

## 16. Northeast

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### Key Messages

- 1. Heat waves, coastal flooding due to sea level rise, and river flooding due to more extreme precipitation events will pose a growing challenge to the region's environmental, social, and economic systems. This will increase the vulnerability of the region's residents, especially populations that are already most disadvantaged.**
- 2. Infrastructure will be increasingly compromised by climate-related hazards including sea level rise and coastal flooding, and intense precipitation events.**
- 3. Agriculture and ecosystems will be increasingly stressed by climate-related hazards, including higher temperatures, sea level rise and coastal flooding, and more extreme precipitation events. A longer growing season may allow farmers to explore new crop options, but this and other adaptations will not be cost or risk-free, and inequities exist in the capacity for adaptation.**
- 4. While a majority of states and several municipalities have begun to incorporate the risk of climate change into their planning activities, implementation of adaptation measures is still at early stages.**

### Introduction

Sixty-four million people are concentrated in the Northeast. The high-density urban coastal corridor from Washington, D.C. north to Boston is one of the most built-up environments in the world, and it contains a huge, long-standing network of supporting infrastructure. The region is home to the world's leading financial center and many of the nation's defining cultural and historical landmarks – they annually draw millions of visitors from all over the world.

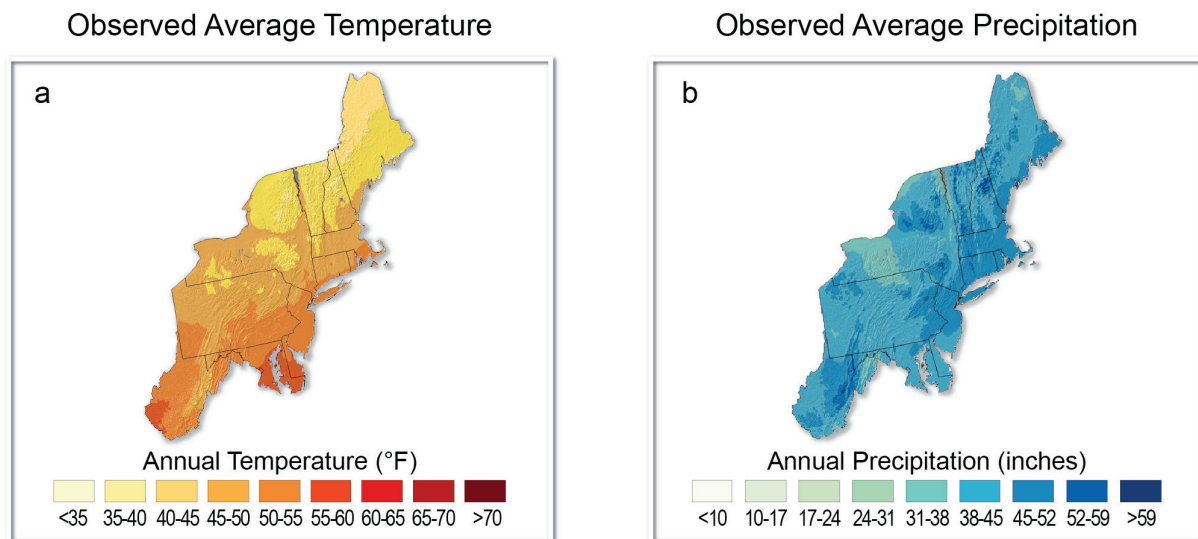
The Northeast also includes large expanses of sparsely populated but ecologically and agriculturally important areas. Much of the Northeast landscape is dominated by forest, but the region also has grasslands, coastal zones, beaches and dunes, and wetlands, and it is known for its rich marine and freshwater fisheries. These natural areas are essential to recreation and tourism sectors and support jobs through the sale of timber, maple syrup, and fish. They also contribute important ecosystem services to broader populations – protecting water supplies, buffering shorelines, and sequestering carbon in soils and vegetation. The twelve Northeastern

1 states have more than 180,000 farms, with \$17 billion in annual sales (USDA 2007). The  
2 region’s ecosystems and agricultural systems are tightly interwoven, and both are vulnerable to a  
3 changing climate.

4 Although urban and rural regions in the Northeast are profoundly different, they both include  
5 populations that are highly vulnerable to climate hazards and other stresses. Both depend on  
6 aging infrastructure that has already been stressed by climate hazards including heat waves, as  
7 well as coastal and riverine flooding due to a combination of sea level rise, storm surge, and  
8 extreme precipitation events.

9 The Northeast is characterized by a highly diverse climate (Horton et al. 2012). Average  
10 temperatures in the Northeast generally decrease to the north and with distance from the coast  
11 and elevation. Average annual precipitation varies by about 20 inches throughout the Northeast  
12 with the highest amounts observed in coastal and select mountainous regions. During winter,  
13 frequent storms bring bitter cold and frozen precipitation, especially to the north. Summers are  
14 warm and humid, especially to the south. The Northeast is often affected by extreme events such  
15 as ice storms, floods, droughts, heat waves, hurricanes, and nor’easters. However variability is  
16 large in both space and time. For example, parts of Southern New England that experienced  
17 heavy snows in the winter of 2010-2011, experienced almost no snow during the winter of 2011-  
18 2012 (although a costly Halloween storm knocked out power for up to 10 days for thousands of  
19 households).

## 20 Observed Climate Change



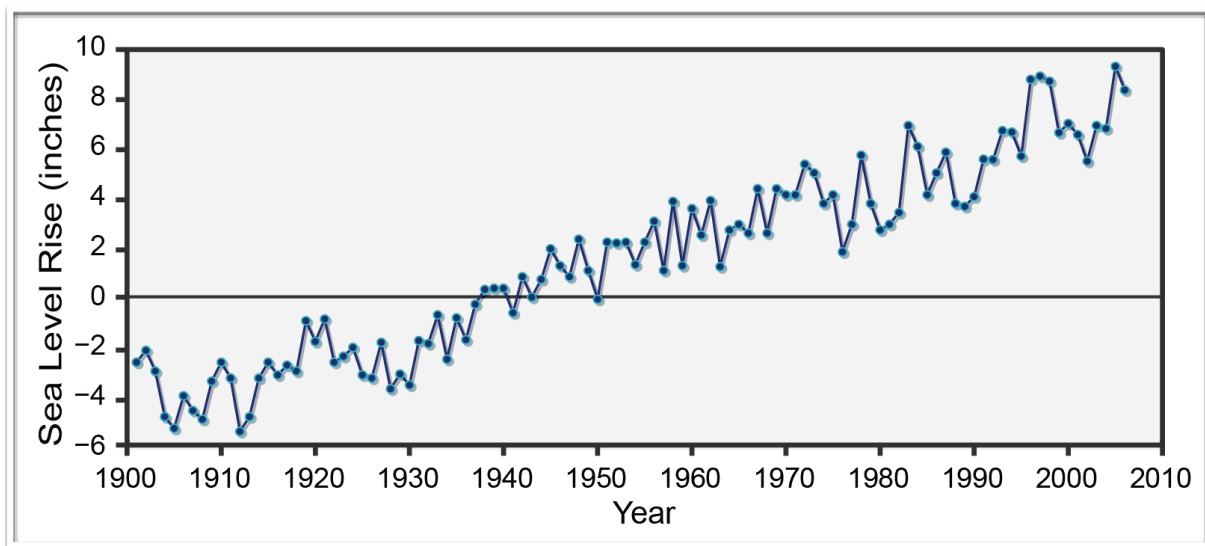
21

### 22 **Figure 16.1:** Observed Average Temperature and Precipitation

23 **Caption:** (a) Annual average temperature (°F) for 1981-2010. Because this average  
24 includes data from more stations at lower elevations than at higher elevations, the map  
25 does not fully represent the full range of temperature, particularly at higher elevations. (b)  
26 Annual average precipitation (inches) for 1981-2010. (Kunkel et al. 2012)

1 Between 1895 and 2011, temperatures in the Northeast increased by almost 2°F (0.16°F per  
 2 decade), and precipitation increased by approximately 5 inches, or more than 10% (0.4 inches  
 3 per decade) (Kunkel et al. 2012). Coastal flooding has increased due to sea level rise of  
 4 approximately 1 foot since 1900. This rate of sea level rise exceeds the global average of  
 5 approximately 8 inches (see Ch. 2: Our Changing Climate, key message 9), due primarily to land  
 6 subsidence (Church et al. 2010), although recent research suggests that changes in ocean  
 7 circulation in the North Atlantic – specifically, a weakening of the Gulf Stream – may also play a  
 8 role (Sallenger et al. 2012).

