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Chapter 3: Effects of Global Change on Human Settlements

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3.1 Introduction

3.1.1 Purpose

Human settlements are where people live and work, including all population centers ranging from small rural communities to densely developed metropolitan areas. This chapter addresses climate change impacts, both positive and negative, on human settlements in the United States. First, the chapter summarizes current knowledge about the vulnerability of human settlements to climate change, in a context of concurrent changes in other non-climate factors. Next, the chapter summarizes opportunities within settlements for adaptation to climate change. Finally, the chapter provides an overview of recommendations for expanding the current knowledge base with respect to climate change and human settlements.

3.1.2 Background

Events such as Hurricane Katrina in 2005 and electric power outages during the hot summer of 2006 have demonstrated how climate-related events can dramatically impact U.S. settlements. Climate affects the costs of assuring comfort at home and work. Climate affects inputs for a good life: water, products and services from agriculture and forestry, pleasures and tourist potentials from nature, biodiversity, and outdoor recreation. Climate also affects the presence and spread of diseases and other health problems, and it is associated with threats from natural disasters, including floods, fires, droughts, wind, hail, ice, and heat and cold waves.

Some U.S. settlements may find opportunities in climate change. Warmer winters are not necessarily undesirable. Periods of change tend to reward forward-looking, effectively-governed communities. Considering climate change effects may help to focus attention on other important issues for the long-term sustainable development of settlements and communities. Furthermore, planning for the future is an essential part of public policy decision-making in urban areas.

Since infrastructure investments in urban areas are often both large and difficult to reverse, climate considerations are increasingly perceived as one of a number of relevant issues to consider when planning for the future (Ruth, 2006a). If U.S. settlements, especially larger cities, respond effectively to climate change concerns, their actions could have far-reaching implications for human well-being, because these areas are where most of the U.S. population lives, large financial decisions are made, political influence is often centered, and technological and social innovations take place.

Meanwhile, the pattern of human settlements in the United States is changing. In addition to shifts of population from frost-belt to sun-belt settlements, patterns are changing in other ways as well. For instance, what once appeared to be an inexorable spread of households from urban centers to peripheries is showing renewal in many city centers as metropolitan areas continue to expand across multiple jurisdictions (Solecki and Leichenko, 2006). Modern information technologies are enabling people to perform what were historically urban functions from relatively remote locations (Riebsame, 1997).

3.1.3 Current State of Knowledge

The current knowledge base provides limited grounds for developing conclusions and recommendations related to climate impacts on human settlements. In many cases, the best that can be done is to sketch out the issue "landscape" that should be considered by both policy-makers and the research community as a basis for further discussion, offering illustrations from the relatively small research literature that is now available.

The fact is that little research has been done to date specifically on the effects of climate change in U.S. cities and towns. Reasons appear to include (i) limitations in capacities to project climate change impacts at the geographic scale of a metropolitan area (or smaller) and (ii) the fact that none of the federal agencies currently active in climate science research has a clear responsibility for settlement impact issues. Improvements in our understanding of the impacts of and adaptation to climate change across different sectors and geographic regions, differential vulnerabilities, and in designing interventions to build resilience are all needed (NRC, 2007).

To some degree, gaps can be filled by referring to several comprehensive analyses that do exist, to literature on effects of climate *variation* on settlements and their responses, to research on climate change impacts on cities in other parts of the world, and to historical analogs of responses of urban areas to significant environmental changes. A text box entitled *Historical Perspective of the U.S. Urban Responses to Environmental Change* is included as Box 3.1. This perspective examines how American cities have been affected by environmental change over the past two centuries. But this is little more than a place to start.

At the current state of knowledge, vulnerabilities to possible impacts are easier to project than actual impacts because they *estimate risks or opportunities* associated with possible consequences rather than *estimating the consequences* themselves, which requires far more detailed information about future conditions. Vulnerabilities are shaped not only by existing exposures, sensitivities, and adaptive capacities but also by the ability of settlements to develop responses to risks.

3.2 Climate Change Impacts and the Vulnerabilities of Human Settlements

This section examines possible impacts of climate change on settlements in the United States including the determinants of vulnerability to such impacts and how those impacts could affect settlement patterns and various systems related to those patterns.

3.2.1 Determinants of Vulnerability

It has been difficult to project impacts of climate change on human settlements in the United States, in part because climate change forecasts are not specific enough for the scale of decision-making (as for other relatively local-scale impact questions) but moreover because climate change is not the only change being confronted by settlements. More often, attention is paid to vulnerabilities to climate change, if those changes should occur.

Vulnerabilities to or opportunities from climate change are related to three factors, both in absolute terms and in comparison to other elements (Clark *et al.,* 2000):

1. *Exposure to climate change*. To what climate changes are settlements likely to be exposed: Changes in temperature or precipitation? Changes in storm exposures and/or intensities? Changes in sea level?

2. *Sensitivity to climate change.* If primary climate changes occur, how sensitive are the activities and populations of a settlement to those changes? For instance, a city dependent substantially on a regional agricultural or forestry economy, or to the availability of abundant water resources, might be considered more sensitive than a city whose economy is based mainly on an industrial sector less sensitive to climate variation.

3. *Adaptive capacity*. Finally, if effects are experienced due to a combination of exposure and sensitivity, how able is a settlement to handle those impacts without disabling damages, perhaps even while realizing new opportunities?

3.2.2 Impacts of Climate Change on Human Settlements

Impacts of climate change on human settlements vary regionally (see Table 3.2 and Vignettes below), and generally relate to some of the following issues:

1. *Effects on health*. It is well-established that higher temperatures in urban areas are related to higher levels of ozone which cause respiratory and cardiovascular problems. There is also some evidence that combined effects of heat stress and air pollution may be greater than simple additive effects (Patz and Balbus, 2001). Moreover, historical data show relationships between mortality and temperature extremes (Rozenzweig and Solecki, 2001a). Other health concerns include changes in exposure to water and food-borne diseases, vector-borne diseases, concentrations of plant species associated with allergies, and exposures to extreme weather events such as storms, floods, and fires (see Chapter 2).

