Synthesis and Assessment Product 4.6

Chapter 2

The Human Dimensions of Global Change in the United States

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2.1 How is climate change likely to affect people and communities in the United States over the coming decades?

Our daily conversations often begin or end with a pronouncement about the day's weather.

"It's too nice to be working indoors."

"We need rain."

"This is the 5th 100-degree day this month."

Our focus on the day-to-day fluctuations of weather reflects the far-reaching impacts that weather has on our sense of well-being and comfort, as well as, our concern about weather extremes that have the capacity to disrupt or even end lives. Against the backdrop of the daily variations in weather, we are becoming more aware of longer-term changes in climate described in the popular press as global warming. Just as our daily experience of weather is tied to where we live and work, so too will our experience of climate variability and change. In the United States, we are beginning to observe the manifestations of a long-term warming trend.

This chapter tells the story of how climate change is likely to be experienced by Americans, both in their daily lives and in the lives of their communities. It examines how the impacts of climate change are determined by where people live and how our health and well-being is inextricably tied to multiple facets of global change. The chapter reviews how demographic patterns in the United States have evolved to create vulnerabilities to climate change and how climate's effects on human health and welfare are determined, at least in part, by the context of place. The chapter analyzes what makes communities livable and how those characteristics interact with climate. Finally, it assesses how adaptation strategies can be employed to mediate climate impacts on human health, human settlements, and individual and collective well-being.

2.1.1. Projected Climate Change: The U.S. experience. [see Sections 1.2, 3.2, 4.2, 5.2]

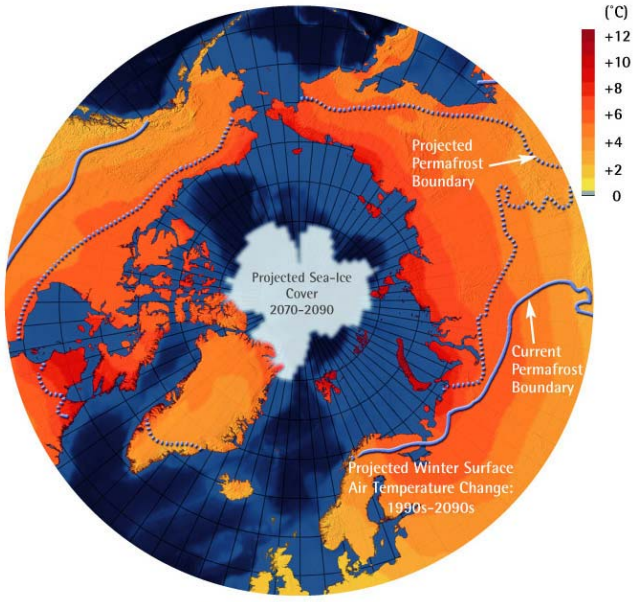
In the United States, we are now observing the evidence of long-term changes in temperature and precipitation consistent with global warming. Projected climate change is expected to exert significant effects on individuals and communities across the country. Climate change is being realized through more intense tropical storms, permafrost thaw, heat waves, droughts, glacial retreat, early melting of snowpack, low reservoir levels, erosion of coastal zones, sea level rise, and heavy precipitation events. Climate change is also realized in indirect effects, such as the large climate-related worsening of ambient air pollution and the indirect effects of climate on disease transmission dynamics.

Tropical storms. Observations indicate that a greater number of more intense tropical storms have occurred since about 1970. If this trend continues, coastal communities along the Gulf Coast and the Southeast Atlantic are likely to experience increased disruptions. The increased risks to these communities in coastal zones and low-lying areas are related to the combination of coastal erosion, storm surge, sea level rise, and the higher peak winds and heavier precipitation associated with the increase in tropical storm intensity. Furthermore, extensive coastal development magnifies the impacts of tropical storms by putting more communities at risk of sustaining a direct hit from a hurricane or a tropical storm. While the number of intense tropical storms appears to be increasing, globally there is little trend in overall tropical storm frequency. The record of tropical storm activity prior to 1970 is of lower quality than the more recent observations, making it more difficult to confidently discern long-term trends.

***Water scarcity*.** Water shortages are the legacy of a generally warmer climate with its associated decreases in snow and spring runoff from snowmelt and of increasing demands related to

population growth. Coping with the consequences of decreased precipitation and increasing temperatures will require major changes in water management and allocation systems, especially in the West. Communities will be called upon to allocate scarce water resources between municipal, industrial, and agricultural uses, between human uses and those of existing ecosystems, and between maintenance of reservoirs and dams for recreation and hydroelectric production.

Arctic warming, permafrost thaw, and coastal flooding. Warming in the Arctic is leading to retreat of sea ice, especially from the northern coast of Alaska, and to coastal erosion and permafrost thaw. Coastal erosion is putting communities at risk and disrupting homes and livelihoods. Native Peoples have been disproportionately affected. Melting permafrost, coupled with storm surge along the coast which until recently was packed with sea ice, have caused entire communities to retreat from the coast. Infrastructure (including oil pipelines, roadways, and buildings) has sustained and will continue to sustain damage associated with permafrost thaw (see Box 1).



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Sinkhole in permafrost near Fairbanks Alaska. Source: NCAR

Box 1 Alaska: The Permafrost Retreat

Global model simulations from the National Center of Atmospheric Research (NCAR) show that more than 50% of the topmost layer of permafrost could thaw by 2050 and as much as 90% by 2100. The study found that approximately 25% of the Northern Hemisphere land mass contains permafrost --- including an active surface layer of as little as a few centimeters to a depth of several meters. Deeper permafrost layers will remain frozen. But recent warming has degraded large sections of permafrost across central Alaska. Results of the thaw include buckled highways and airport runways, destabilized houses, commercial buildings, and pipelines, and "drunken forests" where trees begin to uproot and lean. Further degradation of the permafrost is expected to threaten migratory patterns of caribou and reindeer. Thaw will also impact natural ecosystems through lake drainage, collapse of ground surface, and development of wetlands.

