



Common Themes and Research Recommendations

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5.1 SYNTHESIS AND ASSESSMENT PRODUCT 4.6: ADVANCES IN THE SCIENCE

The Synthesis and Assessment Product 4.6 assesses the impacts of climate variability and change on human systems in the United States. Each of the assessment chapters has drawn on different bodies of literature, with generally more available scientific knowledge on impacts and adaptation related to human health, somewhat less related to human settlements, and still less related to human welfare.

Several themes recur across these chapters and point to advances in the science of climate impacts assessment and the development and deployment of adaptation responses.

1. The connections between climate change and other environmental and social changes are complex and dynamic. In some cases, climate change compounds the effects of other global changes. Socioeconomic factors can, in some cases, determine or moderate the impacts of climate change (5.1.1).
2. Extreme weather events will play a defining role, particularly in the near-term, shaping climate-related impacts and adaptive capacity. While impacts associated with changes in climate averages may be less important now, these averages are expected to have more pronounced long-run effects on sea level rise, permafrost melt, glacial retreat, drought patterns and water supplies, etc. (5.1.2).

3. Climate change will have a disproportionate impact on disadvantaged groups in communities across the United States. Some regions and some resources are more vulnerable to climate impacts, such as coastal zones, drought-prone regions, and flood-prone river basins (5.1.3).
4. Adaptation of infrastructure and services to climate change may be costly, but many communities will have adequate resources. However, for places already struggling to provide or maintain basic public amenities and services, the additional costs of adaptation will impose a potentially insupportable burden (5.1.4).
5. With such a complex scientific and policy landscape, an integrated multi-disciplinary framework is needed for climate change impacts to be measured in meaningful ways and for optimal mitigation and adaptation strategies to be identified, developed, and deployed (5.1.5).

5.1.1 Complex Linkages and a Cascading Chain of Impacts Across Global Changes

Climate is only one of a number of global changes that impact human well-being. The major effects of climate will be shaped by interactions with non-climate stressors. As such, climate change will seldom be the sole or primary factor determining a population's or a location's well-being. Moreover, the impacts of changes in climate will be tied to the effects



of socioeconomic variables, such as population growth, and how these influence key sectors and decisions, such as infrastructure development, habitat preservation, and access to health care. Consequently, while this assessment focuses on the mechanisms by which climate change could affect future health, well-being, and settlements in the United States, the extent of any impacts will depend on an array of non-climate factors, including:

- Demographic changes related to the location, size, age, and characteristics of populations;
- Population and regional vulnerabilities;
- Future social, economic, and cultural contexts;
- Availability of natural resources;
- Human, cultural, and social capital;
- Advances in science and technology;
- Characteristics of the built environment;
- Land use change;
- Public health and public utility infrastructures; and
- The capacity and availability of health and social services.

The effects of climate change very often spread from directly affected areas and sectors to other areas and sectors through extensive and complex linkages. The importance of climate change depends on the directness of the climate impact coupled with demographic, social, economic, institutional, and political factors, including the degree of preparedness. Consider, for example, the damage caused by Hurricanes Katrina and Rita in 2005. Damage was measured not only in terms of lives and

property lost, but also in the devastating impacts on infrastructure, neighborhoods, businesses, schools, and hospitals. In addition, there have been consequences from continuing disruptions to established communities, livelihoods, psychological well-being, and the exacerbation of chronic illnesses. While the impacts of a single hurricane are not readily linked to climate change, such an event demonstrates the disruptive capacity of extreme weather events.

5.1.2 Changes in Climate Extremes and Climate Averages

Past and present climates have been, and are, variable. This variability in all likelihood will continue into the future. Changes in climate occur as changes in particular weather conditions, including extremes, in specific places (unfortunately, projections of climate changes at small geographic scales remain highly uncertain). The meteorological variables of interest from an impacts perspective include changes in both average and extreme conditions. Gradual changes in average temperature and precipitation have the potential to strongly affect, both positively and negatively, human systems. For example, changes in the average length of the growing season can affect agricultural practices, and changes in the timing and amount of spring runoff can affect water resource management. Effects such as these will not be confined to a few individual sectors, nor are the effects across all sectors independent (*e.g.*, changes in water supplies can impact agricultural practices such as irrigation).

