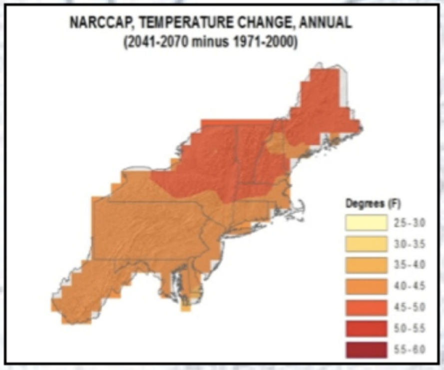
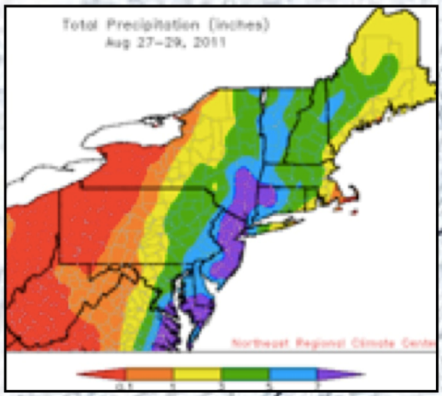
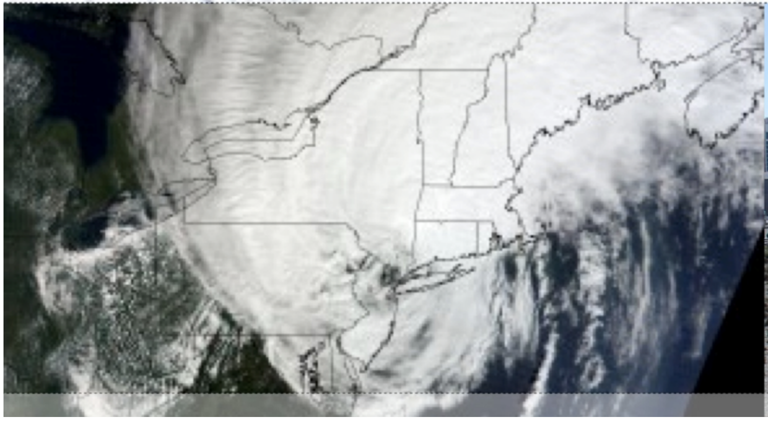
CLIMATE CHANGE IN THE NORTHEAST
A SOURCEBOOK





Draft Technical Input Report Prepared for the U.S. National Climate Assessment



Climate Change in the Northeast
A Sourcebook

Editors

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Edited by - Radley Horton, William Solecki, and Cynthia Rosenzweig

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1. Introduction

Coordinating Lead Authors – Radley Horton, William Solecki, and Cynthia Rosenzweig

This technical input assesses information about climate variability and change, impacts, and adaptation in the Northeast, emphasizing the sundry developments since the prior assessment by the US Global Change Research Program (USGCRP) (Karl et al., 2009). The work builds upon a strong foundation of assessment in the region, as reflected in a range of assesments including the Northeast Climate Impact Assessment (Frumhoff, 2007), the Mid-Atlantic Regional Assessment Team (MARA) report (Fisher et al., 2000) and the Metro East Coast Assessment (MEC) (Rosenzweig and Solecki, 2001).

The intended audience initially for this technical input report is the National Climate Assessment Development and Advisory Committee (NCADAC) and the Northeast Author Team. Other audiences for the report, as it evolves will include policymakers, academics and the public. The research team assembled for this report was encouraged to focus on the scholarly literature, with an emphasis on research findings generated since the 2009 USGCRP Report. The report is intended to be a foundational sourcebook on climate impacts and adaptation in the Northeast, and is designed to be policy relevant but not policy-prescriptive.

Several principles have guided the development of this technical input report:

> The region's diversity is reflected in the authors, who include government and private sector employees, as well as academics and representatives on non-governmental organizations.
>
> Effort has been made to be as inclusive as possible of all the region's voices. In order to represent each of the Northeast's 12 states as equally as possible given their varying level of engagement on climate issues, listening sessions are being conducted throughout the region. These sessions help capture perspectives on impacts and adaptation that may not be covered in the literature, and provide feedback on the Northeast Technical Input report. This technical input report has endeavored to capture the key principles espoused by the 2013 National Climate Assessment team.
>
> This report endeavors to highlight emerging results and activities in the Northeast. This is reflected in the structure of the report, the main body of which begins with an overview of coordinated governance and problem solving in the Northeast and discussion of solutions underway in the various states (Chapter 2) and ends with a practical overview of tools and resources that are available in the region for impact and adaptation assessment (Chapter 6).

The technical input report has also embraced each of the eight guidance topics put forward by the NCA leadership: 1) risk-based framing, 2) confidence characterization and communication, 3) documentation, information quality, and traceability, 4) engagement, communications, and evaluation, 5) adaptation, 6) international context, 7) scenarios and 8) sustained assessment and research needs.

The development of this technical input was supported by the following process. First, a steering committee was formed with representatives across a variety of agencies, sectors and parts of the region. This steering committee convened by phone on a bi-weekly basis. Second, a large workshop with roughly 60 attendees was held at the NASA Goddard Institute for Space Studies in New York on November 17th and 18th 2011 to share information, develop author teams, and identify additional voices and information needed for a comprehensive report. Third, the report drafts have undergone three iterations to date. The second order drafts of the four 'full-content' Chapters (3-6) have each undergone external peer review by 1-3 reviewers, and the authors have responded to the reviewer comments. Post-March 1, the report will continue to be advanced, with at least one round of additional peer review covering all the chapters.

This report structure is as follows:

Chapter 2, 'Climate Change and Problem-Solving in the Northeast: A Legacy of Action' sets the context for the report as a whole by highlighting the long history of coordinated, multi-state and institutional problem solving in the region. This chapter's summary of state-by-state mitigation and adaptation plans makes clear the breadth of activities underway and capacity in the region, with an emphasis on practically conveying both the key elements of each plan and lessons learned.

Chapter 3, 'Need to Know Information' describes baseline conditions and projections that inform impact assessment and the development of adaptation strategies across sectors and systems (Chapter 4) and the Northeast's subregions (Chapter 5). A range of factors that tend to increase vulnerability in the region are first introduced, followed by the observed baseline climate. The latter section includes an overview of Hurricane/Tropical Storm Irene, which both caused devastation in the region and revealed pre-existing vulnerabilities. The next two sections describe the climate projections developed by the National Climate Assessment for the Northeast, and socioeconomic and land use data and projections, respectively.

Chapter 4, 'Climate Change Impacts and Solutions by Systems and Sectors' begins with the Northeastern context, focusing on regionally unique and often iconic aspects. The next two sections describe how the Northeast's sectors and systems are currently affected and may be affected in the future by a changing climate, and outlines the many adaptation strategies already underway or in development. One theme is the interrelatedness and interdependence across sectors and systems, which argues for cooperation and partnership.

Chapter 5, 'Climate Change and Regional and Local Identities' highlights the diversity and range of local voices within the Northeast. In so doing, like Chapter 4 it addresses background context, impacts, and adaptations, but from a geographical perspective. The chapter notes that there is large variation across the Northeast in terms of information about climate impacts and tools for adaptation. To address these information gaps, the chapter includes a description of a listening session conducted in West Virginia to support co-generation of knowledge.

Chapter 6, 'Climate Change Decision Support Tools and Resources', like Chapter 2, is a unique and practically-oriented contribution, that exemplifies the broad range of assessment and risk management activities underway in the region. What each section of the chapter has in common is that it describes a tool or resource that has been used to support improved decision making around climate issues.

The report ends with a brief summary of key conclusions and recommendations.

Throughout the report, text boxes are used to highlight unique voices and projects in the region.

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Acknowledgements

Without the contributions of Lesley Patrick, Daniel Bader, and Angelica Pasqualini, the preparation of this technical input would not have been possible

We gratefully acknowledge the generous support for this effort provided by NASA's Applied Sciences Division and NOAA.

2. Climate Change and Problem-Solving in the Northeast: A Legacy of Action

Coordinating Lead Authors – Lisa Rector and Cameron Wake

This chapter summarizes mitigation and adaptation activities and efforts in the region, while emphasizing lessons learned that might be transferable to other parts of the region, other regions, and the United States as a whole. It is divided into three parts: an overview of regional infrastructure and activities; information on individual state initiatives; and lessons learned from these activities.

2.1 Historical Overview of Governance and Coordinated Problem-Solving in the Northeast US

The Northeast region of the United States encompasses several unique sub-regions: New England, the Mid-Atlantic, Chesapeake Bay Area and Appalachia. While these areas are different in some ways, they share significant characteristics: interconnected physical geographies, natural resources and built environments, and a willingness to work across state boundaries to protect and enhance those resources. Many Northeast states have statutory obligations or other efforts in place to reduce emissions through energy efficiency, renewable energy, and transportation programs. However, the region has long recognized that regardless of any progress to mitigate the causes of anthropogenic climate change in the near future, the Northeast is already experiencing the impacts of a changing climate, and will likely continue to experience warming temperatures, more extreme precipitation events, reduced snow and ice cover and rising relative sea levels (NERA, 2001; Wake et al., 2005; 2006; 2008; Frumhoff et al., 2007; Hayhoe et al., 2008). Many states and municipalities have mandates to develop adaptation plans to identify and implement strategies to make their states more resilient to a changing climate. Leaders throughout the region have supported the implementation of carefully coordinated and executed regional responses to mitigate and adapt to these changes in order to protect the Northeast's wildlife, ecosystems, oceans, coastlines, watersheds, forests, agriculture, and human welfare, including infrastructure, human health, and to ensure the region's economic viability.

History of Interstate Cooperation

While the Northeastern states each have their individual identity, the region as a whole has a long history of interstate cooperation. As early as the 1940s the states (especially in New England) established interstate environmental agencies to address the issues posed by the sharing of natural resources and the downstream impacts of human activities. Today, interstate agencies address air (Northeast States for Coordinated Air Use Management; NESCAUM), water (New England Interstate Water and Pollution Control Commission; NEIWPCC), waste (Northeast Waste Management Officials Association; NEWMOA), coastal (Northeast Regional Association of Coastal and Ocean Observing Systems; NERACOOS), ocean (Northeast Regional Ocean Council NROC), and forestry and fish/wildlife (Northeast Association of Fish and Wildlife Agencies; NEAFWA) issues. These organizations have formal structures that require them to be responsive to their member states, although their primary goal is to assist with implementation of national programs. This work often includes research, policy support, and development of tools,either analytical (such as model development or data analysis) or policy (such as model rules). The interstate agencies work with member states to develop a common understanding and implementation on a variety of topic areas. Many of these organizations are already actively working with their state and federal partners on both mitigation and adaptation strategies to address climate change. These regional efforts may serve as a framework for moving forward on activities relating to both mitigation and adaptation to climate change. Effective cross-state and cross-agency collaboration requires collective strategies for shared resources, and assurances that states and agencies will not compromise the efforts of their regional counterparts.

One of the first major regional climate activities was the New England Governors/Eastern Canadian Premiers (NEG/ECP) 2001 Climate Change Action Plan (NEG/ECP, 2001). The Plan called for programs to substantially reduce the amount of greenhouses gas (GHGs) emissions (a return to 1990 GHG emissions by 2010 regionally, and also set a reduction target of 75-85% below 2001 levels by 2050) and the development of "a plan for the adaptation of the region's economic resource base and physical infrastructure to address the consequences of climate change." The Plan was the first international, multi-jurisdictional climate initiative of its type in the world. While climate change policy in the past has often seen a choice between mitigation and adaptation, in the Northeast there has been a push to address both as critical aspects of the same policy. In hindsight, it is clear that this work drove the development of many regional activities in the Northeast by many organizations, such as the creation of the regional climate registry, the Regional Greenhouse Gas Initiative, GHG standards for vehicles, and the creation of state climate action and adaptation plans.

Regional Efforts

Climate registry.[1] The Climate Registry began as a collaboration between the Eastern Climate Registry (formerly the Regional Greenhouse Gas Registry) coordinated by NESCAUM, and The California Climate Action Registry. The Climate Registry is now a nonprofit organization of states, tribes, and provinces that maintain a common greenhouse gas emissions registry with voluntary and mandatory reporters across North America. States in the Northeast worked together to play a key role in The Climate Registry's success, providing a high level of insight on reporting and evaluation protocols, and forging linkages with other state and regional climate programs.

GHG standards for vehicles. GHG emissions from the transportation sector are a critical source category in the Northeast. To address this issue a study was conducted in 2004 by Northeast States Center for a Clean Air Future (NESCCAF) to identify the technical and economic feasibility of reducing GHG emissions from vehicles. This report served as the underpinning for rulemaking in California and nine Northeastern states (Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont).

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[1] http://www.theclimateregistry.org/

Regional Greenhouse Gas Initiative (RGGI).[2] RGGI is a nine-state initiative encompassing the states of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont (New Jersey was originally a partner in this initiative but pulled out of the initiative in 2011). The goal of this program is to reduce greenhouse gas emissions from power plants via a CO_2 budget-trading program. The strategy used to implement this program was a model rule that was developed through a state consensus process. States adopted this model rule, thereby creating a regional program. Under the model rule, states create a CO_2 Budget Trading Program, which caps emissions of CO_2 from electric power plants, issues CO_2 allowances and establishes a mechanism to participate in regional CO_2 allowance auctions. Power plants that are regulated under the state programs can purchase CO_2 allowances from any state participating in the program. Under this program, individual state regulations function as a single regional compliance market for CO_2 emissions. RGGI is the first mandatory, market-based CO_2 emissions reduction program in the United States and is targeted to reduce GHG emissions from this sector by 10% by 2018. A recent independent analysis quantified the economic benefits resulting from the first three years of the RGGI program (Hibbard et al., 2011). The results show $1.6 billion in economic value added, customer savings of over $1.3 billion over the next decade, and 16,000 jobs created.