National Center for Atmospheric Research. 2005. Most of Arctic's Near-Surface Permafrost May Thaw by 2100. Geophysical Research Letters.

Arctic Climate Impact Assessment. Impacts of a Warming Arctic. 2004. SJ Hassol, editor. Cambridge University Press.

Drought and wildfire. Droughts in the West and Southeast are likely to be more persistent through the 2050s. Drought conditions not only challenge the provision of water for individual consumption, but also the requirements of agricultural and industrial uses. With severe, persistent drought, wildfires and associated displacement of at-risk populations may become more common. Dried vegetation, especially in heavily forested areas will aggravate the risk for wildfire. At the same time, increased development of communities in at-risk areas will imperil lives and properties.

Glacial retreat, snow melt, and lake levels. Climate models also project warming in the intermountain West accompanied by glacial retreat, decreased snow pack, earlier snow melt and reduced summer stream flows on rivers issuing from the snowpack. These changes are affecting rapidly-developing cities in the West and exacerbating water allocation controversies. Conflicts over western water supplies are expected to become more problematic in coming decades. Water levels have fallen dramatically in recent years in large reservoirs across the West. For instance, Lake Mead has historically provided a steady water supply for the Colorado River Basin. However, drought conditions and decreased runoff have threatened the lake's supplies. Retreat of the water in Lake Mead has forced changes in recreational activities with closing or relocation of marinas and other shoreline development. The duration of drought conditions in the Colorado River system is similar in extent to a drought experienced in the late 1950s. It is not known whether the current drought is a sentinel for drought conditions associated with longer-term climate change or whether the drought is background variability in climate conditions.

Lake Mead: As of July 7, 2003 the lake was 1129 Feet (344.1m) above sea level. Full elevation is at 1221.4 (372.3) feet above sea level, according to the Bureau of Reclamations. Photo courtesy of NASA.

Sea level rise and erosion of coastal zones. Erosion of coastal zones associated with sea level rise will be especially severe along the Gulf Coast and the Mid-Atlantic regions of the United States. Higher temperatures are expected to raise sea level by expanding ocean water, melting glaciers and causing ice sheets in Greenland and the Antarctic to melt. In the past century, global sea level rose 5-8 inches. Coupled with subsidence in these coastal areas, projections now suggest that the Gulf Coast and Mid-Atlantic will experience a one to three foot rise in relative sea level during the 21st century. Rising sea level erodes beaches and low-lying lands, increases salinity in bays and estuaries, and contributes to coastal flooding. Adaptation measures (such as replenishing beaches

and constructing seawalls) could adversely affect coastal ecosystems and public access and use of beaches. Complicating concerns about sea level rise is the continuing increase in coastal zone development. Even without changes in sea level, dense coastal development is putting millions of Americans and their properties at risk.

River flooding and extreme precipitation events. There is observational evidence of increases in the number of heavy precipitation events over the past decades, particularly over land, and widespread increases in the frequency of heavy precipitation events across the United States are projected for the future. These findings are consistent with observed and projected warming and associated increases in atmospheric water vapor. In some instances, extreme precipitation events lead to localized flash flooding, in other instances, these events may lead to extensive riverine floods across entire river basins (such as that experienced in the past decade on the Red River of the North, the Sacramento River, and the Fraser River). Costly recovery efforts in the aftermath of these floods have taxed the capacity of insurers, federal, state, and local response agencies, and flood victims.

Urban heat. A large fraction of the U.S. population lives in urban areas. Increases in temperature from global warming will be compounded by increases in temperature due to local urban heat island effects, making cities more vulnerable to higher temperatures than would be expected with warming alone. Existing stresses in urban areas include traffic congestion, degraded air and water quality, and disruptions to everyday life due to decaying or failing infrastructure. Climate change is likely to influence and be influenced by these stressors. Populations of the very old, the very young, and those with preexisting cardiopulmonary conditions are expected to be affected by extreme heat coupled with degraded air quality.

Indirect effects of climate change.

Vector, water, or food-borne diseases exhibit distinct seasonal patterns that suggest *a priori* that weather and/or climate influences their distribution and incidence. Similarly, millions of Americans live in areas that fail to meet the health-based National Ambient Air Quality Standards (NAAQS) for ozone and fine particulates (PM2.5). Both ozone and PM2.5 have well-documented cardiovascular and pulmonary health effects and ambient concentrations of these pollutants have the potential to be influenced by climate change, especially high temperatures.

2.1.2. Complex linkages: the role of non-climate factors

Climate is only one of a number of global changes that affect human well-being. The major impacts of climate are shaped by interactions with non-climate factors that can modify or mediate direct climate impacts. Except in the instance of extreme events, climate variability and change in the United States are seldom the most important among multiple issues (see Table 1). The overall severity of climate impacts depends on an array of non-climate factors, including:

- demographic changes, including immigration and aging of the population;
- region-specific vulnerabilities, e.g., extensively developed coastal zones;
- the social, political, and cultural context;
- economic conditions, e.g., productivity and employment;
- available resources, e.g., budgetary and natural resources;
- available technologies;
- conditions of the built environment, e.g., age and capacity of existing infrastructure;
- land use change; and,
- the availability and quality of public health and social services infrastructure.

Because of joint or multiple paths of causation, assessing climate change impacts requires assumptions about a range of socioeconomic futures. The past half-century has seen sustained economic growth in the United States, stunning levels of technological advancement, and population growth that has concentrated people in urban, coastal and arid settings. There has been overall movement toward the South and West and we have seen shifts of population from frost-belt to sun-belt and the movement of households from urban centers to far flung suburbs. In the United States, population growth in coastal zones magnifies the impacts of climate variability and change just as inadequate storm-drainage infrastructure can aggravate climate impacts in flood-prone areas. In addition, rapid development of new information technologies, such as the internet, and declining costs of airline travel have made previously remote locations more accessible for work, recreation, or retirement. Collectively, these developments indicate the need for socioeconomic scenarios as a mechanism for better characterizing the complex linkages between climate and non-climate factors.

