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Land and the City

Edited by George W. McCarthy, Gregory K. Ingram, and Samuel A. Moody

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CONTENTS

PREFACE

The majority of the world's population now lives in urban areas and depends on urban systems for housing and social and economic goods and services. This number will only increase as cities blossom and expand to accommodate new residents, particularly in developing nations. What remains unchanged, however, is the key role of cities as engines of economic growth, social activity, and cultural exchange. In an effort to support the success and sustainability of cities, this volume explores how policies regarding land use and taxation affect issues as diverse as the sustainability of local government revenues, the impacts of the foreclosure crisis, and urban resilience to climate change.

This collection, based on the Lincoln Institute of Land Policy's 2014 annual land policy conference, addresses the policies that underlie the organization, financing, and development of the world's cities. It is the final volume in the Institute's land policy conference series. Over the years, these meetings have addressed land policy as it relates to a range of topics, including local education, property rights, municipal revenues, climate change, and infrastructure.

We thank Armando Carbonell, Martim Smolka, and Joan Youngman for their advice on the selection of topics and on program design. The conference was organized by our exceptional event team, comprising Brooke Burgess, Sharon Novick, and Melissa Abraham. Our special thanks go to Emily McKeigue for her exemplary management of the production of this volume, to Peter Blaiwas for the cover design, to Nancy Benjamin for maintaining the publication schedule, and to Barbara Jatkola for her tireless and reliable copyediting.

George W. McCarthy
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4

Climate Change and U.S. Cities: Vulnerability, Impacts, and Adaptation

William Solecki

Cities throughout the United States are experiencing climate change through gradual shifts in climate variables and possibly as extreme events, both of which are changing the environmental baseline of these cities (Karl et al. 2009; Melillo, Richmond, and Yohe 2014). This chapter documents the state-of-the-art understanding of current and future climate risk for U.S. cities and urban systems, as well as for the residents who depend on them.

Contemporary climate change has created an era of increasing variability that is driving urban managers and residents to be more flexible and adaptive in response to the dynamic risks it presents. Urban infrastructure, such as water, energy, and transportation systems, is designed and managed to operate within an expected range of environmental conditions. If, as is expected, the impacts of climate change continue, and even increase, in the future, it will place great stress on this infrastructure.

Approximately 245 million people, or 80 percent of the U.S. population, now live in metropolitan areas that include core cities and extended suburban and exurban areas. This number is expected to grow to 364 million by 2050 (U.S. Census Bureau 2010). The built infrastructure (buildings and energy, transportation, water, and sanitation systems) that sustains these populations has become increasingly fragile, deficient, and vulnerable to climate change (Wilbanks et al. 2012). It is expected to become even more stressed over the coming decades and

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Portions of this chapter were based on Cutter et al. (2014) and Solecki (2014).

will be unable, given the status quo, to support a high quality of life for urban residents—especially if the impacts of climate change are added to the equation (McCrea, Stimson, and Marans 2011).

As presented by global climate modeling scenarios, future climate change will manifest in cities as directional shifts in average annual climate-related conditions, such as higher temperature, more rapid sea level rise, and increased frequency and intensity of extreme weather events, including extended heat waves and more intense storms. Observed climate data from the early twentieth century to the present illustrate a shift in the frequency and magnitude of extreme events, particularly with respect to an increased rate of heavy-precipitation events and the occurrence of heat waves. Worst-case scenarios for future climate change include instances in which multiple extreme events occur simultaneously—for example, an extreme heat event coincident with a large coastal storm with a tidal surge and flooding. These climate-related shifts represent significant challenges, as well as potential opportunities, for urban areas.

