Synthesis and Assessment Product 4.6

Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems

Executive Summary

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Abstract

Climate change, interacting with changes in land use and demographics, will affect important human dimensions in the United States, especially those related to human health, settlements and welfare. The challenges presented by population growth, an aging population, migration patterns, and urban and coastal development will be affected by changes in temperature, precipitation, and extreme climate-related events. In the future, with continued global warming, heat waves and heavy downpours are very likely to further increase in frequency and intensity. Cold days and cold nights are very likely to become much less frequent over North America. Substantial areas of North America are likely to have more frequent droughts of greater severity. Hurricane wind speeds, rainfall intensity, and storm surge levels are likely to increase. Other changes include measurable sea-level rise and increases in the occurrence of coastal and riverine flooding. The United States is certainly capable of adapting to the collective impacts of climate change. However, there will still be certain individuals and locations where the adaptive capacity is less and these individuals and their communities will be disproportionally impacted by climate change.

This report – the Synthesis and Assessment Product 4.6 (SAP 4.6) – focuses on impacts of global climate change, especially impacts on three broad dimensions of the human condition: human health, human settlements, and human welfare. The SAP 4.6 has been prepared by a team of experts from academia, government, and the private sector in response to the mandate of the U.S. Climate Change Science Program's Strategic Plan (2003). The assessment examines potential impacts of climate change on human society, opportunities for adaptation, and associated recommendations for addressing data gaps and near- and long-term research goals.

ES.1 Climate Change and Vulnerability

Climate variability and change challenge even the world's most advanced societies. At a very basic level, climate affects the costs of providing comfort in our homes and work places. A favorable climate can provide inputs for a good life: adequate fresh water supplies; products from the ranch, the farm, the forests, the rivers and the coasts; pleasure derived from tourist destinations and from nature, biodiversity, and outdoor recreation. Climate not only supports the provision of many goods and services, but also affects the spread of some diseases and the prevalence of other health problems. It is also associated with threats from extreme events and natural disasters such as tropical storms, riverine and coastal flooding, wildfires, droughts, wind, hail, ice, heat, and cold.

This report examines the impacts on human society of global change, especially those associated with climate change. The impact assessments in this report do not rely on specific emissions or climate change scenarios but, instead, rely on the existing scientific literature with respect to our understanding of climate change and its impacts on human health, settlements and human well-being in the United States. Because climate change forecasts are generally not specific enough for the scale of local decision-making, this report adopts a vulnerability perspective in assessing impacts on human society.

A vulnerability approach focuses on estimating risks or opportunities associated with possible impacts of climate change, rather than on estimating (quantitatively) the impacts themselves which would require far more detailed information about future conditions. Vulnerabilities are shaped not only by existing exposures, sensitivities, and adaptive capacities but also by responses to risks. For example, Boston is generally more vulnerable to heat waves than Dallas because there are fewer air-conditioned homes in Boston than in Dallas. At the same time, human responses (*e.g.,* the elderly not using air-conditioning) also are an important determinant of impacts. This leads to our conclusion that climate change will result in regional differences in impacts in the United States not only due to a regional pattern of changes in climate but the regional nature of our communities in adapting to these changes.

In the United States, we are observing the evidence of long-term changes in temperature and precipitation consistent with global warming. Changes in average conditions are being realized through rising temperatures, changes in annual and seasonal precipitation, and rising sea levels. Observations also indicate there are changes in extreme conditions, such as an increased frequency of heavy rainfall (with some increase in flooding), more heat waves, fewer very cold days, and an increase in areas affected by drought. There have been large fluctuations in the number of hurricanes from year to year which make it difficult to discern trends. Evidence suggests that the intensity of Atlantic hurricanes and tropical storms has increased over the past few decades. However, changes in frequency are currently too uncertain for confident projection.

Changes in the size of the population, including especially sensitive sub-populations, and their geographic distribution across the landscape need to be accounted for when assessing climate variability and change impacts. According to the Census Bureau's middle series projection, the US population will increase to some 570 million people. Moreover, the elderly population is increasing rapidly and many health assessments identify them as more vulnerable than younger age groups to a range of health impacts associated with climate change. Although numbers produced by population projections are important, nearly all trends point to more Americans living in areas that may be especially vulnerable to the effects of climate change. For example, many rapidly growing places in the Mountain West may also experience decreased snow pack during winter and earlier spring melting, leading to lower stream flows, particularly during the high-demand period of summer. Similarly, coastal areas are projected to continue to increase in population, with associated increases in population density, over the next several decades.

