6 Vulnerability Assessment, Climate Change Impacts, and Adaptation Measures

The United States is involved in a wide array of climate assessments, research, and other activities at the local, regional, national, and international levels to increase understanding of impacts and vulnerability needed to initiate effective adaptation measures. These activities range from assessments of adaptation options for a specific sectoral impact in one locale to the modeling of potential impacts worldwide. They inform decision-making processes at all levels and help to increase societal resilience to climate changes. Many of the most successful U.S. programs are demand-driven—they generate research or spur activities in response to the needs and priorities identified by decision makers to address current and near-term risks and opportunities.

The 2002 *U.S. Climate Action Report* (2002 CAR) highlighted findings from the National Assessment of climate change impacts on the United States (NAST 2000), and those of the Intergovernmental Panel on Climate Change (IPCC 2001a, b). The United States continues to use a range of peer-reviewed scientific outputs to inform decision making with regard to climate impacts, spanning domestic scientific articles and assessments to international assessments, such as those of the IPCC.

Since the release of the 2002 CAR, and as described in the *Strategic Plan of the U.S. Climate Change Science Program* (CCSP and SGCR 2003a), the U.S. government has undertaken an ambitious suite of focused assessments addressing high-priority research questions. This open, transparent approach communicates scientific analyses to the public via a set of 21 synthesis and assessment products developed by the U.S. Climate Change Science Program (CCSP). These products consider, evaluate, and summarize the current state of understanding in critical areas related to climate change, its ongoing and potential impacts, and options for responding to these changes. This material is intended for use by a diverse group of decision makers, stakeholders, communicators (e.g., the media), and scientists. The material addresses the Nation's need for sound scientific information that can lead to a better understanding of climate change impacts and vulnerabilities, as well improved design and implementation of adaptation measures. As with previous CCSP outputs, the synthesis and assessment products are reviewed by government and non-government scientists, U.S. government officials, stakeholders, and the general public. These products build on and integrate cutting-edge research and application activities, advanced over the years by the interagency research efforts in climate and global change.[1]

The synthesis and assessment products highlighted in this chapter will provide analyses of ongoing and potential impacts of climate variability and change, adaptability of key systems, and measures that may be taken to reduce vulnerability. In addition, this chapter focuses on activities the United States is undertaking to assess and respond to specific types of impacts and vulnerability, in accordance with Article 12 of the U.N. Framework

[1] More information about CCSP and the synthesis and assessment products may be found in Chapter 8 and at <www.climatescience.gov>.

Convention on Climate Change. It also highlights ongoing U.S. efforts that are generating new insights into the potential impacts of climate change on key physical and biological processes (e.g., snowpack changes, streamflow, drought, extreme events, biodiversity) and changing resilience and vulnerability in a range of socioeconomic sectors (e.g., energy, forestry, agriculture, coastal systems, human health, and transportation). It provides an overview of the current U.S. government approach toward characterizing and reducing uncertainty associated with specific climate-related issues and providing practical scientific information and tools to decision makers via CCSP and other mechanisms. Often these activities take place within broader activities to improve sectoral risk management within the context of many changing social, economic, and environmental factors. Many of these activities are leading to demonstrable reductions in socioeconomic and environmental vulnerability to climate variability and change.

DEVELOPING RESILIENT SOCIETIES AND ECONOMIES

The ultimate goal of adaptation is to develop resilient societies and economies that have the knowledge and capacity to address both the challenges and the opportunities presented by changing climatic conditions. Climate change will alter patterns of climate variability in unknown ways. Resilience is a matter of reducing present vulnerability as well as minimizing the risk of future vulnerability to climate events. Efforts to help sensitive populations adapt to current climate variability have shown that socioeconomic, environmental, and climatic stresses are all connected. Future changes in these conditions could substantially alter the environment in which adaptation must take place. The full range of likely future stresses must be considered. To be sustainable, adaptation efforts must consider options that build resilience to these stresses (Goklany 1995, 2007).

Decision makers and planners in such climate-dependent sectors as agriculture and water generally consider historical patterns of climate variability and extreme events, particularly those that have occurred relatively recently. These include considerations of variations at short time scales (e.g., seasonal and annual variations). Relatively few decision makers, however, consider variations in climate that occur on longer time scales (e.g., decades to a century). Moreover, decision makers do not typically consider how potential climate change could cause patterns of climate variability to differ from historical trends. Although scenario-based assessments regarding the future do not always agree on the type or direction of change that might occur, and these disagreements often increase at smaller geographical scales, global and regional climate models provide a range of projections that can be helpful in communicating climate risks to regional decision makers.

