# 11. Urban Systems, Infrastructure, and Vulnerability

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## Key Messages

1. **Climate change and its impacts threaten the well-being of urban residents in all regions of the U.S. Essential local and regional infrastructure systems such as water, energy supply, and transportation will increasingly be compromised by interrelated climate change impacts.**
2. **In urban settings, climate-related disruptions of services in one infrastructure system will almost always result in disruptions in one or more other infrastructure systems.**
3. **Climate vulnerability and adaptive capacity of urban residents and communities are influenced by pronounced social inequalities that reflect age, ethnicity, gender, income, health, and (dis)ability differences.**
4. **City government agencies and organizations have started urban adaptation efforts that focus on infrastructure systems and public health. However, these efforts face many barriers to implementing and incorporating wider governmental, general public, and private efforts.**

Climate change poses a series of interrelated challenges to the country's most densely populated places: its cities. The U.S. is highly urbanized, with about 80% of its population living in cities and metropolitan areas. Many cities depend on infrastructure, like water and sewage systems, roads, bridges, and power plants, that is aging and in need of repair or replacement. Rising sea levels, storm surges, heat waves, and extreme weather events will compound those issues, stressing or even overwhelming these essential services.

Cities have become early responders to climate change challenges and opportunities due to two simple facts: First, urban areas have large and growing populations that are vulnerable for many reasons to climate variability and change; and second, cities depend on extensive infrastructure systems and the resources that support them, which often extend to, or derive from, rural locations at great distances from urban centers.

Urban dwellers are particularly vulnerable to disruptions in essential infrastructure services, in part because many of these infrastructure systems are reliant on each other to function. For example, electricity is essential to power multiple systems, and a failure in the electrical grid can affect water treatment, transportation services, and public health. These infrastructure systems – lifelines to millions – will be affected by various climate-related events and processes.

As climate change impacts increase, climate-related events will have large consequences for significant numbers of people who live in cities or suburbs. These changing conditions also create opportunities and challenges for urban climate adaptation, and many cities have begun adopting plans to address these changes.

### *Urbanization and Infrastructure Systems*

**Climate change and its impacts threaten the well-being of urban residents in all regions of the U.S. Essential local and regional infrastructure systems such as water, energy supply, and transportation will increasingly be compromised by interrelated climate change impacts.**

Direct and interacting effects of climate change will expose people who live in cities across the U.S. to multiple threats. Climate changes affect the built, natural, and social infrastructure of cities, from storm drains to urban waterways to the capacity of emergency responders. The vulnerability of urban dwellers multiplies when the effects of climate change interact with pre-existing urban stressors – like deteriorating infrastructure, areas of intense poverty, and high population density.

Three fundamental conditions define the key connections among urban systems, residents, and infrastructure (Solecki and Rosenzweig 2012; Wilbanks et al. 2012). First, cities are dynamic, and are constantly being built and rebuilt through cycles of investment, disinvestment, and innovation. Second, infrastructure in many cities is currently aging, resulting in an increasingly fragile system. At both local and regional levels, infrastructure use often exceeds design standards and limitations, and cannot handle increasing demands without a decline in service. Third, urban areas present tremendous social challenges, given widely divergent socioeconomic conditions and dynamic residence patterns that vary in different parts of each city. Heightened vulnerability of coastal cities and other metropolitan areas that are subject to storm surge, flooding, or extreme climate events will exacerbate impacts on populations and infrastructure systems.

U.S. urban areas currently include approximately 245 million residents, and are expected to grow to 364 million by 2050 (U.S. Census Bureau 2008, 2010b, 2010c). Paradoxically, as the economy and population of urban areas grew in the past decades, the built infrastructure within cities and connected to cities deteriorated, becoming increasingly fragile and deficient (Solecki and Rosenzweig 2012; Wilbanks et al. 2012). Existing built infrastructure (such as buildings, energy, transportation, water, sanitation systems, etc.) is expected to become more stressed in its ability to support a good quality of life for urban residents in the next decades – especially when the impacts of climate change are added to the equation (McCrea et al. 2011). As infrastructure is highly interdependent, failure in particular sectors is expected to have cascading effects on most aspects of affected urban economies. As new climate adaptation plans are formed, further expansion of the U.S. urban landscape into suburban and exurban spaces is expected. Significant increases in the costs of infrastructure investments are also expected as population density becomes more diffuse (Burchell et al. 2002).