Low carbon fuel standard. Transportation fuels account for approximately 30% of greenhouse gas emissions from the Northeast and Mid-Atlantic states. In the Northeast, a regional Low Carbon Fuel Standard (LCFS) is under development. This program is a market-based program designed to reduce the greenhouse gas emissions from liquid fuels by lowering their carbon intensity through the use of low-carbon fuel alternatives. In July 2008, Governor Deval L. Patrick of Massachusetts invited the governors of the Northeast and Mid-Atlantic states to work together to evaluate the potential for implementing a LCFS on a regional basis. In response to Governor Patrick's invitation, a letter of intent was signed by environmental and energy agency commissioners in 11 states in December 2008, committing the states to examining low carbon fuel supply options and developing a framework for a regional LCFS. In December 2009, the Governors of the 11 states signed a Memorandum of Understanding, which affirms each state's commitment to continue working together to evaluate and develop a program framework.

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[2] http://rggi.org/

2.2 State-By-State Overview of Adaptation and Mitigation Activities and Programs in the Region.

State Mitigation Activities

Since the year 2000, 11 of the 12 states in the Northeast US have developed Climate Action Plans (**Table 2.1**) that set targets for greenhouse gas emission reductions and provide a plan for how those emission reductions will occur. In two cases (Massachusetts[3] and New Jersey[4]) legislation has been passed that make these greenhouse gas emission reduction targets law. Most plans contain a suite of mitigation strategies across several sectors, including buildings, transportation, electricity generation, agriculture and forestry. Details of each state's proposed strategies are provided in the plans themselves[5]. For example, details of the development of New Hampshire's climate action plan are provided in Wake et al. (2011a).

Table 2.1. Mid-term and long-term greenhouse gas emission reduction targets from Climate Action Plans (CAP) in 12 Northeastern US states.

State	Year	2010	2012	2020	2025-2030	long-term (2050)
CT	2005	1990 levels	---	10% below 1990 levels	---	75% below 1990 levels
ME	2004	1990 levels	---	10% below 1990 levels	---	75% below 1990 levels
MA	2004	1990 levels	---	10-25% below 1990 levels	---	80% below 1990 levels
NH	2009	---	---	---	20% below 1990 levels by 2025	80% below 1990 levels
RI	2002	1990 levels		10% below 1990 levels		75% below 1990 levels
VT	2007	---	25% below 1990 levels	---	50% below 1990 levels by 2028	75% below 1990 levels
DE	2000	7% below 1990 levels	---	---	---	---
MD	2008		10% below 2006 levels	25-50% below 2006 levels	---	90% below 2006 levels
NJ	2009	---	---	1990 levels	---	80% below 2006 levels
NY	2009	---	---	---	40% below 1990 levels by 2030	80% below 1990 levels
PA	2009	---	---	30% below 2000 levels	---	---
WV	No plan	---	---	---	---	---

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[3] Massachusetts Global Warming Solutions Act signed into law in 2008 http://www.mass.gov/dep/air/climate/gwsa.htm

[4] New Jersey Global Warming Response Act signed into law in 2007. http://nj.gov/globalwarming/legislation/

[5] State climate action plans can be reviewed at http://www.climatestrategies.us

All of the climate action plans in the six New England states set long-term greenhouse gas reductions (75-80% below 1990 levels by 2050) that are lower than the long-term goal called for in the New England Governors/Eastern Canadian Premiers 2001 Climate Action Plan (75-85% reduction below 2001 levels; NEG/ECP, 2011). Of the six Northeastern US states that lie south of New England, only New York State has long-term GHG emission reduction goals that are as aggressive as the New England states.

Most of the states in the region will need to reduce their greenhouse gas emissions by less than 2% per year for the next 10-20 years to meet their medium term (2020-2030) greenhouse gas reduction targets (**Table 2.2**). Overall, greenhouse gas emissions from the production and use of energy in the states have been declining over the past five years. This is the result of a variety of efforts ranging from improvements in energy efficiency in buildings to an increase in the amount of electricity generated from renewable and low carbon sources to decreasing vehicle miles traveled and increasing fleet fuel efficiency for automobiles and light duty-trucks to strong and growing land preservation efforts across the region. In addition, the rising cost of gasoline and heating oil from 2002 to a peak in 2008, combined with the downturn in the economy in response to the Great Recession, contributed to decreasing greenhouse gas emissions. One of the significant challenges in the coming years will be to continue and enhance efforts that serve to reduce our collective GHG emissions, even as our economy emerges from the Great Recession and as the funds invested in the energy efficiency and renewable energy projects that were provided through the American Recovery and Reinvestment Act expire**.**

Table 2.2. Greenhouse gas emissions and mid-term emission reduction targets for 12 Northeastern US states.

State	MTCO2 per person (2009)	2009 GHG emissions (MMTCO2e)	Target GHG Emissions (MMTCO2e)	Target Year	% reduction/yr from 2009 to meet target
CT	11.9	41.9	37.5	2020	1.0%
ME	15.5	20.5	19.7	2020	0.3%
MA	11.4	75.3	70.4	2020	0.6%
NH	12.2	16.2	11.1	2025	2.0%
RI	10.9	11.5	10.0	2020	1.2%
VT	13.6	8.4	3.7	2028	2.9%
DE	14.3	12.6	11.1	2010	11.9%
MD	16.8	95.7	71.6	2020	2.3%
NJ	22.4	123.6	121.6	2020	0.1%
NY	6.3	194.6	120.5	2030	1.8%
PA	14.5	182.2	144.4	2020	1.9%
WV	19.5	35.4	na	na	na

State Adaptation Activities

The current and projected impacts of climate change are uniquely manifested according to the nature of a region's weather, ecosystems and built environment. These changes can have large impacts across a broad spectrum of agencies that work at all levels of government, businesses, and not-for-profits. For instance, forests, coastal zones, aquatic resources, a wide variety of infrastructure, public health, and certain industries are all susceptible to impacts from a changing climate. To address these impacts, effective adaptation planning must account for long-term changes in average temperature and precipitation, abrupt climate change, and altered climate variability (i.e. increased frequency and magnitude of extreme events). It must also consider social and economic changes occurring in the region such as growth patterns and resource use. In the Northeast, there is also an understanding that adaptation can play a key role in a state's mitigation strategy. For example, forest health and land use decisions play a key role in determining the ability of our forests to act as a powerful "sink" for carbon dioxide emissions. In order to ensure the viability of this sink, the health of our forests must be maintained, which is a key role of forestry programs at the state and local level. Providing state and local agencies, businesses, not-for-profits, and other stakeholders with information and tools to better understand the impacts of a changing climate on specific regions and specific sectors increases decision-makers' capacity to develop strategies that increase resiliency.

Due to this awareness, Northeast states have put forward significant resources to build resilience to deal with the changing climate, via adaptation planning efforts. In 2010, a nationwide survey found that only 24 states were working on any kind of adaptation planning activities, half of these being in the Northeast (Walker, 2011). Of those 24 states, only 18 were planning or have planned to adapt existing programs and regulations for climate change. While national work in adaptation is limited, there has been a great deal of state activity in this arena in the Northeast. Of the 12 states encompassing the Northeast region for this report, 11 have developed adaptation plans for several sectors and 10 have statewide adaptation plans in place or under development (**Table 2.3**). The Georgetown Climate Center provides a summary of state based adaptation plans[6].

On ecosystems, for example, the Northeast Association of Fish and Wildlife Agencies (NEAFWA), Manomet Center for Conservation Sciences and National Wildlife Federation are evaluating the vulnerabilities of important fish and wildlife habitats in the Northeast to current and future climate change. The research includes application of a predictive model for evaluating climate change impacts to non-coastal resources including forests, grasslands, wetlands, rivers, lakes and ponds, while a user-friendly tool for evaluating the vulnerabilities of coastal sites will be tested. A separate project is focused on implementing a Climate Change Vulnerability Index (CCVI) (developed by NatureServe and Heritage Program collaborators) to provide a rapid, scientifically defensible assessment of species' vulnerability to climate change. The CCVI integrates information about exposure to altered climates and species-specific sensitivity factors known to be associated with vulnerability to climate change.

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[6] http://georgetownclimate.org/node/3324

Table 2.3. Summary of State Adaptation Planning Activities.

State	Adaptation Plan	Sectors
Connecticut	Yes	Natural Resources and Ecological Habitats
		Infrastructure
		Agriculture
		Public Health
Delaware	Underway	Sea Level Rise
Maine	Yes	Built Environment
		Social Environment
		Coastlines
		Forests
		Agriculture
		Water Resources
Maryland	Yes	Existing Built Environment Infrastructure
		Future Built Environment Infrastructure
		Human Health, Safety & Welfare
		Public Awareness
		Resources & Resources-Based Industries
Massachusetts		Natural Resources & Habitat; Local Economy; Human Health and Welfare
		Coastal zone and ocean
New Hampshire		Data Acquisition, Analysis, and Dissemination; At-risk Populations;
		Public Health; Natural Resources; Resilience; Economic Development
New Jersey	Yes	Public Health
		Economy
		Forestry
		Coastlines
New York	Yes	Water Resources
		Coastal Zones
		Ecosystems
		Agriculture
		Energy
		Transportation
		Telecommunications
		Public Health
Pennsylvania	Yes	Infrastructure
		Natural Resources
		Tourism and Outdoor Recreation
		Public Health and Safety
Rhode Island	Underway	Work under development
Vermont	Underway	Work under development
West Virginia	No	

A wide variety of adaptation plans and activities are occuring at the municipal and county level within states. The Georgetown Climate Center keeps a database of several adaptation case studies[7], including many from the Northeast US (including Groton, CT; Lewes, DE; Keene and Seabrook, NH; and New York City). Regional examples include adaptation plans developed by the Deleware River Authority, ongoing planning for sea level rise in Portland and Scarborough-Old Orchard Beach, ME and Boston, MA.

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[7] http://georgetownclimate.org/node/3325

2.3. Lessons Learned from Climate Assessment Processes in the Region

While the above activities are encouraging and places the region in the vanguard nationally, the Northeast faces mounting challenges to move forward on mitigation and adaptation activities. Examining the successes made in the Northeast on GHG reduction activities can perhaps provide a template for successful future activities. Key attributes to these activities included support and direction from high level decision makers, development of regional templates/constructs to ensure consistency across programs and to streamline efforts, and commitment to state implementation such as those used in the RGGI and the GHG standards for vehicles program. These three elements moved mitigation efforts forward in a unified and effective manner.

An analysis of adaptation efforts highlights the consequences of a lack of regional coordination. While states have expended significant effort on gaining high level support and state implementation, these initiatives lack regional coordination. This has led to the creation of state, local and/sector-based plans that rely on different sets of assumptions and projections of future climate trends. **Table 2.4** provides a snapshot of the various scenarios and models used by different states and sectors. Another key lesson that has emerged from this effort is, even with regional coordination, decision makers and stakeholders need place-based decision relevant information on spatial scales ranging from municipalities to watersheds. While progress has been made on providing large cities with this information, there remains the critical need to climate and vulnerability assessments on relatively small spatial scales for regions outside of large cities. Watershed-based assessments in Casco Bay, Maine and Great Bay, NH are already serving as valuable tools for regions as they assess vulnerability to future climate change (Wake et al., 2009; 2011b).

Beyond the lack of coordinated responses to our changing climate, coordination across states and among sectors is important to ensure effective adaptation planning. These plans must account for long-term changes in average temperature and precipitation, abrupt climate change, and climate variability (i.e., extreme events) in the coastal, ocean, fresh water, forest and agricultural environments. It must also address critical social and economic impacts within the region, including population and public health considerations, growth patterns, built infrastructure integrity, and resource usage. Regionally coordinated efforts are critical to ensure an integrated approach to protecting natural and manmade systems within the region from the impacts of climate change that can be implemented by entities at various levels of government.

Numerous and disparate climate adaptation planning and implementation efforts are already underway or commencing in the Northeast. These include: statewide adaptation planning mandates; local climate planning efforts; interstate climate science research projects and reports; federal agency climate-related resources and activities; and federal, interstate and regional collaborations on climate change. To date, there has been limited horizontal and vertical coordination among these efforts (i.e., among various levels of government as well as across agencies). Consequently, there is little consistency in terms of the data sources, scenarios, methodologies, and models being utilized. This lack of integration and consistency can lead to duplicative efforts and lack of streamlining to utilize limited resources.

The key challenges are lack of political support and lack of resources to direct to activities. Other challenges inhibit further action. These include:

Structural challenges. State and local agencies are rarely structured to be interactive among and across sector and/or state boundaries. This hampers ability to proceed in a coordinated fashion on adaptation activities. This lack of coordination across sectors and levels of government leads to duplicative development of tools and efforts.

Lack of coordinated effort. Too many new institutions – as federal agencies have moved into this field, they have created new institutions rather than relying on existing infrastructure to work with constituencies. There is a need to find a way to coordinate the broad spectrum of groups funded to work on climate.

Resources. The lack of directed funding and programs has limited activity. Since it is not a core program for any agency, work happens based on capacity.

Identification of roles. There is no clear identification of what should be happening at the federal, state, and local levels of government. In the Northeast, due to a variety of legal issues many adaptation activities will need to be implemented at the local level. But local governments typically lack the capacity to develop the information to inform activities.

Legal Issues. A whole suite of legal approaches to climate change adaptation is emerging and will require more focused attention in the near future. A starting point was the recent Connecticut Sea Grant conference on legal solutions to coastal climate change adaptation[8]

Table 2.4. Examples of different scenarios that have been used as the basis for adaptation plan across the Northeast US.

