

1 **Synthesis and Assessment Product 4.6**

2

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

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6 **Executive Summary**

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Abstract

Climate change, interacting with changes in land use and demographics, has the capacity to affect important human dimensions in the United States, especially related to human health, human settlements and human welfare. The challenges presented by population growth, an aging population, migration patterns, and urban and coastal development are likely to be compounded by changes in temperature, precipitation, and extreme climate-related events. Climate change will affect where people choose to live, work, and play. Even wealthy societies, like the United States, will be subject to climate impacts. Climate change will affect individuals and communities including impacts related to variation in rainfall, more intense downpours, more frequent heat waves, severe drought conditions with associated water shortages, changes in minimum and maximum temperatures, potential increases in the intensity and frequency of extreme tropical storms, measurable sea-level rise and increases in the occurrence of coastal and riverine flooding. In response to these anticipated changes, the United States is expected to develop and deploy strategies for mitigating greenhouse gases and for adapting to the individual and collective impacts of climate change.

This report – the Synthesis and Assessment Product 4.6 (SAP 4.6) – focuses on how climate change affects what people care most about. It analyzes the impacts of global change, especially those of climate variability and change and of land use and population dynamics, 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.

Survey of Important Findings

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 also provides 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 provides 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, fires, droughts, wind, hail, ice, heat, and cold.

1 Table ES.1 Impacts of Climate Variability and Change on Human Health, Human Settlements, and Human Welfare
 2 in the United States

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Focus Area	Climate factor	Impact	Assessment	Adaptation Strategies
HUMAN HEALTH				
	Extreme temperatures	Heat stress/stroke or hypothermia	Very likely in Midwest and northeast urban centers	Early watch and warning systems and installation of cooling systems in residential and commercial buildings
	Increase in 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	Public health advisories in immediate aftermath of storm; coordinate storm relief efforts to insure that people receive necessary information for safeguarding their health
	Devastating storm events	Post-traumatic stress disorder and related anxiety and depression	Likely in instances of extreme storm events, such as was seen in the aftermath of Hurricane Katrina	Public health response should include identification of persons in need of mental health care; response should coordinate local service providers and emergency providers
	Air pollution aggravated by temperature-related increases in ozone and aeroallergens	Cardiovascular and pulmonary illnesses, including exacerbation of asthma and chronic obstructive pulmonary disorder (COPD)	Very likely in urban centers in the west, the southwest, the mid-Atlantic and the northeast	Public warning via air quality action days; encourage use of alternative fuels in vehicles and in personal and commercial HVAC systems
	Air pollution degraded by wildfire	Asthma and COPD aggravated	Likely in California, the southwest and the southeast	Public health air quality advisories

HUMAN SETTLEMENTS				
	Extreme temperatures	Increase energy demand	Very likely	Expand capacity for heating and 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	Identify new sources through development of reservoirs; encourage conservation of water for personal and public use
	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	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
	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
HUMAN WELFARE				
	Extreme temperatures	Discomfort; limit some outdoor activities / recreation	Very likely in more northern latitudes of the United States	Public health watch/warning advisories
	Late snow fall and early snow melt	Limit some snow-related recreational opportunities	Very likely in intermountain west	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	Purchase flood insurance to limit personal exposure to catastrophic loss

1 Climate variability and change interact with existing and changing settlement patterns. In the
2 United States, we have seen shifts of population from frost-belt to sun-belt, the movement of
3 households from urban centers to far flung suburbs, an overall loss of population in some urban
4 centers in the Midwest and Northeast, and rapid growth in the metropolitan areas of the South
5 and West. Additionally, the proliferation of information technologies and declining costs of
6 airline travel have made previously remote locations more accessible for work or retirement.
7 Together, these trends dramatically alter anticipated impacts from climate because they
8 fundamentally shape the nature and scope of human vulnerability. Understanding the impacts of
9 climate change and variability on the quality of life in U.S. communities implies knowledge of
10 how these dynamics vary by location, time, and socioeconomic group. The following summary
11 examines a range of climate-related impacts on critical human systems, including: human health,
12 human settlements, and human welfare.

13

14 **Summary of Effects of Climate on Human Health.**

15

16 **The United States is a developed country with a temperate climate. There will likely be**
17 **fewer cases of illness and death resulting from climate change than expected in the**
18 **developing world for a number of reasons.** First, greater wealth and more developed
19 infrastructure enhance our ability to respond to changes. In particular, the well-developed public
20 health and medical care infrastructures, along with the involvement of government agencies and
21 non-governmental organizations in disaster planning and response are key assets that will allow
22 the U.S. to adapt to some of the health effects associated with climate change.