Changes in climate extremes, both those that accompany changes in mean conditions (*e.g.*, a shift in the entire temperature distribution) as well as changes in variability are very often of more concern than changes in climate averages. Unfortunately these types of changes (which include prolonged and intense heat waves and drought or severe storms) are especially difficult to project using climate change models. Many human systems have evolved to accommodate the “average climate” and some variation around this average. This evolution takes place in the context of a variety of dynamic social, economic, technological, biophysical, and political settings, which together determine the ability of human



systems to cope. Rapid onset extreme weather events in particular can do serious damage to a settlement's infrastructure, public health, and overall community reputation and quality of life, from which recovery might take years.

Finally, key vulnerabilities are often defined by certain "thresholds," below which effects are incidental but beyond which effects quickly become major. The severity of impacts is therefore not only related to the rate and magnitude of climate change, but also to the presence or absence of thresholds. In general, these climate-related thresholds for human systems in the United States are not well-understood. Focused research on thresholds would substantially improve our understanding of climate impacts and our ability to cope with extreme events.

5.1.3 Vulnerable Populations and Vulnerable Locations

Impacts of climate variability and change on human systems are location- and population-specific. For instance, along densely developed coastlines, populations are especially vulnerable to tropical storms, storm surge, and flooding. Likewise, the very old and the very young residing in urban areas are susceptible to increases in cardiovascular and pulmonary morbidity and mortality caused by extreme heat coupled with degraded air quality. Native American peoples in Alaska and elsewhere are vulnerable because of their limited capacity to prepare for and respond to the impacts of climate change. Just as there are differences across populations, there are important differences in vulnerability across geographic regions, such as the exposure to extreme events along the Gulf Coast and water supply issues in the Southeast, the Southwest and the Inter-Mountain West.

With respect to health impacts from climate variability and change, specific subpopulations may experience heightened vulnerability for climate-related health effects associated with any or all of the following:

1. *Biological sensitivity* relates to age (especially the very young and the very old), the presence of pre-existing chronic medical conditions (such as the sensitivity of people with chronic heart and pulmonary conditions



to heat-related illness), developmental characteristics, acquired factors (such as immunizations from vaccines), the use of certain medications (*e.g.*, some antihypertensive and psychotropic medications), and genetic factors (such as those that play a role in vulnerability to air pollution effects).

2. *Socioeconomic factors* also play a critical role in determining vulnerability to environmental condition factors. The distribution of climate-related effects will vary among those who live alone, among those with limited rights (for instance, some in the immigrant communities), by economic strata, by housing type, and according to other elements that either accentuate or limit vulnerability. Socioeconomic factors can increase the likelihood of exposure to harmful agents, interact with biological factors that mediate risk (such as nutritional status), and/or lead to differences in the ability to adapt or respond to exposures or to early phases of illness and injury.
3. Given their *location*, the underlying vulnerability of some communities is inherently high just as their adaptive capacity is similarly limited. Populations in gently sloping coastal areas are particularly vulnerable to sea level rise, and settlements along floodplains of large rivers are particularly vulnerable to increased variability in precipitation. The potential for increased frequencies of drought put the increasing populations of desert Southwest cities at risk.



It is essential that public health interventions and preventions recognize populations that may experience interactive or synergistic effects of multiple risk factors for health problems. Poor communities and households are already under stress from climate variability and climate-related extreme events such as heat waves, hurricanes, and tropical and riverine flooding. Since they tend to be concentrated in relatively high-risk areas and have limited access to services and other resources for coping, they can be especially vulnerable to climate change. These differential effects raise concerns about social inequity and environmental justice and increase pressure for adaptive responses from local, state, and federal governments.