State	Source	Planning Scenarios	CO_2 Concentration	Planning Timeframes
CT	NPCC, based on IPCC 2007 and GCMs	B1	412; 488; 537	2020; 2050; 2100
		A1B	420; 532; 649	2020; 2050; 2101
		A2	417; 532; 698	2020; 2050; 2102
ME	University of Maine, used Coupled Model Intercomparison Project model with IPCC 2007 scenario	A1B	700 ppb increase over next 100 years	100 years
MA	IPCC 2007	B1	550 ppm	2050
		A1F1	970ppm	2100
NY	ClimAID Global Climate Model based on IPCC scenarios and ClimAID Rapid Ice Scenario	B1		2020
		A1B		2050
		A2		2080
VT	USGCRP, used Coupled Model Intercomparison Project model with IPCC 2007 scenario	B1		2050
		A1		Late century

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3. Need-to-Know Information

Coordinating Lead Authors - William Solecki, Arthur DeGaetano, and Radley Horton

This chapter describes baseline conditions and projections that inform impact assessment and the development of adaptation strategies across sectors and systems (Chapter 4) and the Northeast's subregions (Chapter 5). A range of factors that tend to increase vulnerability in the region are first introduced in section 1, followed by a comprehensive overview of the observed climate (section 2). Embedded in Section 1. is an overview of Tropical Storm Irene, which both caused devastation in the region and revealed pre-existing vulnerabilities. Section 3 presents the climate projections developed by the National Climate Assessment for the Northeast, and section 4. outlines socioeconomic and land use data and projections, which are another key part of resilient planning.

3.1 Climate Change, Vulnerability, and the Northeast US: Critical Considerations

Lead Author - William Solecki

Vulnerability is a key concept when examining the relative impacts of shifts associated with climate change. This section will review several key terms and concepts, indicators and dimensions, issues and sector/service level impacts associated with vulnerability. Where appropriate, connections to climate change vulnerability in the Northeast US will be presented.

Key Terms and Concepts

Several key terms and concepts have been defined for considering vulnerability. The terms have become increasingly codified. For this report, these largely have been drawn from the literature developed as part of the IPCC assessment report process. See the **Box 3.1** below for the definition of these specific terms.

Box 3.1: Key Terms and Concepts

- *Vulnerability* - The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity
- *Exposure* - The nature and degree to which a system is exposed to significant climatic variations
- *Sensitivity* - Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise). See also climate sensitivity.
- *Risk* - Risk is product of likelihood and consequence. Consequence ("importance") can be calibrated in a variety of metrics ranging from *physical impacts* to vulnerability. Where vulnerability depends on exposure and sensitivity and can be modified by the exercise of adaptive capacity, especially taking account of multiple stressors, and synergies/conflicts with other policy objectives –Likelihood depends on interactions of climate variability, forcing, and climate sensitivity

- *Adaptive capacity* - The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Context for Vulnerability

Vulnerability as a concept can be applied to several contexts. These include the people, places, ecosystems, and coupled human-natural systems that are vulnerable. Each context includes different parameters and metrics of vulnerability. Difference in vulnerable of people or populations reflect equity issues with respect to race, income, educational attainment, mobility, and health limitations. Places also have can a wide range of vulnerability. High vulnerability sites include coastal locations, flood and/or drought prone areas, exposed slopes, and places with poor drainage or poor soil quality. Ecosystems have particular vulnerabilities associated with climate change. For example, coastal and freshwater wetlands are particularly at risk to shifts in the moisture levels and water inundation. Exposed upland slopes with shallow soils also are vulnerable to increased water stress as are isolated/remnant ecosystems such as woodland lots in urban areas. Urban systems such as infrastructure, resource delivery, water and waste water management have vulnerabilities that are specific to construction, management, and operation.

Indicators and Dimensions of Vulnerability

Conditions of vulnerability can include many variables. These variables describe measures of absolute or relative values of exposure, sensitivity, and adaptive capacity. Typically these are expressed in terms of numbers of people, economic losses, and metrics of system level disruption. For populations, vulnerabilities can connect to the number of individuals, status of individuals - poor, and whether they are recent migrants with extensive or existing coping mechanisms. Other measures of vulnerability are the amount or level of direct and indirect losses. Direct economic values include damage estimates, assets at risk; and indirect values define losses in economic productivity and short or long term business disruption. Loss estimate also can involve monetary values for which values can be easily derived, and non-monetary values for which it is difficult or impossible to define value - e.g. ecosystem service loss and quality of life.

Additionally, vulnerability can be characterized across several other dimensions including spatial, level of urbanization, and site specific characteristics. Regional variations in vulnerability exist within any extended geographic area where differences in the amount of vulnerability reflect the qualities of the area. Contexts for spatial variation in vulnerability include 1). urban, suburban, exurban, rural (each typically defined by density); and 2). coastal, interior, riverine, mountain. The relative importance of local, site specific vulnerability conditions such as endangered species habitat and institutional population concentrations (e.g. nursing home, prison, mental hospital) also should be considered.

The condition of how the vulnerability will be conceptualized is another important consideration. This includes the rate of onset of the risk or hazards, and the impact of the hazard on the level and/or condition of affected individual or system. Specific illustrations of this condition include gradual vs. extreme events (i.e. long-term chronic shifts as opposed to sudden events), and systems shifts vs. catastrophic shifts (i.e. system level impacts that systems could respond to as opposed to impacts that will respond with a critical transition to which response is difficult or impossible).

Elemental Issues of Vulnerability Relevant to the Regional Context

There a range of elemental issues associated with vulnerability estimates that specifically relevant to the Northeast of the United States and related to the region's intense level of development and physical and social variation. One critical aspect is concentration of high population and high value assets and the fact that extreme coastal storm events including storm surge, coupled with accelerated sea level rise represent the highest potential impact scenario. A second elemental issue is that many of the region's systems are tightly coupled and cascade impacts could set in motion a wide set of impacts within a systems (e.g. drinking water supply systems or across several systems). A third issue is that many of these systems are already stressed. A potential exists that added climate change will further stress some aspects of the region's agricultural economy such as diary industry, result in water supply shortages because lack of infrastructure, aging water, and cause added burden on the region complex and taxed electricity supply infrastructure. Finally, climate change vulnerability will exacerbate already present and growing income disparities, economic decline/transition inner city, core urban areas and chronic economically depressed rural areas, and the ongoing loss of government resources which limit the adaptive capacity of communities.

Key Sector and System Vulnerabilities

Key sector and system vulnerabilities, discussed in more detail in Chapter 4, include:

- *Water* - drinking water supply and quality (4.1)
- *Ecosystems* - coastal habitat loss with sea level risk, loss of endanger species habitat (4.2)
- *Agriculture and food systems* – increased stress on already stressed agricultural production systems – e.g., dairy farming, possibility of food contamination with hotter temperatures (4.3)
- *Coasts and oceans* - storm surge associated with extreme coastal storm event (4.4)
- *Human health* - extended and widespread health impact resulting from a flooding disaster and extreme storm event (4.5)
- *Infrastructure* - transportation, telecommunications, and energy - extended disruption of system function (4.6)
- *Community/Urban; Local Economy and Government* (4.7)

3.2 Baseline Climatology and Observations

Lead Authors - Jessica Rennells, Arthur DeGaetano, and Kenneth E. Kunkel

General Description

The Northeast region of the United States characterized by a highly diverse climate with large spatial variations. The moderating effects of the Atlantic Ocean affect coastal areas, while large water bodies such as the Great Lakes and Lake Champlain influence the inland regions. During much of the year, the prevailing westerly flow transports air masses from the interior North American continent across the entire region. These air masses can bring bitter cold to the region during the winter. The polar jet stream is often located near or over the region during the winter, with frequent storm systems bringing cloudy skies, windy conditions, and precipitation. In the southern portions of the region, the Appalachian Mountains act to partially protect coastal regions from these interior air masses, while also shielding the western part of the region from the warm, humid air masses characteristic of the western Atlantic. The local ranges of the Appalachians (e.g. the Green Mountains of Vermont and the White Mountains of New Hampshire) also influence the climates of northern New England in ways that lead to significant differences vis-à-vis the climates of southern New England as the mountain ranges locally enhance precipitation during storms through forced ascent of air.

Summers are characteristically warm and humid in the southern part of the region due to a semi-permanent high-pressure system over the subtropical Atlantic Ocean that draws warm, humid air into the area. In the north, summers are considerably cooler due to latitude, the blocking effects of the Appalachian Mountains, and the frequent intrusions of cooler air masses from Canada.

The Northeast is subject to a strong seasonal temperature cycle and is often affected by extreme events such as ice storms, floods, droughts, heat waves, hurricanes and nor'easters. Its landscape is extremely diverse, ranging from agricultural land to mountains to coastal beaches and estuaries. Many parts of the region are densely populated and highly urbanized. Thus, it is no surprise that parts of the economy of the Northeastern United States are also sensitive to a range of climate influences. The agriculture, fisheries, forestry, recreation, and tourism sectors are particularly sensitive to climate. (Rosenzweig et al., 2011) (Hayhoe et al. 2006).

Average temperatures in the Northeast generally decrease to the north and with distance from the coast and elevation (**Figure 3.1**). The average annual temperature in the coastal regions, especially the more southern areas, is in the mid-to-upper 50°F range. The coldest average temperatures (between 35°F and 40°F) are observed along the northern border of Maine. Average temperatures in the Northeast generally decrease to the north and with distance from the coast and elevation.

Average annual precipitation varies by about 20 inches throughout the Northeast (**Figure 3.2**). The coast generally receives the most average annual precipitation at around 45 to over 50 inches in some areas. However, orographic (mountain)effects produce localized amounts in excess of 60 inches at inland locations, particularly in the states of West Virginia and New York. This orographic enhancement also leads to pockets of higher precipitation along the spines of the Green and White Mountains. Some lower-elevation areas away from the coast that are partially blocked from oceanic moisture sources by mountains receive less than 40 inches of precipitation annually. As with temperature, the amount of precipitation tends to decrease to the north and further inland.

During winter, blizzards and ice storms can be particularly crippling to local infrastructure and mobility. A particularly disruptive phenomenon in the Northeast is the east coast winter storm, popularly known as the nor'easter. These storms derive their energy from the strong contrast in temperature between the interior of North America and the western Atlantic. The unique juxtaposition of the cold air to the northwest and warm and moist air to the southeast creates optimum conditions for the occasional explosive development of extratropical cyclones. With an abundant supply of moisture, these storms can produce heavy snowfall, flood-producing rainfall, hurricane-force winds, and dangerous cold. Major economic losses and loss of life are a consequence of the strongest of these storms (Kocin and Uccellini 2004b).

Lake-effect snows are another phenomenon affecting areas adjacent to the Great Lakes. Arctic air masses moving over the relatively warm eastern Great Lakes are warmed, humidified and destabilized, often leading to intense bands of heavy snowfall over land areas downwind of Lakes Ontario and Erie.

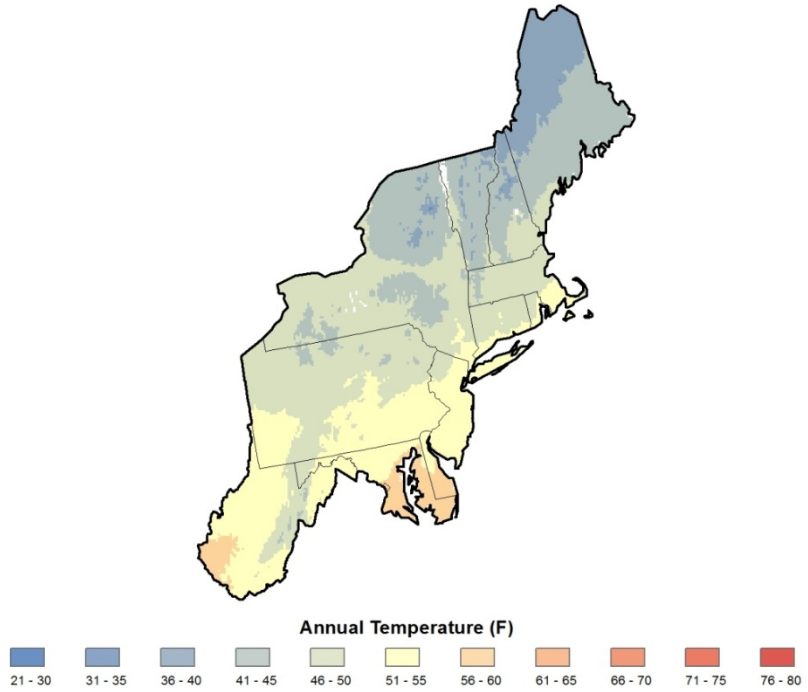


Figure 3.1. Average (1981-2010) annual temperature (°F) based on National Weather Service cooperative observer stations. These stations are preferentially located at lower elevations and the map does not fully represent the full range of temperature, particularly at higher elevations.

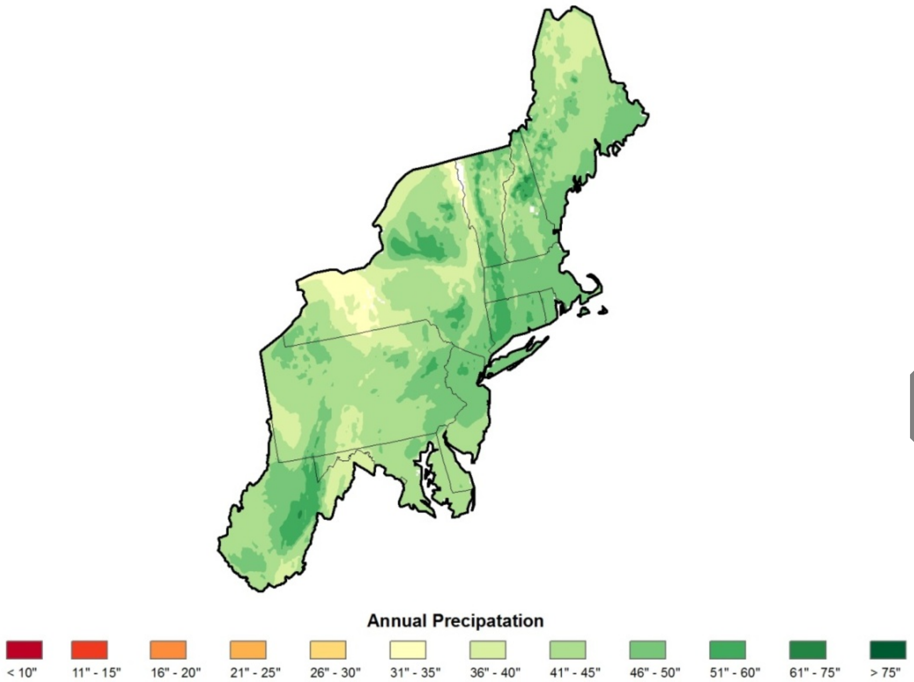


Figure 3.1. Average (1981-2010) annual precipitation (inches) based on National Weather Service cooperative observer stations. These stations are preferentially located at lower elevations and the map does not fully represent the full range of precipitation, particularly at higher elevations.