2. *Effects on water and other urban infrastructures*. Changes in precipitation patterns may lead to reductions in meltwater, river flows, groundwater levels, and in coastal areas lead to saline intrusion in rivers and groundwater, affecting water supply; and warming may increase water demands (Gleick *et al.,* 2000; Kirshen, 2002; Ruth *et al.,* 2007). Moreover, storms, floods, and other severe weather events may affect other infrastructure, including sanitation systems, transportation, supply lines for food and energy, and communication. Exposed structures such as bridges and electricity transmission networks are especially vulnerable. In many cases, infrastructures are interconnected; an impact on one can also affect others (Kirshen, *et al.,* 2007). An example is an interruption in energy supply, which increases heat stress for vulnerable populations (Ruth *et al.,* 2006a). Many of the infrastructures in older cities are aging and are already under stress from increasing demands.

3. *Effects on energy requirements*. 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). 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 (see Vignettes in Boxes 3.2 and 3.3). Higher temperatures also affect costs of living and business operation by increasing costs of climate control in buildings (Amato *et al.*, 2005; Ruth and Lin, 2006c; Kirshen *et al.*, 2007).

4. *Effects on the urban metabolism*. An urban area is a living complex mega-organism, associated with a host of inputs, transformations, and outputs: heat, energy, materials, and others (Decker *et al.*, 2000). An example is the Urban Heat Index, which measures the degree to which built/paved areas are associated with higher temperatures than surrounding rural areas (see Box 3.4: Climate Change Impacts on the Urban Heat Island Effect (UHI)). Imbalances in the urban metabolism can aggravate climate change impacts, such as roles of UHI in the formation of smog in cities. The maps in this box demonstrate how the built environment creates and retains heat in metropolitan settings.

5. *Effects on economic competitiveness, opportunities, and risks.* Climate change has the potential not only to affect settlements directly but also to affect them through impacts on other areas linked to their economies at regional, national, and international scales (Rosenzweig and Solecki, 2006). In addition, it can affect a settlement's economic base if it is sensitive to climate, as in areas where settlements are based on agriculture, forestry, water resources, or tourism (IPCC, 2001b).

6. *Effects on social and political structures.* 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 security. As sources of stress grow and combine, the resilience of social and political structures that are already somewhat unstable is likely to suffer, especially in areas with relatively limited resources (Sherbinin *et al.*, 2006).

7. *Effects on vulnerable populations* (see Chapter 1). Where climate change stresses settlements, it is likely to be especially problematic for vulnerable parts of the population: the poor, the elderly, those already in poor health, the disabled, those living alone, those with limited rights and power (*e.g.*, recent in-migrants with limited English skills), and/or indigenous populations dependent on one or a few resources. As one example, warmer temperatures in urban summers have a more direct impact on populations who live and work without air-conditioning. Implications for environmental justice are clear; see, for instance, Congressional Black Caucus Foundation, 2004.

8. *Effects on vulnerable regions.* Approximately half of the U.S. population, 160 million people, will live in one of 673 coastal counties by 2008 (Crossett *et al.*, 2004). Obviously, settlements in coastal areas – particularly on gently-sloping coasts –should be concerned about sea level rise in the longer term, especially if they are subject to severe storms and storm surges and/or if their regions are showing gradual land subsidence (Neumann *et al.*, 2000; Kirshen *et al.*, 2004). Settlements in risk-prone regions have reason to be concerned about severe weather events, ranging from severe storms combined with sea-level rise in coastal areas to increased risks of fire in drier arid areas. Vulnerabilities may be especially great for rapidly-growing and/or larger metropolitan areas, where the potential magnitude of both impacts and coping requirements could be very large (IPCC, 2001b; Wilbanks *et al*., 2007b).

Different combinations of circumstances are likely to cause particular concerns for cities and towns in the United States as they consider possible implications of climate change.

3.2.3. The Interaction of Climate Impacts with Non-Climate Factors.

In general, climate change effects on human settlements in the United States are imbedded in a variety of complexities that make projections of quantitative impacts over long periods of time very difficult. For instance, looking out over a period of many decades, it seems likely that other kinds of change—such as technological, economic, and institutional—will have more impact on the sustainability of most settlements rather than climate change per se (Wilbanks, *et al*., 2007b). Climate change will interact with other processes, driving forces, and stresses; and its significance, positive or negative, will largely be determined by these interactions. It is therefore difficult to assess effects of climate change without a reasonably clear picture of future scenarios for these other processes.

In many cases, these interactions involve not only direct impacts such as warming or more or less precipitation but, sometimes more important, second, third, or higher-order impacts, as direct impacts cascade through urban systems and other settlement-determined processes (*e.g.*, warming which affects urban air pollution which affects health which affects public service requirements which affect social harmony: Kirshen *et al.*, 2007). Some of these higher-order impacts, in turn, may feed back to create ripple effects of their own. For example, a heat wave may trigger increased energy demands for cooling, which may cause more air conditioners and power generators to be operated, which could lead to higher urban heat island effects, inducing even higher cooling needs.

Besides this “multi-stress” perspective, it is highly likely that effects of climate change on settlements are shaped by certain “thresholds,” below which effects are incidental but beyond where effects quickly become major when a limiting or inflection point is reached. An example might be a city’s capacity to cope with sustained heat stress combined with a natural disaster. In general, these climate-related thresholds for human settlements in the United States are not well-understood. For multi-stress assessments of thresholds, changes in climate extremes are very often of more concern than changes in climate averages. Besides extreme weather events, such as hurricanes or tornadoes, ice

storms, winds, heat waves, drought, or fire, settlements may be affected by changes in daily or seasonal high or low levels of temperature or precipitation, which have not always been projected by climate change models.