### Observed Sea Level Rise in New York City



9

10 **Figure 16.2:** Observed Sea Level Rise in New York City

11 **Caption:** Observed sea level at the Battery, New York City has significantly exceeded  
 12 the global average of 8 inches over the past century, increasing the risk of impacts to  
 13 critical urban infrastructure in low-lying areas. Over 100 years, sea level increased 1.2  
 14 feet (Source: New York City Panel on Climate Change 2010).)

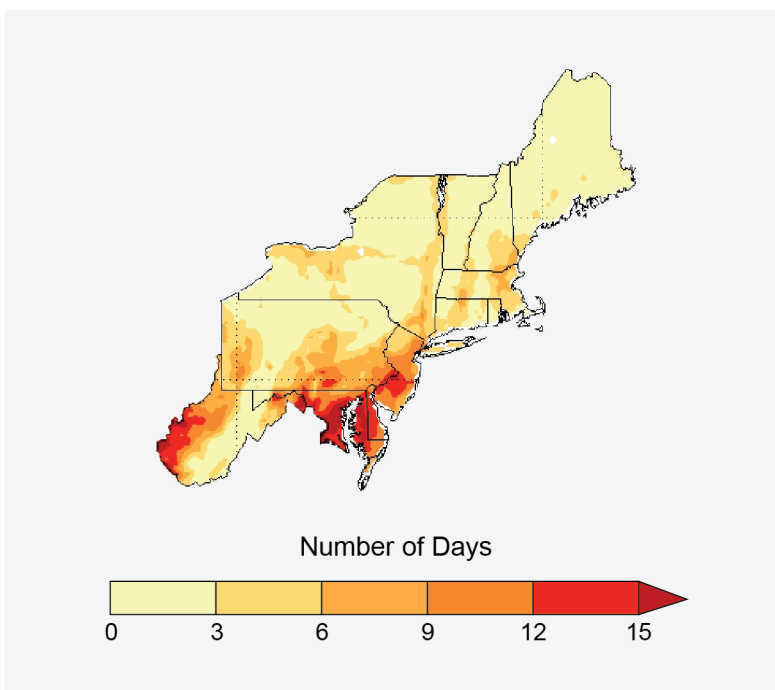
15 The Northeast has experienced a greater increase in extreme precipitation over the past few  
 16 decades than any other region in the U.S.; between 1958 and 2010, the Northeast saw a 74%  
 17 percent increase in the amount of precipitation falling in very heavy events.

## 1 **Projected Climate Change**

2 Warming in the Northeast will be highly dependent on global emissions of heat-trapping gases.  
3 If emissions continue to increase (as in the A2 scenario), warming of 4.5°F to 10°F is projected  
4 by the 2080s; if global emissions were reduced substantially (as in the B1 scenario), projected  
5 warming ranges from about 3°F to 6°F by the 2080s (Kunkel et al. 2012).

6 Under both emissions scenarios, the frequency, intensity, and duration of heat waves is expected  
7 to increase, with larger increases under higher emissions. Regional climate model simulations  
8 suggest that the southern part of the region, including large parts of West Virginia, Maryland,  
9 and Delaware could experience more than a doubling of days per year over 95°F by the 2050s .

### Projected Increases in the Number of Days Over 95°F



10

11 **Figure 16.3:** Projected Increases in the Number of Days over 95°F.

12 **Caption:** Projected average increases in the number of days with a maximum  
13 temperature greater than 95°F between 2041-2070, compared to 1971-2000 assuming  
14 continued increases in global emissions (A2 scenario). (Figure source: NOAA NCDC /  
15 CICS-NC. Data from CMIP3 Daily Multi-model Mean.)

16 Much of the southern portion of the region, including the majority of Maryland, and Delaware,  
17 and southwest West Virginia and New Jersey, are projected to experience more than 15  
18 additional days per year above 95°F, which will impact the regions vulnerable populations,  
19 infrastructure, and agriculture and ecosystems.

1 The frequency, intensity, and duration of cold air outbreaks is expected to decrease as the  
2 century progresses, although some research suggests that this trend may be slowed by  
3 compensating factors such as indirect effects on the region of melting Arctic sea ice (for  
4 example, Liu et al. 2012).

5 Projections of precipitation changes are less certain than projections for temperature increases  
6 (Kunkel et al. 2012). Winter precipitation is projected to increase, especially but not exclusively  
7 in the northern part of the region (Karl et al. 2009; Kunkel et al. 2012; Ch. 2: Our Changing  
8 Climate; Key Messages 5 & 6). A range of model projections for the end of this century under a  
9 high emissions scenario (A2), averaged over the region, suggests 1% to 29% increases in winter  
10 precipitation. Projections in other seasons, and for the entire year, range from moderate decreases  
11 to large increases (Kunkel et al. 2012; Ch. 2: Our Changing Climate; Key Message 5). The  
12 frequency of heavy downpours is projected to continue to increase as the century progresses (Ch.  
13 2: Our Changing Climate). Seasonal drought risk is also projected to increase in summer and fall  
14 as higher temperatures lead to greater evaporation and earlier winter and spring snowmelt  
15 (Horton and Rosenzweig 2010).

16 Global sea levels are projected to rise between 1 to 4 feet by 2100 (Ch. 2: Our Changing Climate,  
17 Key Message 9) depending in large part on the extent to which the Greenland and the West  
18 Antarctic Ice Sheets experience significant melting. Sea level rise in the Northeast is expected to  
19 exceed the global average by up to roughly 4 inches per century due to local land subsidence,  
20 with the possibility of even greater regional sea level rise if the Gulf Stream weakens as some  
21 models suggest (Yin et al. 2009; Yin et al. 2011).

22 Even given the low end of sea level rise scenarios, and without assuming any changes in storms,  
23 the chance of what is now a 1-in-10-year coastal flood event in the Northeast could triple by  
24 2100, occurring roughly once every 3 years, simply in response to higher sea levels (Horton et al.  
25 2011; Tebaldi et al. 2012).

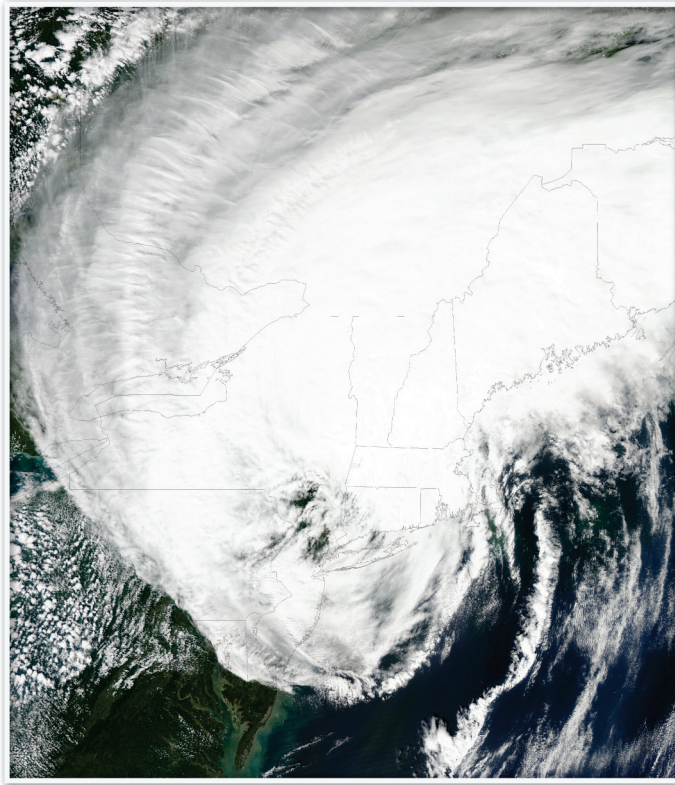
26 Hurricanes such as Irene and Sandy provided a “teachable moment” by demonstrating the  
27 region’s vulnerability to extreme weather events and the efficacy of existing and evolving  
28 adaptation/response plans.