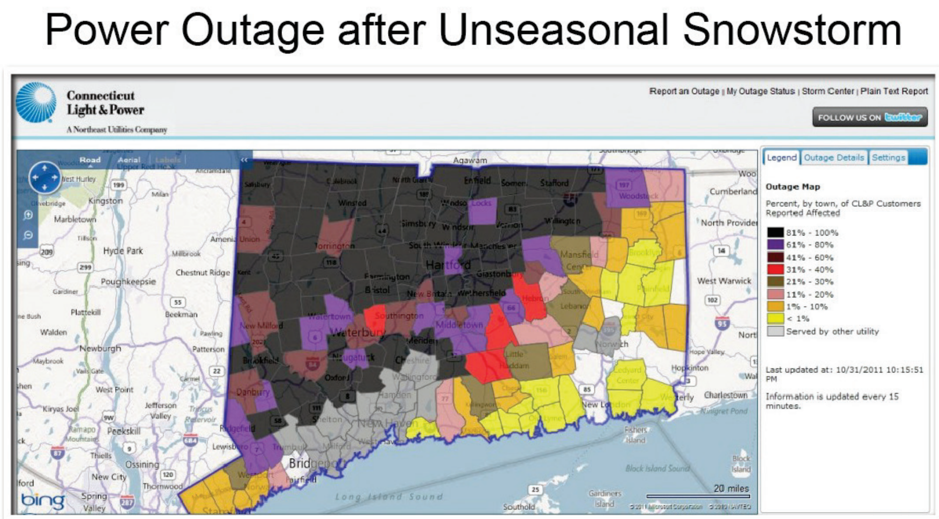


**Figure 11.1:** Power Outage after Unseasonal Snowstorm

**Caption:** Extreme weather events can affect multiple systems that provide services for millions of people in urban settings. Map here shows power outages for Connecticut Light & Power customers after an unusually strong October snowstorm, and just two months after Hurricane Irene hit the East Coast and disrupted power in late August 2011. (Figure source: Connecticut Light & Power.)

The vulnerability of different urban populations to hazards and risks associated with climate change depends on three characteristics: their exposure to particular stressors, their sensitivity to impacts, and their ability to adapt to changing conditions (Depietri et al. 2012; Douglas et al. 2011; Emrich and Cutter 2011). Climate change increases the frequency and intensity of extreme events like extremes of heat, heavy downpours, flooding from intense precipitation and storm surges, and disease incidence from temperature and precipitation changes. But as people begin to respond to new knowledge on climate change through the urban development process, social and infrastructure vulnerabilities can be altered (NPCC 2010). For example, the City of New York conducted a comprehensive review of select building and construction codes and standards in response to increased climate change risk in order to identify adjustments that could be made to increase climate resilience. Climate-change stressors will bundle with other socioeconomic and engineering stressors already connected to urban and infrastructure systems (Solecki and Rosenzweig 2012).

## *Essential Services are Interdependent*

**In urban settings, climate-related disruptions of services in one infrastructure system will almost always result in disruptions in one or more other infrastructure systems.**

Urban areas are linked with other areas through a complex set of infrastructure systems (CCSP 2008). For example, cities depend on other areas for supplies of food, materials, water, energy, and other inputs, and as destinations for products, services, and wastes. If infrastructure and other connections between source areas and cities are affected by climate change, then the dependent urban area also will be affected (Seto et al. 2012). Moreover, the economic base of an urban area depends on regional comparative advantage; therefore if competitors, markets, and/or trade flows are affected by climate change, a particular urban area also is affected (Wilbanks et al. 2012).

Urban vulnerabilities to climate change impacts are directly related to clusters of supporting resources and infrastructures located in other regions. For example, about half of the nation's oil refineries are located in only four states (Zimmerman 2006). Experience over the past decade with major infrastructure disruptions, such as the 2011 San Diego Blackout, the 2003 Northeast Blackout, and Hurricane Irene in 2011, has shown that the greatest losses from disruptive events may be distant from where damages started (Wilbanks et al. 2012). In another example, Hurricane Katrina disrupted oil terminal operations in southern Louisiana, not because of direct damage to port facilities, but because workers could not reach work locations through surface transportation routes and could not be housed locally because of disruption to potable water supplies, housing, and food shipments (Myers et al. 2008).

Although infrastructures and urban systems are often viewed individually – for example, transportation or water supply or wastewater/drainage – they are usually highly interactive and interdependent (Kirshen et al. 2008).