A key component in building resilience into human and natural systems is to expand scientific understanding of the nature and implications of climate variability and change across sectors, often within a place-specific framework that considers the socioeconomic and institutional capacities and decision-making practices. Lessons from early research investments intended to increase understanding of the human and natural sources of vulnerability to climate variability and change have profoundly influenced the approach of the current U.S. research program. As called for in the CCSP strategic plan, research partnerships have been initiated and sustained in some regions to involve decision makers in the process of identifying knowledge gaps of the highest relevance to their decision processes (CCSP and SGCR 2003a). These partnerships have also explored mechanisms for improving the utility and flow of knowledge from the research community to those who can use and benefit from it.

Box 6-1 presents a cross-section of the types of programs being carried out by the United States at the international, federal, state, and local levels to assess impacts of climate change and reduce vulnerability. This list is not comprehensive; rather it is a small sample of the relevant activities being carried out on a variety of scales in the United States. A continuing goal is a coherent program that allows synergies among these many and varied programs.

SECTOR-SPECIFIC U.S. ADAPTATION ACTIVITIES

The sector- and region-specific projects in this section illustrate the variety and scale of adaptation methods utilized within the United States. They represent only a small sample of key areas of investigation the United States has undertaken in its extensive portfolio of past and current adaptation activities.

Water Resources

Changes in atmospheric, surface, and subsurface water storage and flow have been observed over the past several decades in the United States (Groisman et al. 2004). Whether due to anthropogenic or natural causes, these changes have significant implications for the provision of adequate water supply for human consumption, agriculture, energy production, industrial uses, and other needs. While population growth, pollution, and industrial development add stresses to the water supply (U.S. DOI 2003), climate variations and change may significantly exacerbate water supply issues.

For example, despite increases in winter precipitation, in many places a large percentage of the traditionally snow-covered areas of the northwestern United States has experienced a decline in spring snowpack, especially since the middle of the 20th century (Mote et al. 2005). The largest decreases have occurred at lower elevations where snowpack is most sensitive to temperature and in regions where winter temperatures are mild, especially in

the Cascade Mountains and northern California. Substantial declines in snow-water equivalent have been observed in lower elevations of the Pacific Northwest (Mote 2003), along with a significant reduction in spring snow cover over the region during the last half century (Groisman et al. 2004), and about a one-week advance since the mid-1960s in the timing of peak snowmelt in northern Alaska (Stone et al. 2002). The peak of streamflow in the Pacific Northwest and New England, in basins dominated by snowmelt, has typically advanced by 1–2 weeks (Groisman et al. 2004; Hodgkins et al. 2003), thereby providing less river runoff during the late spring and summer.

Another example of potential changes is the severe and extreme drought that is a recurring feature across much of the United States. Research suggests that a broad array of physical mechanisms contributes to droughts, from internal atmospheric variability on the shortest time scales, to interactions with oceans and land surface at seasonal-to-decadal and longer time scales. Among recent scientific studies is one suggesting that drought conditions in the 1998–2002 time frame over North America, parts of southern Europe, and southwest Asia were linked to particular ocean conditions (Hoerling and Kumar 2003). Cold sea-surface temperatures in the eastern tropical Pacific and unprecedented warm sea-surface conditions in the western tropical Pacific and Indian Oceans worked synergistically to cause widespread drying in the mid-latitudes. This synergy suggests an increased risk for severe and synchronized drying of Northern Hemisphere mid-latitudes if similar oceanic conditions occur in the future. The warmer temperatures projected with rising concentrations of greenhouse gases are expected to exacerbate present risks of drought in the United States by increasing the rate of evaporation (Gleick 2000).

BOX 6-1 Sample U.S. Climate Vulnerability and Change Research Programs and Activities

The U.S. government supports several programs and activities that are working to assess the impacts of climate change and reduce vulnerability across sectors. Following is a sample cross-section of the types of programs being carried out at all levels to build resilience into human and natural systems.

International Programs and Activities

NASA and USAID Regional Hubs
The National Aeronautics and Space Administration (NASA) and the U.S. Agency for International Development (USAID) are developing regional hubs around the world to apply remotely sensed information to development assistance. Based on the successful SERVIR hub in Central America, this activity will link available data streams to new applications, develop tools, and build local human and institutional capacity to use this information. These systems will support decision making in a number of areas, including climate change, land management, urban planning, food security, agriculture, and disaster mitigation.

USAID Climate Change Program
Often in partnership with other agencies, USAID leads a number of activities to help build developing country capacity to understand climate change and adapt to its impacts. Its Climate Change Program conducts projects to test methodologies to insert climate information in mainstream development project planning. The projects emphasize stakeholder participation. For example, USAID:

- worked with farmers in Mali, planting crop varieties that are better suited to a hotter climate;
- helped local stakeholders in South Africa identify water demand management and infrastructure requirements as climate changes;
- addressed flooding concerns with coastal residents, businesses, and planning officials in Honduras; and
- helped fishermen and farmers in Thailand determine how to build resilience to warming temperatures and more variable rains.