### 29 **Box: Hurricane Vulnerability**

30 Two recent events contrast existing vulnerability to extreme events: Hurricane Irene, which  
31 produced a broad swath of very heavy rain (greater than 5 inches in total and sometimes 2 to 3  
32 inches per hour in some locations) from southern Maryland to northern Vermont from August 27  
33 to 29, 2011; and Hurricane Sandy which caused massive coastal damage from storm surge and  
34 flooding.

35 The rainfall associated with Irene exceeded the estimated 1-in-500-year storm at Delanson, NY  
36 and Waterbury, VT. These heavy rains were part of a broader pattern of wet weather preceding  
37 the storm that exacerbated the flooding associated with Irene; rainfall totals for August and  
38 September exceeded 25 inches across much of the Northeast.

## Flooding and Hurricane Irene



1

2 **Figure 16.4:** Flooding and Hurricane Irene

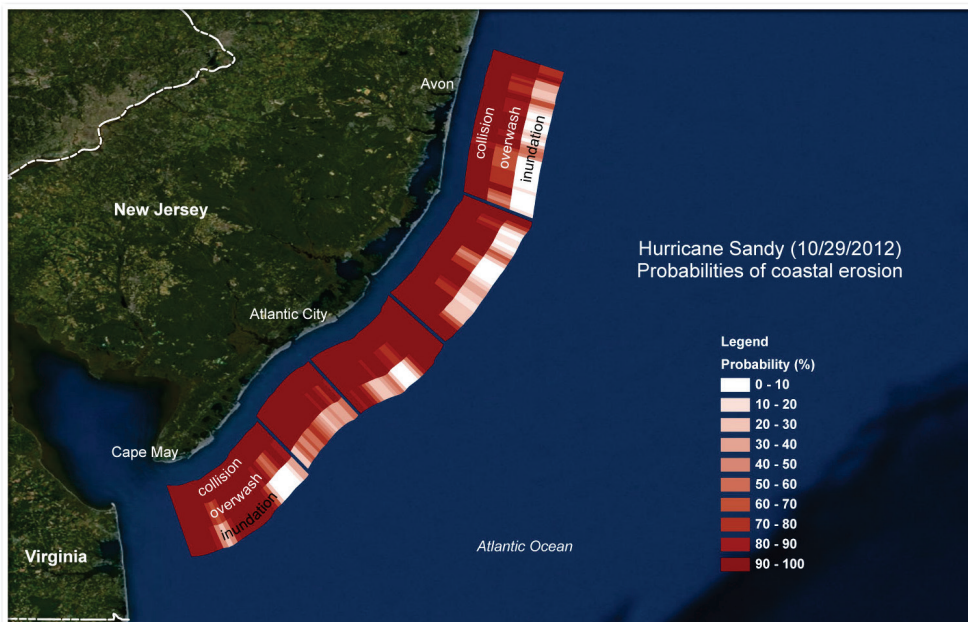
3 **Caption:** Hurricane Irene brought a broad swath of very heavy rain (greater than five  
4 inches in total and 2 to 3 inches per hour in some locations), producing severe flooding  
5 from southern Maryland to northern Vermont from August 27 to 29, 2011. Satellite  
6 image shows Irene over the Northeast on August 28, 2012. The storm also took  
7 approximately 50 lives, and the economic cost was estimated to be approximately \$15  
8 billion (Avila and Cangliosi 2011; Avila and Stewart 2012). (Source: NASA Satellite  
9 Image)

10 In anticipation of Irene, the New York City mass transit system was shut down, and 2.3 million  
11 coastal residents in Delaware, New Jersey, and New York faced mandatory evacuations. But it  
12 was the inland impacts, especially in upstate New York and in central and southern Vermont,  
13 that were most severe. Flash flooding washed out roads and bridges, undermined railroads,  
14 brought down trees and power lines, flooded homes and businesses, and damaged floodplain  
15 forests. In Vermont, over 500 miles of state-owned roadways and approximately 200 bridges  
16 were damaged, with estimated rebuilding costs of \$175-250 million. Hazardous wastes were  
17 released in a number of areas, and 17 municipal wastewater treatment plants were breached by  
18 the floodwaters. Agricultural losses included damage to barn structures and flooded fields of  
19 crops. Infrastructure impacts from river flooding led to many towns and villages being isolated  
20 for many days (Horton et al. 2012).

1 Sandy took approximately 130 lives in the U.S. alone, and monetary impacts on coastal areas,  
 2 especially in New Jersey, New York, Connecticut, and Rhode Island may be approximately \$60  
 3 to \$80 billion (NY Times 11/27; NY Times 12/5). Floodwaters inundated subway tunnels in  
 4 New York City, up to 8 million people lost electricity, and, according to preliminary estimates,  
 5 between 20,000 and 100,000 families may have lost their homes (NY Times 11/27). Many of  
 6 these vulnerabilities to coastal flooding and sea level rise (Ch. 2: Our Changing Climate, Key  
 7 Message 9) and intensifying storms (Ch. 2: Our Changing Climate, Key Message 8) – including  
 8 the projected frequency of flooding of tunnels and airports – were documented as early as 2001  
 9 in a report developed in support of the 2000 National Climate Assessment (Rosenzweig and  
 10 Solecki 2001). The observed vulnerability was not a surprise in New York, given its 600 miles of  
 11 coastline and over half a million people living within the current flood plain.

12 Through follow-on activities in New York City and New York State that included regional  
 13 decision makers such as the Port Authority, Metropolitan Transportation Authority, and utility  
 14 companies, a process, approach, and tools for climate change adaptation in the New York City  
 15 (City of New York 2011; Rosenzweig and Solecki 2010) and New York State (Rosenzweig et al.  
 16 2011b) were formulated. This process, and resulting adaptation efforts including elevating  
 17 infrastructure and restoring green spaces, helped reduce damage and save lives (also see  
 18 discussion of Hurricane Sandy in Ch. 11: Urban Vulnerability and Infrastructure). As rebuilding  
 19 advances, serious consideration of current and projected risks from such events by a full set of  
 20 stakeholders and participants could dramatically improve resilience against future extreme  
 21 events.

### Coastal Flooding Along New Jersey's Shore



22

23 **Figure 16.5:** Coastal Flooding Along New Jersey's Shore

1       **Caption:** Predictions of coastal erosion prior to Sandy’s arrival provided advance  
2 warning of potential vulnerability to the regions residents and decision-makers. The map  
3 shows three bands: collision of waves with beaches causing erosion on the front of the  
4 beach; overwash that occurs when water reaches over the highest point and erodes from  
5 the rear, which carries sand inland; and inundation, when the shore is severely eroded and  
6 new channels can form that leads to permanent flooding. The probabilities are based on  
7 the storm striking at high tide. For New Jersey, the model estimated that 21% of the  
8 shoreline had more than a 90% chance of experiencing inundation. These projections  
9 were realized, and made the New Jersey coastline even more vulnerable to the Nor’easter  
10 that followed Hurricane Sandy by only 10 days. (Source: USGS 2012)