The same social and economic systems that bear the stress of climate change also bear the stress of air and water pollution, the influx of immigrants, and over-burdened infrastructure in rapidly-growing metropolitan centers and coastal zones. While non-climate stressors are currently more pronounced than climate impacts, one cannot assume that this trend will persist. Understanding the impacts of climate change and variability on health and quality of life assumes knowledge of how these dynamics might vary by location and across time and socioeconomic group. The effects of climate change often spread from directly affected areas and sectors to other areas and sectors through complex linkages. The relative importance of climate change depends on the directness of each climate impact and on demographic, social, economic, institutional, and political factors, including, the degree of preparedness.

Consider the wide swath of damage left by Hurricanes Katrina and Rita in 2005. Damage was measured not only in terms of lives and property lost, but also in terms of the devastating impacts on infrastructure, neighborhoods, businesses, schools, and hospitals as well as in the disruption to families and friends in established communities, with lost livelihoods, challenges to psychological well-being, and exacerbation of chronic illnesses. While the aftermath of a single hurricane is not the measure of climate change, such an event demonstrates the disruptive power of climate impacts and paints a picture of the resulting tangle of climate and non-climate stressors that complicate and challenge efforts to respond and to adapt.

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TABLE 1: Current and projected climate change impacts and interaction with non-climate stressors.

Source: Revised from the IPCC Working Group II, Fourth Assessment Report, Technical Summary, 2007.

Climate driven phenomenon	Evidence of current impact / vulnerability	Non-climate stressors	Projected future impact / vulnerability	Regions / Populations Affected
Changes in extreme conditions				
Tropical cyclones / storm surge	Flood and wind damages; economic losses; transportation, infrastructure and tourism losses	Land use Population density Flood defenses Institutional capacities, e.g., emergency preparedness & public health response	Increased vulnerability in storm prone coastal zones; effects on settlements, health, tourism, economic and transportation systems; buildings & infrastructure	Gulf Coast; Southeast Atlantic Coast; Pacific Coast; Alaska Coast
Extreme rainfall / riverine floods	Erosion / landslide; land flooding; impacts to settlements, transportation systems, and infrastructure	Storm drainage infrastructure; river levee systems; flood plain containment	Increased vulnerability in storm prone coastal zones; effects on settlements, health, tourism, economic and transportation systems; buildings & infrastructure	Out-of-bank river floods especially in Midwest and Great Plains
Heat or cold waves	Effects on human health; requirements for energy, water and other services; infrastructure impacts (especially energy and transportation	Building design Interior temperature control Social contexts Institutional capacities	Increased vulnerabilities in some regions and among some populations; health effects; changes in energy requirements	Mid-latitude regions; Very old and very young; Seniors and disabled living alone
Drought	Water availability; livelihoods; energy generation; migration; transportation in water bodies; wild fires	Water systems; competing water uses; energy demand; water demand constraints; draw down of existing reservoir systems	Water resource challenges in affected areas; shifts in locations of population and economic activities; additional investments in municipal and agricultural water supplies; wild fires	Semi-arid and arid regions, e.g. the Intermountain West and the desert Southwest and the Southeast
Changes in average conditions				
Temperature	Energy demands and costs; urban air quality; permafrost thaw; tourism and recreation; retail consumption; livelihoods; loss of melt water	Demographic and economic changes; land use changes; technological innovations; air pollution; institutional capacities	Shifts in energy demand; worsening of air quality; impacts on settlements and livelihoods depending on melt water; threats to settlements and infrastructure from thawing permafrost	Diverse populations, including very young and very old; those without air conditioning; outdoor workers and outdoor recreation
Precipitation	Agricultural livelihoods, saline intrusion, tourism, water infrastructures, tourism; energy supplies	Competition from other regions and sectors; water resource allocations	Depending on the region, vulnerabilities in some areas to effects of precipitation increases (flooding) and decreases (drought)	Poor populations; poor regions; flood zone residents
Sea level rise	Coastal land uses; flood risk; water logging; water infrastructures	Trends in coastal development, settlements, and land uses	Long-term increases in vulnerabilities of low-lying coastal areas	Coastal zones; Poor populations; poor regions

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2.1.3. Brief summary of the impacts of climate change on human well-being in the United States

[see Sections 3.2, 3.3, 4.2, 5.3 of this report]

Climate change impacts in the United States are characterized at varying degrees of certainty. This section provides a brief overview of potential impacts of climate change on human health, human settlements, and human welfare. It includes tables describing the relative likelihood associated with important endpoints in each focus area.

Impacts on human health. The health and well-being of millions of Americans are tied to climate-related exposures to:

- extreme heat
- vector-borne disease
- water-borne disease
- injuries associated with flooding and dangerous storms, and
- cardiopulmonary illnesses aggravated by the interaction of air pollutants (especially ground level ozone) and warmer temperatures.

Northeastern and Midwestern cities experience severe heat waves with adverse health impacts, especially among the elderly or the poor who cannot afford to air condition their homes. Urban heat island effects are real but local. Cities are and will continue to be challenged by the increased number, intensity, and duration of heat waves.

The central message is two-fold. First, health impacts of climate on communities in the United States are likely to be protected by the response capacity of public health and medical care systems. It is widely believed that the health and human service infrastructure in the United States has and will continue to be able to address and contain most health impacts. But, this supposition means that timely, effective adaptation measures will be developed and deployed. We have already seen serious failures of medical and emergency relief systems in the aftermath of Hurricanes Katrina and Rita, so we must conclude that adaptation to human health impacts will require extensive coordination and an ongoing commitment to capacity building in the public health sector (see Box 2). Table 2.XX summarizes a number of human health impacts and their associated likelihood. Note: the characterization of likelihood is described in Chapter 1, Section 1.4.