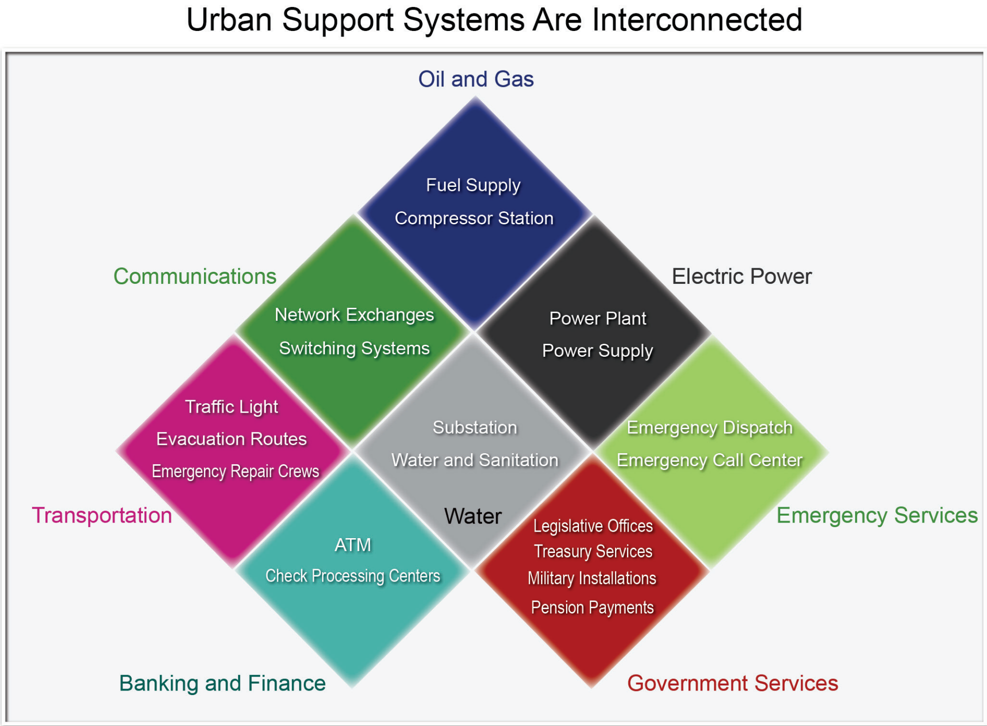


**Figure 11.2:** Urban Support Systems are Interconnected

**Caption:** In urban settings, climate-related disruptions of services in one infrastructure system will almost always result in disruptions in one or more other systems. When power supplies that serve urban areas are interrupted after a major weather event, for example, public health systems, transportation systems, and banking systems may all be affected. Schematic drawing illustrates some of these connections. (Source: DOE 2012)

Experiences in the past decade have shown that such interdependencies can lead to cascading disruptions through urban infrastructures. These disruptions, in turn, can result in unexpected impacts on communication, water, and public health sectors, at least in the short term. On August 8, 2007, New York City experienced an intense rainfall and thunderstorm event during the morning commute. Between 1.4 and 3.5 inches of rain fell within two hours (MTA 2007). The event started a cascade of transit system failures that would eventually strand 2.5 million riders, shut down much of the subway system, and severely disrupt the city's bus system (MTA 2007; Zimmerman and Faris 2010). The storm's impact was unprecedented and, coupled with two other major system disruptions that occurred in 2004 and 2007, became the impetus for a full-scale assessment and review of transit procedures and policy in response to climate change (MTA 2007, 2009; Zimmerman and Faris 2010).

In August 2003, an electric power blackout that caused 50 million people in the U.S. Northeast and Midwest and Ontario, Canada, to lose electric power further illustrates the interdependencies of major infrastructure systems. The blackout caused significant indirect damage, such as shutdowns of water treatment plants and pumping stations. Other impacts included interruptions in communication systems for air travel and control systems for oil refineries. At a more local level, the lack of air conditioning and elevator access meant many urban residents were stranded in their over-heating high-rise apartments. Similar cascading impacts have been observed from extreme weather events such as Hurricanes Katrina and Irene (Wilbanks et al. 2012). In fact, as urban infrastructures evolve to higher degrees of interconnected complexity, the likelihood of large-scale cascading impacts will increase as risks to infrastructure increase (Ellis et al. 1997).

**Box: Hurricane Sandy: Urban Systems, Infrastructure, and Vulnerability**

Hurricane Sandy made landfall on the New Jersey shore just south of Atlantic City on October 28, 2012 and became one of the most damaging storms to strike the continental U.S. Sandy affected cities throughout the Atlantic seaboard, extending across the eastern U.S. to Chicago, Illinois where it generated 20-foot waves on Lake Michigan and flooded the city's Lake Shore Drive. The storm's strength and resulting impact was certainly increased by the fact that the waters of the Atlantic Ocean near the coast were roughly 5˚F above normal and that the region's coastline is experiencing sea level rise as a result of a warming climate (See also Ch.2: Our Changing Climate).

Sandy caused significant loss of life as well as tremendous destruction of property and critical infrastructure. It disrupted daily life for millions of coastal zone residents across the New York-New Jersey metropolitan area, despite this being one of the best disaster-prepared coastal regions in the U.S. The death toll from Sandy in the metropolitan region exceeded 100, and the damage estimates may exceed hundreds of billions of dollars. At its peak, the storm cut electrical power to more than five million customers.