Lessons learned from these projects informed the development of an adaptation guidance manual, which is being applied in additional projects in cooperation with USAID missions around the world. The manual will be disseminated to USAID missions and other development partners to ensure the methods and tools are used broadly.

Local to National Programs and Activities

NASA Applied Sciences Program
This program benchmarks practical uses of NASA-sponsored observations from Earth observation systems and predictions from Earth science models. NASA implements projects that carry forth this mission through partnerships with public, private, and academic organizations developing innovative approaches for using Earth system science information to provide decision support that can be adapted in applications worldwide. The program focuses on applications of national priority to expand and accelerate the use of knowledge, science, and technologies resulting from the NASA goal of improving predictions in the areas of weather, climate, and natural hazards.[2]

EPA Global Change Research Program
The primary emphasis of this U.S. Environmental Protection Agency (EPA) assessment-oriented program is understanding the potential consequences of climate variability and change on human health, ecosystems, and socioeconomic systems in the United States. This work entails (1) improving the scientific basis for evaluating the effects of global change in the context of other stressors and human dimensions (as humans are catalysts of and respond to global change), (2) conducting assessments of the risks and opportunities presented by global change, and (3) assessing adaptation options to improve society's ability to effectively respond to those risks and opportunities as they emerge. EPA's intramural assessment program has four areas of emphasis: (1) human health, (2) air quality, (3) water quality, and (4) ecosystem health. In an attempt to capitalize on expertise in the academic community, a significant portion of the program's resources are dedicated to extramural research grants administered through EPA's STAR (Science to Achieve Results) grants program, which supports science related to assessments of consequences of global change and human dimensions research. [3]

[2] See <http://science.hq.nasa.gov/earth-sun/aplications/index.html>.
[3] See <http://cfpub.epa.gov/gcrp/about_ov.cfm>.

BOX 6-1 (Continued) **Sample U.S. Climate Vulnerability and Change Research Programs and Activities**

NSF Decision Making Under Uncertainty Centers
These National Science Foundation (NSF) centers are comprised of five interdisciplinary research teams studying important aspects of problems associated with understanding climate-related decisions under uncertainty. The increased knowledge generated by recent scientific research on the causes and consequences of climate change and variability has led to a growing need to better understand how decision makers choose among alternative courses of action. These teams are expected to produce new insights of interest to the academic community, generate significant educational benefits, and develop new tools that will benefit decision makers and a range of stakeholders. Research centers are located at Arizona State, Carnegie-Mellon, and Columbia universities. Other interdisciplinary teams are conducting research at the University of Colorado at Boulder and Rand Corporation in Santa Monica, California.

National Water and Climate Center
Administered by the U.S. Department of Agriculture's Natural Resources Conservation Service, the National Water and Climate Center (NWCC) focuses on providing leadership in a partnership effort to help people conserve, improve, and sustain their natural resources and environment. NWCC's mission is to lead the development and transfer of water and climate information and technology that support natural resource conservation through natural resource planning support, data acquisition and management, technology innovation and transfer, and partnerships and joint ventures.[4]

Regional Program

Regional Integrated Sciences and Assessments (RISA) Program
The National Oceanic and Atmospheric Administration's (NOAA's) RISA program supports research that addresses complex climate-sensitive regional issues of concern to decision makers and policy planners. RISA research team members are primarily based at universities, though some are based at government research facilities, nonprofit organizations, and private-sector entities. Research areas include the fisheries, water, wildfire, and agriculture sectors, coastal restoration, and climate-sensitive public health issues.[5]

State Program

California Climate Change Center
The center investigates the range of possible changes to California's climate and the likelihood and rate of progression of such changes. Using the results of this work, the center is assessing the potential future economic and ecological consequences of climate change for California, and is examining a range of impacts and adaptation options concerning, e.g., agriculture and water resources, as well as mitigation strategies. The center manages a robust research program with a dynamic community of California researchers from various scientific disciplines and a worldwide network of peers collaborating on climate change issues of interest to California.[6]

Local Program

King County Global Warming Initiative
Washington State's King County is pursuing aggressive strategies to reduce and adapt to global warming in each of the following areas: land use, public transportation, innovative environmental management, and development of clean energy technologies. The county is one of several jurisdictions that are accounting for climate change in their short- and long-term infrastructural planning. Specific actions being taken by King County that account explicitly for climate change include developing a flood plan and proposed major upgrades in its 119 miles of levees on local rivers, as well as constructing a $28 million reclaimed water system to help address expected water shortages.[7]

However, the effects of drought and low soil moisture on vegetation, including crops, may be offset by higher CO_2 levels—or at least partly offset for a period of time (e.g., Triggs et al. 2004; Nelson et al. 2004).