Table 2.1 Likelihood of Climate Change Impacts on Human Health

Description of Effects	Likelihood
Contributes to current morbidity and premature mortality in the U.S.	More likely than not
Climate-related health impacts will increase over the coming decades.	Very likely
Climate change will seldom be the primary factor affecting the burden of climate-related injuries, illness, and death in a population. Timely and effective adaptation can reduce some projected impacts.	Virtually certain
Climate change will have negative and positive health impacts in the U.S.	Very likely
Morbidity and mortality due to floods, droughts, windstorms, and wildfires will increase with climate change	Likely
Morbidity and mortality will increase due to projected increases in the frequency and intensity of heatwaves and will decrease due to projected decreases in the frequency and intensity of cold spells.	Very likely
The geographic distribution and length of the transmission season of some vector-borne and zoonotic diseases will alter in response to climate change with both increases and decreases.	Very likely
Climate change will increase outbreaks of waterborne diseases	Very likely
Climate change will increase health outcomes related to air pollution	Likely
Populations particularly vulnerable to climate change include older adults, infants, and children, the poor and marginalized, individuals with certain chronic medical conditions, and certain occupational groups	Virtually certain

Table 2.1 Likelihood of Climate Change Impacts on Human Health	
Description of Effects	**Likelihood**
Although the U.S. has high capacity to cope with the projected health impacts of climate change there is a need to strengthen programs and activities aimed at reducing the risks of climate-sensitive health determinants and outcomes	Virtually certain
Additional research is needed to better understand possible climate-related impacts in the context of all key factors that affect health outcomes and reduce uncertainties	Virtually certain

New Orleans in the aftermath of Hurricane Katrina, 2007. Photos: American Red Cross and NOAA.

Box 2. Mental health devastation in hurricane's wake

In the aftermath of Hurricane Katrina, mental health services in New Orleans have been challenged by increased incidence of serious mental illness, including anxiety, major depression, and post-traumatic stress disorder (PTSD). Just as the need for mental health care soars, the facilities and providers available for patient care have plummeted. Barbee, et al. reports in *Time Magazine* (August 1, 2006) about his recent article in the *Journal of the American Medical Association* (JAMA) that "the event is still unfolding. People are losing jobs. They are moving because they are so discouraged by the situation. There is a lot of uncertainty about the future. It is not easy to live here."

Shortly after Katrina, a Centers for Disease Control and Prevention poll found that nearly half of all survey respondents indicated a need for mental health care, yet fewer than 2% were getting professional attention. Troubling also are statistics on suicide, which evidence an increase of 25% in the post-Katrina suicide rate. Barbee cautions that this is likely a low estimate, given that suicide is typically under-reported.

Barbee also reports that psychiatric hospital beds number fewer than 20 in New Orleans, just as the number of psychiatrists available to see patients in the Crescent City has fallen from 196 to as few as 22. Charity Hospital, the teaching hospital for Louisiana State University Medical School has not reopened its 96 psychiatric beds and it is likely that Charity will remain shuttered because of the overwhelming damage from post-Katrina flooding.

Impacts on human settlements. Human settlements are expected to be impacted by climate change in a variety of ways, including:

- Increased energy demand associated with extreme temperatures,
- Strain on municipal, agricultural and industrial water supplies in the intermountain West and the desert Southwest,
- Disruption of infrastructure, including levee systems, river channels, bridges and highway systems, and communication systems in the aftermath of tropical storms and flooding events, and
- Disruption of communities and property loss from wildfires.

Human settlements have used "hard" approaches, such as infrastructure, and "soft" approaches, such as regulations, to protect and adapt settlements to environmental change. Examples include

water supply and waste water systems, drainage networks, buildings, transportation systems, land use and zoning controls, water quality standards and emission caps, and tax incentives. The fact that both regulations and infrastructures vary considerably across the United States is an expression of related cultural, economic, and environmental factors. Mechanisms either now exist or can be anticipated to be developed to meet the challenges of climate change on human settlements. Urban design, which routinely deals with uncertainty, has the capacity to institutionalize adaptation by adapting existing mechanisms and/or developing new ones to meet the challenges of climate change on human settlements. When climate change is incorporated in the planning process, it can be addressed as yet another uncertainty.

Table 2.XX summarizes a number of human settlement impacts and their associated likelihood.

Table 2.2 Likelihood of Climate Change Impacts on Human Settlements

Description of Effects	Likelihood
Climate change will seldom be a primary factor in an area's development compared with other driving forces for development. It is likely to be a secondary factor, with its importance determined mainly by its interactions with other factors, except in the case of major abrupt climate change.	Very likely
Effects of climate change will vary considerably according to location-specific vulnerabilities, and the most vulnerable areas are likely to be Alaska, coastal and river basin locations susceptible to flooding, arid areas where water scarcity is a pressing issue, and areas whose economic bases are climate-sensitive.	Very likely
Except for Alaska, the main impact concerns have to do with changes in the intensity, frequency and/or location of extreme weather events and, in some cases, water availability rather than changes in temperature.	Very likely
Potentials for adaptation through technological and institutional development as well as behavioral changes are considerable, especially where such developments meet other sustainable development needs.	Extremely likely
While uncertainties are very large about specific impacts in specific time periods, it is possible to talk with a higher level of confidence about **vulnerabilities** to impacts for most settlements in most parts of the U.S.	Virtually certain
Clarifying these vulnerabilities and reducing uncertainties about impacts would benefit from a higher level of effort in impact research	Virtually certain
Promoting climate change mitigation and adaptation discussions at an urban scale will benefit from involvement of stakeholders	Virtually certain

Source: Reuters News Service.Telegraph UK, 2001. http://www.telegraph.co.uk/news/main.jhtml?xml=/news/2007/03/12/nfire12.xml

BOX 3. Multiple stressors. Wildfire and the degradation of air quality

Californians currently experience the worst air quality in the nation. More than 90 percent of the population lives in areas that violate air quality standards for either tropospheric ozone or airborne particulate matter. These pollutants can cause or aggravate a wide range of health problems including asthma and other acute respiratory and cardiovascular diseases, and can decrease lung function in children. Combined, ozone and particulate matter contribute to as many as 8,800 deaths and $71 billion in healthcare costs every year in California. If global background ozone levels increase as projected in some climate change scenarios, it may become impossible to meet local air quality standards. Higher temperatures are expected to increase the frequency, duration, and intensity of conditions conducive to air pollution formation. If temperatures rise to the medium warming range, there will be 75 to 85 percent more days with weather conducive to ozone formation in Los Angeles and the San Joaquin Valley, relative to today's conditions. Air quality could be further compromised by increases in wildfires, which emit fine particulate matter that can travel long distances depending on wind conditions. The most recent analysis suggests that if heat-trapping gas emissions are not significantly reduced, large wildfires could become up to 55 percent more frequent toward the end of the century.