The death and injury, physical devastation, multi-day power, heat, and water outages, gasoline shortages, and cascade of collapses from Sandy's impact reveal what happens when the complex, integrated systems upon which urban life depends are stressed and fail. One example is what occurred after a Consolidated-Edison electricity distribution substation in lower Manhattan ceased operation at approximately 9 PM Monday evening, when its flood protection barrier (designed to be 1.5 feet above the 10-foot storm surge of record) was overtopped by Sandy's 14-foot storm surge. As the substation stopped functioning, it immediately caused a system-wide loss of power for more than 200,000 customers. Residents in numerous high rise apartment buildings were left without heat and lights, and also without elevator service and water (which must be pumped to upper floors).

Sandy also highlighted the vast differences in vulnerabilities across the extended metropolitan region. Communities and neighborhoods on the coast were obviously most vulnerable to the physical impact of the record storm surge. Many low-to-moderate income residents live in these areas and suffered the damage or loss of their homes, leaving tens of thousands of people displaced or homeless. As a specific sub-population, the elderly and infirm were highly vulnerable, especially those living in the coastal evacuation zone and those on upper floors of apartment buildings left without elevator service. These individuals had limited adaptive capacity because they could not easily leave their residences.

Even with the extensive devastation, the effects of the storm would have been far worse if local climate resilience strategies had not been in place. For example, the City of New York and the

Metropolitan Transportation Authority worked aggressively to protect life and property by stopping the operation of the city's subway before the storm hit and moving the train cars out of low-lying, flood-prone areas. At the height of the storm surge, all seven of the city's East River subway tunnels flooded. Catastrophic loss of life would have resulted if there had been subway trains operating in the tunnels when the storm struck. The storm also fostered vigorous debate among local and state politicians, other decision-makers, and stakeholders about how best to prepare the region for future storms – especially given the expectation that this type of event will become more frequent with ongoing climate change.

**-- end box --**

## *Social Vulnerability and Human Well-Being*

**Climate vulnerability and adaptive capacity of urban residents and communities are influenced by pronounced social inequalities that reflect age, ethnicity, gender, income, health, and (dis)ability differences.**

"Social vulnerability" describes characteristics of populations that influence their capacity to prepare for, respond to, and recover from hazards and disasters (Adger 2006; Cutter et al. 2003; Füssel 2007b; Laska and Morrow 2006). Social vulnerability also refers to the sensitivity of a population to the impacts of climate change and how different people or groups are more or less vulnerable to those impacts (Cardona et al. 2012). Those characteristics that most often influence differential impacts include socioeconomic status (wealth or poverty), age, gender, special needs, race, and ethnicity (Bates and Swan 2007; NRC 2006; Phillips et al. 2010). Further, inequalities reflecting differences in gender, age, wealth, class, ethnicity, health, and disabilities also influence coping and adaptive capacity, especially to climate change and climate-sensitive hazards (Cutter et al. 2012).

The urban elderly are particularly sensitive to heat waves. They are often physically frail, have limited financial resources, and live in relative isolation in their apartments. They may not have adequate cooling (or heating), or may be unable to temporarily locate to cooling stations. This combination led to a significant number of elderly deaths during the 1995 Chicago heat wave (Klinenberg 2003). The impacts of Hurricane Katrina in New Orleans illustrated profound differences based on race, gender, and class where these social inequalities strongly influenced the capacity of residents to prepare for and respond to the events (Brinkley 2007; Horne 2008; Weber and Peek 2012). It is difficult to assess the specific nature of vulnerability for sub-populations. Urban areas are not homogeneous in terms of their social structures that influence inequalities. Also the nature of the vulnerability is context specific, with both temporal and geographic determinants, and these also vary between and within urban areas.

### *Trends in Urban Adaptation – Lessons from Early Adopters*

**City government agencies and organizations have started urban adaptation efforts that focus on infrastructure systems and public health. However, these efforts face many barriers to implementing and incorporating wider governmental, general public, and private efforts.**

City preparation efforts for climate change include planning for ways in which the infrastructure systems and buildings, ecosystem and municipal services, and residents will be affected. In the first large-scale analysis of U.S. cities, a 2011 survey showed that 58% of respondents are moving forward on climate adaptation, defined as any activity to address impacts that climate change could have on a community. Cities are engaged in activities ranging from assessment to planning to implementation, with 48% reporting that they are in the preliminary planning and discussion phases (Carmin et al. 2012).