The Northeast is the most urbanized region in the US, with metropolitan centers including Boston, New York City (the nation's largest city), Philadelphia, Baltimore, Washington D.C., and Pittsburgh. These cities experience particular climate sensitivities that are unique to specific characteristics of the urban environment. Summer temperature extremes can have large impacts on human health, particularly in cities where the urban heat island effect raises temperatures. Severe storms, both in winter and summer, can result in major disruptions to surface and air transportation. Extreme rainfall causes a host of problems, including storm-sewer overflow, flooding of homes and roadways, and contamination of municipal water supplies. Climate extremes combined with urban pollution sources can create air-quality conditions that are detrimental to human health.

Important Climate Factors

Climate phenomena that have major impacts in the Northeast include:

Floods

Frontal systems, thunderstorms, coastal storms, nor'easters, snowmelt, ice jams, and tropical storms all contribute to flooding in the Northeast. Coastal areas are also susceptible to storm surges. Taking the state of Vermont as an example, rarely does a year elapse without a flooding event of a significant magnitude being reported in at least one of Vermont's fourteen counties or statewide, making this the number-one hazard across the state. Between 1955 and 1999, floods accounted for $16.97 million in damage annually in Vermont (Dupigny-Giroux, 2002).

On the region's largest rivers, spring snowmelt is a major cause of flooding. In Maine, record floods on the Kennebec River occurred in 1936 and 1987 in association with ice jams and melting snow, respectively. Likewise on the Hudson River near Albany, NY, record floods in the early 20th century and more recently in 1977, have resulted from snowmelt and ice jamming. In Pittsburgh, PA both tropical storms and snowmelt have been responsible for floods on the Monongahela River, with the flood of record being a March 1936 rain-on-snow event. The Potomac at Little Falls, MD also reached its peak crest in this event. On the Susquehanna River near Harrisburg, PA, five of the nine major floods since 1786 have occurred since 1972 (Rosenzweig et al. 2012). Three of these floods occurred with tropical cyclones, one was due to precipitation associated with a stationary frontal boundary and the fourth was a rain-on-snow event. Similar mechanisms have been responsible for historical flooding in West Virginia. For instance in 1985 the interaction between the remnants of Hurricane Juan and a secondary low-pressure system produced record floods in West Virginia that killed 47 people.

The region's smaller streams and tributaries are prone to flash flooding. Such floods typically occur during summer in association with intense convective rainfall. Land-surface features such as the steep narrow drainages that characterize areas along and adjacent to the Appalachian Mountains contribute to flash flood risk. Perhaps the most infamous flash flood occurred in 1977 in Johnstown, PA. It killed 74 people and caused millions of dollars in damages. (NOAA, 1977) Nearly 12 inches of rain were measured in 10 hours within the Conemaugh Valley, leading to the failure of several dams. Johnstown was also the site of the Great Flood of 1889 in which 2209 people lost their lives (JAHA,2012).

Urban flooding is also prevalent in the Northeast, because the development and proliferation of impervious paved surfaces limit the infiltration of water into the soil. During intense rainfall, the resulting runoff floods streets and underpasses, impacting automobile traffic. Outside of urban areas, rain on frozen ground, wet antecedent soil conditions, and the passage of tropical storms or hurricane remnants also limits infiltration. In the case of rain on frozen ground, downward percolation is inhibited, leading to intense surface runoff, as occurred during the New England ice storm of January 1998 (Dupigny-Giroux, 2002).

Nor'easters

Winter storms are common occurrences in the Northeast. There have been 45 high-impact storms since 1947 (Kocin and Uccellini 2004a; Kocin and Uccellini 2004b). The Blizzard of '96 was a classic nor'easter with record-breaking snowfall that resulted in 96 deaths as well as many closures and cancellations. In the middle-Atlantic region, the winters of 2009-2010 and 2010-211 saw many locations break daily and seasonal snowfall records as the result of frequent nor'easters. These events resulted in power outages, motor vehicle accidents, and school and event cancellations. Transportation was severely disrupted with widespread economic effects.

Lake-effect Snow

Like nor'easters, lake-effect snows also cause frequent winter climate impacts in portions of the Northeast. These events are dependent on unfrozen, relatively warm lakes, so longer ice-free periods have the potential to extend the period when lake-effect snows are possible. Although the impacts of lake-effect snowstorms are not as widespread as nor'easters, they can be just as significant. In December of 1995, lake-effect snow fell at a rate of 2 to 4 inches per hour, totaling 28-38" in Buffalo, NY. In January of 1997, areas in New York received snowfall at rates of 3 to 6 inches per hour; Montague, NY received a daily total of 95 inches.

Ice Storms

The Northeast is also prone to freezing rain. Cortinas et al. (2004) show that across the United States, the annual number of hours with freezing rain is maximal in the Northeast, largely due to topography and the region's proximity to winter storm tracks. Ice accumulations from freezing rain can be very dangerous. In January of 1998 a massive ice storm affected portions of upstate New York, northern New England and eastern Canada. The extent, thickness of accumulated ice (as much as 2 – 3 inches), duration, and overall impact of the storm are considered the most severe of any ice storm to hit eastern North America in recent history (DeGaetano, 2000). Over 350,000 U.S. homes lost power for as many as 25 days. Ice storms also cause significant disturbance to forest ecosystems. Forestry losses for the 1998 ice storm exceeded 57 million dollars (DeGaetano, 2000)

Heat Waves

High temperatures combined with high humidity can create dangerous heat index values, particularly in the major metropolitan areas of the Northeast. Strings of three or more consecutive days above 90°F are common, occurring almost every year. Three-day runs of 100°F are rare, occurring only twice in over 130 years of record at Central Park, New York and twice in 70 years in Washington, DC and Philadelphia, PA. Two-day runs of 100°F have occurred 10 times in Washington, DC, with five of these occurrences observed since 1990.

In the heat wave of July 1995, temperatures reached or exceeded 90° on all but one of 25 consecutive days in Washington, DC; this heat wave resulted in 19 deaths there as well as 11 deaths in New York City. In addition to negative effects on human health, heat waves cause high power usage and can contribute to brown or black outs, because of increased air-conditioner use.

Drought

In the Northeast, droughts lasting one to three months occur every two or three years. The drought of the 1960s is the 'benchmark' drought that lasted from the fall of 1961 to the spring of 1967, affecting the entire Northeast. Almost 50% of the Northeast was in extreme or severe drought from 1964-1967. Short-lived drought periods also punctuated the 1980s through early 2000s, most notably in 1985-1986, 1988, 1992-1993, and 2000-2003. In addition to agricultural impacts, these droughts have affected water resources. Water-use restrictions, and in some cases, water rationing, were common during these drought periods in the metropolitan and suburban areas of the Northeast.

Tropical Cyclones

Since 1900, coastal counties in the Northeast have experienced up to eight hurricane strikes, with the highest frequencies occurring in Massachusetts (Cape Cod, Nantucket and Martha's Vineyard) and New York's Long Island (**Figure 3.3**). Major hurricanes have struck Suffolk County on the eastern end of Long Island five times since 1900. The most notable storm to strike Long Island was a Category 3 hurricane in 1938. It brought greater than 13-foot storm surges to Rhode Island and claimed more than 600 lives in New York and New England. As the storm tracked inland through New England, considerable flooding and wind damage was reported throughout Massachusetts, Vermont and New Hampshire. In terms of 2010 dollars this storm was the 19th most costly hurricane to affect the United States with estimated damages totaling 6.3 billion dollars (Blake et al. 2011).

In August 2011, Hurricane Irene followed a similar path, making landfall along the southern New Jersey coast as a Category 1 hurricane and then continuing northward over New York City as a tropical storm. Rainfall from Irene caused extensive flooding inland in upstate New York and Vermont, where 2-day rainfall totals exceeded ten inches in some locations. Wind and coastal storm surge damage also accompanied the storm leaving millions of homes and businesses without power. According to National Public Radio, government officials ordered evacuations totaling 370 thousand in New York City, 100 thousand in Delaware, 315 thousand in Maryland, and one million in New Jersey. Public transportation systems were shut down. Preliminary damage estimates are near 7 billion dollars. More information about Hurricane Irene can be found in **Box 3.2**.

Persistent rain from the remnants of tropical systems have produced widespread, and at times, catastrophic flooding in the region. For example, the Great Flood of 1927 in Vermont resulted from record rainfall totals produced by tropical storm remnants on November 3, following October precipitation totals that were already 50 percent above normal. More recently, in 2011, New Jersey, Vermont and New York saw record floods as the remnants of Hurricane Irene and later Tropical Storm Lee traversed inland portions of these states.

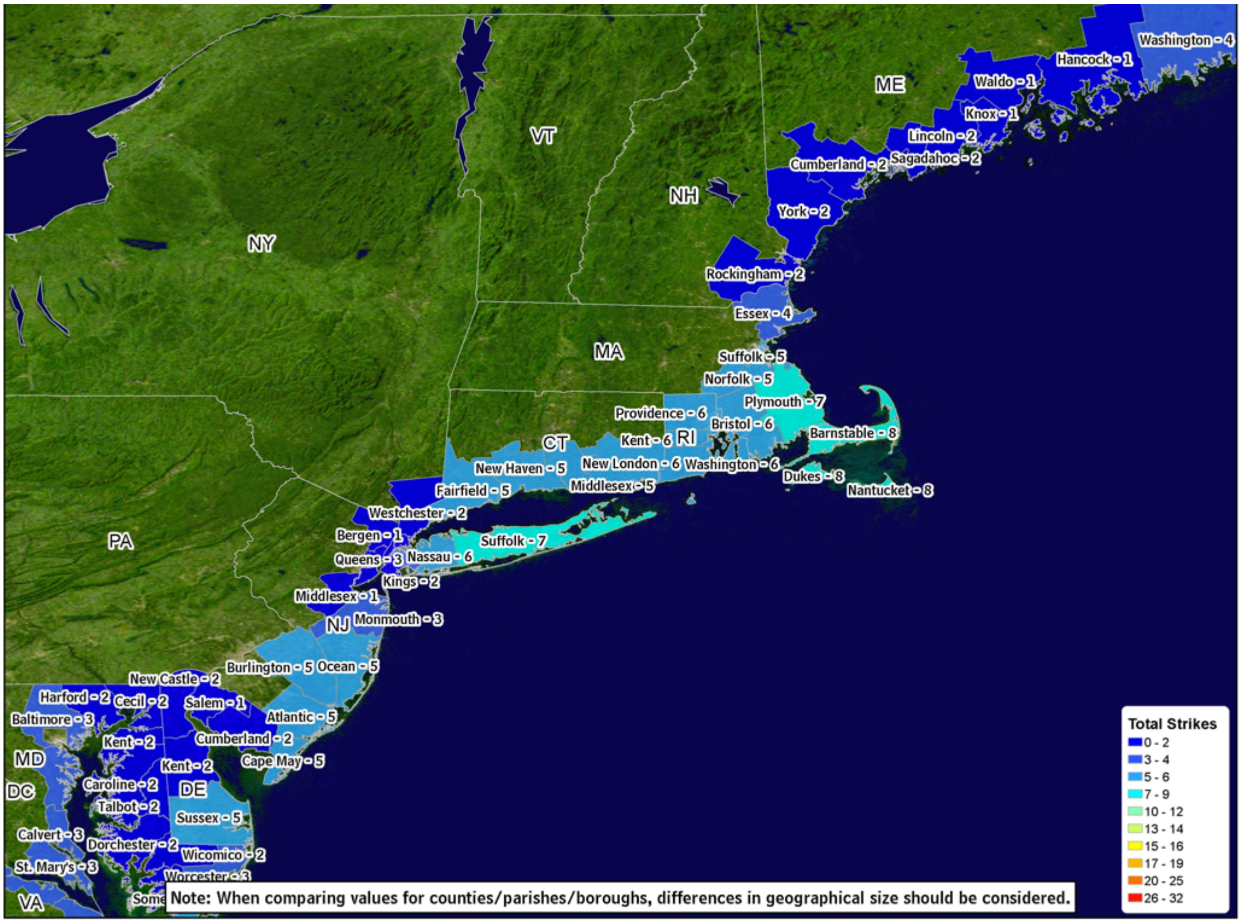


Figure 3.3. Number of hurricane strikes per county along the Northeast coast 1900-2010 (From Jarrell et al., 1992 and update.

Box 3.2: Hurricane Irene and Tropical Storm Lee Case Study
Authors: Arthur DeGaetano, William Solecki, Lesley-Ann Dupigny-Giroux Jessica Rennells, Kathryn Vreeland, and David Robinson

The flooding experienced across the Northeast during the late summer of 2011 provides a "teachable moment" in terms of the risks, vulnerabilities, and adaptation strategies associated with the observed and projected increases in extreme rainfall. While the occurrence of Hurricane Irene and Tropical Storm Lee cannot be attributed to climate change, these storms to highlight the region's vulnerability to inland and coastal floods, a risk that may increase with climate change.