Source: Our Changing Climate: Assessing the Risks to California. 2003. A Summary Report from the California Climate Change Center.

Impacts on human welfare. Climate change impacts on human welfare is expected to include a range of effects, such as:

- Disruption of recreation and outdoor activities due to extreme temperatures,
- Limit on some snow-related recreational activities,
- Reduced job opportunities in areas dependent on natural resources, such as agricultural production and the tourism industry,
- Higher electricity prices resulting from increased demand for air conditioning, and
- Erosion of recreational beaches by sea level rise.

The goal of successful adaptation to climate impacts is to maintain the long-term sustainability and survival of communities. Given their control over shared resources, communities have the capacity to adapt to climate change in larger and more coordinated ways than individuals, by creating plans and strategies to increase resilience in the face of future shocks. At the same time ensuring that the negative impacts of climate change do not fall disproportionately on the most vulnerable populations.

Table 2.3 Likelihood of Climate Change Impacts on Human Welfare	
Description of Effects	Likelihood
Human welfare is a multi-dimensional concept, and the effects of climate change on welfare depend on interdependencies in human and natural systems.	Virtually certain
Climate change will have positive and negative non-market effects on health, recreation, amenities, and communities	Very likely
Ecosystem changes that have already been detected or predicted within this century will have negative effects on some of the services provided by ecosystems, such as air and water quality regulation, crop pollination, or support services such as photosynthesis	Likely
Additional research is needed to understand how climate impacts communities, and how communities are vulnerable (or can b made more resilient) in the face of climate change	Very likely
Additional research is needed to understand the linkages between the effects of climate change on individual sectors and the non-market goods and services valued by humans	Very likely

2.2 What does climate change mean for most Americans? [see Section 1.3]

2.2.1. Some Americans may experience only marginal impacts of climate change.

Given the relative wealth of citizens in the United States, we expect that Americans will generally be less vulnerable to climate change than populations in less developed nations world-wide. We expect increased coping capacity to be associated with greater wealth, such that within the next 50 years, the middle class and the affluent in the United States could remain largely unaffected by climate change. Nevertheless, significant numbers of Americans will be affected by the impacts of climate. Among those who own property in vulnerable regions, wealth alone will not spare them from sustaining costly losses to homes and personal possessions. Economic well-being does not protect individual welfare during severe storm events, flooding, and heat waves. In addition, we have observed that monetary damages associated with weather extremes have markedly increased in recent decades, and that trend is expected to continue. In particular, densely-developed coastal zones have experienced and will continue to experience disproportionate climate-related impacts.

In the international arena, the United States might incur significant burdens related to the impacts of climate change in nations and among peoples who are less able to adapt. For instance, the United States might become the destination for immigrants whose countries of origin suffer drought conditions that severely compromise water supplies, disrupt homes and businesses, cut agricultural production and lead to social unrest. An influx of climate refugees is likely to be most pronounced from areas where rivers form international boundaries and where there are multiple, competing claimants on dwindling water supplies. Similarly, immigrants might arrive from low-lying coastal nations and island nations where sea level rise is expected to cause extensive coastal flooding and associated salt water intrusion into agricultural lands rendering thousands of square kilometers permanently uninhabitable or unproductive. Finally, immigrants to the United States may be more likely to introduce infectious diseases not already prevalent in this country.

2.2.2. However, some Americans, in some locations, will be vulnerable to climate change.

The changes in climate that matter most to people include direct physical impacts and indirect effects such as those on health; income and employment; the availability and price of goods and services; property values; recreational opportunities; the character of the landscape; and the political, social and economic aspects of communities. Climate and non-climate changes are experienced by people where they live, work, and play. Place is a realization of historical

development decisions and of patterns of economic growth and elements of social change. This section describes the relative vulnerability of populations, both in terms of individuals and of communities.

Vulnerable people. Conventional wisdom is that climate change is expected to disproportionately affect vulnerable people in vulnerable places: For instance, impacts of extreme heat on human health are concentrated among the poor, the very young, and the elderly living in homes without air conditioning. Likewise, human health impacts are associated with degraded air quality and are concentrated among patients with existing cardiopulmonary conditions. Similarly, the poor in vulnerable locations are at greater risk to climate change as they tend to have limited capacity for adaptation.

The poor, the elderly, the disabled, and those who live alone are most vulnerable to climate change. In the event of evacuations of low-lying areas during tropical storms, those who stay behind either by choice or by the dictates of circumstance will be vulnerable – for their safety, their well-being, and their property – to extreme wind and rain, storm surge and coastal flooding. It is assumed that the property and life lost associated with extreme events will be concentrated among people with limited capacity to mount an effective response, such as evacuating at-risk locations. There is evidence, however, that many people choose to accept the risk rather than respond to public safety advisories. Some who remain behind do so by choice. Further complicating the failure to evacuate is the impression that many who choose to stay may underestimate their actual risk. In other words, they accept the risks they anticipate but not necessarily the risks as they actually prevail.