11 -- end box --

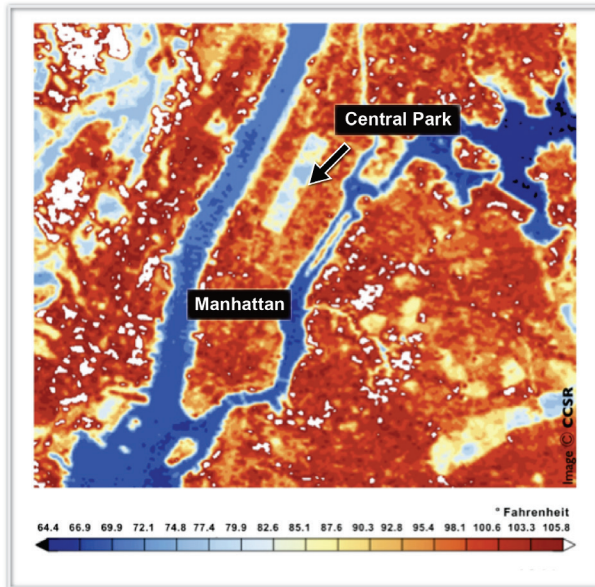
## 12 *Climate Risks to People*

13 **Heat waves, coastal flooding due to sea level rise, and river flooding due to more extreme**  
14 **precipitation events will pose a growing challenge to the region’s environmental, social, and**  
15 **economic systems. This will increase the vulnerability of the region’s residents, especially**  
16 **populations that are already most disadvantaged.**

17 Urban residents have unique and multifaceted vulnerabilities to heat extremes. Temperatures  
18 tend to be higher in urban areas; during extreme heat events, nighttime temperatures in the  
19 region’s big cities are generally several degrees higher (Gaffin et al. 2008) than surrounding  
20 regions, leading to increased heat-related death among those less able to recover from the heat of  
21 the day (Semenza et al. 1996). Since the hottest days in the Northeast are often associated with  
22 high concentrations of ground level ozone and other pollutants (Patz 2000), the combination of  
23 heat stress and poor air quality can pose a major health risk to vulnerable groups: young children,  
24 the elderly, and those with pre-existing health conditions including asthma (Solecki et al. 2011).  
25 Vulnerability is further increased as key infrastructure, including electricity for life-saving  
26 cooling, is more likely to fail precisely when it is most needed – when demand exceeds available  
27 supply. Significant investments may be required to insure that power generation keeps up with  
28 increases in demand associated with rising temperatures, not even accounting for extreme events  
29 (Amato et al. 2005; Ruth and Lin 2006). Finally, vulnerability to heat waves is not evenly  
30 distributed throughout urban areas; outdoor versus indoor air temperatures, air quality, baseline  
31 health, and access to air conditioning are all dependent on socioeconomic factors (Solecki et al.  
32 2011).



## Urban Heat Island



1  
2 **Figure 16.6:** Urban Heat Island

3 **Captions:** Surface temperatures in New York City on a summer’s day show the “urban  
4 heat island”, with temperatures in populous urban areas being approximately 10°F higher  
5 than the forested parts of Central Park. Dark blue reflects the colder waters of the Hudson  
6 and East Rivers. (Source, Data are from NASA Landsat 7, Band 6. Source: Center for  
7 Climate Systems Research, Columbia University.)

8 Increased health-related impacts and costs, such as premature death and hospitalization due to  
9 even modest increases in heat, are predicted (Anderson and Bell 2012; EPA 2006; Huang et al.  
10 2011; Knowlton et al. 2007) in the Northeast’s urban centers. Increased ground-level ozone due  
11 to warming is projected to increase ozone-related asthma emergency department visits by 7.3%  
12 in 2020 in the New York metropolitan area (Sheffield et al. 2011b).

13 Heat wave research has tended to focus on urban areas, but vulnerability to heat may also  
14 become a major issue in rural areas and small towns because air conditioning is currently not  
15 prevalent in parts of the rural Northeast where heat waves have historically been rare. For  
16 western New York and western Massachusetts, it is projected that by the 2050s, an additional 5  
17 or more days per year over 95°F may occur by the 2050s – regions where days over 95°F are  
18 currently relatively rare (Kunkel et al. 2012). It should be noted that winter heating needs, a  
19 significant expense for many Northeastern residents, are likely to decrease as the century  
20 progresses (Hammer et al. 2011).

21 Historical settlement patterns and on-going investment in coastal areas and along major rivers  
22 combine to increase the vulnerabilities of people in the Northeast to sea level rise and coastal  
23 storms. Of the Northeast’s population of 64 million (U.S. Census Bureau 2010), approximately  
24 1.6 million people live within the FEMA 100-year coastal flood zone, with the majority – 63% of

1 those at risk – residing in New York and New Jersey (Crowell et al. 2010). As sea level rise  
2 increases in the future, populations in the current 1-in-100-year coastal flood zone will  
3 experience more frequent flooding, and populations that have historically fallen outside the 1-in-  
4 100-year flood zone will find themselves in that zone. Populations living in coastal flood zones  
5 are vulnerable to direct loss of life and injury associated with tropical storms and Nor'easters.  
6 Flood damage to personal property, businesses, and public infrastructure can also result (see next  
7 section).

8 This risk is not limited to the 1-in-100-year flood zone; in the Mid-Atlantic part of the region  
9 alone, estimates suggest that between 450,000 and 2.3 million people are at risk from a three foot  
10 sea level rise (CCSP 2009), which is in the range of projections for this century.

11 Throughout the Northeast, populations are also concentrated along rivers and their flood plains.  
12 In mountainous regions, including much of West Virginia and large parts of Pennsylvania, New  
13 York, Vermont, and New Hampshire, more intense precipitation events (Kunkel et al. 2012) will  
14 mean greater flood risk to populations, many of whom are concentrated (along with  
15 infrastructure and agriculture) in drainage basins between the mountains.

## 16 ***Stressed Infrastructure***

### 17 **Infrastructure will be increasingly compromised by climate-related hazards, including sea 18 level rise and coastal flooding, and intense precipitation events.**

19 Disruptions to services provided by public and private infrastructure in the Northeast both  
20 interrupt commerce and threaten public health and safety. A 1.5 foot rise in sea level (1 to 4 feet  
21 are projected by 2100; Ch. 2: Our Changing Climate, Key Message 9) would expose  
22 approximately \$6 trillion worth of property to coastal flooding in the Baltimore, Boston, New  
23 York, Philadelphia, and Providence metropolitan areas (Lenton et al. 2009). In New York alone,  
24 two feet of sea level rise is estimated to flood 212 miles of roads, 77 miles of rail, 3,647-acres of  
25 airport facilities, and 539-acres of runways, without substantial investments in adaptation (DOT  
26 2008). Port facilities, such as in Maryland (primarily Baltimore), have similar estimates of  
27 flooding: 298 acres, or 32% percent of the overall port facilities in the state (DOT 2008). These  
28 impacts have potentially significant economic ramifications. For example, in 2006 alone the Port  
29 of Baltimore generated over 50,200 jobs, \$3.6 billion in personal income, \$1.9 billion in business  
30 revenues, and \$388 million in state/county/municipal tax (Maryland Port Administration 2008).  
31 A broader range of impacts across economic sectors, drawn from the New York City Panel on  
32 Climate Change but applicable throughout the region, highlights some of the reality currently  
33 being faced in the aftermath of Hurricane Sandy and in the future.