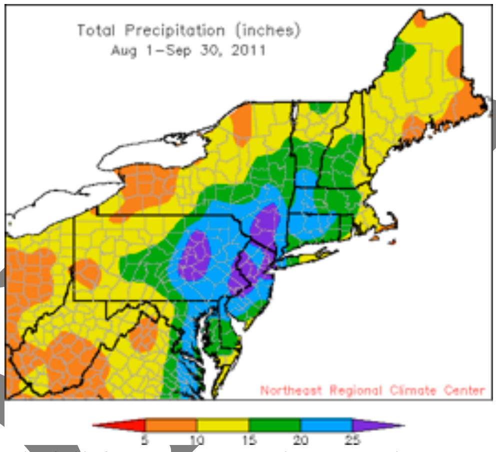
Hurricane Irene and Tropical Storm Lee

Irene made landfall in New Jersey as a strong tropical storm (just under hurricane force). There has not been a hurricane that made landfall in New Jersey in over 100 years. The storm passed just north of Atlantic City, NJ early on August 28th, then weakened to a tropical storm as it approached the New York City metropolitan area. By evening, Irene was an extra tropical cyclone over southern Caledonia County, VT. Other notable tropical systems that followed tracks similar to Irene include: Hurricane Floyd (Sept 1999); Hurricane Gloria (Oct 1985); Tropical Storm Doria (Aug. 1971); Hurricane Donna (Sep. 1960); Hurricane #4 (Sep. 1938); and Hurricane #4 (Aug. 1893). The 1893 hurricane season was similar to that of 2011 in that a second tropical system affected the region in late August and brought flooding to Northern New York and the upper Hudson Valley.

Tropical Storm Lee made landfall along the Louisiana coast on September 4th. Moisture from the remnants of Lee spread northeastward along a frontal boundary that was stalled across the Mid-Atlantic States and southern New York. This resulted in an area of extremely heavy rainfall across these regions from September 5 through 10.

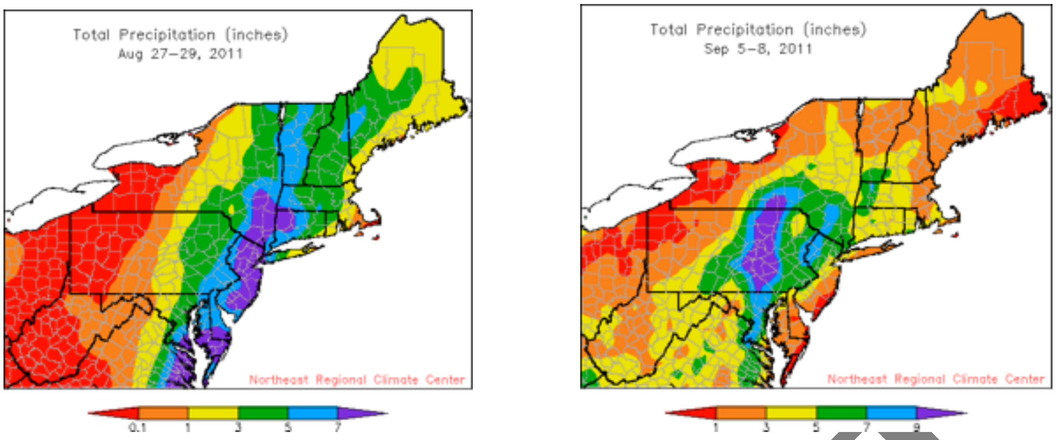
August-September 2011 Rainfall

The heavy rains associated with Irene and Lee were part of a broader pattern of wet weather that exacerbated the flooding associated with the storms themselves. Rainfall totals for August and September exceeded 60 cm (25 in) across the Northeast (**Box Figure 3.1**). These precipitation totals were more than 3 times the normal 2-month accumulation. Most of the precipitation fell in three distinct events, in mid August, late August, and early September.



Box Figure 3.1. Total rainfall for August and September, 2011

A storm system (not tropical in origin) affected New Jersey and the New York City area with in some cases >15 cm (6 in of rainfall) during mid-August. These same areas, received similar precipitation totals in association with Hurricane Irene. Irene produced a broad swath of >5 inches (12 cm) of rain from southern Maryland to northern Vermont from August 27-29 (Figure 2). Finally parts of eastern Pennsylvania and southern New York received in excess of 22 cm (9 inches) of rain associated with the remnants of Tropical Storm Lee. Parts of NJ and NY that saw among the highest rainfall totals with Irene received over 12 cm additional rainfall from September 5-8 (**Box Figure 3.2**).



Box Figure 3.2. Total precipitation associated with Hurricane Irene (left) and Tropical Storm Lee (right)

The rainfall totals associated with these events were in some cases unprecedented. In New York City, August was the wettest of any month on record at both Kennedy and La Guardia Airports. August was New Jersey's wettest month on record. Binghamton, NY experienced the wettest month on record in September. The 2-day rainfall associated with Lee's remnants exceeded the estimated 500-year storm at Owego and Waverly, NY. At both locations more than 20 cm (8 inches) of rain was reported. Overall nine New York stations exceeded their 100-year storm, with three sites receiving rainfall greater with a return frequency of greater than 200 years. The rainfall associated with Irene exceeded the 500-year storm at Delanson, NY and Waterbury, VT. Five other sites in northern Vermont and New York's Adirondack and Catskill Mountain regions reported rainfall amounts in excess of the 200-year storm. New flood stages of record were set at a number of southern and northeastern Vermont river gauging stations. Elsewhere in Vermont, the 1927 and 1938 tropical storm related storm totals, remain as the floods of record.

Impacts

In anticipation of Irene, flights were cancelled, the New York City mass-transit system was shut down, and 2.3 million coastal residents in Delaware, New Jersey and New York faced mandatory evacuations according to National Public Radio reports. As the storm wound down, the impacts to the coastal areas were not as severe as expected, with only a few locations sustaining serious wind damage or beach erosion.

Inland, the already saturated soils could not absorb any more moisture. The resultant flash flooding washed out roads and bridges, undermined railroads, brought down trees and power lines and flooded homes and businesses. Central and southern Vermont bore the brunt of the flood-related damage (**Box Figure 3.2**). Over 500 miles of state-owned roadways and approximately 200 bridges were damaged, with estimated rebuilding costs of $175-250 million. The State Office Complex in Waterbury, VT. Hazardous wastes were mobilized in a number of areas, and 17 municipal wastewater treatment plants were breached by the floodwaters. Agricultural losses included barn structures and flooded cropped fielded that needed to be destroyed. Stream morphology was also affected, even more so as river beds were dredged/excavated immediately following Irene's passage. Finally, many of these infrastructure and riverine impacts led to isolation of many towns and villages in central and southern Vermont. The Civilian Air Patrol (CAP) was critically important in helping to coordinate ground relief efforts by all-terrain vehicles or by helicopter.. In New York, flash floods ravaged towns in the Catskills, washed out roads in the Adirondacks, and closed sections of I-88, the New York Thruway and the Erie Canal. In the Passaic and Raritan River basins of New Jersey, near record floodwater (the second worst flood in each basin) displaced 10,000 people (NY Times estimate) as roads became rivers and homes and businesses filled with water.

Box Figure 3.2. Hurricane Irene damage on Route 4 near Killington, Vermont. Source: Vyto Starinskas, Rutland (Vt.) Herald, via AP.

Irene took at least 23 lives in the Northeast, with people being washed away in floodwaters, electrocuted, and killed by falling trees. Subsequent to the storm, eleven of the Northeast states and the District of Columbia were declared federal disaster areas, making them eligible for federal aid. The economic cost of the storm was estimated to be at least $10 billion (NY Times, August 30, 2011).

A week later, the remnants of Tropical Storm Lee brought similar impacts. Floodwaters on the Susquehanna River in Binghamton, and Owego, NY, and Waverly and Wilkes-Barre, PA crested above the record levels set in June 2006. The Swatara Creek at Hershey, PA crested at 26.8 feet (8.2 m), topping the previous record by more than 10 feet (3.0 m). In anticipation of the flooding, over 100,000 Northeast residents were evacuated in Binghamton, Wilkes-Barre and other affected communities, including 1,000 Maryland residents near the Conowingo Dam. Operators there opened its spill gates to lessen the pressure on the dam. At the height of the event, major highways and minor roads, eroded by rushing water or blocked by mudslides, were closed; one hundred roads and 30 bridges in Pennsylvania remained closed at the end of the month. While the main impact from this event was felt in Pennsylvania and New York, parts of New Jersey and Connecticut that received flooding from Hurricane Irene saw flooding once again from Lee's rainfall. Fifteen counties in New York and 42 counties in Pennsylvania were declared disaster areas.

The total cost of the damage caused by the flooding has not been determined, but one initial estimate, from Dauphin County, PA, where Harrisburg is located, was $151 million. In that county, 294 homes or businesses were destroyed, more than 1000 homes/businesses had major damage, and more than 1200 buildings suffered minor damage. Data compiled by National Weather Service offices estimated Lee's cost at about $1 billion in New York and $294 million in Pennsylvania (Source: Storm Data, NCDC).

Later in September, New York's governor announced additional assistance for flood victims, including $2.4 million to farms affected by Hurricane Irene and Tropical Storm Lee and up to $16 million for a program to provide temporary work to unemployed New Yorkers to assist in rebuilding and reconstruction efforts. In late January 2012, the Maryland, the State Highway Administration was awarded over $6.8 million by the Federal Highway Administration's Emergency Relief Program. The federal dollars were allocated to help cover the costs of repairs to some of the 64 roads and bridges damaged by floodwaters.

Trends

The climate of the Northeast has varied over the last century with temperatures and precipitation generally increasing.

Annual Temperature and Precipitation

Across the Northeast, temperatures have generally remained above the 1895-2010 average for the last 30 years (**Figure 3.4**), both annually and during the winter. The warmest year on record is 1998. The warmest winter on record for the region is 2001-2002. Fifteen of the last twenty winters from 1991-2010 have been above average. Warming has been most pronounced during the winter and spring seasons.

Annual precipitation has varied over time, showing greater variability and higher totals since 1970 **(Figure 3.4)**. The wettest year since 1895 was 1996, while the 4th driest year occurred in 2001. The 1960s were characterized by a very severe, long-term drought that was particularly severe in New England region, where it spanned almost the entire decade. The Northeast's three driest years were 1930, 1941, and 1965. Summer precipitation does not exhibit an overall trend. But, over the past 10 years, there have been a few very wet summers, including the wettest summer of the period 1895-2010 in 2006 and the second wettest in 2009.

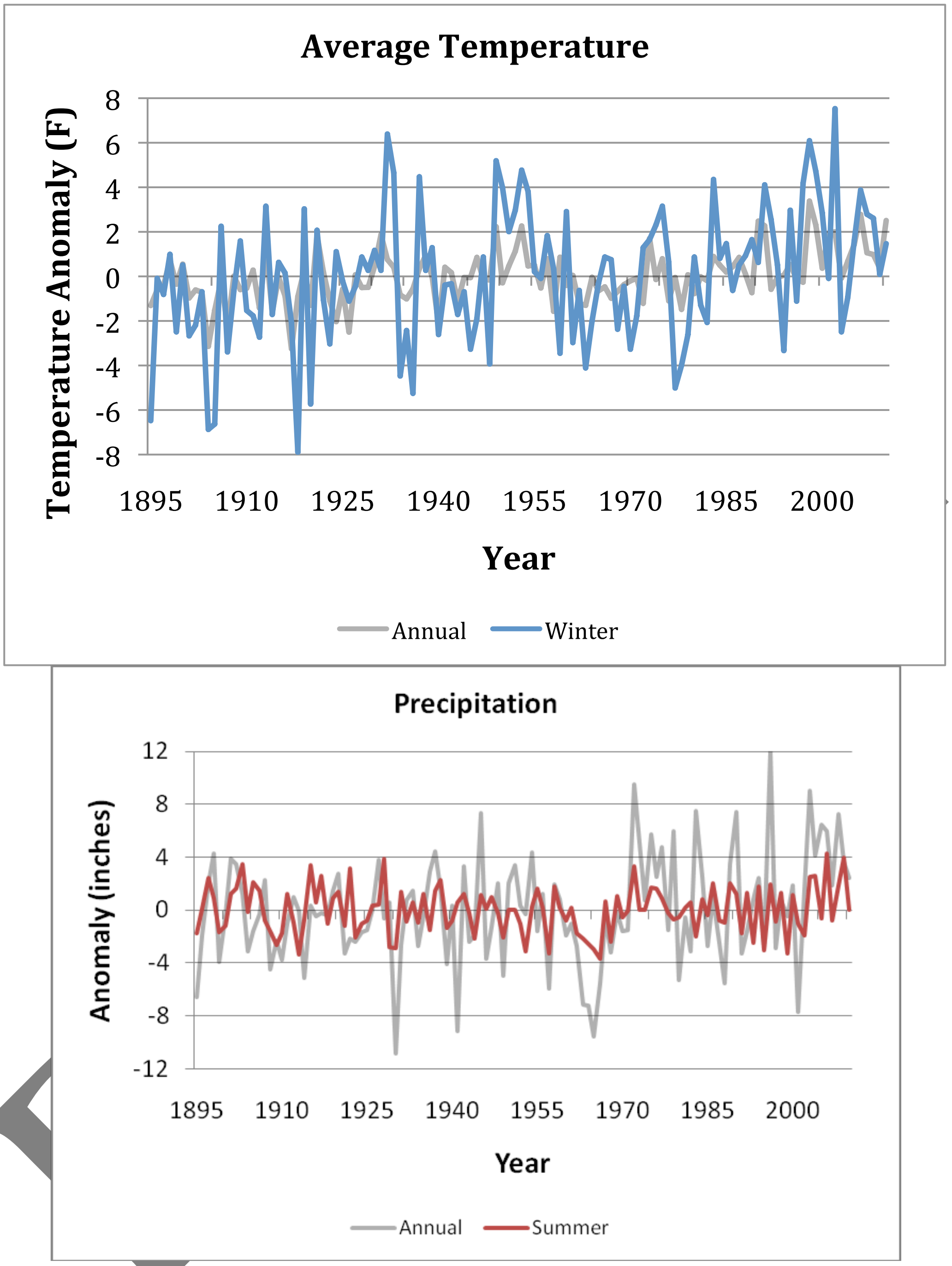


Figure 3.4. Annual and seasonal temperature and precipitation anomalies for DE, ME, NH, VT, MA, RI, CT, NY, NJ, PA, MD, and WV. (Source: Based on data from the National Climatic Data Center for the cooperative observer network).