Population changes have shaped patterns of vulnerability to climate. The United States population has not simply grown, it has also shifted in its makeup and distribution. For example, the 65 and older age group has increased from 1 in 25 in 1900 to 1 in 8 in 2000. Older people are physiologically more vulnerable to heat stress and air pollution. Retirees have migrated in large numbers to the South and the West. This migration pattern is only sustainable because of the nearly universal spread of air conditioning. In 1978, 23% of U.S. homes had air conditioning. By 1997, that share had increased to 47% percent with as many as 93% of homes in the South having air conditioning. (Trends in Residential Air-Conditioning Usage from 1978 to 1997. U.S. Department of Energy). Nonetheless, lives are lost each year in big cities among the elderly and otherwise vulnerable populations who succumb to extreme heat in homes without air conditioning. These deaths are nearly entirely preventable.

Vulnerable places. Places where climate change can be expected to have the most severe consequences include:
(1) urban centers with aging infrastructure and extreme heat concentrated in urban heat islands,
(2) coastal zones and riverine flood plains,
(3) water-stressed arid regions of the mountain and desert West, and
(4) Arctic areas subject to coastal storms and flooding and permafrost melt.
Even sustained economic and population growth can stress vulnerable places through pollution, congestion, and demands on land and water and other natural resources.

In 2000, the population in the United States was 291 million, including: 83.0% in metropolitan areas, 10.3% in micropolitan areas (urban centers that have a population greater than 10,000 and less than 50,000), and only 6.7% outside core statistical areas. Between 1900 and 2000, the mean center of the U.S. population moved about 324 miles to the west and 101 miles to the south. In 1900, 62% of the U.S. population lived in either the Northeast or the Midwest. By 2000, 58% of the population resided in either the South or West. The four most populous states in 2000 —

California, Texas, Florida, and New York — represented 38% of the total growth in the United States during the 20th century and shared significant vulnerability to coastal storms, severe drought, and urban heat island effects.

Population movement to arid regions and changes in water allocation will stress water supplies, especially among native peoples and in the intermountain West, desert Southwest and Great Plains. Overuse of streams and rivers in the West is common in vulnerable regions with high agricultural irrigation demands especially those along the eastern front of the Rocky Mountains in Colorado, in Southern California, and in the Central Valley of California. In forty years (from 1960 to 2000), Colorado's population grew by 245%. Rapid population and economic growth in these arid regions have dramatically increased vulnerability to water shortages.

Communities in coastal zones enjoy certain amenities derived from their proximity to valuable natural resources and recreational opportunities. But, that proximity puts those communities at elevated risk. Population centers along the nation's coastal waters have seen pronounced growth over the past fifty years. Fifty three percent of the total U.S. population lives in the 17% of land area that comprises the coastal zone. This trend is accelerating wetland loss and exacerbating pollution. Also, with the concentration of growth in coastal regions comes increased vulnerability to tropical storms, storm surge, coastal flooding, coastal erosion and sea level rise. Poor communities in these high-risk areas can be especially vulnerable. Certainly, the extent of the devastation of Hurricane Katrina was most pronounced because of the relatively more impoverished population, especially those without reliable transportation, who resided in some of the most flood-prone areas.

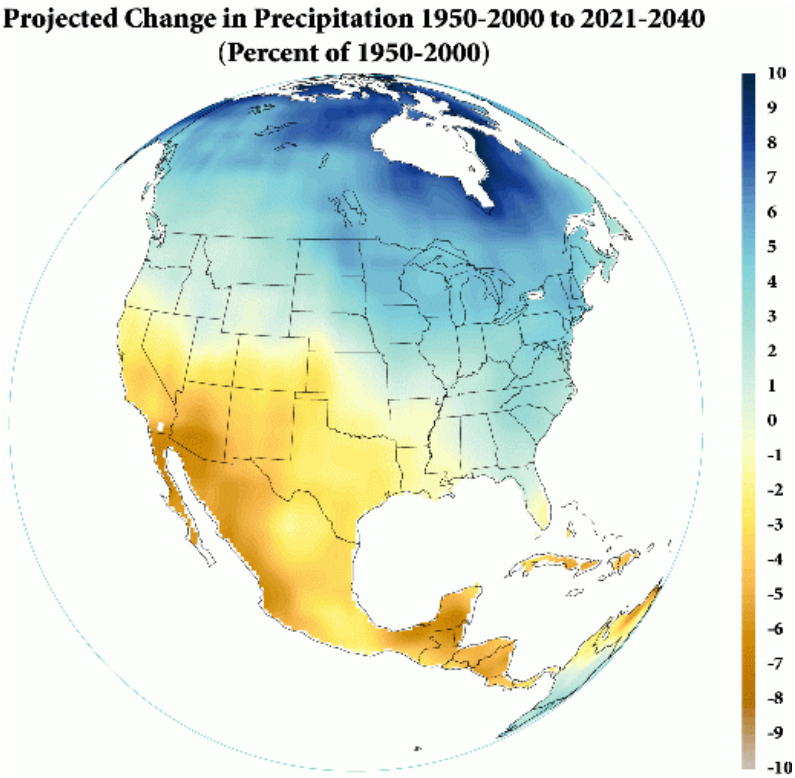
While we anticipate that many Americans will be only marginally affected by climate change in the next 50 years, we conclude that some portion of the population and some places where people live and work will be seriously and disproportionately impacted. The elderly, the very young, those with disabilities and some chronic conditions (e.g., cardiopulmonary illnesses), those who live alone and the poor will be at greater risk to climate change. Similarly some places, including urban heat islands, coastal zones, and arid regions, are relatively more at risk.

Box 4 Perpetual Drought in the Southwest: Water Supply at Risk

The trend toward a hotter and drier southwestern U.S. has begun and is expected to be evident within the next 15-20 years. Drought conditions are expected to resemble the Dust Bowl of the 1930's and the more localized drought of Texas in the 1950's. While those conditions were severe, they were not permanent. The current trend appears to be moving toward a permanent drought. The Columbia University study, led by Richard Seager, examined output from 19 climate models that simulated 49 projections of future temperature, rainfall, and evaporation in the Southwest. All but three of the projections concluded that the region would face serious increase in drought as early as 2021. The area within the U.S. affected by the drought is expected to include all of Texas and parts of New Mexico and Arizona (see Figure 2.4). Water resources will become more limited in a region that is already water scarce. Texas' 2007 State Water Plan proposes doubling the state's water supplies between 2010 and 2060. This plan calls for spending in access of $30 billion on new reservoirs, pipelines and other infrastructure.