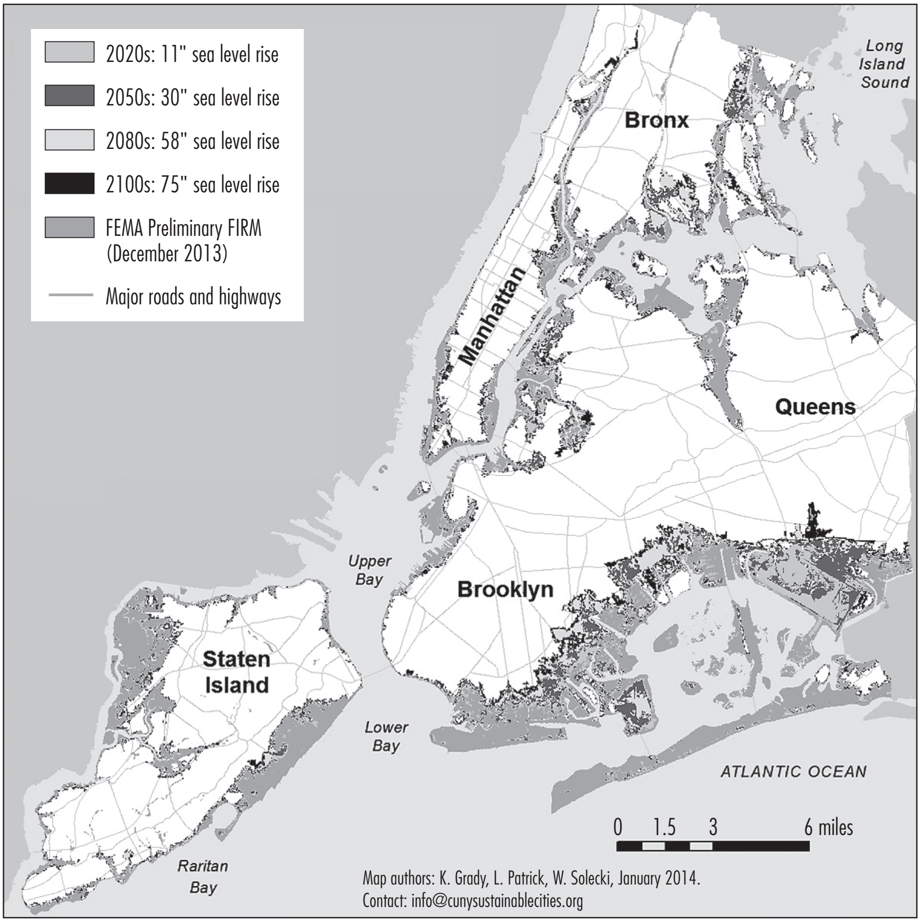
Cities have become early responders to climate change challenges and opportunities due to two simple facts: they have large and growing populations, and they depend on extensive infrastructure systems and the resources that support them (Rosenzweig et al. 2011). These systems often extend to, or derive from, rural locations at great distances from city centers. Urban residents are particularly vulnerable to disruptions in essential services in part because many infrastructure systems are interdependent. For example, electricity is essential to multiple systems, and a failure in the electrical grid can affect water treatment, transportation, telecommunications, and public health. As climate change impacts increase, significant numbers of people, including those living in cities and the extended suburbs of metropolitan regions, will be affected by climate-related events. As a result, many cities have begun adopting plans to address these impacts.

Key Climate Change Impacts on U.S. Cities and Urban Systems

In the short term, the most likely impacts of climate change will be acute—more-frequent extreme weather events and increased climate variability. Over the longer term, other threats, such as sea level rise, will compound the potential for more-frequent intense coastal storms. In New York City, for example, projected sea level rise will change the extent of the FEMA-designated flood zone that has a 1 percent chance of flooding annually. This is also referred to as the 100-year flood zone (figure 4.1).

A critical area for the review of climate effects is cascading system impacts and the associated vulnerabilities, which, together with urban service disruption, could result in wider-scale secondary social and economic costs. Increased impacts will result from the following four broad categories of climate changes: (1) increased frequency of extreme precipitation events; (2) increased frequency

Figure 4.1
Future 100-Year Flood Zones for New York City, 2020s–2100s



Note: Based on projections of the high-estimate 90th percentile sea level rise scenario.
Source: New York City Panel on Climate Change (2015).

of extreme heat days and heat waves; (3) sea level rise and coastal storm surge events; and (4) increased frequency of extreme wind events. Drought also could affect urban systems, but not to the broad degree seen in the other categories. Drought obviously will have the most impact on drinking water supplies. Table 4.1 is a list of climate risks within each category.