Climate is only one of a number of global changes that affect human well-being. These non-climate processes and stresses interact with climate change, determining the overall severity of climate impacts. Socioeconomic factors that can influence exposures, vulnerability and impacts include population, economic status, technology, infrastructure, human capital and social context and behaviors, and institutions. Trends in these factors alter anticipated impacts from climate because they fundamentally shape the nature and scope of human vulnerability. Understanding the impacts of climate change and

variability on the quality of life in the United States therefore implies knowledge of how these factors vary by location, time, and socioeconomic group.

Climate change will seldom be the sole or primary factor determining a population's or a location's well-being. Ongoing adaptation also can significantly influence climate impacts. For example, emergency warning systems have generally reduced deaths and death rates from extreme events, while greater access to insurance and broader, government-funded safety nets for people struck by natural disasters have ameliorated the hardships they face. While this assessment focuses on how climate change could affect the future health, well-being, and settlements in the United States, the extent of any impacts will depend on an array of non-climate factors and adaptive measures. Finally, the effects of climate change very often spread from directly impacted areas and sectors to other areas and sectors through extensive and complex linkages. In summary, 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.

Consistent with all of the Synthesis and Assessment Products being prepared by the CCSP, this report includes statements regarding uncertainty. Each chapter author team assigned likelihood judgments that reflect their assessment of the current consensus of the science and the quality and amount of evidence. The likelihood terminology and the corresponding values that are used in this report are consistent with the latest IPCC Fourth Assessment and are further explained in Chapter 1 of this report. As the focus of this report is on impacts, it is important to note that these likelihood statements refer to the statement of the impact, not statements related to underlying climatic changes.

Table ES.1 provides examples of climate change impacts that are identified in the chapters for human health, settlements, and human welfare and includes potential adaptation strategies. The list of impacts is not comprehensive, but rather includes those that the available evidence suggests may occur. It is important to note that not all effects have been equally well-studied. The effects identified for welfare, in particular, should be taken as examples of effects about which we have some knowledge, rather than a complete listing of all welfare effects.

ES.2 Climate Change and Human Health

The United States is a highly developed country with a wide range of climates. While there may be fewer cases of illness and death associated with climate change in the United States than in the developing world, we nevertheless anticipate increased costs to human health and well being. Greater wealth and a more developed public health system and infrastructure (*e.g.,* water treatment plants, sewers, and drinking water systems; roads, rails and bridges; flood control structures) will continue to enhance our capacity to respond to climate change. Similarly, governments' capacities for disaster planning and emergency response are key assets that should allow the United States to adapt to many of the health effects associated with climate change.

It is very likely that heat-related morbidity and mortality will increase over the coming decades. According to the U.S. Census, the U.S. population is aging; the percent of the population over age 65 is projected to be 13% by 2010 and 20% by 2030 (over 50 million people). Older adults, very young children, and persons with compromised immune systems are vulnerable to temperature extremes. This suggests that temperature-related morbidity and mortality are likely to increase. Similarly, heat-related mortality affects poor and minority populations disproportionately, in part due to lack of air conditioning. The concentration of poverty in inner city neighborhoods leads to disproportionate adverse effects associated with urban heat islands.

There is considerable speculation concerning the balance of climate change-related decreases in winter mortality compared with increases in summer mortality. Net changes in mortality are difficult to estimate because, in part, much depends on complexities in the relationship between mortality and the changes associated with global change. Few studies have attempted to link the epidemiological findings to climate scenarios for the United States, and studies that have done so have focused on the effects of changes in average temperature, with results dependent on climate scenarios and assumptions of future adaptation. Moreover, many factors contribute to winter mortality, making highly uncertain how climate change could affect mortality. No projections have been published for the U.S. that incorporate critical factors, such as the influence of influenza outbreaks.