Regional Integrated Sciences and Assessments

Federally funded researchers are working with water and ecosystem managers as new insights and techniques become available, allowing incorporation of scientific data and information into near- and long-term planning. NOAA's Climate Program Office funds eight programs designed to provide the Nation with experience-based knowledge about how to provide climate services (see Box 6-1).[8] Called Regional Integrated Sciences and Assessments (RISAs), these programs are an important element of CCSP's efforts to support decision making on climate-related issues. Following are some sample RISA programs.

Climate Impacts Group—The University of Washington's Climate Impacts Group (CIG) is using emerging knowledge to help inform decision making related to changing hydroclimatic conditions in the Pacific Northwest. CIG is utilizing its hydrologic modeling and prediction capabilities to evaluate water resource issues, including the consequences of alternative water and hydroelectric power management strategies for salmon restoration efforts, and the consequences of changing water demands and changes in land cover for regional water resources.[9]

Western Water Assessment—The Western Water Assessment (WWA) is examining the interplay between changing hydrologic and climatic conditions, and the complex array of intrastate, interstate,

[4] See <http://www.wcc.nrcs.usda.gov/>.
[5] See <http://www.climate.noaa.gov/cpo_pa/risa/>.
[6] See <http://www.climatechange.ca.gov/research/index. html>.
[7] See <http://www.metrokc.gov/globalwarming/default.sapx>.
[8] See <http://www.climate.noaa.gov/cpo_pa/risa/>.
[9] See <http://www.cses.washington.edu/cig/res/hwr/hwr.shtml>.

and international water agreements in the Colorado River Basin. Recent analyses indicate that current "assumptions about planning in the Colorado basin [are not] borne out by the climate record [of natural variability] and by projections of change" (Pulwarty et al. 2005). Working with water managers, WWA researchers have analyzed how interannual-to-multidecadal climate variability affects critical water issues and what climate information can be used in the resource management decision process to meet multiple and expanding water uses in the basin.[10] Using multidisciplinary teams of experts in climate, water, law, and economics, WWA provides information (usually in the form of climate forecasts and regional vulnerability assessments) designed to assist water-resource decision makers, such as those responsible for managing Denver's water supply.

Climate Assessment for the Southwest—A RISA based at the University of Arizona, titled the Climate Assessment for the Southwest,[11] is developing and using new information on drought to increase societal resilience to this recurrent phenomenon. The impacts of U.S. drought during the last 5–7 years have included sustained and extensive economic losses, significantly reduced reservoir levels, water emergencies, and widespread and severe wildfires.

Creating a more drought-resilient society requires a fundamental shift from crisis management to risk management. Investigators studying the impacts of drought are researching the historical record, evolving demographics and population growth, water law, and ecosystem management. For example, they are working to develop methods to utilize seasonal climate and streamflow forecasts more effectively to mitigate the impact of drought on water supplies. This type of knowledge is expected to become even more valuable in the coming decades, if climate model projections of increasing aridity in continental interiors prove accurate.

National Integrated Drought Information System

The sustained drought in parts of the U.S. West has exposed critical vulnerabilities and has revealed the effects of multiple stresses on institutions designed under different climatological circumstances. This experience has prompted advances in preparedness and a national-scale response through the development of a National Integrated Drought Information System (NIDIS) (WGA 2004). NIDIS is designed as a user-based drought information system that assesses potential drought indicators and impacts to provide tools for anticipating, preparing for, and mitigating the effects of drought. U.S. government services and research aim to provide the scientific knowledge needed for U.S. public and private sectors to anticipate, track, assess, and respond to drought threats at regional and local levels.[12]

New York City Task Force on Climate Change

As in the U.S. West, water issues are of concern in the eastern half of the country as well. The New York City Department of Environmental Protection, which provides water for 9 million people in the New York metropolitan region, has created a Task Force on Climate Change that is comprehensively addressing climate variability and change (Rosenzweig et al. 2007). The task force has developed a robust, dynamic, scenario framework for the region; built a set of adaptation assessment steps that characterizes potential adaptations as operations/management, infrastructure, or policy; and identified key vulnerabilities, such as sea level rise for sewer and wastewater treatment systems and the need for integrated modeling of upstate regions of water supply and reservoirs.