Major investments in cities will be necessary to adapt to climate change. For example, the location of urban transportation systems either at ground level,

Table 4.1
Climate Risks and Hazards That Will Impact U.S. Cities and Urban Systems

Climate Risk and Hazard	Potential Impact
1. Increased frequency of extreme precipitation events	Threat to human health and welfare Street-level Landslide Heavy snowfall
2. Increased frequency of extreme heat days and heat waves	Threat to human health and welfare Excessive heating of equipment and infrastructure; increased fatigue of materials Air-conditioning Wildfire Drought and water shortage Blackout (e.g., from power failure during peak load demand)
3. Sea level rise and coastal storm surge events	Widespread/threat to human health and welfare Wave action and scour Saltwater Saltwater/aquifer
4. Increased frequency of extreme wind events	Threat to human health and welfare Obstruction and loss of equipment (e.g., localized loss of power and overhead wiring) Large-scale

underground, or as elevated roads and railways changes the impacts of various climate variables, particularly flooding (Prasad, Ranghieri, and Shah 2009). Flooding can come from a variety of sources, including storm surges in coastal communities, riverine and lake flooding in inland areas, and street-level flooding from intense precipitation events. Infrastructure in low-lying areas in the floodplain and underground (such as tunnels, vent shafts, and ramps) are clearly at risk of flooding. To deal with flooding, transportation managers will require the use of numerous large-scale pumps, systems for debris removal, and the repair or replacement of key equipment, such as motors, relays, resistors, and transformers.

Besides sea level rise and storm surge vulnerability, steel rail and overhead electrical wires associated with transportation systems also are particularly vulnerable to excessive heat. Overheating can deform transit equipment, for example, causing steel rail lines to buckle and be thrown out of alignment, which can result in train derailments (Mehrotra et al. 2011). In addition, heat can reduce the life of train wheels and vehicle tires. Roadways made of concrete can buckle under extreme heat conditions, and asphalt roads can melt. Downed power lines and telecommunication systems can create additional risks in the transportation network due to power shortages or limited communications, particularly during extreme events and emergencies. Passengers also may experience more heat-related illnesses due to higher temperatures and more-frequent heat waves. In response to these conditions, transit managers need to assess the capacity of their systems to respond to worst-case scenarios, including situations in which multiple hazards occur at the same time.

Urbanization, Urban Systems, and Climate Change Impacts

Residents of U.S. cities will be exposed to multiple threats—including property loss, disruption of daily life, and personal injury or health implications—as a result of the direct and interacting effects of climate change. Climate change affects the operation and utility of cities' built, natural, and social infrastructure, especially in coastal cities and other metropolitan areas that are subject to extreme climate events. The vulnerability of urban residents can increase when climate change impacts interact with other stressors often found in urban areas—such as aging and deteriorating infrastructure, concentrations of intense poverty, large concentrations of aged or infirm populations, clusters of high population density, and extended low-resource suburban areas.

The highly interdependent character of urban infrastructure will increase the possibility of cascading effects on most aspects of the urban, and even national, economy. As the urbanized landscape expands into suburban and exurban spaces, the potential for more-frequent and far-reaching system failures will be heightened (Leichenko and Solecki 2013). Suburban areas, which account for at least half of the total U.S. population, often have the same vulnerabilities as both higher-density urban areas and distant exurban areas (which are associated with limited and far-flung resource response capabilities). Additionally, suburbs often do not have the financial and institutional resources needed for effective and sustained adaptation and resilience efforts (Leichenko and Solecki 2013).

Different levels of vulnerability to climate change among urban populations is directly associated with their exposure to particular stressors, their sensitivity to impacts, and their ability to adapt to changing conditions (Depietri, Renaud, and Kallis 2012; Douglas et al. 2012; Emrich and Cutter 2011). For example, many major U.S. metropolitan areas that are located on or near the coast face higher exposure to particular climate impacts and thus face complex and costly adaptation demands (Cutter et al. 2014). It also should be noted that interaction between the ongoing processes of urban development and climate change will further alter cities' social and infrastructure vulnerability (NPCC 2010) and connected socioeconomic and engineering stressors (Wilbanks et al. 2012). In some cases, this might exacerbate the vulnerability and stressors, and in other cases, lessen them. In response to this issue, the City of New York initiated a comprehensive assessment in the early 2010s of specific building and construction codes and standards to identify changes that could be made to decrease future vulnerability and increase climate resilience.

City centers and their extended metropolitan regions depend on resource flows to and from other areas through complex infrastructure systems (CCSP 2008;

Cutter et al. 2014). Among these resources are food, water, energy, waste products, and other supplies, services, and products. Supply and service chains of this type can range in length from tens of miles to across the globe. Climate change can disrupt these chains and in turn adversely affect urban areas (Seto et al. 2012).