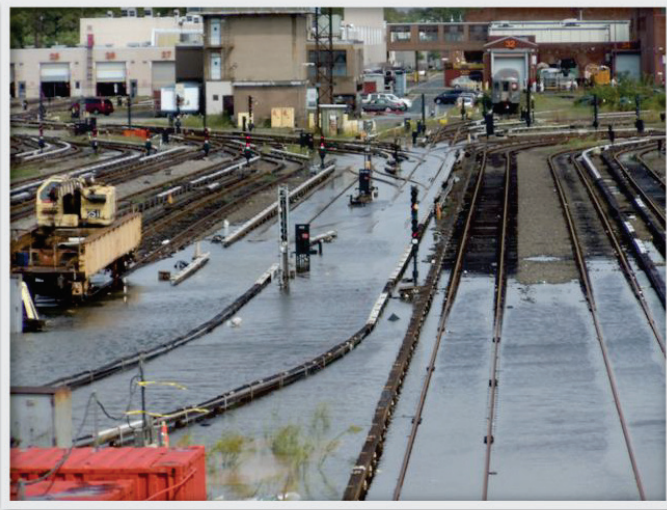
1 **Table 16.1. Impacts of sea level rise, coastal floods, and storms on critical coastal infrastructure**  
 2 **by sector. Sources: Horton and Rosenzweig, (2010); Zimmerman and Faris, (2010)**

Communications	Energy	Transportation	Water and Waste
<b>Higher average sea level</b>			
<ul style="list-style-type: none"> <li>• Increased salt water encroachment and damage to low-lying communications infrastructure not built to withstand saltwater exposure</li> <li>• Increased rates of coastal erosion and/or permanent inundation of low-lying areas, causing increased maintenance costs and shortened replacement cycles</li> <li>• Cellular tower destruction or loss of function</li> </ul>	<ul style="list-style-type: none"> <li>• Increased rates of coastal erosion and/or permanent inundation of low-lying areas, threatening coastal power plants</li> <li>• Increased equipment damage from corrosive effects of salt water encroachment, resulting in higher maintenance costs and shorter replacement cycles</li> </ul>	<ul style="list-style-type: none"> <li>• Increased salt water encroachment and damage to infrastructure not built to withstand saltwater exposure</li> <li>• Increased rates of coastal erosion and/or permanent inundation of low-lying areas, resulting in increased maintenance costs and shorter replacement cycles</li> <li>• Decreased clearance levels under bridges</li> </ul>	<ul style="list-style-type: none"> <li>• Increased salt water encroachment and damage to water and waste infrastructure not built to withstand saltwater exposure</li> <li>• Increased release of pollution and contaminant runoff from sewer systems, treatment plants, brownfields, and waste storage facilities</li> <li>• Permanent inundation of low-lying areas, wetlands, piers, and marine transfer stations</li> <li>• Increased saltwater infiltration into freshwater distribution systems</li> </ul>
<b>More frequent and intense coastal flooding</b>			
<ul style="list-style-type: none"> <li>• Increased need for emergency management actions with high demand on communications infrastructure</li> <li>• Increased damage to communications equipment and infrastructure in low-lying areas</li> </ul>	<ul style="list-style-type: none"> <li>• Increased need for emergency management actions</li> <li>• Exacerbated flooding of low-lying power plants and equipment, as well as structural damage to infrastructure due to wave action</li> <li>• Increased use of energy to control floodwaters</li> <li>• Increased number and duration of local outages due to flooded and corroded equipment</li> </ul>	<ul style="list-style-type: none"> <li>• Increased need for emergency management actions</li> <li>• Exacerbated flooding of streets, subways, tunnel and bridge entrances, as well as structural damage to infrastructure due to wave action</li> <li>• Decreased levels of service from flooded roadways; increased hours of delay from congestion during street flooding episodes</li> <li>• Increased energy use for pumping</li> </ul>	<ul style="list-style-type: none"> <li>• Increased need for emergency management actions</li> <li>• Exacerbated street, basement, and sewer flooding, leading to structural damage to infrastructure</li> <li>• Episodic inundation of low-lying areas, wetlands, piers, and marine transfer stations</li> </ul>

3

4

1 In the transportation sector, many of the region’s key highways (including I-95) and rail systems  
2 (including Amtrak) span areas that are prone to coastal flooding. In addition to temporary service  
3 disruptions, saltwater damage associated with storm surge flooding can severely undermine or  
4 disable critical infrastructure along coasts, including subway systems, wastewater treatment  
5 plants, and electrical substations.



6

7 **Figure 16.7**8 **Caption:** Flooded subway tracks in Coney Island after Hurricane Irene. (SOURCE: MTA  
9 (<http://www.flickr.com/photos/mtaphotos/6089071863/sizes/o/in/photostream/>)10 ***Agricultural and Ecosystem Impacts***

11 **Agriculture and ecosystems will be increasingly stressed by climate-related hazards,**  
12 **including higher temperatures, sea level rise and coastal flooding, and more extreme**  
13 **precipitation events. A longer growing season may allow farmers to explore new crop**  
14 **options, but this and other adaptations will not be cost- or risk-free, and inequities exist in**  
15 **the capacity for adaptation.**

16 Farmers in the Northeast are already experiencing consequences of climate change. In addition to  
17 direct crop damage from more intense precipitation events, wet springs delay planting for grain  
18 and vegetables, for example, and subsequently delay harvest dates and reduce yields (Ohlemeier  
19 2011). This is an issue for agriculture nationally (Hatfield et al. 2011), but is particularly acute  
20 for the Northeast where heavy rainfall events have increased more than any other region of the  
21 country (Groisman et al. 2004). In the future, farmers may also face too little water in summer to  
22 meet increased crop water demand as summers become hotter and growing seasons lengthen  
23 (Hayhoe et al. 2007; Wolfe et al. 2011b). Increased frequency of summer heat stress is also  
24 projected, which can negatively affect crop yields and milk production (Wolfe et al. 2008).

25 Despite a trend toward warmer winters, the risk of frost and freeze damage continues, and has  
26 paradoxically increased over the past decade (See also Ch. 8: Ecosystems and Biodiversity).

1 Increased weed and pest pressure associated with longer growing seasons and warmer winters  
2 will be an increasingly important challenge; there are already examples of earlier arrival and  
3 increased populations of some insect pests such as corn earworm (Wolfe et al. 2008).  
4 Furthermore, many of the most aggressive weeds, such as kudzu, benefit more than crop plants  
5 from higher atmospheric carbon dioxide, and become more resistant to herbicide control (Ziska  
6 and Runion 2007).

7 Effects of rising temperatures on the Northeast's ecosystems have already been clearly observed  
8 (See also Ch. 8: Ecosystems and Biodiversity). Wildflowers (Abu-Asab et al. 2001) and woody  
9 perennials are blooming earlier (Primack et al. 2004; Wolfe et al. 2005) and migratory birds are  
10 arriving sooner (Butler 2003). Several bird species have expanded their ranges northward  
11 (Rodenhouse et al. 2009) as have some invasive insect species such as the hemlock wooly  
12 adelgid (Paradis et al. 2008), which has devastated hemlock trees. Warmer winters and less snow  
13 cover in recent years have contributed to increased deer populations (Wolfe et al. 2011a) that  
14 degrade forest understory vegetation (Stromayer and Warren 1997).

15 Although suitable habitats will be shrinking for some species (cold water fish such as brook  
16 trout) and expanding for others (warm water fish such as bass), it is difficult to predict what  
17 proportion of species will be able to move or adapt as their optimum climate zones shift (Jenkins  
18 2010). As each species responds uniquely to climate change, disruptions of important species  
19 interactions (plants and pollinators, predators and prey) can be expected. For example, it is  
20 uncertain what form of vegetation will move into the Adirondack Mountains when the suitable  
21 habitat for spruce-fir forests disappears (Iverson et al. 2008). Increased productivity of some  
22 northern hardwood trees in the Northeast is projected (due to longer growing seasons and  
23 assuming a significant benefit from higher atmospheric carbon dioxide), but summer drought and  
24 other extreme events may override this potential (Mohan et al. 2009).

25 In contrast, many insect pests, pathogens, and invasive plants like kudzu appear to be highly and  
26 positively responsive to recent and projected climate change (Dukes et al. 2009). Their  
27 expansion will lead to an overall loss of biodiversity, function, and resilience of some  
28 ecosystems.

29 The Northeast's coastal ecosystems are also highly vulnerable to rising seas. For example, a five  
30 foot sea level rise through 2100 (within the range of the 6.6 foot scenario useful for risk-averse  
31 planning (Parris et al. 2012; Ch.2: Our Changing Climate; Key Message 9)) is projected to lead  
32 to the loss of over 93% of tidal marshes and swamps, and the inundation of over 32,000-acres  
33 within the Blackwater National Wildlife Refuge by 2100 (Maryland Department of Natural  
34 Resources 2008). Beach and dune erosion is also a major issue in the Northeast (Buonaiuto et al.  
35 2011; Gornitz et al. 2001).