New York City and Sea Level Rise

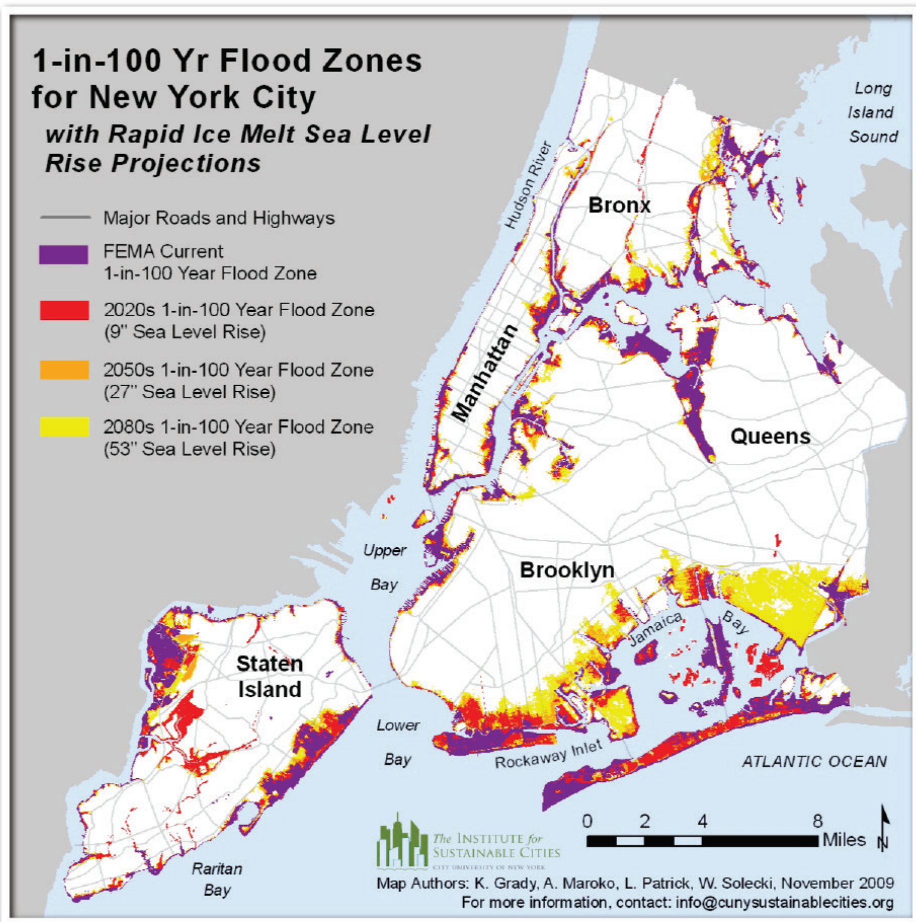


**Figure 11.3:** New York City and Sea Level Rise

**Caption:** Map shows areas in New York's five boroughs that are projected to face increased flooding over the next 70 years, assuming an increased rate of sea level rise from the past century's average. As sea level rises, storm surges reach further inland. Map does not represent precise flood boundaries, but illustrates projected increases in areas flooded under various sea level rise scenarios.

Cities either develop separate strategic adaptation plans (Carmin et al. 2012; Zimmerman and Faris 2011) or integrate adaptation into community or general plans (as have Seattle, Portland, Berkeley, and Homer, Alaska) (Solecki and Rosenzweig 2012). Cities develop or integrate adaptation into climate action plans targeted at certain sectors (like critical infrastructure) (City of Santa Cruz 2012; Cooney 2011; Füssel 2007a, 2007b; Maibach et al. 2008), and these have been effective in diverse contexts ranging from hazard mitigation and public-health planning to coastal-zone management and economic development. Climate adaptation planning requires both intra- and inter-governmental agency and department coordination (see Box on "New York City Climate Action"). As a result, many cities focus on sharing information and examining what aspects of government operations will be affected by climate change impacts in order to gain support from municipal agency stakeholders and other local officials (Moser and Ekstrom 2011). Cities also have shared climate change action experiences with other cities, both within the U.S. and internationally, as is the case with ongoing communication between decision-makers in New York City and London, England.

National, state, and local policies play an important role in fostering and sustaining adaptation. There are no national regulations specifically designed to promote urban adaptation. However, existing federal policies, like the National Environmental Protection Act, can provide incentives for adaptation strategies for managing federal property in urban areas (DOI 2011; Solecki and Rosenzweig 2012; U.S. Fish and Wildlife Service 2010). Policies and planning measures at the local level, such as building codes, zoning regulations, land-use plans, water supply management, green infrastructure initiatives, health care planning, and disaster mitigation efforts, can support adaptation (Dodman and Satterthwaite 2008; Solecki and Rosenzweig 2012; Wilbanks et al. 2012).

Engaging the public in adaptation planning and implementation has helped to inform and educate the community at large about climate change, while ensuring that information and ideas flow back to policymakers (Carmin et al. 2011; Van Aalst et al. 2008). Engagement also can help in identifying vulnerable populations (Foster et al. 2011) and in mobilizing people to encourage policy changes and take individual actions to reduce and adapt to climate change (Moser 2009). For instance, the Cambridge Climate Emergency Congress selected a demographically diverse group of resident delegates and engaged them in a deliberative process intended to express preferences and generate recommendations to inform climate action (City of Cambridge 2010; Fishkin 1991). In addition, the Boston Climate Action Leadership Committee was initiated by the Mayor's office with the expectation that they would rely on public consultation to develop recommendations for updating the city's climate action plan (City of Boston 2010, 2011).