The connection between urban quality of life and vulnerability and resilience is related in part to the amount of redundancy in and the interconnection of resource supply chains and supporting infrastructure (Cutter et al. 2014; Kirshen, Ruth, and Anderson 2008). With proper redundancies in place, cities can respond effectively to disruptions of services and supplies.

Significant service disruptions can result when multiple systems are affected simultaneously and when climate risk impacts cascade from one system to another. For example, power supply interruptions after a major weather event affect public health systems, communication systems, transportation systems, and banking systems (Solecki 2014; Wilbanks et al. 2012). An example of this occurred on August 8, 2007, when New York City experienced an intense thunderstorm during the morning commute in which 1.4 to 3.5 inches of rain fell within two hours (MTA 2007). The rainstorm 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 (MTA 2007; Zimmerman and Faris 2010). Coupled with two other huge recent rain events that occurred in 2004 and early in 2007, this storm became the impetus for a full-scale assessment of transit procedures and policies in regard to climate change (MTA 2007, 2009; Solecki 2014; Zimmerman and Faris 2010).

Cutter et al. (2014) and Wilbanks et al. (2012) examined several major infrastructure disruptions in the United States over the past decade, including the 2011 San Diego blackout, the 2003 Northeast blackout, and Hurricanes Katrina (2005), Irene (2011), and Sandy (2012). According to Wilbanks et al. (2012), the greatest losses from such extreme events may be distant from the event itself. For 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 accommodated locally because of the disruption of potable water supplies, food shipments, and housing facilities (Myers, Slack, and Singelmann 2008). Conversely, in the wake of Hurricane Sandy, the New York metropolitan area suffered from a severe gasoline shortage not only because of the loss of power at local gas stations and the increased difficulty of employees getting to work, but also, and more importantly, because of the physical damage to gas transfer facilities located at the water's edge, which significantly limited the capacity of the supply chain and the ability to transport large volumes of gasoline into the region.

The most recent U.S. National Climate Assessment (2014) documents that changes in many extreme weather and climate events have been observed over the past several decades. These changes include a decrease in the number of cold days, an increase in the number of warm days and nights, and an increase in the frequency or intensity of heavy-precipitation events. It is expected that climate change will continue to influence the frequency and severity of these events. The potential effects could take several different trajectories, as shown in figure 4.2, which illustrates extreme event shifts with and without climate change. Changes in extremes include a simple shift in the mean, resulting in, for example, less extreme cold weather and more extreme hot weather (figure 4.2a). Another scenario illustrates a condition of increased variability with a greater number of extreme events at both tails of the distribution (figure 4.2b). A third possibility includes a change in overall symmetry in the distribution of extreme events (figure 4.2c). Translating these projected shifts to New York City, the number of days with temperatures greater than 32.2°C (90°F) will increase from a baseline of 18 days during 1971–2000 to as many as 57 days in the 2050s.

Extreme event frequency can be best understood by examining the past, current, and future conditions of heat stress. It is virtually certain that there will generally be more and longer hot temperature extremes and fewer cold temperature extremes over most land areas on daily and seasonal time scales as global mean temperatures increase (IPCC 2012). In some areas, rapid urban development or land use change will create or exacerbate urban heat island conditions, resulting in substantially greater temperature increases. Urban heat islands result from the changes in local and regional energy balances associated with intense urban development. These changes cause warmer temperatures in cities as opposed to outlying exurban and suburban areas. The urban heat island phenomenon is particularly evident at night.[1]