5.1.4 The Cost of and Capacity for Adaptation

The United States is capable of considerable adaptation. The success of adaptation plans and/or measures will depend heavily on the competence and capacity of individuals; communities; federal, state, and local governments; and available financial and other social resources. While adaptation to climate change will come at a cost that will likely reduce resources available to cope with other societal burdens, the potential for adaptation through technological and institutional development and behavioral changes is considerable, especially where such options meet other sustainable development needs.



With scarce resources, communities should also choose adaptation options with co-benefits that help ameliorate other issues or where they can easily add climate concerns to existing response plans. The focus on all-hazards response within public health agencies can simply add climate impacts to its list of hazards for which to prepare. This will likely improve their response plans to events in the near term such as storms that happen in a variable climate, whether or not they increase in frequency or intensity with a changing climate. Planting trees and creating green roofs can help reduce the urban heat island effect. In addition to creating more aesthetically pleasing locations, green roofs can also help with energy conservation in the buildings upon which they are located. Thus, some adaptation measures can also be considered mitigation measures.

5.1.5 An Integrative Framework

Human well-being is an emerging concept, and in theory could encompass human health and settlements—the two key focuses of this Product—as well as other critical aspects of the effect of climate change on human systems and the services provided by natural systems. As an organizing principle, human well-being could provide a paradigm for identifying and categorizing climate impacts, and may ultimately provide a framework for integrating multiple impacts into an internally consistent, coherent framework for assessing costs, benefits, and tradeoffs. As an integrating concept, human well-being can develop insights into the linkages between climate change impacts and human happiness. Just as health can be considered a component of well-being (*i.e.*, physical health is closely tied to individual measures of happiness, contentment, and quality of life) aspects of human settlements also determine well-being and could be incorporated into a broader framework of well-being or welfare.

The impacts of climate variability and change on human health and human settlements are fairly well characterized in broad terms, although additional research is needed to refine impact assessments and provide better decision support (particularly with respect to deploying adaptation measures). However, the potential for utilizing concepts of human well-

being to develop an integrating framework is not yet mature. Additional conceptual work and research will be needed, such as developing valuation methodologies (in the case of economic welfare), or developing metrics of well-being or quality of life (in the case of a place-based indicators, or similar, approach).

An alternative integrating framework could revolve around settlements or the more expansive concept of communities (see Section 4.2.3 for an elaborated discussion). There is a growing awareness that the built environment can have a profound impact on our health and quality of life.¹ A major goal of community design is to create more vibrant and livable communities, making sure that they address the needs of residents and improve their quality of life. More specifically, “green communities,” “smart communities,” “smart growth,” and “sustainable development” are intended to offer alternatives to traditional settlement patterns, aiming to meet the goals of creating livable, desirable communities while minimizing the collective footprint of communities on natural resources, ecosystems, and pollution.

As an integrating framework, communities could be evaluated based on how well they protect human health and welfare. Put slightly differently, adaptation could be realized as increasing resilience within communities. Resilience is measured by a community’s capacity for absorbing climate changes and the shocks of extreme events without breakdowns in its economy, natural resources, and social systems. Resiliency, as a central concept in measuring the vulnerability and adaptability of communities and individuals, depends not only on physical infrastructure, but also on social infrastructure and the natural environment. As with welfare, these concepts involving settlements or communities as an integrating framework are not yet mature.