Finally, human settlements may be affected by climate change mitigation initiatives as well as by climate change itself. Examples include effects on policies related to energy sources and uses, environmental emissions, and land use. The most direct and short-term effects would likely be on settlements in regions whose economies are closely related to the production and consumption of large quantities of fossil fuels. Indirect and longer term effects are less predictable.

As climate change affects settlements in the United States, impacts are realized at the intersection of climate change with underlying forces. Most of the possible effects are linked with changes in regional comparative advantage, with consequent migration of population and economic activities (Ruth and Coelho, in press). Examples of these complex interactions and issues include:

1. *Regional risks and availability of insurance*. It is possible that regions exposed to risks from climate change will see movement of population and economic activity to other locations. One reason is public perceptions of risk, but a more powerful driving force may be the availability of insurance. The insurance sector is one of the most adaptable of all economic sectors, and its exposure to costs from severe storms and other extreme weather events is likely to lead it to withdraw (or to make much more expensive) private insurance coverage from areas vulnerable to climate change impacts (Wilbanks, *et al*., 2007b), which would encourage both businesses and individual citizens to consider other locations over a period of several decades.

2. *Areas whose economies are linked with climate-sensitive resources or assets.* Settlements whose economic bases are related to such sectors as agriculture, forestry, tourism, water availability, or other climate-related activities could be affected either positively or negatively by climate change, depending partly on the adaptability of those sectors (*i.e.*, their ability to adapt to changes without shifting to different locations).

3. *Shifts in comparative living costs, risks, and amenities.* Related to a range of possible climate change effects – higher costs for space cooling in warmer areas, higher costs of water availability in drier areas, more or less exposure to storm impacts in some areas, and sea level rise – regions of the United States and their associated settlements are likely to see gradual changes over the long term in their relative attractiveness for a variety of human activities. One example, although its likelihood is highly uncertain, would be a gradual migration of the “Sun Belt” northward, as retirees and businesses attracted by environmental amenities find that regions less exposed to very high temperatures and seasonal major storms are more attractive as places to locate.

4. *Changes in regional comparative advantage related to shifts in energy resource use.* If climate mitigation policies result in shifts from coal and other fossil resources toward non-fossil energy sources, or if climate changes affect the prospects of renewable energy sources (especially hydropower), regional economies related to the production and/or use of energy from these sources could be affected, along with regional economies more closely linked with alternatives. (citation: SAP 4.5)

5. *Urban "footprints" on other areas*. Resource requirements for urban areas involve larger areas than their own bounded territories alone. Ecologists have sought to estimate the land area required to supply the consumption of resources and compensate for emissions and other wastes from urban areas (*e.g.*, Folke *et al.*, 1997). By possibly affecting settlements, along with their resource capacities for their inputs and destinations of their outputs, climate change could affect the nature, size, and geographic distribution of these footprints.

Human settlements are foci for many economic, social, and governmental processes, and historical experience has shown that catastrophes in cities can have significant economic, financial, and political effects much more broadly. The case which has received the most attention to date is insurance and finance (Wilbanks, *et al*., 2007b).

3.2.4 Realizing Opportunities from Climate Change in the United States

Climate change can have positive as well as negative implications for settlements. Examples of potential positive effects include:

1. *Reduced winter weather costs and stresses.* Warmer temperatures in periods of the year that are normally cold are not necessarily undesirable. They reduce cold-related stresses and costs (*e.g.*, costs of warming buildings and costs of clearing ice and snow from roads and streets), particularly for cold-vulnerable populations. They expand opportunities for warmer-weather recreational opportunities over larger parts of the year, and they expand growing seasons for crops, parks, and gardens.

2. *Increased attention to long-term sustainability*. One of the most positive aspects of climate change can be that its capacity to stimulate a broader discussion of what sustainability means for settlements (Wilbanks, 2003; Ruth, 2006). Even if climate change itself may not be the most serious threat to sustainability, considering climate change impacts in a multi-change, multi-stage context can encourage and facilitate processes that lead to progress in dealing with other sources of stress as well.

3. *Improved competitiveness compared with settlements subject to more serious adverse impacts.* While some settlements may turn out to be "losers" due to climate change impacts, others may be "winners," as changes in temperature or precipitation result in added economic opportunities (see the following section), at least if climate change is not severe. In addition for many settlements climate

change can be an opportunity not only to compare their net impacts with others, seeking advantages as a result, but to present a progressive image by taking climate change (and related sustainability issues) seriously.

3.2.5 Examples of Impacts on Metropolitan Areas in the United States

Possible impacts of climate change on settlements in the United States are usually assessed by projecting climate changes at a regional scale: temperature, precipitation, severe weather events, and sea level rise (see Table 3.2 and Boxes 3.2 and 3.3). Ideally, these regional projections are at a relatively detailed scale, and ideally they consider seasonal as well as annual changes and changes in extremes as well as in averages; but these conditions cannot always be met.

The most comprehensive assessments of possible climate change impacts on settlements in the United States have been two studies of major metropolitan areas:

1. New York: This assessment concluded that impacts of climate change on this metropolitan area are likely to be primarily negative over the long term, with potentially significant costs increasing as the magnitude of climate change increases, although there are substantial uncertainties. (Rosenzweig and Solecki, 2001a; Rosenzweig and Solecki, 2001b; Solecki and Rosenzweig, 2006).

2. Boston: This assessment concluded that long-term impacts of climate change are likely to depend at least as much on behavioral and policy changes over this period as on temperature and other climate changes (Kirshen *et al.*, 2004; Kirshen *et al.*, 2006; Kirshen *et al.*, 2007)

Other U.S. studies include Seattle (Hoo and Sumitani, 2005) and Los Angeles (Koteen *et al.*, 2001) (Table 3.1). Internationally, studies have included several major metropolitan areas, such as London (London Climate Change Partnership, 2004) and Mexico City (Molina *et al.*, 2005) as well as possible impacts on smaller settlements (*e.g.*, AIACC: see www.aiaccproject.org). A relevant historical study of effects of an urban heat wave in the United States is reported by Klinenberg (2003).