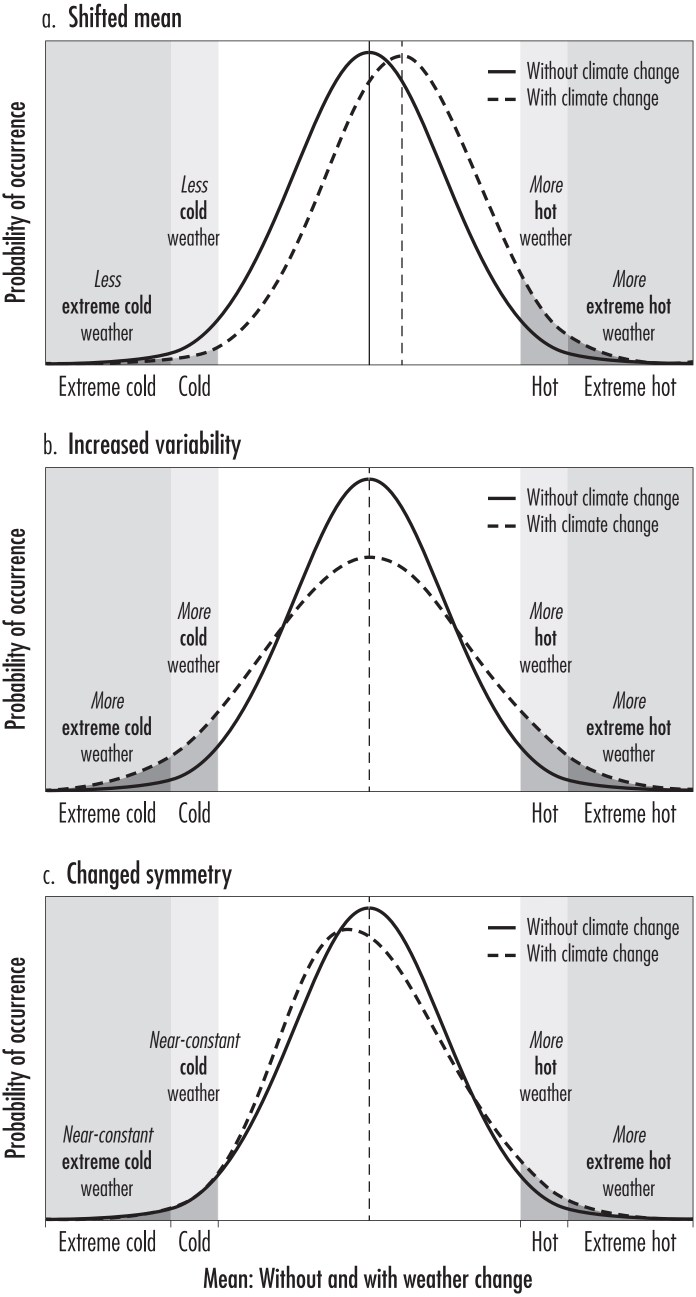
Social Vulnerability to Climate Change in U.S. Cities

Social vulnerability describes characteristics of populations that influence their capacity to prepare for, respond to, and recover from hazards and disasters (Adger 2006; Cutter, Boruff, and Shirley 2003; Füssel 2007a; Laska and Morrow 2006). Social vulnerability also refers to the sensitivity of a population to climate change impacts (Cardona et al. 2012). The 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 2011; 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. Often they are physically frail, have limited financial resources, and live in relative isolation in

1. Observed global temperature data have been partially corrected for the urban heat island effect. It is unlikely that any uncorrected urban heat island effects and land use change effects have raised the estimated centennial globally averaged land surface air temperature trends by more than 10 percent of the reported trends.

Figure 4.2
Changes in Distribution of Weather Extremes with and Without Climate Change



Source: IPCC (2012).

their apartments. They may not have adequate cooling (or heating) or be able to temporarily relocate to a cooling (or warming) station. This combination of factors led to a significant number of elderly deaths during the 1995 Chicago heat wave (Klinenberg 2003). In New Orleans, social inequalities based on race, gender, and class strongly influenced the capacity of residents to prepare for and respond to Hurricane Katrina (Brinkley 2007; Horne 2008; Weber and Peek 2012). It is difficult to assess the specific nature of the vulnerability of subpopulations. 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 factors also vary between and within urban areas.

Hurricane Sandy illustrates many of the extreme event impacts on U.S. cities. It made landfall on the New Jersey shore just south of Atlantic City on October 29, 2012, and became one of the most damaging storms ever to strike the continental United States. Sandy affected cities throughout the Atlantic seaboard, extending across the eastern United States to Chicago, where it generated 20-foot waves on Lake Michigan and flooded the city's Lake Shore Drive. The storm's strength and impacts were increased by two contributing factors: (1) the waters of the Atlantic Ocean near the coast were roughly 3°C (5°F) above normal; and (2) the region's coastline is experiencing sea level rise as a result of global warming.

Sandy caused significant loss of life and tremendous destruction of property and critical infrastructure. The death toll in the metropolitan region exceeded 100, and damage estimates range up to $62 billion. At its peak, the storm cut electrical power to more than 8.5 million customers. It affected millions of coastal zone residents across the New York–New Jersey metropolitan area, in spite of the fact that the region is relatively well prepared for a coastal disaster.

