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 U.S. regions. Essential infrastructure systems such as water, energy supply, and transportation will increasingly be compromised by interrelated climate change impacts. The nation's economy, security, and culture all depend on the resilience of urban infrastructure systems.**
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 adaptation plans that focus on infrastructure systems and public health. To be successful, these adaptation efforts require cooperative private sector and governmental activities, but face many barriers to implementing these combined 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 these 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. These systems are often connected to rural locations at great distances from urban centers.

The term infrastructure is used broadly and includes systems and assets that are essential for national and economic security, national public health or safety, or to the overall well-being of residents. These include energy, water and wastewater, transportation, public health, banking and finance, telecommunications, food and agriculture, and information technology, among others.

Urban dwellers are particularly vulnerable to disruptions in essential infrastructure services, in part because many of these infrastructure systems are reliant on each other. For example, electricity is essential to 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 continue to 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 living in cities or suburbs. Also at risk from climate change are historic properties and sites as well as cultural resources and archeological sites. Vulnerability assessments and adaptation planning efforts could also include these irreplaceable resources. Changing conditions also create opportunities and challenges for urban climate adaptation (Ch. 28: Adaptation), and many cities have begun planning to address these changes.

Urbanization and Infrastructure Systems

Climate change and its impacts threaten the well-being of urban residents in all U.S. regions. Essential infrastructure systems such as water, energy supply, and transportation will increasingly be compromised by interrelated climate change impacts. The nation's economy, security, and culture all depend on the resilience of urban infrastructure systems.

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. Climate change increases the risk, frequency, and intensity of certain extreme events like intense heat waves, heavy downpours, flooding from intense precipitation and coastal storm surges, and disease incidence related to temperature and precipitation changes. The vulnerability of urban dwellers multiplies when the effects of climate change interact with pre-existing urban stressors, such as deteriorating infrastructure, areas of intense poverty, and high population density.

Three fundamental conditions define the key connections among urban systems, residents, and infrastructure.[1,2] First, cities are dynamic, and are constantly being built and rebuilt through cycles of investment and innovation. Second, infrastructure in many cities has exceeded its design life and continues to age, resulting in an increasingly fragile system. At both local and national levels, infrastructure requires ongoing maintenance and investment to avoid 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.

Approximately 245 million people live in U.S. urban areas, a number expected to grow to 364 million by 2050.[3] Paradoxically, as the economy and population of urban areas grew in past decades, the built infrastructure within cities and connected to cities deteriorated, becoming increasingly fragile and deficient.[1,2] Existing built infrastructure (such as buildings, energy, transportation, water, and sanitation systems) is expected to become more stressed in the next decades – especially when the impacts of climate change are added to the equation.[4] As infrastructure is highly interdependent, failure in particular sectors is expected to have cascading effects on most aspects of affected urban economies. Further expansion of the U.S. urban landscape into suburban and exurban spaces is expected, and new climate adaptation and resiliency plans will need to account for this (Ch. 28: Adaptation).[5] Significant increases in the costs of infrastructure investments also are expected as population density becomes more diffuse.[6]

Figure 11.1: Blackout in New York and New Jersey after Hurricane Sandy

Caption: Extreme weather events can affect multiple systems that provide services for millions of people in urban settings. The satellite images depict city lights on a normal night (left) and immediately following Hurricane Sandy (right). Approximately five million customers in the New York metropolitan region lost power. (Figure source: NASA Earth Observatory).

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.[7,8] Many major U.S. metropolitan areas, for example, are located on or near the coast and face higher exposure to particular climate impacts like sea level rise and storm surge, and thus may face complex and costly adaptation demands (Ch: 25: Coasts; Ch. 28: Adaptation). But as people begin to respond to new information about climate change through the urban development process, social and infrastructure vulnerabilities can be altered. [9] 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.[1]

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 rely on links to multiple jurisdictions through a complex set of infrastructure systems.[10] For example, cities depend on other areas for supplies of food, materials, water, energy, and other inputs, and surrounding areas are destinations for products, services, and wastes from cities. If infrastructure and other connections among source areas and cities are disrupted by climate change, then the dependent urban area also will be affected.[11] 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 is also affected.[2]