There are many barriers to action at the city level. Adaptation requires that anticipated climate changes and impacts are evaluated and addressed in the course of the planning process (Hallegatte and Corfee-Morlot 2011; Howard and Monbiot 2009; Ch. 26: Decision Support). This means that climate or assessment data must be available, but most U.S. cities are unable to access suitable data or perform desired analyses (CCATF 2011). To address technical aspects of adaptation, cities are promoting cooperation with local experts, such the New York City Panel on Climate Change, which brings together experts from academia and the public and private sectors to consider how the region's critical infrastructure will be affected by, and can be protected from, future climate change (Rosenzweig and Solecki 2010; Rosenzweig et al. 2011). A further illustration comes from Chicago, where multi-departmental groups are focusing on specific areas identified in Chicago's Climate Action Plan (2010).

**Box: New York City Climate Action**

New York City leaders recognized that climate change represented a serious threat to critical infrastructure and responded with a comprehensive program to address climate change impacts and increase resilience (Solecki and Rosenzweig 2012; Wilbanks et al. 2012). The 2010 "Climate Change Adaptation in New York City: Building a Risk Management Response" report was prepared by the New York City Panel on Climate Change as a part of PlaNYC, the City's long-term sustainability plan (NPCC 2010). Major components of the process and program include:

- Multiple participatory processes, including obtaining broad public input through PlaNYC and establishment of a Climate Change Adaptation Task Force that included private and public stakeholders (NRC 2010a);
- Formation of an expert technical advisory body, the New York City Panel on Climate Change (NPCC), to support the Task Force;
- Development of a Climate Change Assessment and Action Plan that helps improve responses to present-day climate variability as well as projected future conditions;
- Defined "Climate Protection Levels" to address the effectiveness of current regulations and design standards to respond to climate change impacts; and
- Produced adaptation assessment guidelines that recognize the need for flexibility to reassess and adjust strategies over time. The guidelines include a risk matrix and prioritization framework intended to become integral parts of ongoing risk management and agency operations.

**-- end box --**

Private sector involvement can be influential in promoting city-level adaptation, yet to date there are limited examples of such involvement. Instances where cooperation has taken place include property insurance companies (NRC 2010a; Solecki and Rosenzweig 2012), and engineering firms that provide consulting services to cities. For example, firms providing infrastructure system plans have begun to account for projected changes in precipitation in their projects (van der Tak et al. 2010). With city and regional infrastructure systems, recent attention has focused on the potential role of private sector-generated smart technologies to advance early warning of extreme precipitation and heat waves, as well as establishing information systems that can inform local decision-makers about the status and efficiency of infrastructure (IBM News Room 2009; NRC 2010a).

Uncertainty in both the climate system and modeling techniques often is viewed as a barrier to adaptation action (Corfee-Morlot et al. 2011; Mastrandrea et al. 2010). Urban and infrastructure managers, however, recognize that uncertainty values will continue to be refined (Foster et al. 2011), and that an incremental and flexible approach to planning that draws on both structural and nonstructural measures is prudent (Carmin and Dodman 2012; NRC 2010a; Rosenzweig et al. 2010). Gaining the commitment and support of local elected officials for adaptation planning and implementation is another important challenge (Carmin et al. 2012). A compounding problem is that cities and city administrators face a wide range of other stressors demanding their attention, and have limited financial resources (NRC 2010a; see Box on “Advancing Climate Adaptation in a Metropolitan Region”) .

**Box: Advancing Climate Adaptation in a Metropolitan Region**

A major challenge of adaptation planning and practice is coordinating efforts across many jurisdictional boundaries in extended metropolitan regions and associated regional systems. Regional government institutions may be well-suited to address this challenge, as they cover a larger geographic scope than individual cities, and have potential to coordinate the efforts of multiple jurisdictions (Solecki and Rosenzweig 2012). California already requires metropolitan planning organizations to prepare Sustainable Communities Strategies (SCS) as part of the Regional Transportation Plan process (California Senate 2008). While its focus is on reducing emissions, SCS plans prepared to date have also introduced topics related to climate change impacts and adaptation (SACOG 2012; SANDAG 2011; SCAG 2012). Examples of climate change vulnerabilities that could benefit from a regional perspective include water shortages, transportation infrastructure maintenance, loss of native plant and animal species, and energy demand.