Heavy Precipitation

There is substantial decadal-scale variability in the number of extreme precipitation events since around 1935. **Figure 3.5** is a time series of an index of the number of Northeast precipitation events exceeding a 1 in 5-year recurrence interval for events with a 1-day and 5-day duration. The index has generally been high since the 1990s, indicating more frequent and extreme precipitation during that period. The time series for 1-day and 5-day events track each other fairly well throughout the time period. The highest index values for both the 1-day and 5-day events occurred in 2008. The Index was very low in the 1960s, coinciding with widespread drought conditions that affected the Northeast.

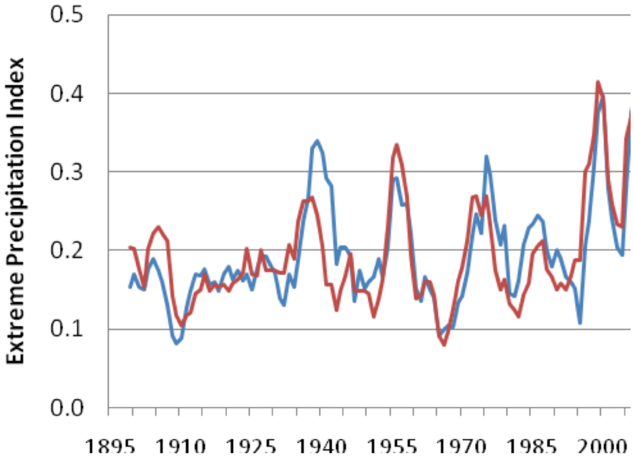


Figure 3.5. Time series of extreme precipitation index (using 5-year running average) for the occurrence of 1-day, 1-in-5 year extreme precipitation events (red) and 5-day, 1-in-5 year events (blue). Analysis is average for the states of DE, ME, NH, VT, MA, RI, CT, NY, NJ, DE, MD, PA, and WV. Based on data from the National Climatic Data Center for the cooperative observer network and updated from Kunkel et al. (2003).

The recent elevated level in extreme precipitation also manifests itself in estimates of longer recurrence intervals for rainfall. These values are used in engineering design and governmental regulations. Commonly these rainfall extremes are known as the 50- or 100-year storm and represent the amount of rainfall that can be expected to occur on average once in 50 (or 100) years. In terms of design specifications, an increase in extreme rainfall lowers the expected recurrence interval of a specific precipitation amount. Thus the amount of rain that was expected to occur once in 100 years, may now occur on average once every 60 years. This could lead to the premature failure of infrastructure or more frequent infrastructure disruptions. DeGaetano (2009) showed that what would be expected to be a 100-year event based on 1950-1979 data, occurs with an average return interval of 60-years when data from the 1978-2007 period are considered. Similarly, the amount of rain that constituted a 50-year event during 1950-1979 is expected to occur on average once every 30 years based on the more recent data.

Extreme Temperature

Figures 3.6 and 3.7 are time series of an index of the number of 4-day and 7-day cold wave and heat wave events, respectively, exceeding a threshold for a 1-in-5-year recurrence interval. Extreme events are first identified for each individual climate observing station. Then, to compute an annual index, the individual station events were summed and divided by the total number of observing stations. There is a large amount of interannual variability in extreme cold periods and extreme hot periods, reflecting the fact that, when they occur, such events affect large areas and thus a large number of stations in the region simultaneously experience an extreme event exceeding the 1-in-5-year threshold. The frequency of extreme cold periods was high early in the record, followed by a quieter period and has been generally less since a peak in the 1970s and early 1980s (**Figure 3.6**). During the period of 1977-1984, the cold wave index averaged more than double the 1895-2010 average, while since 1985 the index has averaged about 30% below the long-term average. The highest value for the 4-day index occurred in 1979. Other notable years with high values of the index were 1912 and 1961. The period of the 1920s into the early 1950s was characterized by very low values of the cold wave index. Such decreases in cold-temperature extremes are also illustrated by the northern migration of plant hardiness zones on the recently released USDA plant hardiness map (http://planthardiness.ars.usda.gov/PHZMWeb/). These zones are based on extreme winter temperatures.

The occurrence of heat waves, as illustrated by the heat wave index time series shown in **Figure 3.7**, can be divided into 3 periods. The period from the late 19th century into the 1950s was characterized by a moderately high number of heat waves. From the late 1950s into the early 1980s, there were few intense heat waves. Since the late 1980s, the frequency of heat waves has been similar to the early half of the 20th century. The highest value of the heat wave index occurred in 1988, a year of intense drought throughout much of the nation. More recently, the years of 2001, 2002, 2006, and 2010 were characterized by moderately high values of the heat wave index.

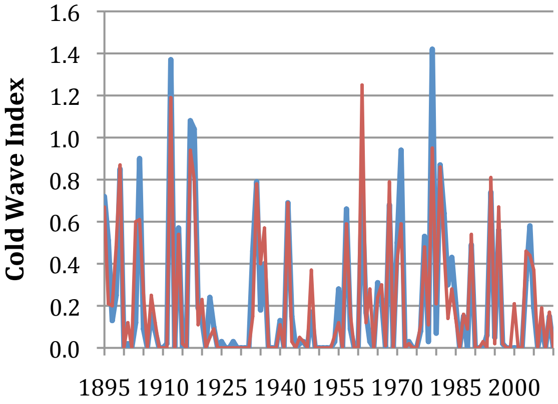


Figure 3.6. Time series of a cold wave index for the occurrence of cold waves defined as 4-day periods (blue) and 7-day periods (red) that are colder than the threshold for a 1-in-5 year

recurrence. Based on data from the National Climatic Data Center for the cooperative observer network and updated from Kunkel et al. (1999).

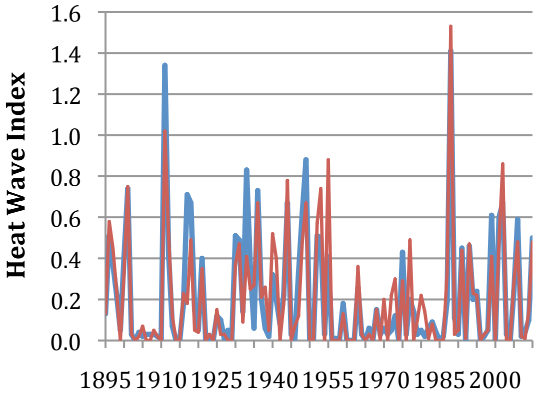


Figure 3.7. Time series of a heat wave index for the occurrence of heat waves defined as 4-day periods (blue) and 7-day periods (red) that are hotter than the threshold for a 1-in-5 year recurrence. Based on data from the National Climatic Data Center for the cooperative observer network and updated from Kunkel et al. (1999).

Growing Season

The freeze-free season length in the Northeast exhibited relatively minor fluctuations in the decadal-scale average from the beginning of the record (1895) into the 1980s (**Figure 3.8**). There has been a generally increasing trend since the mid-1980s in growing (freeze-free) season length. The last occurrence of 32°F in the spring has been occurring earlier and the first occurrence of 32°F in the fall has been happening later, with the change in the spring date more pronounced than the fall (Hayhoe et al., 2006). The longest and second longest growing season occurred in 2007 and 2004, respectively. The average growing season length during 1991-2010 was about 10 days longer than during 1961-1990. This latter period included a 5-yr sequence of years (1963-1967) with very short growing seasons.

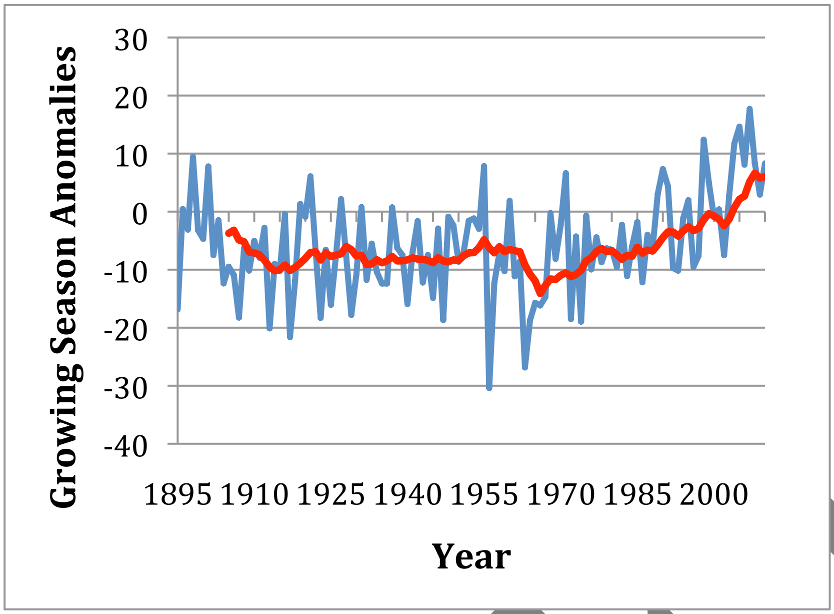


Figure 3.8. Growing season anomalies shown as number of days per year. Length of the growing season is defined as the period between the last occurrence of 32°F in the spring and first occurrence of 32°F in the fall. The red line is a 11-yr moving average. Based on data from the National Climatic Data Center for the cooperative observer network and updated from Kunkel et al. (2004).

River Flow

The spring center of volume date is a measure of the seasonality of river flow volume. It defines the date on which half of the total river flow volume over the period from January through May passes a point. In terms of climate, this is an integrative measure as the volume of river flow is a function of temperature, particularly with regard to snowmelt, precipitation and antecedent soil moisture. Hodgkins et al. (2003) analyzed spring center of volume data from 27 rural, river-gauging stations in New England over the period 1900-2000 (**Figure 3.9**). These streams were selected such that their flow had minimal human influence and thus climate effects were the clearest. On all streams, the spring center of volume date has become earlier. This is especially true on the eleven streams where spring flow is most affected by runoff from snowmelt. On average over the last 30 years, these dates have occurred one to two weeks earlier in the year. Such changes in the timing of spring stream flow affect fish, including salmon, and other aquatic organisms in both the streams and coastal estuaries. Human activities such as recreation (e.g.. rafting) and reservoir recharge rules are also affected. These practices may have to be modified to accommodate the earlier timing of runoff.

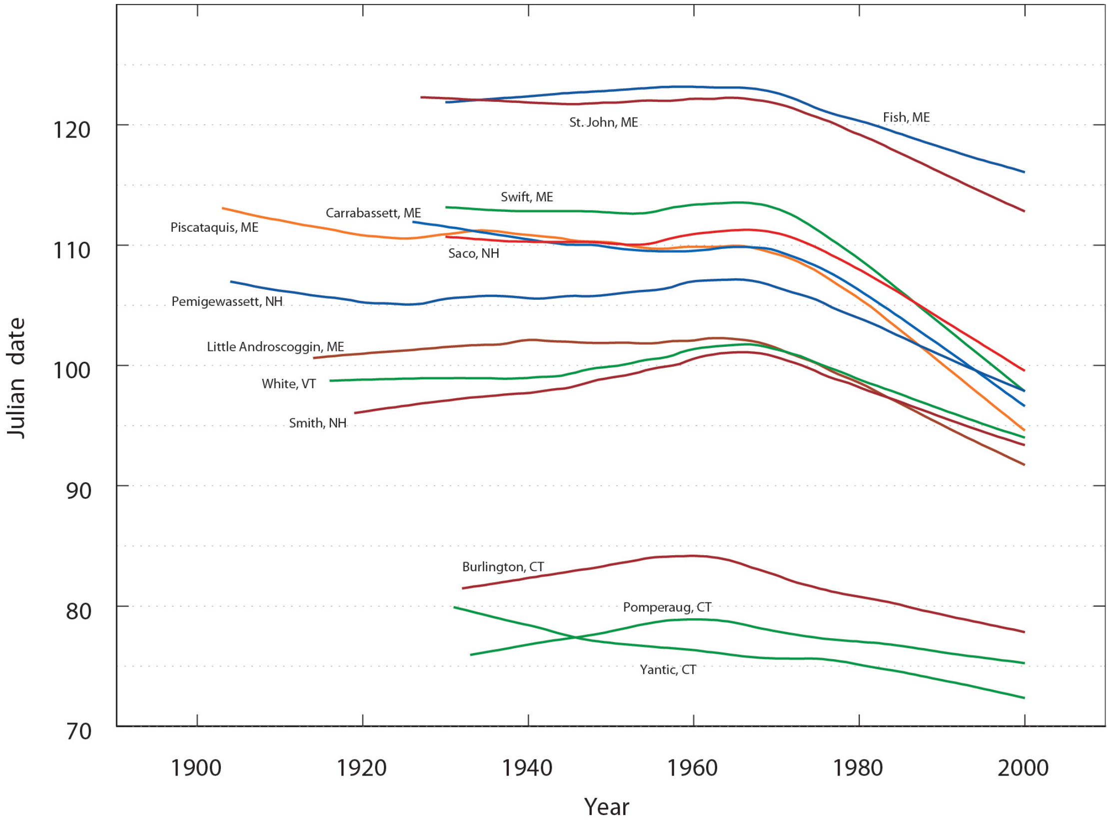


Figure 3.9. Smoothed winter/spring center of volume dates for the 13 longest-record rural, unregulated rivers in New England. (From Hodgkins et al. 2003)

Lake Ice Cover

A long-term record of the date of ice-in on Lake Champlain between New York and Vermont shows that the lake now freezes approximately two weeks later than it did in the early 1800s and over a week later than it did 100 years ago **(Figure 3.10).** Later ice-in dates are an indication of warmer lake temperatures, as it takes longer for the warmer water to freeze in winter. Prior to 1950, the absence of winter ice cover on Lake Champlain was rare, occurring three times in the 1800s and another three times between 1900 and 1940. Since 1970 Lake Champlain has remained ice-free during 18 winters (Figure 3.10).

