change impacts.

Recommendation 1: Expand our understanding of climate change impacts.

There is a clear need to increase understanding of how ecosystems, social and economic systems, human health, and the built environment will be affected by climate change in the context of other stresses. New understanding will come from a mix of activities including sustained and systematic observations, field and laboratory experiments, model development, and integrated impacts assessments. These will incorporate shared learning among researchers, practitioners (such as engineers and water managers), and local stakeholders.

Ecosystems

Ecosystem changes, in response to changes in climate and other environmental conditions, have already been documented. These include changes in the chemistry of the atmosphere, precipitation, vegetation patterns, growing season length, plant productivity, species distributions, and the frequency and severity of pest outbreaks and fires. These observations not only document climate-change impacts, but also provide critical input to understanding how and why these changes occur. In this way, records of observed changes can aid projections of future impacts related to various climate-change scenarios.

In addition to observations, large-scale, whole-ecosystem experiments are essential for improving projections of impacts. Ecosystem-level experiments that vary multiple factors, such as temperature, moisture, and atmospheric carbon dioxide, will provide process-level understanding of the ways ecosystems could respond to climate change in the context of other environmental stresses. Such experiments are particularly useful for identifying potential thresholds or tipping points in ecosystems.

Insights regarding ecosystem responses to climate change gained from both observations and experiments are the essential building blocks of ecosystem simulation models. These models, when rigorously developed and tested, provide powerful tools for exploring the ecosystem consequences of alternative future climates. The incorporation of ecosystem models into an integrated assessment framework that includes socioeconomic, atmospheric chemistry, and atmospheric-ocean general circulation models should be a major goal of impacts research.

Economic Systems, Human Health, and the Built Environment

As natural systems experience changes due to a changing climate, social and economic systems will be affected. Food production, water resources, forests, parks, and other managed systems provide life support for society. Their sustainability will depend on how well they can adapt to a future climate that will be different form historical experience.

At the same time, climate change is exposing human health and the built environment to risk. Among the likely impacts are the expansion of the ranges of insects and other animals that carry diseases, and the greater incidence of health threatening air pollution events

compounded by unusually hot weather as a result of climate change. In coastal areas, sea-level rise and storm surge threaten infrastructure including homes, roads, ports, and oil and gas drilling and distribution facilities. In other parts of the country, floods, droughts, and other weather and climate extremes pose threats.

Careful observations combined with climate and Earth system models run with a range of emissions scenarios can help society think clearly about these risks and plan actions to minimize them. Work in this area would include assessments of the performance of systems, such as those for regional water and electricity supply, so that climate change impacts can be evaluated as changes in risk to system performance. It will be particularly important to understand when effects on these systems are extremely large and/or rapid, similar to tipping points and thresholds in ecosystems.

Recommendation 2:
Refine ability to project climate change at local scales.

One of the main messages to emerge from the past decade of synthesis and assessments is that while climate change is a global issue, it has a great deal of regional variability. There is an indisputable need to improve understanding of climate system effects at these smaller scales, because these are often the scales of decision-making in society. Although much progress has been made in understanding important aspects of this variability, important uncertainties remain. Because region-specific climate changes will occur in the context of other environmental and social changes that are also region-specific, it is important to continue to refine our understanding of regional details, especially those related to precipitation and soil moisture. This requires further testing of models against observations using established metrics designed to evaluate and improve the realism of regional model simulations. Success will also require development of improved higher resolution climate models and extensive climate model experiments, higher resolution regional observations, and increased computational capacity. This will enable and improve methods for downscaling climate projections so that they are geographically specific enough to be useful to decision makers in government, business, and the general population.

Extreme weather and climate events are a key component of regional climate. Additional attention needs to be focused on improved observations, research, and analysis of the potential for future changes in extremes. Impacts analyses indicate that extreme weather and climate events often play a major role in determining climate-change consequences.

Recommendation 3:
Expand capacity to provide decision makers and the public with relevant information on climate change and its impacts.

The United States has tremendous potential to create more comprehensive measurement, archive, and data-access systems that could provide great benefit to society. Improved climate monitoring can be efficiently achieved by following the Climate Monitoring Principles recommended by the National Academy of Sciences and the Climate Change Science Strategic Plan in addition to integrating current efforts of governments at all levels. Such a strategy complements a long-term commitment to the measurement of the set of essential climate variables identified by both the Climate Change Science Program and the Global Climate Observing System. Attention must be placed on the global to regional scales critical for decision-making.

Improved impacts monitoring would include information on physical and economic effects of extreme events (such as floods and droughts), available from emergency preparedness and resource management authorities. This would require regular archiving of information about impacts.

Easily accessible data and information archives could substantially enhance society's ability to respond to climate-change. Available information should include a set of baseline indicators and measures of environmental conditions that can be used to track the effects of changes in climate. Services that provide reliable, well documented, and

easily used climate information are an essential part of this much-needed capacity.

Recommendation 4:
Improve understanding of and ability to identify thresholds likely to lead to abrupt changes in the climate system.

Paleoclimatic data shows that climate can and has changed quite abruptly when certain thresholds are crossed. Similarly, there is evidence that ecological and human systems can undergo abrupt change when tipping points are reached.

Within the climate system there are a number of key risks to society where understanding is still quite limited. Additional research is needed in some key areas, including identifying thresholds that lead to human-induced rapid changes in ice sheet dynamics and changes in the water cycle. Sea-level rise is a major concern and improved understanding of the sensitivity of the major ice sheets to sustained warming requires improved observing capability, analysis, and modeling. Estimates of sea-level rise in previous assessments, such as the recent Intergovernmental Panel on Climate Change 2007 assessment, could not definitively quantify the magnitude and rate of future sea-level rise due to inadequate scientific understanding of potential instabilities of the Greenland and Antarctic ice sheets. Another issue is potential rapid increases in rainfall intensity which, when combined with sea-level rise, exacerbate coastal zone inundation. Rapid changes in the water cycle can also have profound impacts on other human and ecological systems, as well as the carbon cycle and the amount of carbon dioxide in the atmosphere. Such complex interactions should be factored into assessments of carbon dioxide emission reduction strategies.

Recommendation 5:
Enhance understanding of how society can adapt to climate change in the context of multiple stresses.

There is currently limited knowledge about the ability of communities, regions, and sectors to adapt to future climate change. It is essential to improve understanding of how the capacity to adapt to a changing climate might be exercised, and the vulnerabilities to climate change and other environmental stresses that might remain. Interdisciplinary research on adaptation should thus be a high priority.

There is a large amount of information on how people and institutions have responded to climate variability and other environmental changes in the past. The potential now exists to provide insights into the possible effectiveness of adaptation options that might be considered in the future. To realize this potential, new research will be required that documents past responses, analyzes the underlying reasons for them, and explains how individual and institutional decisions were made.

A major difficulty for the analysis of adaptation strategies in this report has been the lack of information about the potential costs of adaptation measures, their effectiveness within scenarios of climate change, the time horizons required for their implementation, and unintended consequences. These types of information should be systematically gathered and shared with decision makers as they consider a range of adaptation options.

Finally, it is important to carry out regular assessments of adaptation measures that address combined scenarios of future climate change, population growth, and economic development paths. This is an important opportunity to create shared learning exercises in which researchers, practitioners, and stakeholders collaborate using observations, models, and dialogue to explore adaptation as part of long-term sustainable development planning.