The impacts of higher temperatures in urban areas and likely associated increases in tropospheric ozone concentrations can contribute to or exacerbate cardiovascular and pulmonary illness if current regulatory standards are not attained. In addition, stagnant air masses related to climate change are likely to degrade air quality in some densely populated areas. It is important to recognize that the United States has a well-developed and successful national regulatory program for ozone, PM2.5, and other criteria pollutants. That is, the influence of climate change on air quality will play out against a backdrop of ongoing regulatory control that will shift the baseline concentrations of air pollutants. Studies to date have typically held air pollutant emissions constant over future decades (*i.e.,* have examined the sensitivity of ozone concentrations to climate change rather than projecting actual future ozone concentrations). Physical features of communities, including housing quality and green space, social programs that affect access to health care, aspects of population composition (level of education, racial/ethnic composition), and social and cultural factors are all likely to affect vulnerability to air quality.

Hurricanes, extreme precipitation resulting in floods, and wildfires also have the potential to affect public health through direct and indirect health risks. SAP3.3 indicates that there is evidence for a human contribution to increased sea surface temperatures in the tropical Atlantic and there is a strong correlation to Atlantic tropical storm frequency, duration, and intensity. However, a confident assessment will require further studies. The health risks associated with such extreme events are thus likely to increase with the size of the population and the degree to which it is physically, mentally, or financially constrained in its ability to prepare for and respond to extreme weather events. For example, coastal evacuations prompted by imminent hurricane landfall are only moderately successful. Many of those who are advised to flee to higher ground stay

behind in inadequate shelter. Surveys find that the public is either not aware of the appropriate preventive actions or incorrectly assesses the extent of their personal risk.

There will likely be an increase in the spread of several food and water-borne pathogens among susceptible populations depending on the pathogens' survival, persistence, habitat range and transmission under changing climate and environmental conditions. While the United States has successful programs to protect water quality under the Safe Drinking Water Act and the Clean Water Act, some contamination pathways and routes of exposure do not fall under regulatory programs (e.g., dermal absorption from floodwaters, swimming in lakes and ponds with elevated pathogen levels, etc.).The primary climate-related factors that affect these pathogens include temperature, precipitation, extreme weather events, and shifts in their ecological regimes. Consistent with our understanding of climate change on human health, the impact of climate on food and water-borne pathogens will seldom be the only factor determining the burden of human injuries, illness, and death.

Health burdens related to climate change will vary by region. For the continental United States, the northern latitudes are likely to experience the largest increases in average temperatures; they will also bear the brunt of increases in ground-level ozone and other airborne pollutants. Because Midwestern and Northeastern cities are generally not as well adapted to the heat as Southern cities, their populations are likely to be disproportionately affected by heat related illnesses as heat waves increase in frequency, severity, and duration. The range of many vectors is likely to extend northward and to higher elevations. For some vectors, such as rodents associated with Hantavirus, ranges are likely to expand, as the precipitation patterns under a warmer climate enhance the vegetation that controls the rodent population. Forest fires with their associated decrements to air quality and pulmonary effects are likely to increase in frequency, severity, distribution, and duration in the Southeast, the Intermountain West and the West. **Table ES.2 summarizes regional vulnerabilities to a range of climate impacts.**

Finally, climate change is very likely to accentuate the disparities already evident in the American health care system. Many of the expected health effects are likely to fall disproportionately on the poor, the elderly, the disabled, and the uninsured. The most important adaptation to ameliorate health effects from climate change is to support and maintain the United States' public health infrastructure.

ES.3 Climate Change and Human Settlements

Effects of climate change on human settlements are likely to vary considerably according to location-specific vulnerabilities, with the most vulnerable areas likely to include Alaska with increased permafrost melt, flood-risk coastal zones and river basins, and arid areas with associated water scarcity. The main climate impacts have to do with changes in the intensity, frequency and location of extreme weather events and, in some cases, water availability rather than temperature change.