**-- end box --**

Integrating climate change action in everyday city and infrastructure operations and governance (referred to as “mainstreaming”) is an important planning and implementation tool for advancing adaptation in cities (NRC 2010a; Rosenzweig et al. 2010). By integrating climate-change considerations into daily operations, these efforts can forestall the need to develop a new and isolated set of climate-change specific policies or procedures (Foster et al. 2011). This strategy enables cities and other government agencies to take advantage of existing funding sources and programs, and achieve co-benefits in areas such as sustainability, public health, economic development, disaster preparedness, and environmental justice. Pursuing low-cost, no-regrets options is a particularly attractive short-term strategy for many cities (Foster et al. 2011; NRC 2010a).

Over the long term, responses to severe climate change impacts, such as sea level rise and greater frequency and intensity of other climate-related hazards, are of a scale and complexity that will likely require major expenditures and structural changes (NRC 2010a; Solecki and Rosenzweig 2012), especially in urban areas. When major infrastructure decisions must be made in order to protect human lives and urban assets, cities need access to the best available science, decision support tools, funding, and guidance. The federal government is seen by local officials to have an important role here by providing adaptation leadership and financial and technical resources, and by conducting and disseminating research (CCATF 2011; Foster et al. 2011; NRC 2010a).

# Traceable Accounts

## Chapter 11: Urban Systems, Infrastructure, and Vulnerability

**Key Message Process:** In developing key messages, the report author team engaged in multiple technical discussions via teleconference. A consensus process was used to determine the final set of key messages which support extensive evidence documented in two Technical Report Inputs to the U.S. National Climate Assessment on urban systems, infrastructure, and vulnerability: (Wilbanks et al. 2012) Climate Change and Infrastructure, Urban Systems, and Vulnerabilities: Technical Report For The U.S. Department of Energy in Support of the National Climate Assessment, and (Solecki and Rosenzweig (2012) U.S. Cities and Climate Change: Urban, Infrastructure, and Vulnerability Issues). Other Technical Input reports (56) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

| **Key message #1/4** | **Climate change and its impacts threaten the well-being of urban residents in all regions of the U.S. Essential local and regional infrastructure systems such as water, energy supply, and transportation will increasingly be compromised by interrelated climate change impacts.** |
|---|---|
| **Description of evidence base** | Recent studies have reported that population and economic growth have made urban environments more fragile and deficient (Solecki and Rosenzweig 2012; Wilbanks et al. 2012), with work projecting increased stresses due to climate change (McCrea et al. 2011) and increased costs of adaptation plans due to urban development (Burchell et al. 2002). Additionally, a few publications have assessed the main drivers of vulnerability (Depietri et al. 2012; Douglas et al. 2011; Emrich and Cutter 2011) and the effects of the amalgamation of climate-change stresses with other urban and infrastructure stressors (Solecki and Rosenzweig 2012) |
| **New information and remaining uncertainties** | Since population trends and infrastructure assessments are well established and documented, the largest uncertainties are associated with the rate and extent of potential climate change<br><br>Current publications have explored the driving factors of vulnerability in urban systems (Depietri et al. 2012; Douglas et al. 2011; Emrich and Cutter 2011) and the effects of the combined effect of climate-change and existing urban stressors (Solecki and Rosenzweig 2012). |
| **Assessment of confidence based on evidence** | Given the evidence base and remaining uncertainties, confidence is **Very High** that climate change and its impacts threaten the well-being of urban residents in all regions of the U.S.<br><br>Given the evidence base and remaining uncertainties, confidence is **Very High** that essential local and regional infrastructure systems such as water, energy supply, and transportation will increasingly be compromised by interrelated climate change impacts. |

| **CONFIDENCE LEVEL** | | | |
|---|---|---|---|
| **Very High** | **High** | **Medium** | **Low** |
| Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus | Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus | Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought | Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts |

# Chapter 11: Urban Systems, Infrastructure, and Vulnerability

**Key Message Process:** See key message #1.

| **Key message #2/4** | **In urban settings, climate-related disruptions of services in one infrastructure system will almost always result in disruptions in one or more other infrastructure systems.** |
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| **Description of evidence base** | The interconnections between urban systems and infrastructures have been noted in the past (Ellis et al. 1997), with recent work expanding on this principal to assess the risk this interconnectivity poses. Kirshen et al. (2008) explored the misconception of independent systems and stressed their interactive and interdependent nature. Seto et al. (2012) explored how the effects of climate change on one system ultimately affect systems that are dependent upon it. Wilbank et al. (2012) looked at economic effects from climate change and how they will affect urban areas. Noted examples of this interconnectivity can be found in a number of publications concerning hurricane Katrina (Myers et al. 2008), intense weather in New York City (MTA 2007; Zimmerman and Faris 2010), and the vulnerability of U.S. oil refineries and electric power plants (Wilbanks et al. 2012; Zimmerman 2006). |
| **New information and remaining uncertainties** | The extensive number of infrastructure assessments has resulted in well-documented system interdependencies and cascade effects. Therefore, the most significant uncertainties are associated with the rate and extent of potential climate change.<br><br>Recent work has delved deeper into the interconnectivity of urban systems and infrastructure (Seto et al. 2012; Wilbanks et al. 2012) and has expressed the importance understanding these interactions when adapting to climate change. |
| **Assessment of confidence based on evidence** | Given the evidence base and remaining uncertainties, confidence is **Very High** that in urban settings, climate-related disruptions of services in one infrastructure system will almost always result in disruptions in one or more other infrastructure systems. |