5.2 EXPANDING THE KNOWLEDGE BASE

The present state of the science suggests that opportunities remain for addressing critical research areas. SAP 4.6 concludes that climate observations and modeling are becoming increasingly important for a wide segment of public and private sector entities, such as water resource managers, public health officials, agribusinesses, energy providers, forest managers, insurance companies, and urban and transportation planners. In order to more accurately portray the consequences of climate change and support better-informed adaptation strategies, research efforts should focus on:

- Deriving socioeconomic scenarios that describe how the world may evolve in the future, including assumptions about changes in societal characteristics, governments, and public policy, as well as economic and technological development;
- Connecting socioeconomic scenarios to downscaled climate models in order to evaluate future actions that might address changes in climate, including the intensity and severity of extreme weather events, at the regional and local scales;
- Characterizing the costs of climate change, both those that relate to impacts and those that relate to response strategies (including adaptation and mitigation);
- Estimating the damages avoided by stabilizing or reducing emissions;

¹ See for example, the CDC website on healthy places: www.cdc.gov/healthyplaces/.

- Determining the factors that contribute to synergies between adaptive capacity and sustainable development as well as synergies between adaptation and mitigation;
- Pursuing cross-disciplinary efforts that focus on the human dimensions of climate change in an integrated fashion;
- Improving capacity to incorporate scientific knowledge about climate, including uncertainty, into existing adaptation strategies;
- Conducting research at regional and sectoral levels that promotes understanding how human and natural systems respond to multiple stressors;
- Evaluating the adaptation strategies that effectively address challenges presented by current non-climate stressors (e.g., land use and population dynamics) and develop comprehensive estimates of the co-benefits of actions to address anticipated climate change;
- Investigating adaptation measures to address the near- and long-term responses to climate change, using regional and local stakeholders as key contributors for recommending effective, responsive, and timely adaptation policies;
- Advancing the concept of human welfare as an integrating framework by developing methods to achieve comparable and comprehensive valuations across diverse impacts and sectors;
- Determining which climate impacts exhibit thresholds. Threshold-based damage functions can be fundamentally different in their nature and extent than continuous damage functions; and
- Supporting the development, implementation, and evaluation of adaptive responses, as well as expanding our understanding of impacts, by collecting high quality time-series measurements and other observations of both climate and human systems.

This report concludes that periodic assessments of the impacts of global change on human health, human settlements, and human welfare are necessary to support a rapidly developing knowledge base, especially related to impacts and adaptation. Gaps should be addressed that characterize exposure and sensitivity at the local or regional level. Research should evaluate the adaptive capacity of places and institutions to climate-induced risks. Key research and development areas should address short-term risk assessment and evaluation of the costs and effectiveness of near-term adaptive strategies as well as longer-term impacts and responses.

The following sections provide a more detailed discussion of research needs and recommendations by topic: human health, human settlements, and human welfare. There is significant overlap across topics with opportunities for investigating cross-disciplinary pursuits of research opportunities and adaptation responses.

5.2.1 Human Health Research Gaps

An important shift in perspective has occurred since the Health Sector Assessment of the First National Assessment in 2001. There is a greater appreciation of the complex pathways by which weather and climate affect individual and societal health and well-being. In the research community, there is a more finely honed understanding of the interaction of multiple non-climate, social, and behavioral factors and impacts on risks from injury and disease. While significant gaps remain, several gaps identified in the First National Assessment have been addressed, including:



- A better understanding of the differential effects of temperature extremes by community, demographic, and biological characteristics;
- Improved characterization of the exposure-response relationships for extreme heat; and
- Improved understanding of the public health burden posed by climate-related changes from heat waves and air pollution.

Despite these advances, the body of literature has only limited quantitative projections of future impacts. Research related to the human health impacts of climate change will lead to a better understanding in this area.

Specific suggestions for research on climate change and human health include the following.

- Increase the skill with which we characterize exposure-response relationships, including identifying thresholds and particularly vulnerable groups, considering relevant factors that affect the geographic range and incidence of climate-sensitive health outcomes, and including disease ecology and transmission dynamics;
- Develop quantitative models of possible health impacts of climate change that can be used to explore a range of socioeconomic and climate scenarios;
- Evaluate effectiveness of current adaptation projects, including the costs and benefits of interventions. For example, heat wave and health early warning systems have not been effective. Further research is needed to understand how public health messages can be made more helpful;
- Characterize with local stakeholders the local and regional scale vulnerability and adaptive capacity related to the potential risks and the time horizon over which climate risks might arise; and,
- Anticipate requirements for infrastructure such as may be needed to provide protection against extreme events, to alter urban design to decrease heat islands, and to maintain drinking and wastewater treatment standards and source water and watershed protection.