Changes in precipitation patterns will affect water supplies nationwide, with precipitation varying across regions and over time. Likely reductions in snowmelt, river flows, and groundwater levels, along with increases in saline intrusion into coastal rivers and groundwater will reduce fresh water supplies. All things held constant, population growth will increase the demand for drinking water even as changes in precipitation will change the availability of water supplies. Moreover, storms, floods, and other severe weather events are likely to affect infrastructure such as sanitation, transportation, supply lines for food and energy, and communication. Some of the nation's most expensive infrastructure, such as exposed structures like bridges and utility networks, are especially vulnerable. In many cases, water supply networks and stressed reservoir capacity interact with growing populations (especially in coastal cities and in the Mountain and Pacific West). The complex interactions of land use, population growth and dynamics of settlement patterns further challenge supplies of water for municipal, industrial, and agricultural uses. In the Pacific Northwest the electricity base dominated by hydropower is directly dependent upon the water flows from snowmelt. Reduced hydropower would mean the need for supplemental electricity sources, resulting in a wide variety of negative ripple effects to the economy and to human welfare. Similarly, along the West Coast, communities are likely to experience greater demands on water supplies even as regional precipitation declines and average snow packs decrease.

Communities in risk-prone regions, such as coastal zones, have reason to be concerned about potential increases in severe weather events. The combined effects of severe storms and sea-level rise in coastal areas or increased risks of fire in more arid areas are examples of how climate change may increase the magnitude of challenges already facing risk-prone regions. Vulnerabilities may be especially pronounced for rapidly-growing and/or larger metropolitan areas, where the potential magnitude of both impacts and coping requirements are likely to be very large. On the other hand, such regions have greater opportunity to adapt infrastructure and to make decisions that limit vulnerability.

Warming is virtually certain to increase energy demand in U.S. cities for cooling in buildings while it reduces demands for heating in buildings (see SAP 4.5 *Effects of Climate Change on Energy Production and Use in the United States*). Demands for cooling during warm periods could jeopardize the reliability of service in some regions by exceeding the supply capacity, especially during periods of unusually high temperatures. Higher temperatures also affect costs of living and business operation by increasing costs of climate control in buildings

Climate change has the potential not only to affect communities directly but also indirectly through impacts on other areas linked to their economies. Regional economies that depend on sectors highly sensitive to climate such as agriculture, forestry, water resources, or recreation and tourism could be affected either positively or negatively by climate change. Climate change can add to stress on social and political structures by increasing management and budget requirements for public services such as public health care, disaster risk reduction, and even public safety. As sources of stress grow and combine, the resilience of social and political structures are expected to be

challenged, especially in locales with relatively limited social and political capital.

Finally, population growth and economic development is occurring in those areas that are likely to be vulnerable to the effects of climate change. Approximately half of the U.S. population, 160 million people, will live in one of 673 coastal counties by 2008. Coastal areas – particularly those on gently-sloping coasts and zones with gradual land subsidence – will be at risk for sea level rise, especially related to severe storms and storm surges.

ES.4 Climate Change and Human Welfare

The terms human welfare, quality of life, and well-being are often used interchangeably, and by a number of disciplines as diverse as psychology, economics, health science, geography, urban planning, and sociology. There is a shared understanding that all three terms refer to aspects of individual and group life that improve living conditions and reduce chances of injury, stress, and loss.

Human well-being is typically defined and measured as a multi-dimensional concept. Taxonomies of place-specific well-being or quality of life typically converge on six dimensions: 1) economic conditions, 2) natural resources and amenities, 3) human health, 4) public and private infrastructure, including transportation systems, 5) government and public safety and 6) social and cultural resources. Climate change will likely have impacts across all of these dimensions – both positive and negative. In addition, the positive and negative effects of climate change will affect broader communities, as networks of households, businesses, physical structures, and institutions are located together across space and time.

Quantifying impacts of climate change on human well-being requires linking effects in quality of life to the projected[1] physical effects of climate change and the consequent effects on human and natural systems. Economic analyses provide a means of quantifying and, in some cases, placing dollar values on welfare effects. Even in cases where welfare effects have been quantified, it is difficult to compare and aggregate a range of effects across a number of sectors.