23

24 **It is very likely that the burden of heat-related morbidity and mortality will increase over**
25 **coming decades.** The U.S. population is aging; the percent of the population over age 65 is
26 projected to be 13% by 2010 and 20% by 2030 (over 50 million people). Older adults are
27 vulnerable to temperature extremes. This suggests that temperature-related morbidity and
28 mortality are likely to increase. Heat-related mortality affects poor and minority populations
29 disproportionately, in part due to lack of air conditioning. In fact, the concentration of poverty in
30 inner city neighborhoods leads to disproportionate adverse effects related to urban heat islands.

31 **The impacts of higher temperatures in urban areas and associated increases in**
32 **tropospheric ozone concentrations are likely to cause or exacerbate cardiovascular and**
33 **pulmonary illness.** In addition, stagnant air masses related to climate change are likely to
34 increase air pollution in some local areas. Physical features of communities, including housing
35 quality and green space, social programs that affect access to health care, aspects of population
36 composition (level of education, racial/ethnic composition), and social and cultural factors are all
37 likely to affect vulnerability to temperature extremes.

38 **Hurricanes, extreme precipitation resulting in floods, and wildfires also have the potential**
39 **to affect public health through direct and indirect health risks.** Health risks associated with
40 extreme events are likely to increase with the size of the population and the degree to which it is
41 physically, mentally, or financially constrained in its ability to prepare for and respond to
42 extreme weather events. For example, heat wave early warning systems are designed to warn

1 the public of risks of dangerously hot ambient temperatures, but a survey of older adults found
2 that the public was not aware of the appropriate preventive actions.

3 **Several food and water-borne pathogens are likely to be transmitted among susceptible**
4 **populations depending on the pathogens' survival, persistence, habitat range and**
5 **transmission under changing climate and environmental conditions.** The primary climate-
6 related factors that may affect these pathogens include temperature, precipitation, extreme
7 weather events, and ecological shifts. Nonetheless, climate change will seldom be the primary
8 factor affecting the burden of climate-related injuries, illness, and death.

9 **Health burdens related to climate change will vary by region.** The northern latitudes of the
10 United States are likely to experience the largest increases in average temperatures; they will also
11 bear the brunt of increases in ground-level ozone and other airborne pollutants. Populations in
12 Midwestern and Northeastern cities are likely to be disproportionately affected by heat related
13 illnesses as heat waves increase in frequency, severity, and duration. The distributions of disease
14 vectors are likely to widen. The range of many vectors is likely to extend northward and to
15 higher elevations. For some vectors, such as rodents associated with Hantavirus, ranges are
16 likely to expand, based on decreased, rather than increased, precipitation. The West Coast is
17 likely to experience even greater demands on water supplies as regional precipitation declines
18 and average snow packs decrease. Forest fires with their associated decrements to air quality are
19 likely to increase in frequency, severity, distribution, and duration in the Southeast, the
20 Intermountain West and the West.

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

26 **Summary of the Effects of Climate Change on Human Settlements**

27 **Effects of climate change on human settlements are very likely to vary considerably**
28 **according to location-specific vulnerabilities, with the most vulnerable areas likely to**
29 **include: Alaska, flood-risk coastal zones and river basins, arid areas with associated water**
30 **scarcity and areas where the economic base is climate sensitive.** Except for Alaska, the main
31 climate impacts have to do with changes in the intensity, frequency and location of extreme
32 weather events and, in some cases, water availability rather than temperature change.

33 **Changes in precipitation patterns will affect water supplies nationwide. Likely reductions**
34 **in snowmelt, river flows, and groundwater levels, along with increases in saline intrusion**
35 **into coastal rivers and groundwater will shrink fresh water supplies even as population**
36 **growth taxes demand.** Moreover, storms, floods, and other severe weather events are likely to
37 affect infrastructure such as sanitation, transportation, supply lines for food and energy, and
38 communication. Some of our most expensive infrastructure, such as exposed structures like
39 bridges and utility networks, are especially vulnerable. In many cases, water supply networks
40 and stressed reservoir capacity interact with growing populations (especially in coastal cities and
41 in the Mountain and Pacific West). The complex interactions of land use, population growth and

1 dynamics of settlement patterns further challenge supplies of water for municipal, industrial, and
2 agricultural uses.

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5 Hurricane Katrina flooding in New Orleans Louisiana. National Oceanic and Atmospheric Administration.
6 www.katrina.noaa.gov/helicopter/helicopter-2.html

7 **Communities in risk-prone regions have reason to be particularly concerned about any**
8 **potential increase in severe weather events.** The combined effects of severe storms and sea-
9 level rise in coastal areas or increased risks of fire in drier arid areas are examples of how climate
10 change may increase the magnitude of challenges already facing risk-prone communities.
11 Vulnerabilities may be especially great for rapidly-growing and/or larger metropolitan areas,
12 where the potential magnitude of both impacts and coping requirements are likely to be very
13 large. On the other hand, such regions have greater opportunity to put more adaptable
14 infrastructure in place and make decisions that limit vulnerability.