### 36 **Box: The Chesapeake Bay**

37 The Chesapeake Bay, with a drainage basin that extends over six states, is an example of a  
38 critical and highly integrated natural and economic system threatened by changing land use  
39 patterns and a changing climate – including sea level rise, higher temperatures, and more intense  
40 precipitation events. The ecosystem has a central role in the economy, including providing  
41 sources of food for people and the region's other inhabitants, and cooling water for the energy  
42 sector. It also provides critical ecosystem services.

## Chesapeake Bay



1  
2 **Figure 16.8**

3 (Source: NASA)

4 – end box --

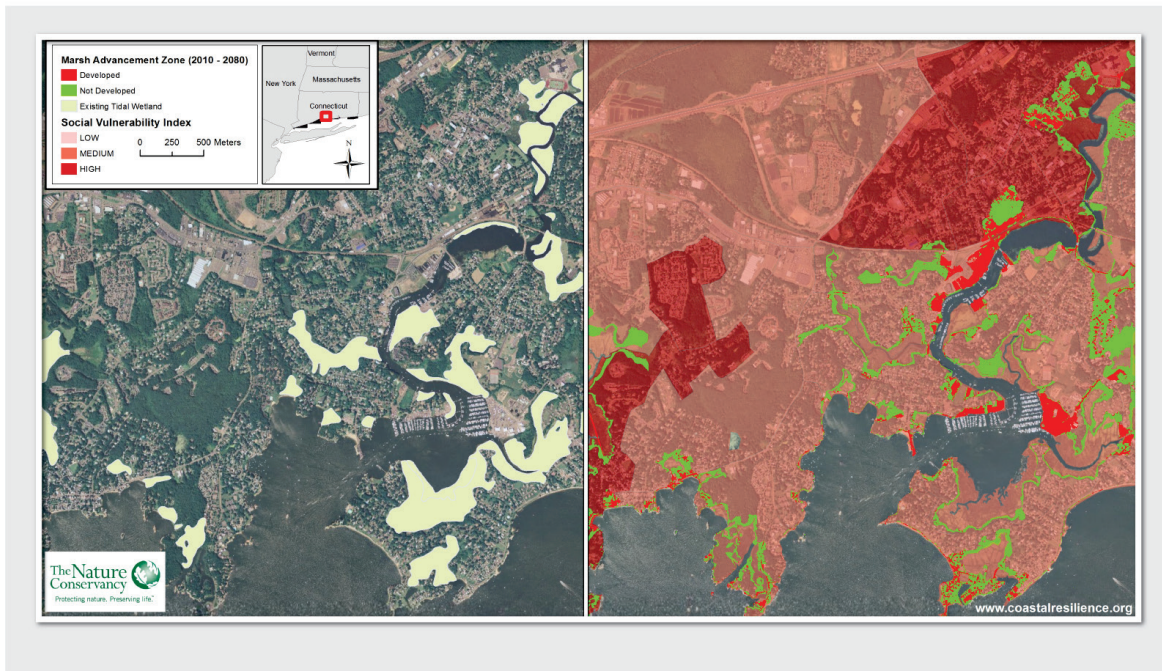
### 5 *Planning and Adaptation*

6 **While a majority of states and several municipalities have begun to incorporate the risk of**  
7 **climate change into their planning activities, implementation of adaptation measures is still**  
8 **at early stages.**

9 Of the 12 states in the Northeast, 11 have developed adaptation plans for several sectors and 10  
10 have released, or plan to release, statewide adaptation plans (Georgetown Climate Center 2012).  
11 Given the interconnectedness of climate change impacts and adaptation, multi-state coordination  
12 could help to ensure that information is shared efficiently and that emissions reduction and  
13 adaptation strategies do not operate at cross-purposes.

14 Local and state governments in the Northeast have been leaders and incubators in utilizing legal  
15 and regulatory opportunities to foster climate change policies (Sussman 2008). The Regional  
16 Greenhouse Gas Initiative (RGGI) was the first market-based regulatory program in the U.S. to  
17 reduce greenhouse gas emissions; it is a cooperative effort among nine northeastern states (RGGI  
18 2011). Massachusetts became the first state to officially incorporate climate change impacts into  
19 its environmental review procedures by adopting legislation that directs agencies to “consider  
20 reasonably foreseeable climate change impacts, including additional greenhouse gas emissions,  
21 and effects, such as predicted sea level rise” (State of Massachusetts 2012).

## Connecticut Coastline and Expanding Salt Marshes



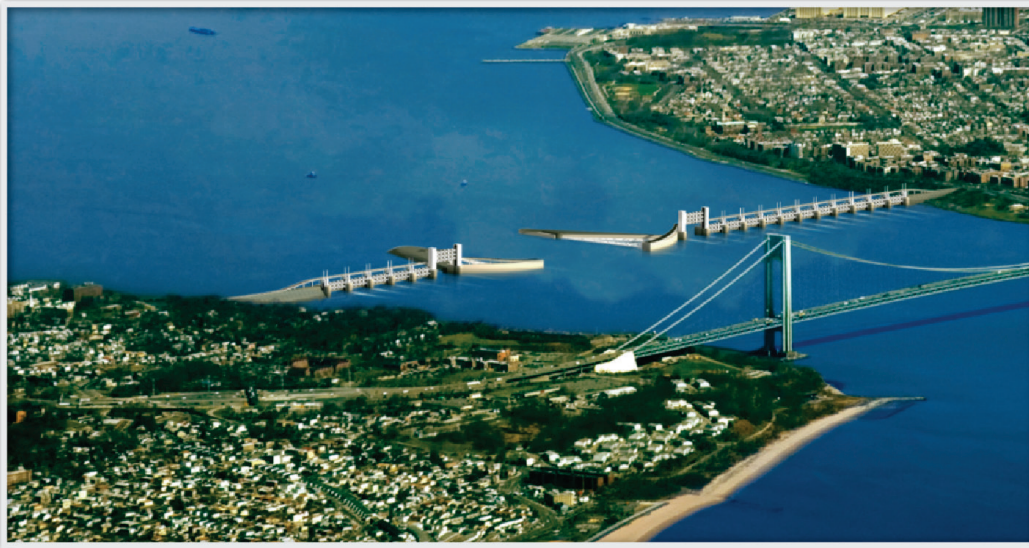
1

2 **Figure 16.9:** Connecticut Coastline and Expanding Salt Marshes

3 **Caption:** The Nature Conservancy’s adaptation decision-support tool shows projected  
 4 inundation of land along the Connecticut coast by the 2080s. The maps show both  
 5 building-level impacts and potential marsh ecosystem responses as sea levels rise.  
 6 (Source: The Nature Conservancy 2012)

7 Northeast cities have employed a variety of mechanisms to respond to climate change, including  
 8 land use planning, provisions to protect infrastructure, regulations related to the design and  
 9 construction of buildings, and emergency preparation, response, and recovery (see ORNL 2012).  
 10 While significant progress has been made, local governments still face limitations of legal  
 11 authority, geographic jurisdiction, and resource constraints that could be addressed through  
 12 effective engagement and support from higher levels of government.

13 Keene, New Hampshire has been a pilot community for ICLEI’s Climate Resilient Communities  
 14 program for adaptation planning (Sussman 2009) – a process implemented through innovative  
 15 community engagement methods (Engert 2010). New York City has taken numerous steps to  
 16 implement PlaNYC, a far reaching sustainability plan for the city, including amending the  
 17 construction code and the zoning laws and the implementation of measures focused on  
 18 developing adaptation strategies to protect the City’s public and private infrastructure from the  
 19 effects of climate change (Rosenzweig et al. 2011a); some major investments in protection have  
 20 even been conceptualized.