Source: R. Seager, M.F. Ting, I.M. Held, Y. Kushnir, J. Lu, G. Vecchi, H.-P. Huang, N. Harnik, A. Leetmaa, N.-C. Lau, C. Li, J. Velez, N. Naik, 2007. Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America. *Science*, DOI: 10.1126/science.1139601

Figure.4 Projected change in precipitation for the 2021-2040 period minus the average over 1950-2000 as a percent of the 1950-2000 precipitation. Results are averaged over simulations with 19 different climate models. Figure by G. Vecchi.



2.3. How can adaptation strategies reduce the impacts of climate change? [see Sections 3.5, 4.3]

Strategies for adapting to climate change hinge on building resilient communities across the United States. Resilient communities are those characterized both by their demonstrated capacity for sustainable development across time and by their ability to adopt strategies to successfully adapt to climate change and co-occurring changes in non-climate factors. Sustainable development is that which satisfies the needs of present generations without compromising the resources – natural and human-made – that will allow future generations to meet their needs. Sustainability inherently promotes strong inter-generational equity.

In this section, we examine the desirable characteristics of communities and identify those characteristics that increase resilience to climate change. Even if climate change itself may not be the most serious threat to sustainability, considering climate change impacts in a multi-change context can encourage and facilitate processes that lead to progress in dealing with other stressors. We consider how desirable features in communities have evolved to include urban planning concepts such as sustainability and smart growth. Finally, we consider a number of key adaptation strategies that may promote resilience to climate change in the United States.

2.3.1. Desirable communities and resilience to climate: A post-WWII perspective on development

After the turn of the 20th century, the rural population in the United States fell as farmers were displaced by mechanization and migrated in large numbers to urban factory jobs. The growth of urban centers, especially on the East and West coasts, mirrored the growth of the baby boom generation after World War II. Communities developed as more- or less-desirable based, at least in part, on their responsiveness to the needs of growing baby boom families.

Following World War II, metropolitan areas began to sprawl from city centers to the suburbs. The move to the suburbs was evidence of the gaining popularity of the automobile and government-insured home loans. The penetration of the passenger car into nearly every household led to reliance on the car for daily trips to work and school and errands. The introduction of the family car into American life was central in determining the development and the desirability of communities. Lengthy car commutes became common, if not the rule, in cities across the country.

But, there are tradeoffs related to automobile ownership. The costs to owners include the cost of the vehicle, taxes, insurance, maintenance, fuel, and parking and the costs associated with idling in congested traffic. The benefits realized by car owners include mobility, independence, convenience, and freedom. Beyond individual costs and benefits, there are social costs to car ownership that accrue to communities, including: demands for road repair and maintenance, air pollution from vehicle emissions, injury and death from car crashes, demands for public safety and law enforcement, and demands for urban planning to accommodate vehicle traffic while providing viable mass-transit options. Coupled with the unprecedented growth of the family car in the United States, federal and state transportation planning has revolved around construction of “super highways.” The interstate highway system has been a huge success. Suburban development has largely been supported because of transportation infrastructure that promises to bring jobs in urban centers within reach of a reasonable commute.

In all, the success of post World War II communities in the United States was derived from their having met the requirements of citizens for infrastructure (including sanitation, water supplies, electric and natural gas utilities, telephone service), for the provision of public safety and of health

care and public health services, road construction, free or inexpensive recreational opportunities, public schools, arts and entertainment, and strong economic growth and available jobs.

2.3.2. Desirable communities and resilience to climate: A 21st Century concept.

With urban sprawl – the extension of urban areas into more and more remote suburban areas – accrues negative environmental, socioeconomic, and public health outcomes. The cost of the construction and maintenance of highway infrastructure and air pollution associated with billions of vehicle miles has caused reconsideration of the form and utility of communities.

Sustainable development is an alternative to traditional urban/suburban settlement patterns. The focus on sustainability has evolved in recent years in response to the impacts of individual consumption and to the collective footprint of communities on natural resources, ecosystem destruction, pollution, growing inequality in cities, the degradation of human living conditions and human-induced climate change. The emphasis of sustainable development is on creating livable communities and promoting physical well-being and desirable lifestyles. Put slightly differently, sustainability is realized as resilient 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 resource base, or social systems.

Smart growth has been described as the alternative to sprawl, traffic congestion, disconnected neighborhoods and central city decay. It explicitly considers long-term costs and consequences of growth and not just near-term benefits. For instance, a focus on mass transit can improve quality of life and encourage a healthier pedestrian-based lifestyle with less pollution. The community of the 21st Century is moving away from suburban sprawl, long commutes, vehicle emissions, and sedentary lifestyles and adopting sustainable development practices that will cushion the impacts of climate change on American communities and enhance their overall resilience.

2.3.3. The capacity for adaptation: strategies for responding to climate change.

There are substantial opportunities in the United States for individuals and communities to minimize the negative impacts of climate variability and change while maximizing the benefits. People have always adjusted or adapted to prevailing climate conditions. The adaptive capacity of the United States is considerable but that capacity has not been uniformly adequate to avoid significant losses and disruption in the aftermath of extreme weather events. Hurricanes, wild fires, river flooding, and other extreme events have tested readiness and response. Long-term changes in average and extreme conditions are expected to cause significant, widely distributed effects. To date, responses have tended to be decentralized and unorganized with uneven results.

The degree of adaptation that will be required by climate change depends on an array of factors, including:

- the current burden of climate-sensitive outcomes,
- the effectiveness of current interventions,
- projections of where, when, and how quickly the burdens to health and welfare could change with changes in climate and climate variability,
- the feasibility of implementing additional cost-effective interventions,
- other stressors that could increase or decrease resilience to impacts, and
- the social, economic, and political context within which interventions are implemented.