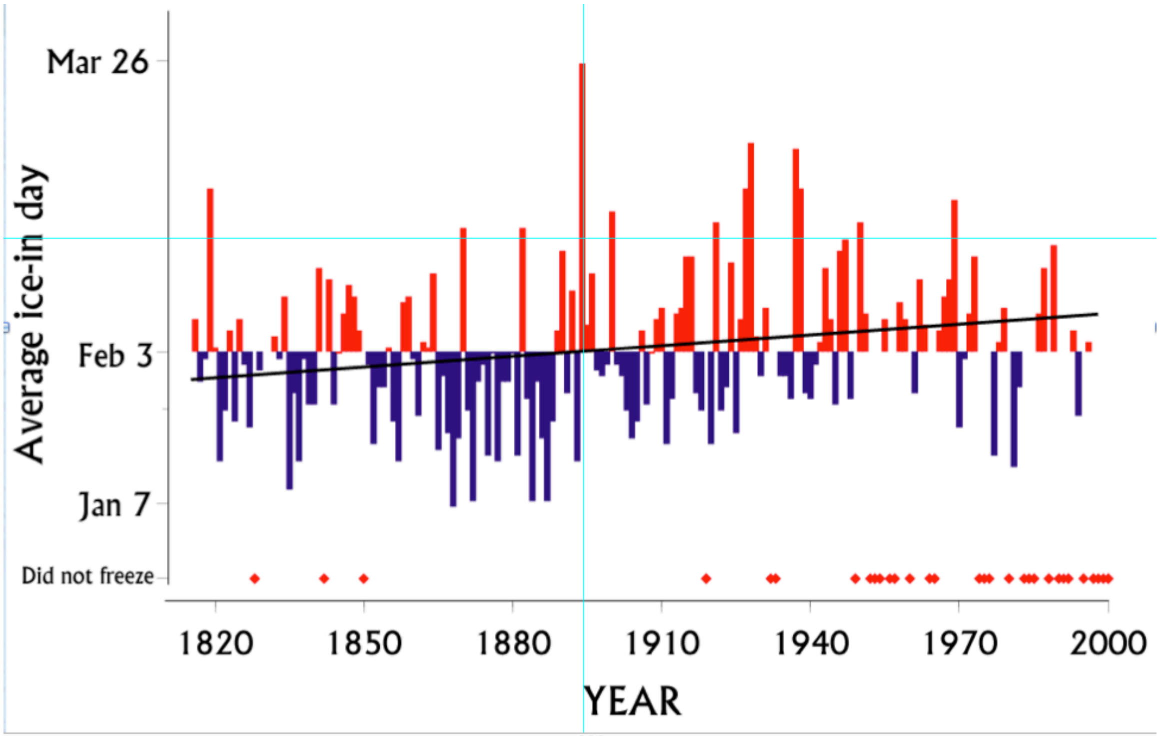


Figure 3.10. Date of ice-in on the main portion of Lake Champlain. Asterisks denote years in which the Lake remained ice-fee. [Data from NOAA http://www.erh.noaa.gov/btv/climo/lakeclose.shtml]

Snow Depth

Like other winter phenomena, snow depth has shown decreases over recent decades. In Maine, Hodgkins and Dudley (2006) analyzed snow depth data from 23 long-term snow-depth measurement sites. Eighteen of the sites had statistically significant decreases in snow depth (**Figure 3.11**). At mountainous sites along the Maine-New Hampshire border, average snow depth decreased by approximately 16% from 1926-2004. Across the region, snow depth data from the NOAA Historical Climatology Network stations show a decrease in the number of days with at least an inch of snow on the ground.

Hayhoe et al. 2007, show the number of snow-cover days, defined mean snow water equivalent is greater than 0.2 inches (5 mm) has decreased at a rate of 0.04 days/month/decade during the 1950-1999 period and a rate of 0.5 days/month/decade during the 1970-1999 period across the Northeast (**Figure 3.12**). These data are simulated based on observed temperature and precipitation data using the Variable Infiltration Capacity (VIC) model (Ling et al. 1994).

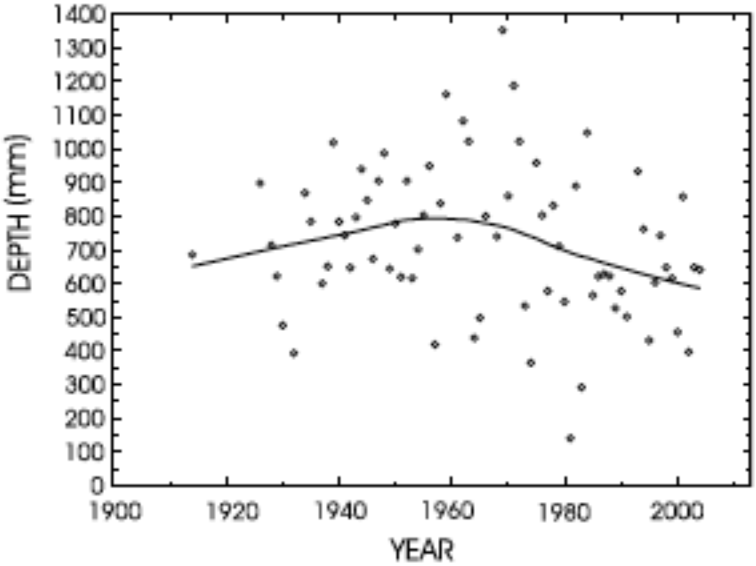


Figure 3.11. Time series of average snow depth at 23 snow course sites in Maine. Data from Hodgkins and Dudley (2006)

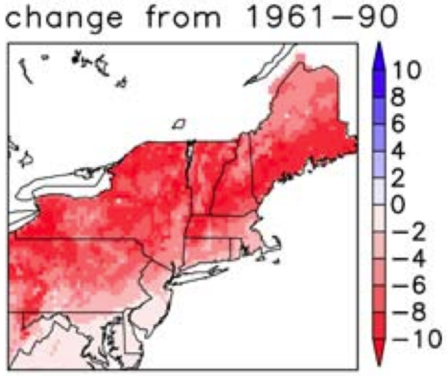


Figure 3.12. Difference in number of snow-covered days per winter month (DJF) averaged over 1961-90 (Hayhoe et al. 2007).

Sea Level Rise

Sea level along the Northeast Coast has varied through time but accelerated sea level rise has been observed during the 20th century (Rosenzweig, et al. 2012). Over the past thousand years, regional sea level was rising at a rate of 0.34 to 0.43 inch per decade. This rise varied geographically along the east coast and was primarily the result of the sinking of the Earth's crust, as it continued to adjust from the melting of the ice sheets associated with the last ice age. Such adjustment is a slow geological process. More recently, the rate of sea level rise along the Northeast Coast has increased. On average during the 20th century, sea level rose by 1.2 inches per decade. This reflects the increase in ocean water volume as the oceans warm as well as the melting of glaciers and ice sheets, in addition to the geological processes. **Figure 3.13** shows the change in sea level at four major northeast coastal cities. The rate of change at each site has been similar in recent decades.

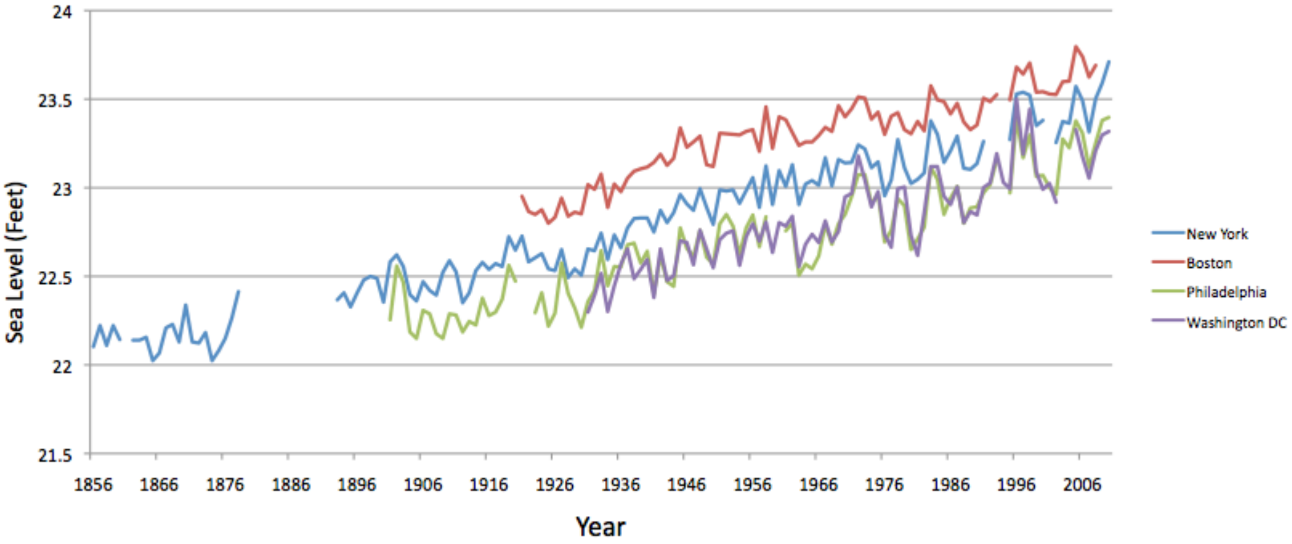


Figure 3.13. Annual mean sea level for gauges at four major Northeast coastal cities. Data from http://www.psmsl.org/data/obtaining/.

Great Lakes

One fifth of the world's fresh water resides in the Great Lakes. Lakes Erie and Ontario border the Northeast region to the north and west. They are an important resource for water supply, hydropower generation, recreation, and transportation (particularly via the St Lawrence Seaway). Long-term water levels in Lake Ontario and Lake Erie have remained fairly constant through time, in part because the levels can be manually regulated by locks and dams. Nonetheless, Lake levels show marked variability from year to year and decade to decade (**Figure 3.14**). The major drought that characterized the early 1960s in the Northeast is reflected in the Lake level record.

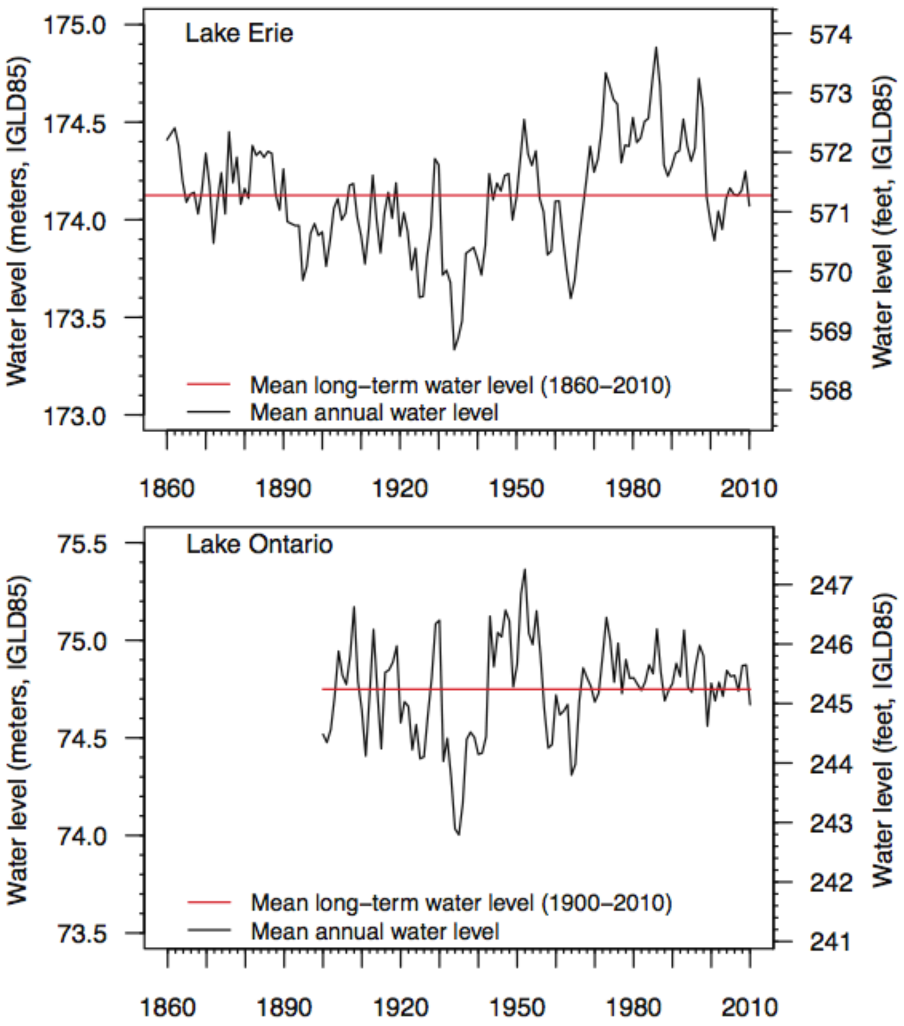


Figure 3.14 Time series of water levels in Lake Erie and Lake Ontario based on the most recent standard reference point (IGLD85).

Lake water temperatures are also an important climate indicator for the Lakes. They affect the health of the Lake's ecosystems, the cooling capacity of lakeshore power generation plants and the potential for winter lake-effect snow. **Figure 3.15** shows a time series (1968-2002) of surface water temperature from different sections of Lake Ontario (Dobiesz and Lester, 2009). Significant trends toward warmer lake temperatures are apparent in three of the four sub basins. Across the four basins, August temperatures have increased by 2.9°F. Surface water temperatures in Lake Erie have also increased, but at a much lower rate of 0.045 °F/year across all basins. The other Great Lakes are not excluded from this warming trend. Lake Huron's temperatures have had the largest increase for August of 5.22 °F (0.151 °F/year) (Dobiesz and Lester, 2009). A study of July through September lake temperatures determined that Lake Superior had increased at a rate of 0.216°F/year from 1979 to 2006 and Lake Michigan had increased at a rate of 0.116°F/year during the same period (Austin and Colman, 2007).