3.3 Opportunities for Adaptation of Human Settlements to Climate Change

Settlements are important in considering prospects for adaptation to climate change, both because they represent concentrations of people and because buildings and other infrastructures offer ways to manage risk and monitor/control threats associated with climate extremes and other non-climate stressors.

Where climate change presents risks of adverse impacts for U.S. settlements and their populations, there are two basic options to respond to such concerns (a third is combining the two). One response is to contribute to climate change **mitigation** strategies, *i.e.*, by taking actions to reduce their greenhouse gas emissions and by showing leadership in encouraging others to support such actions (see Box 3.5: Roles of Settlements in Climate

Change Mitigation). The second response is to consider strategies for **adaptation**, *i.e.*, finding ways either to reduce sensitivity to projected changes or to increase the settlement's coping capacities. Adaptation can rely mainly on anticipatory actions to avoid damages and costs, such as "hardening" coastal structures to sea-level rise; or adaptation can rely mainly on response potentials, such as emergency preparedness; or it can include a mix of the two approaches. Research to date suggests that anticipatory adaptation may be more cost-effective than reactive adaptation (Kirshen *et al.*, 2004).

Adaptation strategies will be important to the well-being of U.S. settlements as climate change evolves over the next century. As just one example, the New York climate impact assessment (Rosenzweig and Solecki, 2001a) projects significant increases in heat-related deaths based on historical relationships between heat stress and mortality, unchanged by adaptation. The Boston CLIMB assessment (Kirshen *et al.*, 2004) projects that, despite similar projections of warming, heat-related deaths will decline over the coming century because of adaptation. Whether or not adaptation to climate change occurs in U.S. cities is therefore a potentially serious issue. The CLIMB assessment includes analyses showing that in many cases adaptation actions taken now are better than adaptation actions delayed until a later time (Kirshen *et al.*, 2006).

3.3.1. Perspectives on Adaptation by Settlements

For decision-makers in U.S. settlements climate change is yet one more source of possible risks that need to be addressed. Climate change is different as an issue because it is relatively long-term in its implications, future impacts are uncertain, and public awareness is growing from a relatively low level to a higher level of concern. Because climate change is different in these ways, it is seldom attractive to consider allocating massive amounts of funding or management attention to current climate change actions. What generally makes more sense is to consider ways that actions which reduce vulnerabilities to climate change impacts (or increase prospects for realizing benefits from climate change impacts) are also desirable for other reasons as well: often referred to as "co-benefits." Examples include actions that reduce vulnerabilities to current climate variability regardless of long-term climate change, actions that add resilience to water supply and other urban infrastructures that are already stressed, and actions that make metropolitan areas more attractive for their citizens in terms of their overall quality of life.

Cities and towns have used both "hard" approaches such as developing infrastructure and "soft" approaches such as regulations to address impacts of climate variability. 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. All of these are designed in part with climate and environmental conditions in mind. The setting of regulations has always been a context of benefit-cost analysis and political realities; and infrastructure is also designed in a benefit-cost framework, subject to local design codes. The fact that both regulations and infrastructures vary considerably across the United States reflects cultural, economic, and environmental factors; and this suggests that mechanisms exist to respond to concerns about climate change. Urban designers and managers deal routinely with uncertainties,

because they must consider uncertain demographic and other socioeconomic changes; thus, if climate change is properly institutionalized into the urban planning process, it can be handled as yet another uncertainty.

3.3.2 Major Categories of Adaptation Strategies

Adaptation strategies for human settlements, large and small, include a wide range of possibilities such as:

1. *Changing the location of people or activities (within or between settlements)* – especially addressing the costs of sustaining built environments in vulnerable areas: *e.g.,* siting and land use policies and practices to shift from more vulnerable areas to less, adding resilience to new construction in vulnerable areas, increased awareness of changing hazards and associated risks, and assistance for the less-advantaged (including actions by the private insurance sector as a likely driving force).

2. *Changing the spatial form of a settlement* – managing growth and change over decades without excluding critical functions (*e.g.*, architectural innovations improving the sustainability of structures, reducing transportation emissions by reducing the length of journeys to work, seeking efficiencies in resource use through integration of functions, and moving from brown spaces to green spaces). Among the alternatives receiving the most attention are encouraging "green buildings" (*e.g.*, green roofs: Parris, 2007; see Rosenzweig *et al.*, 2006a; Rosenzweig *et al.*, 2006b) and increasing "green spaces" within urban areas (*e.g.*, Bonsignore, 2003).

3. *Technological change to reduce sensitivity of physical and linkage infrastructures – e.g.*, more efficient and affordable interior climate control, surface materials that reduce heat island effects (Quattrochi *et al.*, 2000), waste reduction and advanced waste treatment, and better warning systems and controls. Physical design changes for long-lived infrastructure may also be appropriate, such as building water-treatment or storm-water runoff outflow structures based on projected sea level rather than the historical level.

4. *Institutional change to improve adaptive capacity,* including assuring effective governance, providing financial mechanisms for increasing resiliency, improving structures for coordinating among multiple jurisdictions, targeting assistance programs for especially impacted segments of the population, adopting sustainable community development practices, and monitoring changes in physical infrastructures at an early stage (Wilbanks *et al.*, 2007a). Policy instruments include zoning, building and design codes, terms for financing, and early warning systems (Kirshen *et al.*, 2005).

5. *"No regrets" or low net cost policy initiatives* that add resilience to the settlement and its 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.

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."