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.[12] 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.[2] 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.[13]

Although infrastructures and urban systems are often considered individually – for example, transportation or water supply or wastewater/drainage – they are usually highly interactive and interdependent.[14]

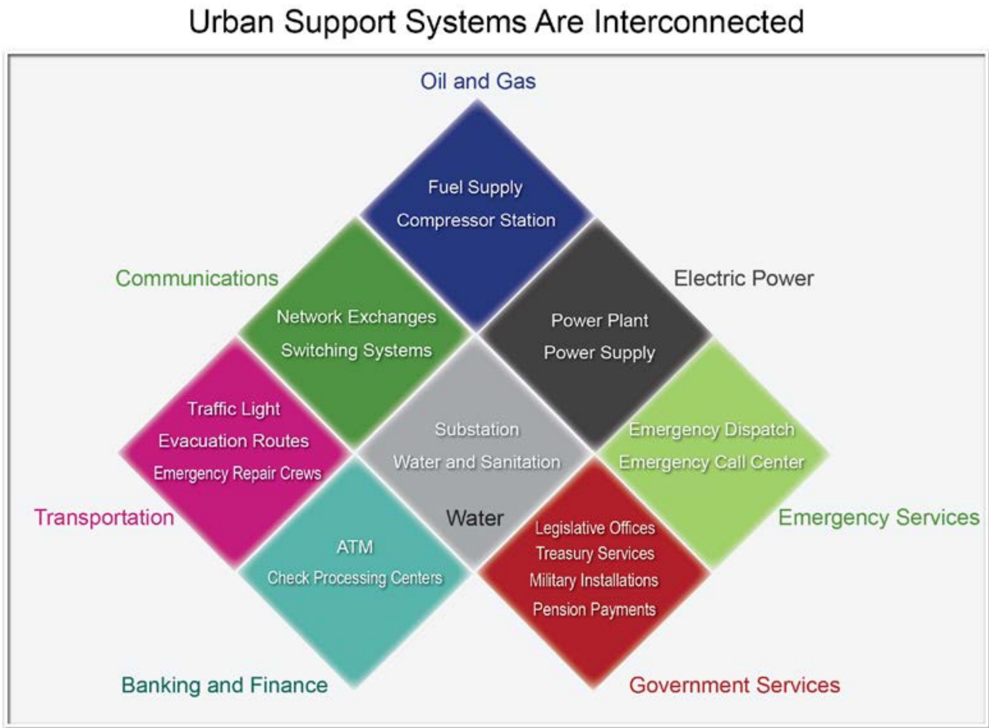

Figure 11.2: Urban Support Systems are Interconnected

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, transportation, and banking systems may all be affected. This schematic drawing illustrates some of these connections. (Figure source: adapted from Wilbanks et al. 2012[2]).

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, where between 1.4 and 3.5 inches of rain fell within two hours.[15] The event started a cascade of transit system failures – eventually stranding 2.5 million riders, shutting down much of the subway system, and severely disrupting the city's bus system.[15,16] 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. [15,16,17]

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 over-heating high-rise apartments. Similar cascading impacts have been observed from extreme weather events such as Hurricanes Katrina and Irene.[2] In fact, as urban infrastructures become more interconnected and more complex, the likelihood of large-scale cascading impacts will increase as risks to infrastructure increase.[18]

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

Hurricane Sandy made landfall on the New Jersey shore just south of Atlantic City on October 29, 2012, and became one of the most damaging storms to strike the continental United States. 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 has been correlated with Atlantic Ocean water temperatures near the coast that were roughly 5˚F above normal, and with sea level rise along the region's coastline as a result of a warming 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 country. The death toll from Sandy in the metropolitan region exceeded 100, and the damage was estimated to be at least 65 billion dollars.[19,20] At its peak, the storm cut electrical power to more than 8.5 million customers.[20]

The death and injury, physical devastation, multi-day power, heat, and water outages, gasoline shortages, and cascade of problems 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 most vulnerable to the physical impact of the record storm surge. Many low- to moderate-income residents live in these areas and suffered damage to 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. Planning is especially important given the expectation of increases in flood frequency resulting from more numerous extreme precipitation events and riverine and street level flooding, and coastal storm surge flooding associated with accelerated sea level rise and more intense (yet not necessarily more numerous) tropical storms.