Ecosystems

Climate is an important factor influencing the distribution, structure, function, and services of ecosystems. Ongoing climate changes are interacting with other environmental changes to affect biodiversity and the future condition of ecosystems (e.g., IPCC 2001b; McCarty 2001; Parmesan and Yohe 2003). Significant climate change would affect many U.S. ecosystems, including wetlands, forests, grasslands, rivers, and lakes (NRC 2001). The extent to which ecosystem conditions will be affected will depend on the magnitude of climate change, the degree of sensitivity of the ecosystem and nonclimate pressures on biodiversity to that change, the availability of adaptation options for effective ecosystem management, and the willingness to deploy those options.

Adaptation Strategies and Options

CCSP addresses management strategies for facilitating ecosystem adaptation to climate variability and change. The goal of these adaptation strategies is to reduce the risk of adverse outcomes through activities that increase the resilience of ecological systems to climate change, and to take advantage of positive outcomes (Turner et al. 2003; Tompkins and Adger 2004; Scheffer et al. 2001). Because changes in the climate system are likely to persist into the future regardless of emissions mitigation, adaptation is an essential response for future protection of climate-sensitive ecosystems.

Adaptation options for enhancing ecosystem resilience include changes in processes, practices, or structures to reduce anticipated damages or enhance beneficial responses associated with climate variability and change. In some cases, opportunities for adaptation offer stakeholders multiple benefit outcomes, such as the addition of riparian buffer strips that, for example, manage pollution loadings from agricultural land into rivers or provide a protective barrier to increases in both pollution and sediment loadings that may be associated with future climate or other environmental change. Adaptation options also include measures that would reduce current vulnerabilities to ecosystems—e.g., loss of habitat and migratory corri-

[10] See <http://wwa.colorado.edu/about/>.
[11] See <http://www.ispe.arizona.edu/climas>.
[12] For example, see <http://www.drought.noaa.gov/>.

dors—by enhancing the productivity of current food and agricultural practices (Goklany 1995, 1998, 2007). Such options could reduce what is frequently considered to be an important threat to biodiversity, as well as conserve carbon stocks and sinks, but the potential for those systems to be affected by a changing climate needs to be taken into account as adaptation and mitigation options are evaluated.

A range of adaptation options is possible for many ecosystems, but a lack of information or resources may impede successful implementation. In some cases, managers may not have the knowledge or information they need to address climate change impacts. In other instances, managers may understand the issues and have the relevant information but lack resources to implement adaptation options. Furthermore, even with improvement in the knowledge and communication of available and emerging adaptation strategies, the feasibility and effectiveness of adaptation will depend on the adaptive capacity of the ecological system or social entity.

Thus, increasing adaptive capacity will require information and tools that aid in (1) understanding the combined effects on ecosystems of climate changes and nonclimate stressors, and consequent implications for achieving specific management goals; (2) applying existing management options or developing new adaptation approaches that reduce the risk of negative outcomes; and (3) understanding the opportunities and barriers that affect successful implementation of management strategies to address climate change impacts.

CCSP's Ecosystem Adaptation Work

One example of work by CCSP in improving the adaptive capacity of ecosystems relates to understanding climate and wildfire interactions on a regional scale for the western United States (Roads et al. 2005; Reinbold et al. 2004), development of long-lead forecasts for use by wildfire managers (Brown et al. 2003), and compilation of a comprehensive new western U.S. 21-year fire history to facilitate climate-based predictions of the potential severity of the fire season several months in advance (Westerling et al. 2003). The United States supports yearly regional meetings to prepare fire forecasts that integrate the complex pattern of fire potential anomalies, current and evolving climate conditions, fuel types, extended climate predictions, and disturbance factors, such as drought- or insect-induced forest mortality.[13]

Another example of CCSP's adaptation work related to managed ecosystems involves the agricultural sector. Building on assessments of the impacts of El Niño on particular crops, and interactions with farmers and extension agents, U.S. research scientists are contributing information and climate predictions tailored to the specific needs of farmers, enabling them to plan in advance seasons, or longer, to increase productivity and decrease exposure.[14] Methods are also currently being developed for limiting potential damages from global warming in irrigated and rainfed cropping systems, while sustaining agricultural yields.

The polar and subpolar regions, another CCSP priority, have exhibited more rapid changes than the lower latitudes. The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) is the lead U.S. government laboratory for polar and subpolar expertise. CRREL research has examined the impacts of climate change on retreating Arctic sea ice to assist in defining the requirements for U.S. Coast Guard ice-breaking ships for the next 30 years. Satellite data show that the extent of Arctic sea ice has decreased by about 10 percent, and the upward-looking sonar data from U.S. Navy submarines between 1957 and 2000 show the average ice thickness has decreased by 33–42 percent.