3.3.3 Examples of Current Adaptation Strategies

In most cases in the United States, settlements have been more active in climate change mitigation than climate change adaptation (see Box 3.5), but there are some indications that adaptation is growing as a subject of interest (Solecki and Rosenzweig, 2005; Ruth, 2006). Bottom-up grassroots activities currently under way in the United States are considerable, and that number appears to be growing. For example, Boston has built a new wastewater treatment plant at least one-half meter higher than currently necessary to cope with sea level rise, and in a coastal flood protection plan for a site north of Boston the U.S. Corps of Engineers incorporated sea-level rise into their analysis (Easterling *et al.*, 2004). California is considering climate change adaptation strategies as a part of its more comprehensive attention to climate change policies (Franco, 2005). And, Alaska is already pursuing ways to adapt to permafrost melting and other climate change effects.

Meanwhile, in some cases, settlements are taking actions for other reasons that add resilience to climate change effects. An example is the promotion of water conservation, which is reducing per capita water consumption in cities that could be subject to increased water scarcity (City of New York, 2005).

It seems very likely that local governments will play an important role in climate change responses in the United States Many adaptation options must be evaluated at a relatively local scale in terms of their relative costs and benefits and their relationships with other urban sustainability issues, and local governments are important as guardians of public services, able to mobilize a wide range of stakeholders to contribute to broad community-based initiatives (as in the case of the London Climate Change Partnership, 2004). Because climate change impact concerns and adaptation potentials tend to cross jurisdictional boundaries in highly fragmented metropolitan areas, local actions might encourage cross-boundary interactions that would have value for other reasons as well.

While no U.S. communities have developed comprehensive programs to ameliorate the effects of heat islands, some localities are recognizing the need to address these effects. In Chicago, for example, several municipal buildings have been designed to accommodate "green" rooftops. Atlanta has had a Cool Communities "grass roots" effort to educate local and state officials and developers on strategies that can be used to mitigate the UHI. This Cool Communities effort was instrumental in getting the State of Georgia to adopt the first commercial building code in the country emphasizing the benefits of cool roofing technology (Young, 2002; Estes, Jr. *et al.*, 2003). The "Excessive Heat Events Guidebook" developed by the Environmental Protection Agency in collaboration with NOAA, CDC, and DHS provides information for municipal officials

in the event of an excessive heat event: http://www.epa.gov/hiri/about/heatguidebook.html.

3.3.4: Strategies to Enhance Adaptive Capacity

In most cases, the likelihood of effective adaptation is related to the capacity to adapt, which in turn is related to such variables as knowledge and awareness, access to fiscal and human resources, and good governance (IPCC, 2001b). Strategies for enhancing such capacities in U.S. settlements are likely to include the development and use of local expertise on climate change issues (AAG, 2003), attention to the emerging experience with climate change effects and response strategies globally and in other U.S. settlements, information sharing about adaptation potentials and constraints among settlements and their components (likely aided by modern information technology), and an emphasis on participatory decision-making, where local industries, institutions, and community groups are drawn into discussions of possible responses.

3.4. Conclusions

Even from a current knowledge base that is very limited, it is possible to conclude several things about effects of climate change on human settlements in the United States:

1. Climate change takes place in the context of a variety of factors driving an area's development: it is likely to be a secondary factor in most places, with its importance determined mainly by its interactions with other factors, except in the case of major abrupt climate change (very likely).

2. 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 basins susceptible to flooding, arid areas where water scarcity is a pressing issue, and areas whose economic bases are climate-sensitive (very likely).

3. The main impact concerns, in areas other than Alaska, 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).

4. Over the time period covered by current climate change projections, the potential for adaptation through technological and institutional development as well as behavioral changes are considerable, especially where such developments meet other sustainable development needs as well, especially considering the initiatives already being shown at the local level across the United States (extremely likely).

5. 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 United States (virtually certain).

3.5 Expanding the Knowledge Base

A number of sources, including NACC, 1998; Parson *et al.*, 2003; Ruth, 2006; and Ruth *et al.*, 2004, have considered research pathways for improving the understanding of effects of climate change on human settlements in the United States.
The following list suggests a number of research topics that would help expand the knowledge base about the linkages between climate change and human settlements.

- Advance understanding of settlement vulnerabilities, impacts, and adaptive responses in a variety of different local contexts around the country through case studies. In addition to identifying vulnerable settlements, these studies should also identify vulnerable populations (such as the urban poor and native populations on rural and/or tribal lands) that have limited capacities for response to climate change, within those settlements. Better understanding of climate change at the community scale would provide a basis for adaptation research that addresses social justice and environmental equity concerns.

- Develop better projections of climate change at the scale of U.S. metropolitan areas or smaller, including scenarios projecting extremes and scenarios involving abrupt changes.

- Improve abilities to associate projections of climate change in U.S. settlements with changes in other driving forces related to impacts, such as changes in metropolitan/urban patterns and technological change.

- Design practically implementable, socially acceptable strategies for shifting human populations and activities away from vulnerable locations.

- Improve the understanding of vulnerabilities of urban inflows and outflows to climate change impacts, as well as second and third-order impacts of climate change in urban environments, including interaction effects among different aspects of the urban system.

- Improve the understanding of the relationships between settlement patterns (both regional and intra-urban) and resilience/adaptive capacity.

- Improve understanding of how urban decision-making is changing as populations become more heterogeneous and decisions become more decentralized, especially as this affects adaptive responses.

- Review current policies and practices related to climate change responses to help inform community decision-makers and other stakeholders about potentials for relatively small changes to make a large difference.

- Evaluate and document experiences with urban/settlement climate change responses while involving decision-making, research and stakeholder communities more actively in discussions of climate change impacts and response

issues. Focus attention on the costs, benefits, and possible limits and potentials of adaptation to climate change vulnerabilities in U.S. cities and smaller settlements.

- Improve tools and approaches for infrastructure planning and design to reduce exposure and sensitivity to climate change effects while increasing adaptive capacity.

- Enhance coordination within federal government agencies to improve understanding about impacts, vulnerabilities and responses to climate change for the nation's cities and smaller settlements. Connections with U.S. urban decision-makers can enable integration of climate change considerations into what they do with building codes, zoning, lending practices, etc. as mainstreamed urban decision processes.