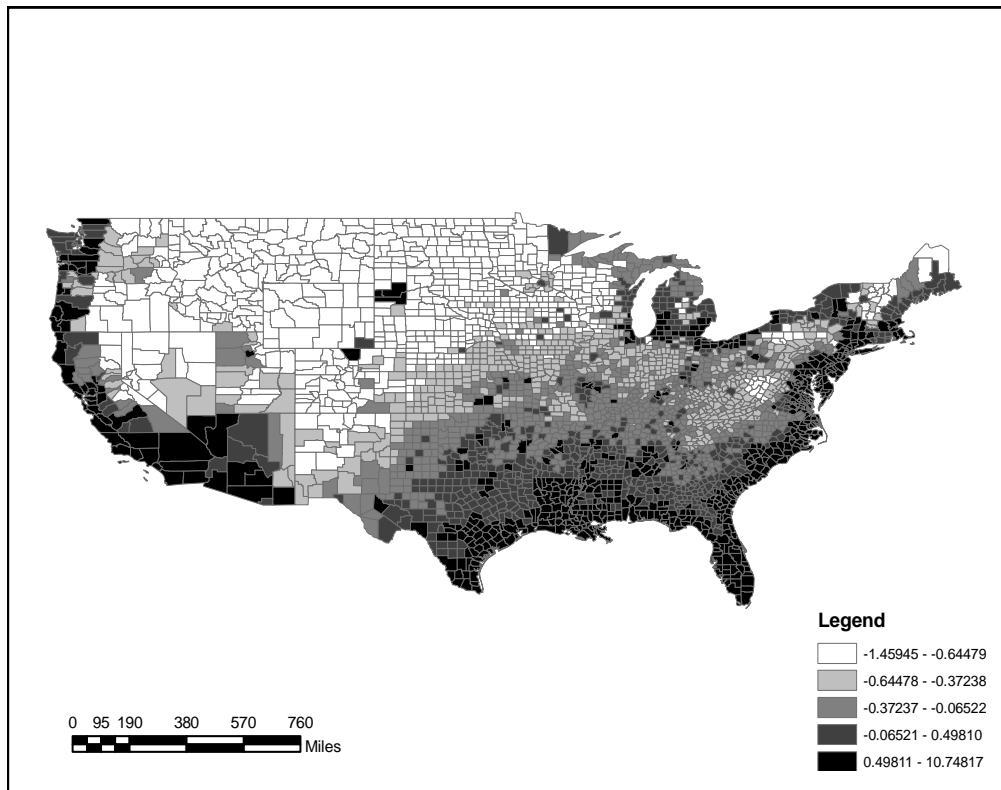
15 **Warming is virtually certain to increase overall energy demand in U.S. cities** (see SAP 4.5
16 Effects of Climate Change on Energy Production and Use in the United States). Even though
17 some regions will have less demand related to winter heating, increased demand for cooling
18 during unusually warm periods will most likely be larger. This increased demand is also more
19 likely to jeopardize energy service reliability in areas where failures of the electric grid occurs
20 more frequently in over-taxed urban systems. The increasing climate control needs in homes,
21 schools, hospitals and commercial buildings will have inflate business and household energy
22 costs.

23 **Climate change has the potential not only to affect communities directly but also through**
24 **undermining their economic bases.** In particular, some regional economies are dependent on
25 sectors highly sensitive to changes in climate: agriculture, forestry, water resources, or tourism.
26 Climate change can add to stress on social and political structures by increasing management and

1 budget requirements for public services such as public health care, disaster risk reduction, and
 2 even public safety. As sources of stress grow and combine, the resilience of social and political
 3 structures are expected to suffer, especially in locales with relatively limited social and political
 4 capital.

5 **Finally, growth and development is generally moving toward areas more likely to be**
 6 **vulnerable to the effects of climate change.** For example, approximately half of the U.S.
 7 population, 160 million people, will live in one of 673 coastal counties by 2008. Coastal areas –
 8 particularly those on gently-sloping coasts – should be concerned about sea level rise in the
 9 longer term, especially if they are subject to severe storms and storm surges and/or if their
 10 regions are showing gradual land subsidence. The map (figure ES.2) identifies the concentrations
 11 of highly vulnerable counties as lying along the east and west coasts and Great Lakes, with
 12 medium vulnerability counties mostly inland in the southeast, southwest, and northeast. The
 13 study uses measures of both *physical vulnerability* (expected temperature change, extreme
 14 weather events, and coastal proximity) and *adaptive capacity* (as represented by economic,
 15 demographic, and civic participation variables that constitute a locality’s socioeconomic capacity
 16 to commit to costly climate change policy initiatives).