State-of-the-art knowledge on ecosystem impacts, adaptation, and vulnerability will be addressed in three different CCSP synthesis and assessment products: S&A Product 4.2, *State-of-Knowledge of Thresholds of Change That Could Lead to Discontinuities in Some Ecosystems and Climate-Sensitive Resources*; S&A Product 4.3, *The Effects of Climate Change on Agriculture, Biodiversity, Land, and Water Resources*; and S&A Product 4.4, *Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources.*

International Ecosystem Adaptation Activities

Internationally, the United States collaborates with developing country partners in a broad range of activities designed to better understand climate and its implications for development and to build resilience to climate variability and change. These activities include analyzing data from Earth observations, developing decision-support tools, and integrating climate information into development projects. For example, USAID and NOAA collaborate with developing country partners to operate the Famine Early Warning System Network (FEWS NET), which combines data from satellite observations with local meteorological, crop, and livelihood information to provide decision makers with early warnings of food security risks. FEWS NET operates in 21 countries and has been providing early warnings for 20 years. Similar programs are being developed to warn of risks of malaria, meningitis, and pests.

Public Health

Throughout the world, the prevalence of some diseases and other threats to human health depends largely on local climate. Given the complexity of the factors that influence human health, assessing health impacts related to climate change poses a difficult challenge (NRC 2001). The extent and nature of climate change impacts on human health vary by region, by relative sensitivity of population

[13] For example, see <http://www.iawfonline.org/conferences.shtml>, <http://www.sftrforest.org>, <http://www.wildfirecolorado.org>, <http://www.stateforesters.org>.

[14] For example, see <http://www.agclimate.org/Development/apps/agClimate/controller/perl/agClimate.pl>.

groups, by the extent and duration of exposure to climate change itself, and by society's ability to adapt to or cope with the change (Rose et al. 2001). The U.S. government has undertaken several initiatives to better understand and to develop and implement responses to these potential changes.

Centers for Disease Control and Prevention Research

A variety of efforts are underway in the United States to reduce negative health outcomes related to climate variability and change. For example, the Division of Environmental Hazards and Health Effects within the U.S. Department of Health and Human Services' Centers for Disease Control and Prevention (CDC) conducts intramural research to investigate morbidity and mortality associated with exposure to excessive heat. Also, renewed concern about emerging and re-emerging infectious diseases has prompted increased attention to a variety of diseases whose incidence would be affected by environmental change. CDC's Division of Vector-Borne Infectious Diseases is currently collaborating on studies to outline adaptation measures for vector-borne infectious diseases that may be affected by climate change. Its Guatemala field station is studying the impact that adverse climatological events, such as El Niño and Hurricane Gilbert, have had on the transmission dynamics of malaria and other diseases. These catastrophic events result in tremendous changes that can simultaneously create new vector habitat, reduce the levels of sanitation, and overwhelm the ability of public health systems to respond.

Global Change Research Program Assessments

EPA's Global Change Research Program is undertaking important work assessing the relationships between climate change and human health. This assessment work goes beyond basic epidemiological research to develop integrated health assessment frameworks that consider the effects of multiple stresses, their interactions, and human adaptive responses. Along with health sector assessments, conducted in conjunction with the U.S. Global Change Research Program's National Assessment process, the work includes research and assessment activities focused on the consequences of global change on weather-related morbidity and vector- and waterborne diseases. In addition, the results from the Global Change Research Program's air quality assessments will be used to evaluate health consequences.[15]

Decision-Support Tools

One example of a decision-support tool that has been developed to help reduce the negative effects of climate variability and change on human health is work on encephalitis viruses. The risk of infection from these viruses depends in part on temperature-related factors. Activities are underway that use climate forecasting at various spatial scales to alert local and state public health officials to changing risks of encephalitis infection. A risk model has been developed that characterizes climate factors related to encephalitis outbreaks (e.g., indicators for rainfall, runoff, and temperature) in California. The model demonstrates that mosquito abundance patterns and associated patterns of encephalitis risk vary spatially across the different biomes of California and show strong links to climate variations (Barker et al. 2003).

Another example of a decision-support tool is the *Excessive Heat Events Guidebook*, developed by EPA and other federal agencies responsible for addressing "excessive heat events" (EHEs) (U.S. EPA/OAP 2006a). The guidebook provides interested public health officials with information on risks and impacts from EHEs, including guidance on EHE forecasting and identification. It also provides a menu of notification and response actions to consider when developing or enhancing a local EHE program based in part upon a review of various EHE response programs.[16]

CCSP S&A Product 4.6, *Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems*, will provide a timely update to the 2000 Health Sector Assessment (Patz et al. 2000). This product will, in part, report on the potential human health effects of global environmental change, and the climate, socioeconomic, and environmental information that is needed to assess the cumulative risk to health in the United States from these effects. It will also inform adaptations in the provision of public health and health care interventions.