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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.[21,22,23] Social vulnerability also refers to the sensitivity of a population to climate change impacts and how different people or groups are more or less vulnerable to those impacts.[24] Those characteristics that most often influence differential impacts include socioeconomic status (wealth or poverty), age, gender, special needs, race, and ethnicity.[25] 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.[26]

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 relocate to cooling stations. This combination led to a significant number of elderly deaths during the 1995 Chicago heat wave.[27] Similarly, 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.[28] It is difficult to assess the specific nature of vulnerability for particular groups of people. Urban areas are not homogeneous in terms of the 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 Current Adopters

City government agencies and organizations have started adaptation plans that focus on infrastructure systems and public health. To be successful, these adaptation efforts require cooperative private sector and governmental activities, but face many barriers to implementing these combined 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 (Ch. 28: Adaptation), defined as any activity to address impacts that climate change could have on a community. Cities are engaged in activities ranging from education and outreach to assessment, planning, and implementation, with 48% reporting that they are in the preliminary planning and discussion phases.[29]

New York City and Sea Level Rise

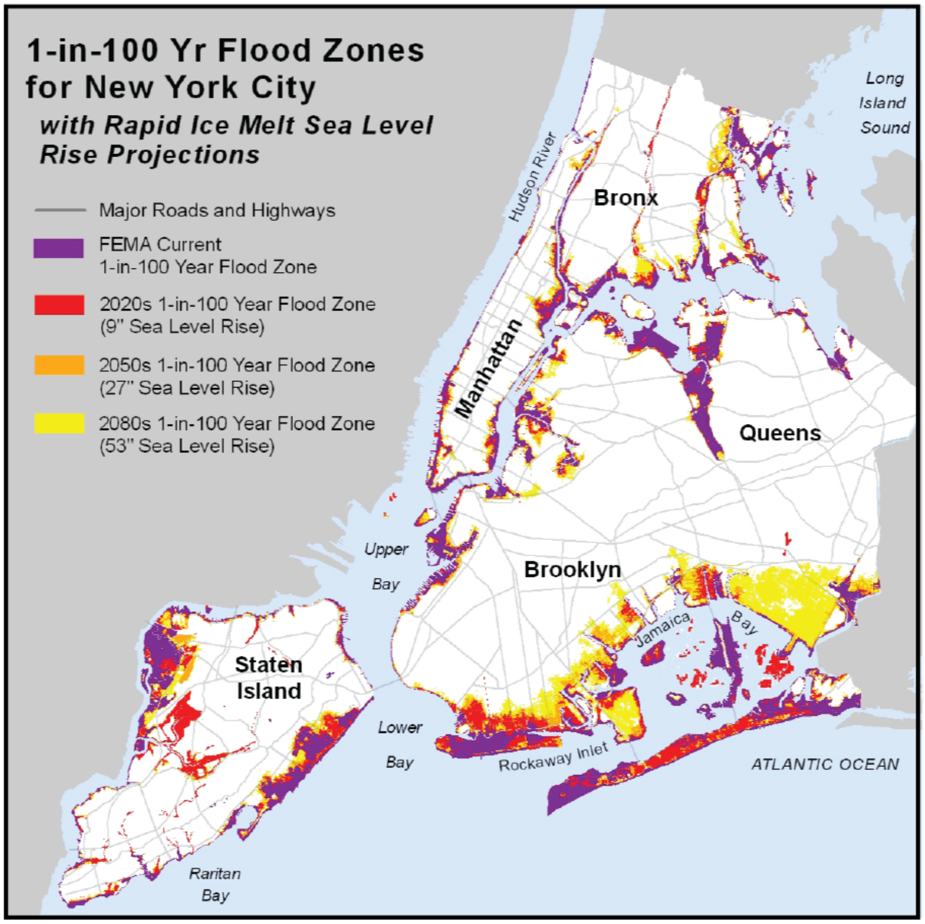

Figure 11.3: New York City and Sea Level Rise

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. (Figure source: New York City Panel on Climate Change 2013).