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3.7 Boxes

Box 3.1: U.S. Urban Responses to Environmental Change: A Historial Perspective

Over time, American cities have been affected by environmental change. City founders often showed an important disregard with respect to siting of settlements, focusing on aspects of location such as commercial or recreational opportunities rather than on risks such as flood potential, limited water, food or fuel supplies, or the presence of health threats. Oftentimes settlers severely exploited their environments, polluting ground water and adjacent water bodies, building in unsafe and fragile locations, changing landforms, and filling in wetlands. Construction of the urban built environment involved vast alterations in the landscape, as forests and vegetation and wildlife species were eliminated and replaced by highways, suburbs, and commercial buildings. The building of wastewater and water supply systems had the effect of altering regional hydrology and creating large vulnerabilities. In other cases settlers concluded that the weather was changing for the good, that technology would solve problems or that new resources could be discovered.

Technological fixes were pursued to seek ways to modify or control environmental change. Cities exposed to flooding built levees and seawalls and channelized rivers. When urbanites depleted and polluted local water supplies cities went outside their boundaries to seek new supplies: building reservoirs, aqueducts, and creating protected watersheds. When urban consumption exhausted local fuel sources, cities adapted to new fuels, embraced new technologies, or searched far beyond city boundaries for new supplies. Many of these actions resulted in the extension of the urban ecological footprint, so that urban growth and development affected not only the urban site but also increasingly the urban hinterland and beyond.

There are few examples of environmental disasters or climate change actually resulting in the abandonment of an urban site. One case appears to be that of the Hohokam Indians of the Southwest, who built extensive irrigation systems, farmed land, and built large and dense settlements over a period of approximately 1,500 years (Krech, 1999: 45-72). Yet, they abandoned their settlements and disappeared into history. The most prominent explanation for their disappearance is an ecological one -- that the Hohokam irrigation systems suffered from salinization and water logging, eventually making them unusable. Other factors besides ecological ones may have also entered into the demise of their civilization and abandonment of their cities, but the ecological explanation appears to have the most supporters.

In the case of America in the 19th and 20th centuries, however, no city has been abandoned because of environmental or climatic factors. Galveston, Texas suffered from a catastrophic tidal wave but still exists as a human settlement, now protected by an extensive sea wall. Johnstown, Pennsylvania has undergone major and destructive flooding since the late 19th century, but continues to survive as a small city. Los Angeles and San Francisco are extremely vulnerable to earthquakes, but still continue to increase in population. And, in coming years New Orleans almost certainly will experience a hurricane as or more severe than Katrina, and yet rebuilding goes on, encouraged by the belief that technology will protect it in the future. Whether or not ecological disaster or extreme risk will eventually convince Americans to abandon some of their settlements, as the Hohokam did, has yet to be determined (Colten, 2005; Steinberg, 2006; Vale and Campanella, 2005).

Box 3.2: Vignettes of Vulnerability - I

Alaskan Settlements

No other region in the United States is likely to be as profoundly changed by climate change as Alaska, our nation's part of the polar region of Earth (ACIA, 2004). Because warming is more pronounced closer to the poles, and because settlement and economic activities in Alaska have been shaped and often constrained by Arctic conditions, in this region warming is especially likely to reshape patterns of human settlement.

Human settlements in Alaska are already being exposed to impacts from global warming (ACIA, 2004), and these impacts are expected to increase. Many coastal communities see increasing exposure to storms, with significant coastal erosion, and in some cases facilities are being forced either to relocate or to face increasing risks and costs. Thawing ground is beginning to destabilize transportation, buildings, and other facilities, posing needs for rebuilding, with ongoing warming adding to construction and maintenance costs. And indigenous communities are facing major economic and cultural impacts. One recent estimate of the value of Alaska's public infrastructure at risk from climate change set the value at tens of billions of today's dollars by 2080, with the replacement of buildings, bridges, and other structures with long lifetimes having the largest public costs (Larsen *et al.*, 2007).

Besides impacts on built infrastructures designed for permafrost foundations and effects on indigenous societies, many observers expect warming in Alaska to stimulate more active oil and gas development (and perhaps other natural resource exploitation), and if thawing of Arctic ice permits the opening of a year-round Northwest sea passage it is virtually certain that Alaska's coast will see a boom in settlements and port facilities (ACIA, 2004).

Coastal Southeast Settlements

While there is currently no evidence for a long-term increase in North American mainland land-falling hurricanes, concerns remain that certain aspects of hurricanes, such as wind speed and rainfall rates may increase (CCSP, 2008). In addition, sea level rise is expected to increase storm surge levels (CCSP, 2008). Recent hurricanes striking the coast of the U.S. Southeast cannot be attributed clearly to climate change, but they suggest a range of possible impacts. As an extreme case, consider the example of Hurricane Katrina. In 2005, the city of New Orleans had a population of about half a million, located on the delta of the Mississippi River along the U.S. Gulf Coast. Urban development throughout the 20th Century has significantly increased land use and settlement in areas vulnerable to flooding, and a number of studies had indicated growing vulnerabilities to storms and flooding. In late August 2005, Hurricane Katrina moved onto the Louisiana and Mississippi coast with a storm surge, supplemented by waves, reaching up to 8.5 m above sea level. In New Orleans, the surge reached around 5m, overtopping and breaching sections of the city's 4.5m defenses, flooding 70 to 80 % of New Orleans, with 55 % of the city's properties inundated by more than 1.2 m and maximum flood depths up to 6 m. 1101 people died in Louisiana, nearly all related to flooding, concentrated among the poor and elderly. Across the whole region, there were 1.75 million private insurance claims, costing in excess of $40 billion (Hartwig, 2006), while total economic costs are projected to be significantly in excess of $100 billion. Katrina also exhausted the federally backed National Flood Insurance Program (Hunter, 2006), which had to borrow $20.8 billion from the Government to fund the Katrina residential flood claims. In New Orleans alone, while flooding of residential structures caused $8-$10 billion in losses, $3-6 billion was uninsured. 34,000-35,000 of the flooded homes carried no flood insurance, including many that were not in a designated flood risk zone (Hartwig, 2006). Six months after Katrina, it was estimated that the population of New Orleans was 155,000, with the number projected to rise to 272,000 by September 2008 – 56% of its pre-Katrina level (McCarthy *et al*., 2006).