Coasts

Sea level is rising 2–3 millimeters (0.08–0.12 inches) per year along most of the U.S. coast (Zervas 2001). Accounting for local subsidence, coastal scientists are considering the possible impacts of a 1–3-foot rise in sea level over the next century (IPCC 2001a). Key concerns associated with these changes include land loss, increased flooding of low-lying coastal communities, coastal erosion, barrier island migration, vertical accretion of wetlands, and increased salinity of aquifers and estuaries, especially during droughts.

Approximately half the U.S. population—153 million people—lives in one of the 673 coastal counties; this number is expected to grow by 7 million by 2008 (U.S. DOC/NOAA 2004). Increases in coastal vulnerability are strongly affected by increasing coastal populations (Höppe and Pielke 2006), as well by as the effects of sea level rise and changes in the intensity and frequency of coastal storms. After a period of relatively light activity, the Atlantic basin has recently experienced an increase in hurricane activity, the cause of which is the subject of ongoing scientific debate (e.g., Webster et al. 2005; Hoyos et al. 2006; Kossin et al. 2007; Landsea et al. 2006). Concern over this increasing societal vulnerability is leading some insurance companies to increase rates or deny property coverage to communities along the Gulf and Atlantic coasts (Mills 2005). Due

[15] See <http://cfpub.epa.gov/gcrp/>.
[16] See <http://www.epa.gov/heatisland/about/heatguidebook.html>.

largely to improved warning systems, death and death rates from extreme weather events have generally declined since the beginning of the 20th century.

Reducing Vulnerability to Sea Level Rise

In recognition of significant potential impacts from climate change, the Federal Coastal Zone Management Act states: "Because global warming may result in a substantial sea-level rise with serious adverse effects in the coastal zone, coastal states must anticipate and plan for such an occurrence (16 US Code § 1451)." Property owners and federal, state, and local governments are already starting to take measures to prepare for the consequences of rising sea level. Most coastal states are working with the U.S. Army Corps of Engineers to place sand onto their beaches to offset shore erosion. Property owners are elevating existing structures in many low-lying areas, which provide resilience to episodic storms as well as long-term change.

Shoreline erosion along estuaries has led many property owners to defend their property by erecting shore protection structures such as bulkheads, which eliminate the intertidal wetlands and beaches that would otherwise be found between the water and the dry land. Several states have adopted policies to ensure that beaches, dunes, or wetlands are able to migrate inland as sea level rises. Some states prohibit new houses in areas likely to be eroded in the next 30–60 years (e.g. North Carolina Coastal Resources Commission). Concerned about the need to protect property rights, Maine, Rhode Island, South Carolina, and Texas have implemented some version of "rolling easements," in which people are allowed to build, but only on the condition that they will remove the structure if and when it is threatened by an advancing shoreline (IPCC 2001b).

Developing Data for Addressing Sea Level Rise

Many agencies and individuals are developing data that can provide insights regarding the implications of sea level rise. Following are some examples of these efforts:

- NASA, with its partner the French space agency, continues to provide climate-quality global sea level data every 10 days.
- The Federal Emergency Management Agency (FEMA), the U.S. Army Corps of Engineers, and several states are developing elevation data for floodplain management.
- NOAA and the U.S. Geological Survey (USGS) are developing Digital Elevation Models that use a common vertical reference frame for both topographic and bathymetric maps (Hess et al. 2004).
- Local governments and major coastal land conservancies are developing geographic information system land-use data for managing ecosystems and economic growth.
- The U.S. Fish and Wildlife Service is developing relevant wetlands data.
- NOAA's Coastal Change Analysis Program periodically provides a comprehensive assessment of land cover changes in the U.S. coastal zone.
- USGS collects high-resolution LIDAR elevation data for producing assessments of shoreline erosion and other coastal processes through its National Assessment of Coastal Change Hazards. FEMA has conducted similar analyses.
- USGS also evaluates the ability of wetlands to keep pace with rising relative sea level.
- EPA has been working with local governments to create county-scale maps that identify the areas likely to require shore protection as sea level rises.
- The New York City Department of Environmental Protection is analyzing the effects of current and future sea level rise on its coastal infrastructure (Rosenzweig et al. 2007).
- CCSP S&A Product 4.1, *Coastal Elevations and Sensitivity to Sea Level Rise*, will synthesize information from the ongoing mapping efforts by federal and nonfederal researchers related to the implications of rising sea level.

Transportation

Transportation accounts for approximately one-quarter of total U.S. greenhouse gas emissions. Climate change will most likely have significant impacts on transportation infrastructure and operations (U.S. DOT 2006b). The safety and security of the national transportation infrastructure, as well as emergency and routine transportation operations, could also be affected (U.S. DOT 2006b). Examples of specific types of impacts include softening of asphalt roads, warping of railroad rails, decreased airplane "lift" in extremely hot air, and damage to roads and opening of shipping routes in polar regions (IPCC 2001b).