1

2 **Figure 16.10**3 **Caption:** Conceptual Design of a Storm Surge Barrier in NYC. (Source: Aerts et al.  
4 2009)

5 One well-known adaptation-planning tool is the eight-step iterative approach developed by the  
6 New York City Panel on Climate Change; it was highlighted in the contribution of the National  
7 Academy of Science's Adaptation Panel to America's Climate Choices and adopted by the  
8 Committee on America's Climate Choices. It describes a practical procedure that decision-  
9 makers at all levels can use (and have already begun to use, for example in support of the  
10 National Climate Assessment) to design a flexible adaptation pathway to address infrastructure  
11 and other response issues through inventory and assessment of risk. The key, with respect to  
12 infrastructure, is to link adaptation strategies with capital improvement cycles and adjustment of  
13 plans to incorporate emerging climate projections (Rosenzweig and Solecki 2010; Rosenzweig et  
14 al. 2011b) – but the insights are far more general than that (see the Adaptation Panel Report  
15 (NRC 2010).

16 In most cases, adaptation requires information and tools coupled to a decision-support process  
17 steered by strong leadership, and there are a growing number of examples in the Northeast. At  
18 the smaller municipal scale, coastal pilot projects in Maryland (Cole 2008; Maryland Department  
19 of Natural Resources 2008), Delaware (Delaware Coastal Programs 2011), New York and  
20 Connecticut (Ferdaña et al. 2010) are underway.





1

**Figure 16.11**

2 **Caption:** NASA facilities managers and climate scientists work together closely to plan  
3 appropriate adaptation strategies for their physical plant in response to hazard-specific  
4 local information and climate scenarios.  
5

6 Research and outreach efforts are underway in the region to help farmers find ways to cope with  
7 a rapidly changing climate, take advantage of a longer growing season, and reduce greenhouse  
8 gas emissions (Wolfe et al. 2011b; Wolfe et al. 2011c), but inequities in farmer access to capital  
9 and information for strategic adaptation and mitigation remain a challenge.

10 Regional activities in the Northeast are also being linked to federal efforts. For example,  
11 NASA's Agency-wide Climate Adaptation Science Investigator Workgroup (CASI) brings  
12 together NASA facilities managers with NASA climate scientists in local Climate Resilience  
13 Workshops. This approach was in evidence at the Goddard Space Flight Center in Maryland,  
14 where scientists helped institutional managers address energy and stormwater management  
15 vulnerabilities.

**Box: Culverts as Adaptation**

17 Culverts, the ubiquitous, mostly out-of-sight large pipes that carry water under roads, trails, and  
18 embankments are constantly being built, replaced, or upgraded. In Maine, the State Department  
19 of Transportation manages over 97,000 culverts, but even more are managed by individual  
20 property owners or small towns; Scarborough, Maine, for example, has 2,127 culverts.

21 Culverts are increasingly being washed out during intense precipitation events; storms that used  
22 to occur once in 100 years in the 1950s through the 1970s occurred every 60 years during the  
23 recent 1978-2007 period (DeGaetano 2009). When 71 town managers and officials in coastal  
24 Maine were surveyed as part of the statewide Sustainable Solutions Initiative, culverts, with their  
25 50-65 year expected lifespan, emerged atop a wish list for help in adapting to climate change.

1 By mapping town managers' decisions to the sources of climate information, engineering design,  
2 mandated requirements, and decision calendars, a culvert governance map from local to global  
3 scales emerged (Gray et al. 2012). The complexity of the map, and its many levels of  
4 governance, illustrates the challenge of widespread adaptation for even such simple actions as  
5 using larger culverts. To help towns adapt culverts to expected climate change over their  
6 lifetimes, the Sustainability Solutions Initiative is creating decision tools to map culvert  
7 locations, schedule maintenance, estimate needed culvert size, analyze replacement needs and  
8 costs, and identify funding sources, their application forms, and calendars.

9 -- end box --

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## Traceable Accounts

1

### 2 Chapter 16: Northeast Region

3 **Key Message Process:** Results of the NE Regional Climate assessment workshop that was held on November 17<sup>th</sup>  
 4 and 18th, 2011 at Columbia University, with approximately 60 attendees - the beginning of the process that lead to  
 5 the foundational Technical Input Report (TIR) report (Horton et al. 2012) – were critically important in our  
 6 assessment. That 313-page report consisted of 7 chapters by 13 Lead authors and more than 60 authors in total.  
 7 Public and private citizens or institutions who service and anticipate a role in maintaining support for vulnerable  
 8 populations in NE Region cities and communities indicated that they are making plans to judge the demand for  
 9 adaptation services. These interactions were surveyed and engaged in the preparation of this chapter, because we are  
 10 confident that the TIR authors made a vigorous attempt to engage various agencies at the state level and NGO’s who  
 11 have broader perspectives.

12 The author team engaged in multiple technical discussions via teleconferences, which included careful review of the  
 13 foundational TIR (Horton et al. 2012) and approximately 50 additional technical inputs provided by the public, as  
 14 well as the other published literature, and professional judgment. Discussions were followed by expert deliberation  
 15 of draft key messages by the authors, and targeted consultation with additional experts by the lead author of each  
 16 subset of this key message.

<b>Key message #1/4</b>	<b>Heat waves, coastal flooding due to sea level rise, and river flooding due to more extreme precipitation events will add stresses to the region’s already burdened environmental, social, and economic systems. This will increase the vulnerability of the region’s residents, especially populations that are already most disadvantaged.</b>
<b>Description of evidence base</b>	<p>The key message and supporting text summarizes extensive evidence documented in the NE Technical Input Horton et al (2012). Nearly 50 Technical Input reports, on a wide range of topics, were also received and reviewed as part of the Federal Register Notice solicitation for public input.</p> <p>Numerous peer-reviewed publications (including many that are not cited) describe increasing hazards associated with sea level rise and storm surge, heat waves, and intense precipitation for the Northeast. For sea level rise, the authors relied on the NCA SLR scenario (Parris et al. 2012) and experience on the topic (e.g., Horton and Rosenzweig 2010). Recent work by Gaffin et al. (2008) summarizes the literature on heat islands and extreme events, and Kunkel et al. (2012) worked closely with the region’s state climatologists on both the climatology and projections.</p> <p>Many relevant and recent peer-reviewed publications (Anderson and Bell 2012; Crowell et al. 2010; EPA 2006; Huang et al. 2011; Knowlton et al. 2007; Sheffield et al. 2011b; Solecki et al. 2011) that describe how human vulnerabilities to climate hazards in the region can be augmented by socio-economic and other factors were also considered. Evaluating coupled multi-system vulnerabilities is an emerging field; as a result, additional sources including white papers have informed this major message as well.</p> <p>Various regional assessments were also consulted, such as PlaNYC (<a href="http://www.nyc.gov/html/planyc2030">http://www.nyc.gov/html/planyc2030</a>) or Boston’s Climate Plan (<a href="http://www.cityofboston.gov/Images/Documents/A%20Climate%20of%20Progress%20-%20CAP%20Update%202011_tcm3-25020.pdf">http://www.cityofboston.gov/Images/Documents/A%20Climate%20of%20Progress%20-%20CAP%20Update%202011_tcm3-25020.pdf</a>) to capture key issues, concerns and opportunities in the region.</p>
<b>New information and remaining</b>	Important new evidence (cited above) confirmed many of the findings from a prior Northeast assessment; see

<p><b>uncertainties</b></p>	<p><a href="http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/regional-climate-change-impacts/northeast">http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/regional-climate-change-impacts/northeast</a>).</p> <p>This evidence included results from improved models and updated observational data, and the assessment included insights from stakeholders collected in a series of distributed engagement meetings that confirm its relevance and significance for local decision-makers.</p> <p>There is wide diversity of impacts across the region driven by both exposure and sensitivity that are location and socio-economic context specific. Future vulnerability will be influenced by changes in demography, economics, and policies (development, economic, and climate driven) that are difficult to predict and dependent on international and national considerations. Another uncertainty is the potential for adaptation strategies (and to a lesser extent mitigation and geoengineering) to reduce these vulnerabilities.</p> <p>There are also uncertainties associated with the character of the interconnections and the positive and negative synergies. For example, a key uncertainty is how systems will respond during extreme events (climatically and otherwise) and adjust their short to long-term planning to take account of a dynamic climate, since such events are by definition, manifestations of historically rare and therefore relatively undocumented climatology but nonetheless correlated, when considered holistically, with dynamic climate change driven to some degree by human interference with the climate system; these are the uncertainties in exposure. There are also uncertainties associated with sensitivity to future changes driven in to some (potentially significant) degree by non-climate stressors, including background health of the human population and development decisions. Other uncertainties include how much effort will be put into making systems more resilient, and their success.</p>
<p><b>Assessment of confidence based on evidence</b></p>	<p><b>Very high</b> for sea level rise and coastal flooding as well as heat waves</p> <p><b>High</b> for intense precipitation events and riverine flooding.</p> <p><b>Very high</b> confidence for both added stresses on systems and for increased vulnerability, esp. those most disadvantaged.</p>