Box 3.3: Vignettes of Vulnerability – II

Arid Western Settlements

Human settlements in the arid West are affected by climate in a variety of ways, but perhaps most of all by water scarcity and risks of fire. Clearly, access to water for urban populations is sensitive to climate, although the region has developed a vast system of engineered water storage and transport facilities, associated with a very complex set of water rights laws (NACC, 2001). It is very likely that climate change will reduce winter snowfall in the West, reducing total runoff – increasing spring runoff while decreasing summer water flows. Meanwhile, water demands for urban populations, agriculture, and power supply are expected to increase, and conflicts over water rights are likely to increase. If total precipitation decreases or becomes more variable, extending the kinds of drought that have affected much of the interior West in recent years, water scarcity will be exacerbated, and increased water withdrawals from wells could affect aquifer levels and pumping costs. Moreover, drying increases risks of fire, which have threatened urban areas in California and other Western areas in recent years. The five-year average of acres burned in the West is more than 5 million, and urban expansion is increasing the length of the urban-wild lands interface (Morehouse *et al.*, 2006). Drying would lengthen the fire season, and pest outbreaks such as the pine beetle could affect the scale of fires.

Summer 2006 Heat Wave

In July and August 2006, a severe heat wave spread across the United States, with most parts of the country recording temperatures well above the average for that time of the year. For example, temperatures in California were extraordinarily high, setting records as high as 130°. As many as 225 deaths were reported by press sources, many of them in major cities such as New York and Chicago. Electric power transformers failed in several areas, such as St. Louis and Queens, New York, causing interruptions of electric power supply, and some cities reported heat-related damages to water lines and roads. In many cities, citizens without home air-conditioning sought shelter in public and office buildings, and city/county health departments expressed particular concern for the elderly, the young, pregnant women, and individuals in poor health. Although this heat wave cannot be attributed directly to climate change, it suggests a number of issues for human settlements in the United States as they contemplate a prospect of temperature extremes in the future that are higher and/or longer-lasting than historical experience.

Box 3.4: Climate Change Impacts on The Urban Heat Island Effect (UHI)

(Lo and Quattrochi, 2003; Brazel and Quattrochi, 2006; Ridd, 2006; Stone, 2006)

Climate change impacts on the Urban Heat Island (UHI) effect will primarily depend upon the geographic location of a specific city, its urban morphology (*i.e.,* landscape and built-up characteristics), and areal extent (*i.e.,* overall spatial "footprint"). These factors will mitigate or exacerbate how the UHI phenomenon (Figure 3.1) is affected by climate change, but overall, climate change is likely to impact the UHI effect in the following ways:

- Exacerbation of the intensity and areal extent of the UHI as a result of warmer surface and air temperatures along with the overall growth of urban areas around the world. Additionally, as urban areas grow and expand, there is a propensity for lower albedos which forces a more intense UHI effect. (There is also some indication that sustained or prolonged higher nighttime air temperatures over cities that may result from warmer global temperatures will have a more significant impact on humans than higher daytime temperatures.)

- As the UHI intensifies and increases, there could be a subsequent impact on deterioration of air quality, particularly on ground level ozone caused by higher overall air temperatures and an increased background effect produced by the UHI as an additive air temperature factor that helps to elevate ground level ozone production. Additionally, particulate matter ($PM_{2.5}$) could increase due to a number of human induced and natural factors (*e.g.,* more energy production to support higher usage of air conditioning).

- The UHI has an impact on local meteorological conditions by forcing rainfall production either over, or downwind, of cities. As the UHI effect intensifies, there will be a higher probability for urban-induced rainfall production (dependent upon geographic location) with a subsequent increase in urban runoff and flash flooding.

- Exacerbation and intensification of the UHI would have impacts on human health:
    - increased incidence of heat stress
    - impact on respiratory illnesses such as asthma due to increases in particulate matter caused by deterioration in air quality as well as increased pollination production because of earlier pollen production from vegetation in response to warmer overall temperatures

Figure 3.1. Example of urban surface temperatures and albedo for the Atlanta, Georgia Central Business District (CBD) area derived from high spatial resolution (10m) aircraft thermal remote sensing data.

The image on the left illustrates daytime surface heating for urban surfaces across the CBD. White and red colors indicate very warm surfaces (~40-50°C). Green relates to surfaces of moderately warm temperatures (~25-30°C). Blue indicates cool surfaces (e.g., vegetation, shadows) (~15-20°C). Surface temperatures are reflected in the albedo image on the right where warm surfaces are dark (i.e., low reflectivity) and cooler surfaces are in red and green (i.e., higher reflectivity). The images exemplify how urban surface characteristics influence temperature and albedo as drivers of the urban heat island effect (Quattrochi *et al.,* 2000).

Box 3.5: Roles of Settlements in Climate Change Mitigation

Although U.S. government commitments to climate change mitigation policies at the national level have emerged only recently, an increasing number of state and local authorities are involved in strategies to mitigate greenhouse gas emissions (Selin and Vandeveer, 2005; Rabe, 2006; Selin, 2006). U.S. states and cities are joining such initiatives as ICLEI (ICLEI, 2006), the U.S. Mayor Climate Protection Agreement, the Climate Change Action Plan, the Regional Greenhouse Gas Initiative (RGGI) (Selin, 2006), and the Large Cities Climate Leadership Group.[1] These initiatives focus on emissions inventories; on such actions aimed at reducing GHG emissions as switching to more energy efficient vehicles, using more efficient furnaces and conditioning systems, and introducing renewable portfolio standards (RPS). These strategies, which mandate an increase in the amount of electricity generated from renewable resources also adapt to negative social, economic and environmental impacts; and on actions to promote public awareness (see references in footnote 1).