The United States is working to provide better information to decision makers across the transportation sector about what future climate variability and change could mean for existing and planned infrastructure and about the set of potential response strategies that might be implemented to adapt to future climate.

DOT Programs, Initiatives, and Studies

The Center for Climate Change and Environmental Forecasting is an initiative of the U.S. Department of Transportation (DOT) dedicated to fostering awareness of the potential links between transportation and global climate change, and to formulating policy options to deal with the challenges posed by climate change and variability.[17] Several DOT programs are helping to curb greenhouse gas emissions and pollution from transportation, including the Automotive Fuel Economy Program, the Congestion Mitigation and Air Quality Improvement Program, and the Voluntary Airport Low Emissions Program. DOT research projects are investigating the potential impacts of climate variability and change on transportation

[17] See <www.dot.gov/climate>.

infrastructure and its operation, and are providing guidance as to how transportation planners and decision makers may incorporate this information into transportation planning decisions to ensure a reliable and robust future transportation network.

DOT has partnered with the National Academies of Science/Transportation Research Board (TRB) to study strategies for the transportation system to adapt to potential impacts of climate change. The DOT/TRB study will reexamine the role of design standards for transportation infrastructure considering potential impacts from climate change, develop operational responses to potential climate change impacts, and review approaches to decision making under uncertainty.

A related DOT study is focusing on the central U.S. Gulf Coast. The region's unique transport modes and commercial significance add texture and interest to its transportation sector, while its unusual topography and geographic location make it particularly vulnerable to sea level rise and the threat of severe weather events. Results from this research will be reported in CCSP S&A Product 4.7, *Impacts of Climate Change and Variability on Transportation Systems and Infrastructure.*

Energy

Energy production and use are sensitive to changes in climate. For example, increasing temperatures will reduce consumption of energy for heating but will increase energy used for cooling buildings. The net effects of these changes on energy production, use, and utility bills will vary by region and by season (Hadley et al. 2006; Scott et al. 2005). There may be changes in energy consumed for other climate-sensitive processes, such as pumping water for irrigation in agriculture (Peart et al. 1995; IPCC 2001b). Depending on the magnitude of these possible energy consumption changes, it may be necessary to consider changes in energy supply or conservation practices to balance demand (Franco and Sanstad 2006; CEPA 2006).

Hydropower

To date, less research has been undertaken on how climate change may affect energy production. Hydropower generation is the energy source that is likely to be most directly affected by climate change because it is sensitive to the amount, timing, and geographic pattern of precipitation and temperature (IPCC 2001b). However, changes in precipitation are difficult to project at the regional scale, which means that climate change will affect hydropower either positively or negatively, depending on the region.

Renewable Energy

Some renewable sources of energy could be affected by climate change, although these changes are very difficult to predict. If climate change leads to increased cloudiness, solar energy production could be reduced. Wind energy production would be reduced if wind speeds rise above or fall below the acceptable operating range of the technology. Changes in growing conditions could affect biomass production—a transportation and power plant fuel source that is starting to receive more attention (IPCC 2001b). Climate change may also have complex effects on U.S. energy conditions through effects on global and hemispheric energy markets and policies.

Energy Infrastructure

Infrastructure for energy production, transmission, and distribution could be affected by climate change as well. For example, changes in the frequency and magnitudes of more extreme weather events, such as windstorms, ice storms, floods, tornadoes, and hail, and associated damages to the transmission systems of electric utilities may affect the rate of failure with attendant costs (IPCC 2001b). Power plant operations can be affected by the frequency and magnitude of extreme heat and cold waves. For example, intake water that is normally used to cool power plants may become warm enough during extreme heat events to compromise power plant operations, or ice storms may bring down transmission lines.

Energy Supply and Demand

Climate change effects on energy supply and demand will depend not only on climatic factors, but also on patterns of economic growth, land use, population growth and distribution, technological change, and social and cultural trends that shape individual and institutional actions (IPCC 2001b).

Prospects for Adaptation

Because of the lack of research to date, prospects for adaptation to climate change effects by energy providers, energy users, and society at large are speculative, although the potentials are considerable. Perhaps the greatest challenges could be in connection with possible increases in the intensity of extreme weather events and possible significant changes in regional water supply regimes. But adaptation prospects depend considerably on the availability of information about possible climate change effects to inform decisions about adaptive management, along with technological change in the longer term. Given that the current knowledge base is so limited, CCSP S&A Product 4.5, *Effects of Global Change on Energy Production and Use*, will summarize what is currently known about effects of climate change on energy production and use in the United States and will address needs for expanded research, through broad-based collaboration among federal and state governments, industry, nongovernmental institutions, and academia.