Although there are uncertainties about future climate change, failure to invest in appropriate adaptation responses may leave communities poorly prepared and increase the probability of adverse consequences. Whether it entails relocating populations and activities away from vulnerable areas, adopting technologies that reduce the sensitivity of the built environment, institutional changes to improve capacities for preparedness and response to extreme events, or no-regrets policies that improve resilience to projected changes, the choice of adaptation will be as targeted and extensive as the climate impact it is designed to address. Climate change challenges the resolve and capacity of individuals and communities to plan and implement adaptive responses.

Important strategies for adaptation to climate impacts. Potential adaptation strategies for individuals and communities include:

1. Changing the location of people or activities – especially as such solutions address the costs of sustaining built environments in vulnerable areas. Strategies here address not only out-migrations from areas in the immediate aftermath of an extreme event but also more sustained or even permanent moves from vulnerable areas to safer or more desirable locations. Siting and land use policies can be used to encourage movement from more vulnerable areas to less, to add resilience to new construction within vulnerable areas, to increase awareness of climate-related hazards and risks, and to assist the disadvantaged (see Box 2.4).

2. Changing the spatial form of communities to improve sustainability of the built environment, to reduce lengths of daily trips to work and school with associated decreases in emissions, and to encourage green spaces and green buildings. A widely-used tool for achieving smart growth is the local zoning law. Through zoning, new development can be restricted to specific areas and density incentives can be offered for brownfield or greyfield land. Zoning can also be used to establish parking set asides as well as set-asides for parks and other community amenities.

3. Technological change that reduces the sensitivity of people and their environments to climate by adopting innovations that improve individual and community well being. Technological "fixes" may be used to reduce sensitivity of physical infrastructure, including updating sewer systems to decrease combined sewer overflows (CSOs), updating levee systems, and coastal hardening. For example, the U.S. Army Corp of Engineers (USACE) is developing technology-based responses for reservoir management to accommodate uncertain spring runoff and to allocate water storage among agricultural, domestic, and industrial needs. In addition, advances in technology can substantially increase our capacity for solving individual and collective health problems related to climate change. Adaptive strategies that are protective of human health involve a range of technologies, including watch-warning systems, air conditioning, pollution controls, vector control, vaccinations, and water treatment.

4. Institutional change to improve coping capacity, including assuring effective governance, providing financial mechanisms for increasing resiliency, improving coordination across multiple jurisdictions, targeting assistance programs for impacted segments of the population, and adopting sustainable community development practices. Policy instruments include zoning, building and design codes, terms for financing, and early warning systems. Institutional change to improve coping capacity can include coordination of governmental responses to weather-related emergencies, mandatory flood insurance for at-risk property

owners, discontinuation of underwriting for areas with a history of repeated insurance losses, incentives to subsidize permanent out-migration from at-risk areas, building codes and zoning ordinances that improve the durability of all new construction in at-risk areas.

5. "No regrets" strategies or low-net-cost policy initiatives that add resilience to communities and to physical capital – e.g., in coastal areas changing building codes for new construction to require coping with projected amounts of sea-level rise over the expected lifetimes of the structures. No regrets policies generate net social benefits whether or not there is climate change.

6. The choice of strategies from among the options is likely to depend on "co-benefits" in terms of other social, economic, and ecological driving forces, the availability of fiscal and human resources, and political aspects of "who wins" and "who loses."

Aftermath of the 1997 Red River of the North flood and downtown Grand Forks, North Dakota, fire. Source: U S Geological Survey, 1997. http://nd.water.usgs.gov/photos/1997RedFlood/

Figure 2.4 Relocation in the Aftermath of the 1997 Red River Flood

The Red River Flood of 1997 occurred during April and May during the annual thaw of the River and its tributaries. The cities of Fargo, ND and Winnipeg were affected, as were the communities of Grand Forks and East Grand Forks where flood waters spread to as far as 3 miles inland. The flooding accompanied the rising river and overland flooding as the Red River was unable to adequately drain snowmelt. The Red River is a northward flowing river in which ice derived from its southern reaches meets freshly broken ice as it flows north, leading to slowing or damming of the water flow. Overall there was $2 billion in damages to Grand Forks and East Grand Forks. Thousands of people relocated after the flood. Grand Forks lost 3% of its population from 1997 to 2000, while East Grand Forks lost nearly 17% of its residents. There was no loss of life associated with the flood event. Winnipeg survived the Red River flood, because an emergency flood channel had been constructed around the city decades earlier.

Source: North Dakota State University. http://www.ndsu.edu/fargogeology/whyflood.htm; U.S. Geological Survey, North Dakota Water Science Center, 1997

2.4. Conclusion.

The first section of this chapter examined how climate change is likely to affect people and communities in the United States, how projected climate change will be experienced across the nation, and how non-climate factors might interact with climate factors to realize complex impacts. That section briefly summarized impacts on human health, human settlements, and human welfare.

The second section considered how climate change is likely to affect most Americans, concluding that, in the near term, many Americans are likely to be only marginally affected by climate change. Nonetheless, the report finds that some people and some places will be especially vulnerable to climate change. Those who live in arid, drought-prone places are at risk as are those located in coastal zones and those living in urban areas where extreme heat exacerbates negative health outcomes. Finally, populations are at risk whose age (very young and very old), poverty, and pre-existing conditions and disabilities put them at increased risk.

The third section explored how adaptation strategies can be developed to reduce the impacts of climate change in the United States and how an overall strategy of developing resilient communities may improve outcomes in both near and long-term time horizons. By investing in a range of adaptation strategies, including, for example, relocating population centers, adapting the spatial form of communities, employing new technologies, adapting institutions, and improving resilience, American communities can successfully respond to the challenges of climate change. In addition, resilient communities that succeed in focusing on long-term sustainable development, e.g., via smart growth models, will be best prepared for the challenges posed by climate variability and change. Central to the success of sustainable communities is the explicit inclusion of climate change risks in the development of communities and in the planning for and management of natural resources.

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