The death and injury; physical devastation; multiday power, heat, and water outages; gasoline shortages; and cascade of collapses resulting from Sandy reveal what can happen when the complex integrated systems upon which urban life depends are stressed and fail. When the Con Edison electricity distribution substation in lower Manhattan failed at approximately 9:00 p.m. Monday evening, 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 surge. As the substation stopped functioning, it immediately caused a systemwide loss of power for more than 200,000 customers. Residents in numerous high-rise apartment buildings were left without heat and lights, elevator service, and water (which must be pumped to upper floors). A situation that was initially seen as a novelty or inconvenience rapidly became a potential public health disaster.

Sandy also highlighted the vast differences in vulnerabilities across the extended metropolitan region. Communities and neighborhoods on the coast obviously were most vulnerable to the physical impact of the 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 them displaced or homeless. As a specific subpopulation, 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. Those 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 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 ceasing operation of the city's subway system before the storm hit and moving the 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 subway trains had been operating in the tunnels when the storm struck.

The storm fostered vigorous debate among local and state politicians, as well as other decision makers and stakeholders, about how best to prepare the region for future storms—especially given the expectation of increased flooding frequency resulting from more numerous extreme precipitation events.

Climate Adaptation and Resilience Practice

Cities in the United States have begun to consider the challenges of climate change and possible strategies for adaptation and enhanced resilience (Cutter et al. 2014). Preparation efforts include planning for ways in which infrastructure systems and buildings, ecosystem and municipal services, and residents will be affected by climate change. Based on a 2011 survey of city managers, Carmin, Nadkarni, and Rhie (2012) reported that 58 percent of respondents indicated that their cities were moving forward on "climate adaptation"—defined as any activity to address the impacts that climate change could have on a community. Activities range from assessment to planning to implementation, with the vast majority focused on the early stages of action, including preliminary planning and discussion (Carmin, Nadkarni, and Rhie 2012). Other early activities include education and outreach on how climate action can take place, often with a focus on both adaptation and mitigation (i.e., the reduction of greenhouse gas emissions) and the interplay between them (Solecki, Patrick, and Springings 2015).

Two general models of how climate action emerges within cities have been identified (Cutter et al. 2014): (1) cities develop separate climate initiatives, often with complete adaptation plans (Carmin, Nadkarni, and Rhie 2012; Zimmerman and Faris 2011); or (2) they integrate adaptation efforts into general government services, operations, and planning efforts, as seen in Seattle; Portland, Oregon; Berkeley, California; and Homer, Alaska (Wilbanks et al. 2012). Some cities connect climate action planning to particular sectors, such as the water supply, other critical infrastructure, coastal zone management, economic development, or public health (City of Santa Cruz 2012; Cooney 2011; Füssel 2007a, 2007b; Maibach et al. 2008).

U.S. cities are employing many different strategies to promote adaptation efforts within their communities. Collaboration within and across individual municipal agencies is often required (Carmin, Nadkarni, and Rhie 2012). Many cities emphasize data and information sharing and outreach in order to facilitate coordination and enhance opportunities for support from local officials, residents, and other stakeholders (Moser and Ekstrom 2011). In addition, national and international city networks focused on climate change have emerged in the past decade. Organizations such as the C40, ICLEI, and Mayors Summit have been instrumental in linking cities together. Some cities have developed independent partnerships to work on these issues. New York, London, and Tokyo, for example, regularly communicate on topics related to climate adaptation and mitigation.

Emerging local adaptation policies are actively being integrated into national and state policies. Many states have conducted comprehensive studies on the potential risks of climate change and have shared their results with local authorities and stakeholders. Currently, there are no national-level regulations focused on urban adaptation, but there is a series of federal initiatives designed to promote adaptation and resilience within communities. The U.S. Department of Housing and Urban Development (HUD) has taken a leadership role in this regard in the post-Sandy context, especially through the use of design competitions to promote climate change adaptation. Other federal agencies are connected to climate adaptation through existing mandates and regulatory requirements (Cutter et al. 2014). Federal policies, such as the National Environmental Policy Act (NEPA), could play an important role in future adaptation opportunities. NEPA, through the impact assessment provision and evaluation criteria process, could be used to provide incentives for adaptation strategies for managing federal property in urban areas (Wilbanks et al. 2012; USBR 2011; USFWS 2010).