17
 18 Figure ES.1 Geography of Climate Change Vulnerability at the County Scale Source: Zahran *et al.*, forthcoming.
 19



20 21 22 Summary of the Effects of Climate Change on Human Welfare

23
 24 The terms human welfare, quality of life, and well-being are often used interchangeably,
 25 and by a number of disciplines as diverse as psychology, economics, health science,

1 **geography, urban planning, and sociology. Welfare is typically defined and measured as a**
2 **multi-dimensional concept.** Quality of life taxonomies typically converge on six dimensions:
3 1) economic conditions, 2) natural resources and amenities, 3) human health, 4) public and
4 private infrastructure, 5) government and public safety and 6) social and cultural resources.
5 Climate change will most likely have impacts across all of these dimensions – both positive and
6 negative. In addition, the positive and negative effects of climate change will together have
7 effects on broader communities, which are the networks of households, businesses, physical
8 structures, and institutions located together in geographic space.

9
10 **Quantifying impacts of climate change on human welfare requires linking effects in the**
11 **quality of life dimensions to the projected physical effects of climate change and the**
12 **consequent effects on human and natural systems. Economics provides one means of**
13 **quantifying and, in some cases, placing dollar values on welfare effects.** Most of the climate
14 research, however, has not focused on quantifying linkages from climate change to specific
15 endpoints or services, which are the foundation of welfare. In addition, even in cases where
16 welfare effects have been quantified, it is difficult to compare and aggregate disparate effects
17 across different sectors, because of the different metrics that each sector uses (e.g., human illness
18 and morbidity vs. reductions in numbers of species).

19
20 **This report examines four types of effects: those on ecosystems, human health, recreation,**
21 **and amenities associated with climate.** Some of the less tangible effects of climate change can
22 be difficult to quantify and value, because they represent effects on good and services that are
23 not traded in markets. For example, ecosystems provide a variety of services, including: food
24 and fiber, regulating air and water quality, support services such as photosynthesis, and cultural
25 services such as recreation and aesthetic or spiritual values. Ecologists have already detected or
26 predict within this century a number of ecological impacts, including the shifting, break up, and
27 loss of ecological communities; plant and animal extinctions and a loss in biodiversity; shifting
28 ranges of plant and animal populations; and changes in ecosystem processes, such as nutrient
29 cycling and decomposition.

30
31 **Little research has been done linking these ecological changes to changes in services, and**
32 **still less has been done to quantify, or place dollar values on, these changes.** Ecosystem
33 impacts also extend beyond the obvious direct effects within the natural environment to indirect
34 effects on human systems. Nearly 90% of Americans take part in outdoor recreation. The length
35 of the season of some of these activities may be favorably affected by slightly increased
36 temperatures, however ambient conditions may eventually have adverse effects on outdoor
37 activities like walking or beach recreation that is affected by sea level rise. Snow sports are the
38 most obvious casualty among vulnerable recreation activities with the reduction in visitor use
39 occurring primarily from a shorter season. But, the decrements associated with snow-based
40 recreation are more than outweighed by increases in other outdoor activities, including boating,
41 fishing, golf, and beach and stream recreation.

42
43 **An agenda for understanding the impacts of climate change on human welfare may require**
44 **taking steps both to develop a framework for addressing welfare, and to address the data**
45 **and methodological gaps inherent in the estimation and quantification of effects.** To that
46 end, the study of climate change on human welfare is still developing, and, to our knowledge, no

1 study has made a systematic survey of the full range of welfare impacts associated with climate
 2 change, much less attempted to quantify them.

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Table ES.2. The regional texture of climate endpoints associated with U.S. population growth to 2030, by census region. The expected growth is concentrated in the relatively more vulnerable areas of the South Atlantic, the Gulf Coast (West South Central) and the West.

U.S. Census Region	Pop Growth by 2030 (millions)	Climate-Related Issues							
									
New England ME VT NH MA RI CT	2.0			✓	✓				
Middle Atlantic NY PA NJ	3.9	✓	✓	✓					
East North Central WI MI IL IN OH	4.2		✓				✓		
West North Central ND MN SD IA NE KS MO	3.1		✓				✓	✓	
South Atlantic WV VA MD NC SC GA FL	15.7	✓	✓		✓		✓	✓	✓
East South Central KY TN MS AL	3.3	✓	✓		✓		✓		
West South Central TX OK AR LA	10.6	✓	✓		✓		✓	✓	✓
Mountain MT ID WY NV UT CO AZ NM	7.3	✓	✓	✓			✓	✓	✓
Pacific AK CA WA OR HI	22.2	✓	✓	✓			✓	✓	✓

Snowpack / snowmelt		Degraded summer air quality	
Urban heat islands		Hurricanes	
Extreme rainfall events		Wildfires	
Drought		Heat wave	

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