This report examines four types of effects on economic welfare: those on ecosystems, human health, recreation, and amenities associated with climate. Many of the goods and services affected by climate are not traded in markets; as a result, they can be difficult to value." For example, ecologists have already identified a number of ecological impacts of climate change, including the shifting, break up, and loss of certain ecological communities; plant and animal extinctions and a loss in biodiversity; shifting ranges of plant and animal populations; and changes in ecosystem processes, such as

[1] A climate projection is the calculated response of the *climate system* to *emissions* or concentration *scenarios* of *greenhouse gases* and *aerosols*, or *radiative forcing scenarios*, often based on simulations by *climate models*. Climate projections are distinguished from *climate predictions*, in that the former critically depend on the emissions/concentration/*radiative forcing* scenario used, and therefore on highly uncertain assumptions of future socio-economic and technological development.

nutrient cycling and decomposition. While ecosystems provide a variety of services to humans, including food and fiber, regulating air and water quality, support services such as photosynthesis, and cultural services such as recreation and aesthetic or spiritual values, these typically are not traded in markets.

Little research has been done linking these ecological changes to changes in services, and still less has been done to quantify, or place dollar values on, these changes. Ecosystem impacts also extend beyond the obvious direct effects within the natural environment to indirect effects on human systems. For instance, nearly 90% of Americans take part in outdoor recreation. The length of season of some of these activities, such as hiking, boating, or golfing, may be favorably affected by slightly increased temperatures. However, snow and ice sport seasons are likely to be shortened, resulting in lost recreation opportunities. The net effect is unclear as decrements associated with snow-based recreation may be more than outweighed by increases in other outdoor activities.

An agenda for understanding the impacts of climate change on human welfare may require taking steps both to develop a framework for addressing welfare, and to address the data and methodological gaps inherent in the estimation and quantification of effects. To that end, the study of climate change on human welfare is still developing, and, to our knowledge, no study has made a systematic survey of the full range of welfare impacts associated with climate change, much less attempted to quantify them**.**

ES.5 Tables

Table ES.1 Examples of Possible Impacts (present to 2050) of Climate Variability and Change on Human Health, Settlements, and Welfare in the United States and Potential Adaptation Strategies)

Focus Area	Climate Event	Examples of Possible Impacts	Likelihood of Impact Given Climate Event Occurs[1]	Potential Adaptation Strategies
HUMAN HEALTH				
	Extreme temperatures More heat waves and higher maximum temperatures Fewer cold waves and higher minimum temperatures	Heat stress/stroke or hyperthermia Uncertain impacts on mortality[2]	Very likely in Midwest and northeast urban centers	Early watch and warning systems and installation of cooling systems in residential and commercial buildings,
	Changes in precipitation, especially extreme precipitation	Contaminated water and food supplies with associated gastrointestinal illnesses, including *salmonella* and *giardia*	Likely in areas with out-dated or over-subscribed water treatment plants	Improve infrastructure to guard against combined sewer overflow; public health response to include "boil water" advisories
	Hurricane and storm surge	Injuries from flying debris and drowning / exposure to contaminated flood waters and to mold and mildew / exposure to carbon monoxide poisoning from portable generators	Likely in coastal zones of the southeast Atlantic and the Gulf Coast	Increase knowledge and awareness of vulnerability to climate change (*e.g.,* maps showing areas vulnerable to storm surges); public health advisories in immediate aftermath of storm; coordinate storm relief efforts to insure that people receive necessary information for safeguarding their health
	Temperature-related effects on ozone[3]	Ozone concentrations more likely to increase than decrease; possible contribution to cardiovascular and pulmonary illnesses, including exacerbation of asthma and chronic obstructive pulmonary disorder (COPD) if current regulatory standards are not attained	Likely in urban centers in the mid-Atlantic and the northeast	Public warning via air quality action days; encourage public transit, walking and bicycling to decrease emissions