Cities either develop separate strategic adaptation plans[29,30] or integrate adaptation into community or general plans (as have Seattle, Washington; Portland, Oregon; Berkeley, California; and Homer, Alaska) (Ch. 28: Adaptation).[1] Some climate action plans target certain sectors like critical infrastructure,[23,31] and these have been effective in diverse contexts ranging from hazard mitigation and public-health planning to coastal-zone management and economic development.

Cities have employed several strategies for managing adaptation efforts. For example, some approaches to climate adaptation planning require both intra- and inter-governmental agency and department coordination (see Box on "New York City Climate Action") (Ch. 28: Adaptation). 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.[32] Some cities also have shared climate change action experiences, 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 Historic Preservation Act and National Environmental Policy Act – particularly through its impact assessment provision and evaluation criteria process – can provide incentives for adaptation strategies for managing federal property in urban areas.[1,33] In addition, recent activities of federal agencies focused on promoting adaptation and resilience have been developed in partnership with cities like Miami and New York. (CEQ 2011) 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.[1,2,34]

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.[35] Engagement can also help in identifying vulnerable populations[36] and in mobilizing people to encourage policy changes and take individual actions to reduce and adapt to climate change.[37] 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.[38] 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.[39]

There are many barriers to action at the city level. Proactive adaptation efforts require that anticipated climate changes and impacts are evaluated and addressed in the course of the planning process (Ch. 26: Decision Support; Ch. 28: Adaptation).[40] This means that climate projections and impact assessment data must be available, but most U.S. cities are unable to access suitable data or perform desired analyses.[41] To address technical aspects of adaptation, cities are promoting cooperation with local experts, such as 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.[9,42] A further illustration comes from Chicago, where multi-departmental groups are focusing on specific areas identified in Chicago's Climate Action Plan.[43]

Box: New York City Climate Action

New York City leaders recognized that climate change represents a serious threat to critical infrastructure and responded with a comprehensive program to address climate change impacts and increase resilience.[1,2] 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 the City's long-term sustainability plan.[9] Major components of the process and program include:

- establishing multiple participatory processes to obtain broad public input, including a Climate Change Adaptation Task Force that included private and public stakeholders;[44]
- forming an expert technical advisory body, the New York City Panel on Climate Change (NPCC), to support the Task Force;
- developing a Climate Change Assessment and Action Plan that helps improve responses to present-day climate variability as well as projected future conditions;
- defining "Climate Protection Levels" to address the effectiveness of current regulations and design standards to respond to climate change impacts; and
- producing 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.

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Private sector involvement can be influential in promoting city-level adaptation (Ch. 28: Adaptation). Many utilities, for example, have asset management programs that do address risk and vulnerabilities, which could also serve to address climate change. Yet to date there are limited examples of private sector interests working cooperatively with governments to limit risk. Instances where cooperation has taken place include property insurance companies[1,44] 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.[45] With city and regional infrastructure systems, recent attention has focused on the potential role of private sector-generated smart technologies to improve 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.[44,46]

Uncertainty, in both the climate system and modeling techniques, is often viewed as a barrier to adaptation action (Ch. 28: Adaptation).[47] Urban and infrastructure managers, however, recognize that understanding of sources and magnitude of future uncertainty will continue to be refined,[36] and that an incremental and flexible approach to planning that draws on both structural and nonstructural measures is prudent.[42,44,48] Gaining the commitment and support of local elected officials for adaptation planning and implementation is another important challenge.[29] A compounding problem is that cities and city administrators face a wide range of other stressors demanding their attention, and have limited financial resources (See Box on "Advancing Climate Adaptation in a Metropolitan Region").[44]

Box: Advancing Climate Adaptation in a Metropolitan Region

Coordinating efforts across many jurisdictional boundaries is a major challenge for adaptation planning and practice in extended metropolitan regions and associated regional systems (Ch. 28: Adaptation). 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.[1] California already requires metropolitan planning organizations to prepare Sustainable Communities Strategies (SCS) as part of the Regional Transportation Plan process.[49] While its focus is on reducing emissions, SCS plans prepared to date have also introduced topics related to climate change impacts and adaptation.[50] 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.