5.2.2 Human Settlements Research Gaps

Preceding chapters examine the vulnerabilities and impacts of climate change and variability on human settlements. The following list enumerates topics where a better understanding of the linkages between climate change and human settlements is appropriate.

- Advance the understanding of settlement vulnerabilities, impacts, and adaptive responses in a variety of different local contexts around the country.
- Develop plans for out-migration from vulnerable locations via realistic, socially acceptable strategies for shifting human populations away from vulnerable zones.
- Improve the understanding of vulnerable populations (such as the urban poor and native populations on rural, tribal lands) that have limited capacities for response to climate change in order to provide a basis for adaptation research that addresses social justice and environmental equity concerns.
- Improve the understanding of how urban decision-making is changing as populations become more heterogeneous and decisions become more decentralized, especially in so far as these changes affect adaptive responses.



- Improve researchers' abilities to associate projections of climate change in U.S. settlements with changes in other driving forces related to impacts, such as changes in metropolitan/urban patterns, changes in transportation infrastructure, and technological change. With continued growth in vulnerable regions, research is needed to consider alternative growth futures and to minimize the vulnerability of new development, to insure that communities adopt measures to manage significant changes in sea level, temperature, rainfall, and extreme weather events.
- Improve the understanding of relationships between settlement patterns (both regional and intra-urban) and resilience/adaptation.
- Improve the understanding of vulnerabilities of urban population inflows and outflows to climate change impacts.
- Improve the understanding of second- and third-order impacts of climate change in urban environments, including interactive effects among different aspects of the urban system.
- Review current policies and practices related to climate change responses to help inform community decision-makers and other stakeholders about potentials for relatively small changes that make a large difference.

Meeting these needs is likely to require well-developed partnerships across local, state, and federal governments; industry; non-governmental organizations; foundations; stakeholders; resource managers; urban planners; public utility and public health authorities; and the academic research community.

5.2.3 Human Welfare Research Gaps

Despite the potential for impacts on human well-being, little research focuses directly on understanding the relationship between well-being and climate change. Completely cataloging the effects of global change on human well-being or welfare would be an immense undertaking, and no well-accepted structure for doing so has been developed and applied. Moreover, identifying the potentially lengthy list of climate-related changes in

lifestyle, as well as in other, more tangible, features of well-being (such as income), is itself a daunting task—and may include changes that are not easily captured by objective measures of well-being or quality of life.

Developing an understanding of the impacts of climate change on human welfare will require steps designed to develop a framework for addressing individual and community welfare and well-being, as well as to fill the data gaps associated with the estimation and quantification of effects.

Regarding climate change and human welfare, there is a range of topics associated with human welfare impacts and adaptations where improved understanding would be useful.

- Design an appropriate method for systematically categorizing and identifying impacts on welfare/well-being.
- Identify priority categories for data collection and research in order to establish and quantify the linkage from climate to effects on welfare/well-being.
- Decide which metrics should be used for these categories and, more generally, which components of welfare/well-being should be measured in natural or physical units, and which should be monetized.
- Investigate methods by which diverse metrics can be aggregated, or at least weighted and compared in policy decisions where aggregation is impossible.
- Develop an approach for addressing those human welfare effects that are difficult to look at in a piecemeal way, such as welfare changes on communities or ecosystem services.
- Identify appropriate top-down and bottom-up approaches for estimating impacts and value (whether economic or otherwise) of the most critical categories of welfare/well-being.

Together, these steps should enable researchers to make progress towards promoting the consistency and coordination in analyses of welfare/well-being that will facilitate developing the body of research necessary to analyze impacts on human welfare, well-being, and quality of life.