Focus Area	Climate Event	Examples of Possible Impacts	Likelihood of Impact Given Climate Event Occurs[1]	Potential Adaptation Strategies
	Wildfires	Degraded air quality, contributing to asthma and COPD aggravated	Likely in California, the Intermountain West, the southwest and the southeast	Public health air quality advisories
HUMAN SETTLEMENTS				
	Extreme temperatures More heat waves and higher maximum temperatures Fewer cold waves and higher minimum temperatures	Increased net energy demand and expand capacity for peak cooling Reduced cold-related stresses and costs	Very likely	Expand capacity for cooling through public utilities; invest in alternative energy sources
	Drought	Strain on municipal and agricultural water supplies	Very likely in intermountain west, desert southwest, and southeast	Reallocate water among current users; develop water markets to encourage more efficient allocation; identify new sources through expansion of reservoirs; encourage conservation of water for personal and public use; develop drought resistant crops,
	Hurricane and storm surge	Disruption of infrastructure, including levee systems, river channels, bridges, and highway systems; disruption of residential neighborhoods	Very likely in southeast Atlantic Coast and Gulf Coast	Increase knowledge and awareness of climate impacts (*e.g.,* maps showing areas vulnerable to storm surges); harden coastal zones or retreat or relocate; insure against catastrophic loss due to flooding and high winds
	Wildfires	Disruption of communities and property destruction	Very likely in intermountain west, desert southwest, and southeast	Clear vegetation away from buildings; issue emergency evacuation orders, prescribed burns, thinning of combustible matter

Focus Area	Climate Event	Examples of Possible Impacts	Likelihood of Impact Given Climate Event Occurs[1]	Potential Adaptation Strategies
	Late snow fall and early snow melt	Disruption of water supplies for municipal and agricultural use	Very likely in intermountain west	Build reservoirs; conserve water supplies; divert supply from agricultural to municipal use; modify operation of existing infrastructure to account for changes in hydrology; develop drought resistant crops, water prices at replacement cost, enable trading by working with states to develop property rights
HUMAN WELFARE				
	Extreme temperatures More heat waves and higher maximum temperatures	Discomfort; limit some outdoor activities / recreation	Very likely in more northern latitudes of the United States and in Alaska	Public health watch/warning advisories
	Fewer cold waves and higher minimum temperatures	Limit some snow- and cold-related recreational opportunities; substantial economic disruption to recreation industry	Very likely in intermountain west, Northern New England and the Upper Great Lakes	Engage in alternative recreation activities
	Late autumn snow fall and early spring snow melt	Limit some snow-related recreational opportunities; substantial economic disruption to recreation industry	Very likely in intermountain west, Northern New England and the Upper Great Lakes	Engage in alternative recreation activities
	Extreme precipitation events	Local flooding and contamination of water supplies	Very likely nationwide	Issue flood advisories / warnings
	Hurricane and coastal storms	At-risk properties experience flood and wind damage; individuals experience disruption to daily life	Very likely in coastal zone of the Gulf Coast and the southern Atlantic	Relocate dwellings and business, and reinforce structures and infrastructure to reduce disruptions

[1] Based on impacts identified in the published, peer-reviewed literature and expert opinion. Does not include an evaluation of likelihood of the climate event. May include some adaptation (*e.g.,* in the baseline estimate) but generally does not account for additional changes or developments in adaptive capacity.

[2] Many factors contribute to winter mortality, making highly uncertain how climate change could affect mortality. No projections have been published for the United States that incorporates critical factors, such as the influence of influenza outbreaks.

[3] If areas remain in compliance with National Ambient Air Quality Standards, people will not be exposed to unhealthy air (*i.e.,* cardiovascular and pulmonary illnesses will not occur). More stringent emissions controls may be required to remain in compliance although this is uncertain and additional study is needed.

Table ES.2 Summary of Regional Vulnerabilities to Climate-Related Impacts[1]

United States Census Regions	Climate-Related Impacts								
	Early Snowmelt	Degraded Air Quality	Urban Heat Island	Wildfires	Heat Waves	Drought	Tropical Storms	Extreme Rainfall with Flooding	Sea Level Rise
New England ME VT NH MA RI CT	●	●	●		●	●		●	●
Middle Atlantic NY PA NJ	●	●	●		●	●	●	●	●
East North Central WI MI IL IN OH	●	●	●		●	●		●	
West North Central ND MN SD IA NE KS MO	●		●		●	●		●	
South Atlantic WV VA MD MC SC GA FL DC		●	●	●	●	●	●	●	●
East South Central KY TN MS AL					●	●	●		●
West South Central TX OK AR LA		●	●	●	●	●	●	●	●
Mountain MT ID WY NV UT CO AZ NM	●	●	●	●	●	●			
Pacific AK CA WA OR HI	●	●	●	●	●	●	●	●	●

[1] Based on impacts identified in the published, peer-reviewed literature and expert opinion.