1

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

2

3

1 **Chapter 16: Northeast Region**

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

<b>Key message #2/4</b>	<b>Infrastructure will be increasingly compromised by climate-related hazards, including sea level rise and coastal flooding, and intense precipitation events.</b>
<b>Description of evidence base</b>	<p>The text summarizes extensive evidence documented in the NE Technical Input (Horton et al. 2012). Technical Input reports (48) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.</p> <p>Various regional assessments were also consulted, such as PlaNYC (<a href="http://www.nyc.gov/html/planyc2030">http://www.nyc.gov/html/planyc2030</a>) or Boston’s Climate Plan (<a href="http://www.cityofboston.gov/Images/Documents/A%20Climate%20of%20Progress%20-%20CAP%20Update%202011_tcm3-25020.pdf">http://www.cityofboston.gov/Images/Documents/A%20Climate%20of%20Progress%20-%20CAP%20Update%202011_tcm3-25020.pdf</a>) to capture key issues, concerns and opportunities in the region.</p> <p>In addition, the cited DOT (2008) report provided extensive documentation that augmented Lenton et al. (2009), but this is an NGO publication with an uncertain review process. Nonetheless, all of these sources supported this key message.</p>
<b>New information and remaining uncertainties</b>	<p>Important new evidence (cited above) confirmed many of the findings from the prior Northeast assessment:</p> <p>(<a href="http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/regional-climate-change-impacts/northeast">http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/regional-climate-change-impacts/northeast</a>).</p> <p>These new sources relied on improved models that have been calibrated to new observational data across the region.</p> <p>It is important to note, of course, that there is wide diversity across the region because both exposure and sensitivity are location and socio-economic context specific. The conventional wisdom derived from many previous assessments by the National Academies, the New York Panel on Climate Change, and the Intergovernmental Panel on Climate Change indicates that future vulnerability at any specific location will be influenced by changes in demography, economics, and policy that are difficult to predict at local scales even as they depend on international and national considerations. The potential for adaptation strategies (and to a lesser extent mitigation and geoengineering) to reduce these vulnerabilities is yet another source of uncertainty that expands as the future moves into the middle of this century.</p>
<b>Assessment of confidence based on evidence</b>	<p>Based on our review of the literature and submitted input and defended internally and externally in conversation with local decision-makers and representatives of interested NGO’s (as well as the extensive interactions across the region reported in NE Technical Input (TIR) noted above, we have <b>very high</b> confidence for sea level rise and coastal flooding, and high confidence for intense precipitation events.</p> <p><b>Very high</b> confidence for added stresses on infrastructure is based on the clear evidence of impacts on current infrastructure from hazards such as Hurricane Irene (see text), and from the huge deficit of needed renewal identified by a diverse engineering community.</p>

3

<b>CONFIDENCE LEVEL</b>			
<b>Very High</b>	<b>High</b>	<b>Medium</b>	<b>Low</b>
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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2

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1 **Chapter 16: Northeast Region**

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

<p><b>Key message #3/4</b></p>	<p><b>Agriculture and ecosystems will be increasingly stressed by climate-related hazards, including higher temperatures, sea level rise and coastal flooding, and more extreme precipitation events. A longer growing season may allow farmers to explore new crop options, but this and other adaptations will not be cost- or risk-free, and inequities exist in the capacity for adaptation.</b></p>
<p><b>Description of evidence base</b></p>	<p>The text again summarizes extensive evidence documented in the NE Technical Input (Horton et al. 2012). Technical Input reports (48) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input. Please consult the Traceable Account documentation for our first key message for evidence base on sea level rise, flooding and precipitation.</p> <p>Various regional assessments were also consulted to capture key issues, concerns and opportunities in the region with particular focus on managed (agriculture) and unmanaged (ecosystems) systems.</p> <p>Species and ecosystem vulnerability have been well documented historically in numerous peer-reviewed papers in addition to the ones cited in this key message (See Horton et al. 2012). There have also been many examples of agricultural impacts of climate variability and change in the Northeast, although most note that there is potential for significant benefits associated with climate changes to partially offset expected negative outcomes for these managed systems.</p>
<p><b>New information and remaining uncertainties</b></p>	<p>Important new evidence (cited above) confirmed many of the findings from the prior Northeast assessment</p> <p><a href="http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/regional-climate-change-impacts/northeast">http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/regional-climate-change-impacts/northeast</a>).</p> <p>These new sources also relied on improved models that have been calibrated to new observational data across the region.</p> <p>Both agriculture and ecosystems in the Northeast are strongly linked to climate and other changes occurring outside the region and beyond the boundaries of the United States. These changes can influence the price of crops and agricultural inputs such as fertilizer, for example, as well as the abundance of ecosystem and agricultural pests. Other uncertainties include imprecise understandings of how complex ecosystems will respond to climate and non-climate induced changes, and the extent to which organisms may be able to adapt to a changing climate.</p>
<p><b>Assessment of confidence based on evidence</b></p>	<p>Based on our assessment and defended among ourselves and external experts, we have <b>very high</b> confidence for climate impacts (especially SLR and storm surge) on ecosystems; and we have <b>high</b> confidence for climate impacts on agriculture (ameliorated so some degree by uncertainty about the efficacy and implementation of adaptation options).</p>

3

4

<b>CONFIDENCE LEVEL</b>			
<b>Very High</b>	<b>High</b>	<b>Medium</b>	<b>Low</b>
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

1  
2

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1 **Chapter 16: Northeast Region**

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

<b>Key message #4/4</b>	<b>While a majority of states and several municipalities have begun to incorporate the risk of climate change into their planning activities, implementation of adaptation measures is still at early stages.</b>
<b>Description of evidence base</b>	<p>The text again relies heavily on extensive evidence documented in the NE Technical Input (Horton et al. 2012). Technical Input reports (48) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input. Many of the key references cited reflected experiences and processes developed in iterative stakeholder engagement concerning risk management (Rosenzweig et al. 2011b; Rosenzweig et al. 2009) that have been heavily cited and employed in new venues – local communities like Keane (NH) and New York City, for example.</p> <p>Various regional assessments were also consulted to capture key issues, concerns and opportunities in the region. In addition, there have been agency and government white paper reports describing proposed adaptation strategies based on climate impact assessments. We discovered that ten of the 12 states in the Northeast have statewide adaptation plans in place or under development.</p>
<b>New information and remaining uncertainties</b>	<p>That most NE states have begun to plan for adaptation is a matter of record. That few adaptation plans have been implemented is confirmed in submissions to the National Climate Assessment process as well as prior assessments.</p> <p>See, for example, (<a href="http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/regional-climate-change-impacts/northeast">http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/regional-climate-change-impacts/northeast</a>).</p> <p>Key uncertainties in looking forward include: 1) the extent to which proposed adaptation strategies will be implemented given a range of factors including competing demands and limited funding, 2) the role of the private sector and individual action in adaptation, which can be difficult to document, 3) the extent of the federal role in adaptation planning and implementation in the future, and 4) how changes in technology and the world economy may change the feasibility and attractiveness of specific adaptation strategies.</p>
<b>Assessment of confidence based on evidence</b>	This KM is simply a statement of observed fact, so confidence language is not applicable.

3

<b>CONFIDENCE LEVEL</b>			
<b>Very High</b>	<b>High</b>	<b>Medium</b>	<b>Low</b>
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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