At the local level, municipal policies and planning strategies also can be adjusted to promote climate adaptation (Dodman and Satterthwaite 2008; Wilbanks et al. 2012). Such strategies include a broad range of building codes and standards, zoning regulations, land use planning, drinking water supply management, green infrastructure initiatives, public health and healthcare planning, and hazard mitigation efforts. In the post-Sandy context, the City of New York initiated modifications of building codes and standards that have a direct bearing on climate adaptation, such as requiring people building new structures in coastal flood zones to take sea level rise into consideration in construction plans (Solecki and Rosenzweig 2014).

Although adaptation advancements have been made in many cities, a range of barriers to action have been identified (Cutter et al. 2014). Key limitations include lack of capital and human resources, lack of clear scientific data and information on climate risk, and adaptation strategy effectiveness (CEQ 2011). In some cases, efforts are also hindered by a lack of commitment or engagement with the issue of climate change—that is, is it viable to engage politically with the issue? In many cities, the term *climate adaptation* has been replaced by *climate resilience*, which focuses more on immediate and future risks and does necessarily acknowledge climate change as a scientific reality. To ensure support of local initiatives, some cities, especially large cities such as New York, Chicago, Los Angeles, and Seattle, have undertaken efforts to promote understanding of current changes in the climate and predictions of future changes (see as an early example a report prepared for the City of Chicago in 2008 [City of Chicago 2008]). New York has been most aggressive, with the creation of the New York City Panel on Climate Change, comprising local academic experts and public and private sector representatives, to assess current and future climate risks to the city's critical infrastructure and general quality of life (Rosenzweig et al. 2011).

Specific metropolitan and municipal agencies (e.g., water supply utilities, transit agencies, and public health agencies) are now actively involved in climate risk reduction and adaptation. In New York City, the Department of Environmental Protection (which manages the city's water supply), the Department of Health, and the Metropolitan Transit Authority (a state-level entity that operates the city's and suburban transit systems) all have been engaged in vulnerability assessment and climate resilience since the late 2000s.

Other emerging climate change actors include the wide diversity of local civic organizations that have begun to focus on climate adaptation and resilience (Moser 2009). In some cases, these groups have been engaged by local governments, and in others they have taken up the issue on their own. Public involvement in adaptation planning and implementation has helped ensure meaningful climate action and provide valuable feedback to policy makers (Carmin, Dodman, and Chu 2011; Van Aalst, Cannon, and Burton 2008). Local groups have helped identify vulnerable populations (Foster, Winkelman, and Lowe 2011) and motivate local officials and others to promote community action. The Boston Climate Action Leadership Committee, for example, was initiated by the Mayor's Office with the expectation that the committee would rely on public consultation to develop recommendations for updating the city's climate action plan (City of Boston 2010, 2011). In New York in the wake of Hurricane Sandy, environmental groups such as the New York Environmental Justice Alliance and the Alliance for a Just Rebuilding have worked aggressively to highlight vulnerable populations and promote justice-focused climate resilience actions.

In many cases, focusing events play a significant role in spurring agencies and organizations into action. This action can in turn have a positive effect on other elements of government. For instance, in New York City the MTA has been highly focused on climate risk and enhanced climate dynamics since the intense rainstorm of August 7, 2007, shut down most of the city's subways and resulted in massive ridership disruption and loss of business. Hurricanes Irene (2011) and Sandy (2012) presented additional opportunities and policy windows to catalyze new and larger-scale climate action. Irene caused approximately $65 million in damage to the MTA (MTA 2012), and Sandy dealt the transit system an even bigger blow, resulting in approximately $4.75 billion in damage, much of it resulting from the storm surge (MTA 2013).

MTA system managers have begun assessing the potential impacts of enhanced climate variability and change, considering both immediate and long-term effects. Immediate impacts would include loss of revenue from train cancellations and expenses to restore damaged assets and infrastructure. Longer-term impacts would be associated with increased capital expenditures for replacing and updating infrastructure, such as engineering, signaling, and power distribution facilities, and with increased expenses to pay for training of system operators and staff. A spectrum of significant adaptation challenges face the MTA, not the least being how to pay for retrofitting the existing systems to meet emerging climate risks. The MTA has taken a series of short- and longer-term steps to address these challenges, including launching 36 construction projects with a total value of $578 million and initiating another 151 projects in planning, design, and procurement for a total of $777 million in contracts now under way. Much of the funding for these projects has come from the federal government. The MTA's approach to resilience includes three elements: (1) protective measures to keep water out; (2) asset protection to minimize damage if water enters the system; and (3) recovery measures to expedite restoration of service.