Different drivers lie behind these mitigation efforts. Public and private entities have begun to "perceive" such possible impacts of climate change as rising sea level, extreme shifts in weather, and losses of key resources. They have realized that a reduction of GHG emissions opens opportunities for longer economic development (*e.g.*, investment in renewable energy: Rabe, 2006). In addition, climate change can become a political priority if it is reframed in terms of local issues (*i.e.*, air quality, energy conservation) already on the policy agenda (Betsill, 2001; Bulkeley and Betsill, 2003; Romero Lankao, 2007)

The promoters of these initiatives face challenges related partly to inertia (*e.g.*, the time it takes to replace energy facilities and equipment with a relatively long life of 5 to 50 years: Haites *et al.*, 2007). They can also face opposition from organizations who do not favor actions to reduce GHG emissions, some of whom are prepared to bring legal challenges against state and local initiatives (Rabe, 2006:17). But the number of bottom-up grassroots activities currently under way in the United States is considerable, and that number appears to be growing.

[1] ICLEI is the International Council for Local Environmental Initiatives. Local governments participating in ICLEI's Cities for Climate Protection (CCP) Campaign commit to a) conduct an energy- and emissions-inventory and forecast, b) establish an emissions target, c) develop and obtain approval for the Local Action Plan, d) Implement policies and measures, and e) monitor and verify results (ICLEI, 2006: April 20 2006 www.iclei.org). The Large Cities Climate Leadership Group is a group of cities committed to the reduction of urban carbon emissions and adapting to climate change. It was founded following the World Cities Leadership Climate Change Summit organized by the Mayor of London in October 2005. For more information on the US Mayor Climate Protection Agreement see http://www.seattle.gov/mayor/climate/

3.8 Tables

Table 3.1. Overview of Integrated Assessments of Climate Impacts and Adaptation in U.S. Cities. "x" indicates that the reference addresses a category of interest.

	Bloomfield *et al.*, 1999	**Kooten *et al.*, 2001**	**Rosenzweig *et al.*, 2000**	**Kirshen *et al.*, 2004**	**Hoo and Sumitani, 2005**
Location:	Greater Los Angeles	New York	Metropolitan New York	Metropolitan Boston	Metropolitan Seattle
Coverage:					
Water supply	✓	✓	✓	✓	
Water Quality				✓	
Water Demand				✓	
Sea-level Rise	✓		✓	✓	✓
Transportation				✓	✓
Communication					
Energy			✓	✓	
Public Health					
Vector-borne Diseases					
Food-borne Diseases		✓			
Temperature-related Mortality				✓	
Temperature-related Morbidity	✓	✓			
Air-quality Related Mortality					
Air-quality Related Morbidity			✓		
Other Health Issues	✓	✓	✓		
Ecosystems					
Wetlands					
Other Ecol.(Wildfires)	✓		✓		
Urban Forests (Trees and Vegetation)		✓			
Air Quality		✓			✓
Extent of:					
Quantitative Analysis	Low	Medium	Medium	High	Low
Computer-based Modeling	None	Low	Low	High	None
Scenario Analysis	None	None	Medium	High	Medium
Explicit Risk Analysis	None	None	None	Medium	None
Involvement of:					
Local Planning Agencies	None	None	High	High	High
Local Government Agencies	None	None	High	High	High
Private Industry	None	None	None	Low	None
Non-profits	None	None	Low	High	None
Citizens	None	None	None	Medium	None
Identification of:					
Adaptation Options	X	X	X	X	X
Adaptation Cost			X	X	
Extent of Integration Across Systems	None	None	Low	Medium	Low
Attention to Differential Impacts (*e.g.*, on individual types of businesses, populations)	None	None	Low	Low	Low

Table 3.2. Regional vulnerabilities of settlements to impacts of climate change in the United States

REGIONAL VULNERABILITIES OF SETTLEMENTS TO IMPACTS OF CLIMATE CHANGE

Region	Vulnerabilities	Major Uncertainties
Metro NE	Flooding, infrastructures, health, water supply, sea-level rise	Storm behavior, precipitation
Larger NE	Changes in local landscapes, tourism, water, energy needs	Ecosystem impacts
Mid-Atlantic	Multiple stresses; *e.g.*, interactions between climate change and aging infrastructures	Ecosystem impacts
Coastal SE	More intense storms, sea-level rise, flooding, heat stress	Storm behavior, coastal land use, sea-level rise
Inland SE	Water shortages, heat stress, UH1, economic impacts	Precipitation change, development paths
Upper Midwest	Lake and river levels, extreme weather events, health	Precipitation change, storm behavior
Inner Midwest	Extreme weather events, health	Storm behavior
Appalachians	Ecological change, reduced demand for coal	Ecosystem impacts, energy policy impacts
Great Plains	Water supply, extreme events, stresses on communities	Precipitation changes, weather extremes
Mountain West	Reduced snow, water shortages, fire, tourism	Precipitation changes, effects on winter snowpack
Arid Southwest	Water shortages, fire	Development paths, precipitation changes
California	Water shortages, heat stress; sea level rise	Temperature and precipitation changes, infrastructure impacts
Northwest	Water shortages, ecosystem stresses, coastal effects	Precipitation changes, sea-level rise
Alaska	Effects of warming, vulnerable populations	Warming, sea-level rise
Hawaii	Storms and other weather extremes, freshwater supplies, health, sea-level rise	Storm behavior, precipitation change

3.9 Figures

Figure 3.1. Example of urban surface temperatures and albedo for the Atlanta, Georgia Central Business District (CBD) area derived from high spatial resolution (10m) aircraft thermal remote sensing data.

(Quattrochi *et al.*, 2000)