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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 (Ch. 28: Adaptation).[42,44] 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.[36,44]

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,[1,44] 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 (Ch. 28: Adaptation).[36,41,44]

Traceable Accounts

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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 are supported by extensive evidence documented in two Technical Report Inputs to the National Climate Assessment on urban systems, infrastructure, and vulnerability: 1) *Climate Change and Infrastructure, Urban Systems, and Vulnerabilities: Technical Report for the U.S. Department of Energy in Support of the National Climate Assessment* [2], and 2) *U.S. Cities and Climate Change: Urban, Infrastructure, and Vulnerability Issues* .[1] 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 U.S. regions. Essential infrastructure systems such as water, energy supply, and transportation will increasingly be compromised by interrelated climate change impacts. The nation's economy, security, and culture all depend on the resilience of urban infrastructure systems.**
Description of evidence base	Recent studies have reported that population and economic growth have made urban infrastructure more fragile and deficient, [1,2] with work projecting increased stresses due to climate change[4] and increased costs of adaptation plans due to more extensive urban development.[6] Additionally, a few publications have assessed the main drivers of vulnerability[7,8] and the effects of the amalgamation of climate change stresses with other urban and infrastructure stressors.[1]
New information and remaining uncertainties	Given that population trends and infrastructure assessments are well established and documented, the largest uncertainties are associated with the rate and extent of potential climate change. Since the prior National Climate Assessment,[51] recent publications have explored the driving factors of vulnerability in urban systems[7,8] and the effects of the combined effect of climate change and existing urban stressors.[1]
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. 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

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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.**
Description of evidence base	The interconnections among urban systems and infrastructures have been noted in the past[18], with recent work expanding on this principle to assess the risk this interconnectivity poses. One study[14] explored the misconception of independent systems, and stressed instead the interactive and interdependent nature of systems. The effects of climate change on one system ultimately affect systems that are dependent upon it.[11] One of the foundational Technical Input Reports examined the economic effects from climate change and how they will affect urban areas.[2] Noted examples of this interconnectivity can be found in a number of publications concerning Hurricane Katrina,[13] intense weather in New York City,[15,16] and the vulnerability of U.S. oil refineries and electric power plants.[2,12]
New information and remaining uncertainties	Recent work has delved deeper into the interconnectivity of urban systems and infrastructure,[2,11] and has expressed the importance of understanding these interactions when adapting to climate change. The extensive number of infrastructure assessments has resulted in system interdependencies and cascade effects being well documented. Therefore, the most significant uncertainties are associated with the rate and extent of potential 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			
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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Key Message Process: See key message #1.

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,[21,22,23] with some work detailing the social characteristics that are the most influential.[25] More recent work has addressed the vulnerability of populations to climate change[24] and how social inequalities influence capacity to adapt to climate change.[26] Some empirical studies of U.S. urban areas were explored concerning these issues.[8]
New information and remaining uncertainties	Given that 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. Recent work has addressed the social vulnerabilities to climate change at a more detailed level than in the past, [22,24] providing information on the constraints that social vulnerabilities can have on 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

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Key Message Process: See key message #1.

Key message #4/4	**City government agencies and organizations have started adaptation plans that focus on infrastructure systems and public health. To be successful, these adaptation efforts require cooperative private sector and governmental activities, but face many barriers to implementing these combined efforts.**
Description of evidence base	Urban adaptation is already underway with a number of cities developing plans at the city[29,30,31] and state levels,[29] with some integrating adaptation into community plans[1] and sharing information and assessing potential impacts.[32] Some recent publications have explored how incentives and administrative and financial support can benefit climate adaptation through policy planning at the local level[1,2,34] and by engaging the public.[35,36,37] Barriers exist that can hinder the adaptation process, which has been demonstrated through publications assessing the availability of scientific data[29,41] that is integral to the evaluation and planning process,[40] uncertainty in the climate system and modeling techniques,[47] and the challenges of gaining support and commitment from local officials.[29,44]
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.[29]
Assessment of confidence based on evidence	Given the evidence base and remaining uncertainties, 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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