The involvement of the private sector can also be influential in promoting city-level adaptation. Many utilities, for example, have asset management programs that address risk and vulnerabilities. These programs could also address climate change, but to date there are few examples of such involvement. Instances in which cooperation has taken place include property insurance companies and engineering firms that have provided consulting services to cities (NRC 2011; Wilbanks et al. 2012). For example, engineering firms that create infrastructure system plans have begun to account for projected changes in precipitation in their projects (Van der Tak et al. 2010). Regarding 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 (IBM 2009; NRC 2011).

Uncertainty, in both the climate system and modeling techniques, is often 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 and metrics will continue to be refined and that it is prudent to use an incremental and flexible approach to planning that draws on both structural and nonstructural measures (Carmin and Dodman 2013; NRC 2011; Rosenzweig et al. 2010).

Another important challenge to policy makers is obtaining the commitment and support of local elected officials for adaptation planning and implementation (Carmin, Nadkarni, and Rhie 2012). Cities and administrators face a wide range of other issues demanding their attention and competing with climate adaptation for limited financial resources (Leichenko and Solecki 2013; NRC 2011).

Adaptation planning and practice in extended metropolitan regions and associated regional systems is additionally inhibited by the challenge of coordinating efforts across many jurisdictional boundaries. Regional government institutions may be well suited to address this challenge, as they cover a larger geographic scope than individual cities and have the potential to coordinate the efforts of multiple jurisdictions (Wilbanks et al. 2012). California requires each of its metropolitan planning organizations to prepare a sustainable communities strategy (SCS) as part of its regional transportation plan (California Senate 2008). While the focus of the SCS is on reducing emissions, some plans have also addressed topics related to climate change impacts and adaptation (SACOG 2012; SANDAG 2011; SCAG 2012). Examples of climate change issues that could benefit from a regional perspective include water shortages, transportation infrastructure maintenance, and loss of native plant and animal species.

Integrating climate change action into everyday city and infrastructure operations and governance, referred to as *mainstreaming*, is an important planning and implementation tool for advancing adaptation in cities (NRC 2011; Rosenzweig et al. 2010). These efforts can forestall the need to develop a new and isolated set of climate-change-specific policies or procedures (Foster, Winkelman, and Lowe 2011). Adopting this strategy would enable cities and government agencies to take advantage of existing funding sources and programs and to 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, Winkelman, and Lowe 2011; NRC 2011).

Over the long term, responses to severe climate change impacts will likely require major expenditures and structural changes, especially in urban areas (NRC 2010; Wilbanks et al. 2012). When major infrastructure decisions need to be made in order to protect human lives and urban assets, cities must have access to the best available science, decision support tools, funding, and guidance. In this regard, local officials look to the federal government to provide adaptation leadership, financial and technical resources, and funding for cutting-edge research (CEQ 2011; Foster, Winkelman, and Lowe 2011; NRC 2011).

Overall, empirically defining the benefits and costs of adaptation strategies has proved to be very challenging, particularly to the extent that they could be included in decision-making strategies and protocols. Very few highly detailed assessments of benefits and costs have been conducted, especially with respect to the benefits of different types of interventions. For climate adaptation and resilience planning to move to the next step, this type of data must be gathered, and the capacity to translate it into appropriate public or private decision-making frames must be created.

Conclusions

It is clear that climate change has begun to impact U.S. cities and to shift the environmental baselines of these locales. It is also evident that city managers and residents have begun to actively engage in the discussion of how to promote climate adaptation and resilience within their cities. One of the greatest challenges they face is how to define and frame the actions that could be taken. In many cases, there is a tendency to focus on engineering and safety measures that will enable a city to "bounce back" after a disaster. While those efforts are logical and laudable, the greater challenge is to embrace the broader, longer-term aspects of adaptation and resilience, which, given the projections for future climate change, could require more profound transformative actions undertaken by metropolitan and municipal authorities and urban residents themselves. In short, adaptation efforts and resilience planning will increasingly demand flexibility and the capacity to adjust as climate science and the risks of climate change evolve.

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