| **CONFIDENCE LEVEL** | | | |
|---|---|---|---|
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# Chapter 11: Urban Systems, Infrastructure, and Vulnerability

**Key Message Process:** See key message #1.

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| **Key message #3/4** | **Climate vulnerability and adaptive capacity of urban residents and communities are influenced by pronounced social inequalities that reflect age, ethnicity, gender, income, health, and (dis)ability differences.** |
| **Description of evidence base** | The topic of social vulnerability has been extensively studied (Adger 2006; Cutter et al. 2003; Füssel 2007b; Laska and Morrow 2006), with some work detailing the social characteristics that are the most influential (Bates and Swan 2007; NRC 2006; Phillips et al. 2010) . More recent work has addressed the vulnerability of populations to climate change (Cardona et al. 2012) and how social inequalities influence the adaptive capacity to climate change (Cutter et al. 2012). Some empirical studies of U.S. urban areas were explored concerning these issues (Emrich and Cutter 2011). |
| **New information and remaining uncertainties** | Since population trends and socio-economic factors associated with vulnerability and adaptive capacity are well established and documented, the largest uncertainties are associated with the rate and extent of potential climate change.<br><br>Recent work has addressed the social vulnerabilities to climate change at a more detailed level than in the past (Cardona et al. 2012; Cutter et al. 2003), which informs of the constraints they can have to climate change adaptation. |
| **Assessment of confidence based on evidence** | Given the evidence base and remaining uncertainties, confidence is **Very High** that the climate vulnerability and adaptive capacity of urban residents and communities are influenced by pronounced social inequalities that reflect age, ethnicity, gender, income, health, and (dis)ability differences. |

| **CONFIDENCE LEVEL** | | | |
|---|---|---|---|
| **Very High** | **High** | **Medium** | **Low** |
| Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus | Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus | Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought | Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts |

# Chapter 11: Urban Systems, Infrastructure, and Vulnerability

**Key Message Process:** See key message #1.

| | |
|---|---|
| **Key message #4/4** | **City government agencies and organizations have started urban adaptation efforts that focus on infrastructure systems and public health. However, these efforts face many barriers to implementing and incorporating wider governmental, general public, and private efforts.** |
| **Description of evidence base** | Urban adaptation is already underway with a number of cities developing plans at the city (Carmin et al. 2012; City of Santa Cruz 2012; Cooney 2011; Füssel 2007b; Maibach et al. 2008; Zimmerman and Faris 2011) and state levels (Carmin et al. 2012), with some integrating adaptation into communities (Solecki and Rosenzweig 2012) and sharing information and assessing potential impacts (Moser and Ekstrom 2011). Some recent publications have explored how incentives and support can benefit climate adaptation through policy planning at local level (Dodman and Satterthwaite 2008; Solecki and Rosenzweig 2012; Wilbanks et al. 2012) and engaging the public (Carmin et al. 2011; Foster et al. 2011; Moser 2009; Van Aalst et al. 2008).<br><br>Studies have shown that some barriers exist that can hinder the adaptation process, which has been demonstrated through publications assessing the availability of scientific data (Carmin et al. 2012; CCATF 2011) that is integral to the evaluation and planning process (Hallegatte and Corfee-Morlot 2011; Howard and Monbiot 2009), uncertainty in the climate system and modeling techniques (Corfee-Morlot et al. 2011; Mastrandrea et al. 2010), and gaining support and commitment from local officials (Carmin et al. 2012; NRC 2010a). |
| **New information and remaining uncertainties** | Besides uncertainties associated with the rate and extent of potential climate change, uncertainties emerge from the fact that to-date, there have been few extended case studies examining how U.S. cities are responding to climate change (<10 studies). Furthermore, only one large-scale survey of U.S. cites has been conducted for which results have been published and widely available. |
| **Assessment of confidence based on evidence** | Given the evidence base, confidence is **Very High** that city government agencies and organizations have started urban adaptation efforts that focus on infrastructure systems and public health. |

| CONFIDENCE LEVEL | | | |
|---|---|---|---|
| **Very High** | **High** | **Medium** | **Low** |
| Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus | Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus | Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought | Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts |

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