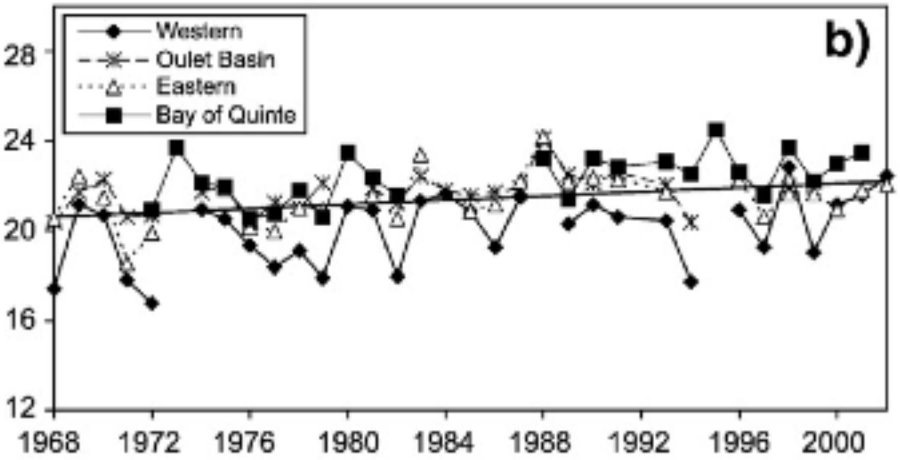


Figure 3.15. Surface water temperatures in four sub-basins of Lake Ontario in August, from (Dobiesz and Lester, 2009).

Summary

The Northeastern United States is characterized by a number of unique climate and societal features. Large coastal population centers are vulnerable to rising sea level as well as potential changes in the frequency and strength of coastal storm systems. Unlike other U.S. coastal areas, strong extratropical storms impact the coast in winter (Nor'easters) while tropical cyclones are a risk in late summer. Inland, the Appalachian Mountains provide a focus for increased flood risk, while the Great Lakes are responsible for heavy Lake effect snowstorms.

Since 2000, the Northeast has seen continued trends toward warmer temperatures, particularly in winter, and increased rainfall. Trends in extreme rainfall have been especially pronounced, where data show that rainfall totals that were considered 1-in-100-year events in the 1950-1978 period occur with an average of return frequency of 60 years when data from the 1978- 2007 period are considered. Recent trends toward earlier high river flows, reduced snow cover and decreased lake ice occurrence highlight the impacts of winter warming in the region.

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Acknowledgements

Document and graphics support provided by Brooke Stewart and by the Department of Atmospheric Sciences, University of Illinois at Urbana-Champaign (Prof. Don Wuebbles and Emily Janssen). Analysis support provided by Russell Vose of NCDC. We thank the following State Climatologists: Paul Knight (Pennsylvania), Dave Robinson (New Jersey), Lesley-Ann Dupigny-Giroux (Vermont) and Kevin Law (West Virginia) for their contributions and suggestions.

3.3 Climate Projections

Lead Authors - Kenneth E. Kunkel, Radley Horton, Daniel Bader, Scott E. Stevens, Laura E. Stevens, and Cynthia Rosenzweig

Background

The core source of projections is the set of model simulations performed for the IPCC Fourth Assessment Report (AR4), also referred to as the Climate Model Intercomparison Project 3 (CMIP3) suite. These have undergone extensive evaluation and analysis. A second source is a set of statistically-downscaled data sets based on the CMIP3 simulations. A third source is a set of dynamically-downscaled simulations, driven by CMIP3 models. This outlook does not incorporate any CMIP5 simulations as relatively few are available at the present time.

The following outlook information provides statistics for the periods of 2021-2050, 2041-2070, and 2070-2099, with changes calculated with respect to the historical climate reference period of 1971-2000. These future periods are denoted by the 2030s, 2050s, and 2080s, respectively.

Description of Data Sources

This initial outlook for the National Climate Assessment (NCA) Northeast region is based on the following model data sets:

- CMIP3 GCM output – Fifteen global climate models identified in the 2009 NCA report were used. These also serve as the basis for the following downscaled data sets.

- Statistically-downscaled monthly temperature and precipitation – These data are at 1/8° (latitude and longitude) resolution. The data were downscaled using the bias-corrected spatial disaggregation (BCSD) method. Sixteen models were downscaled for the period of 1961-2100.

- Statistically-downscaled daily temperature and precipitation – These data are also at 1/8° (latitude and longitude) resolution. Daily data were created from the monthly data by randomly sampling historical months and adjusting the values using the “delta” method. Sixteen models were downscaled for the period of 1961-2100.

- The North American Regional Climate Change Assessment Program (NARCCAP) – This multi-institutional program is producing regional climate model (RCM) simulations in a coordinated experimental approach. At this time, there are 9 simulations available using different combinations of a RCM driven by a GCM. Each simulation includes the periods of 1971-2000 and 2041-2070 for the A2 scenario only, and is at a resolution of approximately 50 km.

Mean Temperature Projections

Figure 3.16 shows the spatial distribution of the 15 CMIP3 multi-model mean annual temperatures for the Northeast for the three future time periods (2030s, 2050s, 2080s) and two emissions scenarios (A2, B1). Changes along the coastal areas are slightly smaller than inland areas. Also, the warming tends to be slightly larger in the north, from the Great Lakes along the Canadian border into Maine.

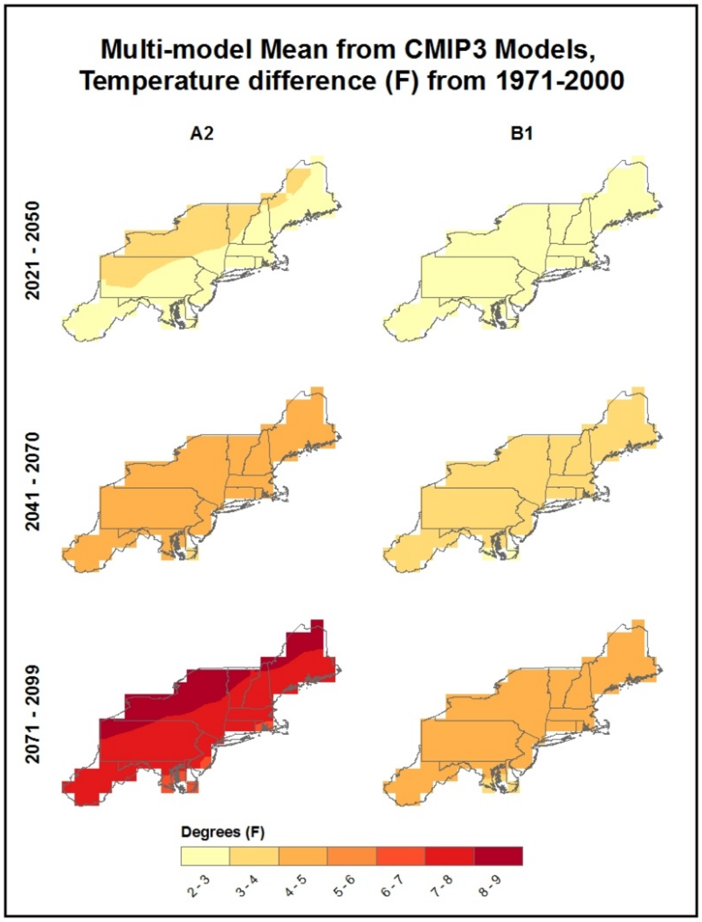


Figure 3.16. Multi-model mean annual differences in temperature (°F) between the 3 future periods and 1971-2000, from the 15 CMIP3 model simulations.

Figure 3.17 shows the mean annual and seasonal temperature changes between 2041-2070 and 1971-2000 for the A2 scenario, for the 9 NARCCAP regional climate model simulations. Annual warming increases with latitude, ranging from 3.5-4°F near Chesapeake Bay to 4.5-5°F in upstate New York and much of New England. Seasonal changes show more spatial variability, with winter increases ranging from 3.5- 4°F in the southwestern part of the region to 5.5- 6°F in northern Maine. Springtime increases are similar, although smaller in magnitude, ranging from 3-3.5°F in the southwestern part of the region to 4-4.5°F in isolated spots along the coastline from eastern Massachusetts to Maine. Summer and fall show a reversed spatial pattern, with the greatest increases in the southwestern part of the region. Summer shows a maximum increase of 5 to 5.5°F in western Pennsylvania and West Virginia, and the smallest change in Maine, approximately 4 to 4.5°F. Fall shows less spatial variability, with values ranging between 4 and 4.5°F in New England to between 4.5 and 5°F over the remainder of the region.

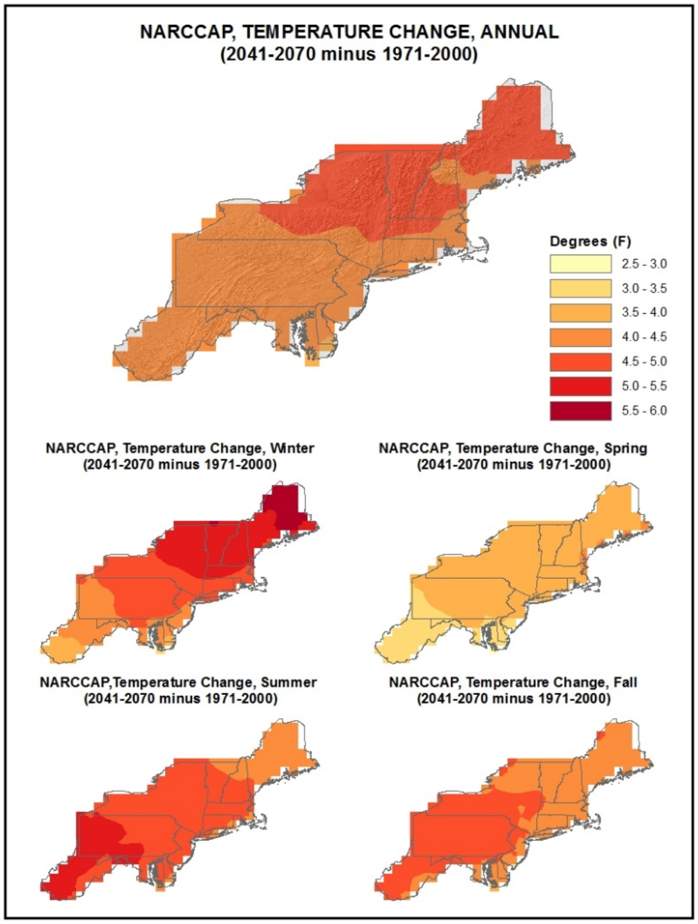


Figure 3.17. Multi-model mean annual and seasonal differences in temperature (°F) between 2041-2070 and 1971-2000, from the 9 NARCCAP regional climate model simulations.

Figure 3.18 shows the mean annual temperature changes for each future time period and both emissions scenarios, averaged over the entire Northeast region for the 15 CMIP3 models. In addition, averages for the 9 NARCCAP simulations and the 4 GCMs used in the NARCCAP experiment are shown for the 2050s (A2 scenario only). The small plus signs are values for each individual model, and the circles depict the overall means. For the A2 scenario, the CMIP3 models project average increases of 2.7°F by the 2030s, 4.3°F by the 2050s, and 7.5°F by the 2080s. The difference between the two emissions scenarios widens over time, with average increases for the B1 scenario of 2.1°F by the 2030s, just over 3°F by the 2050s, and approximately 4°F by the 2080s. For the 2050s, the average temperature change simulated by the NARCCAP models is close to that of the average of all of the CMIP3 GCMs and the average of the 4 NARCCAP GCMs.

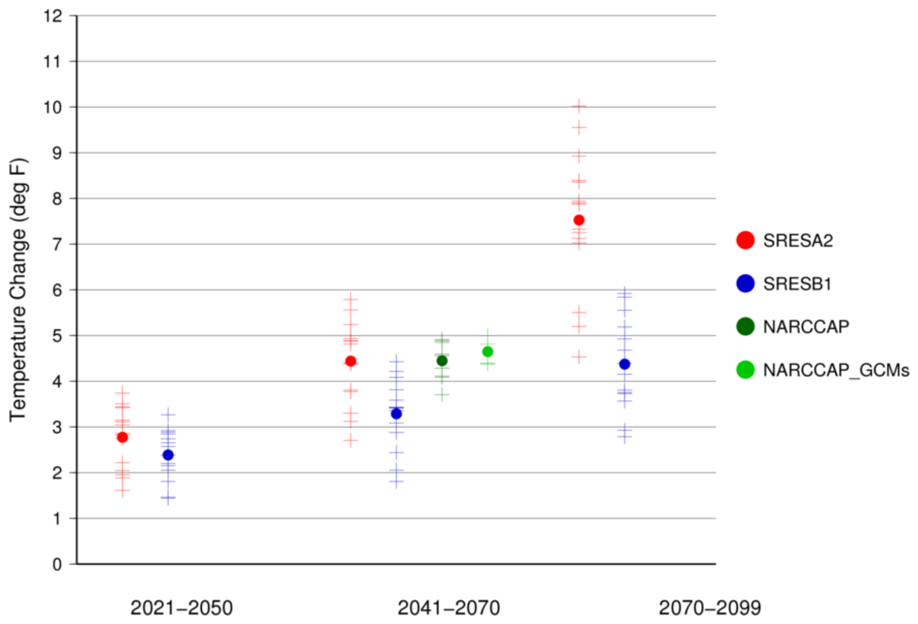


Figure 3.18. Mean annual temperature changes (°F) for each future time period with respect to the reference period of 1971-2000 for all 15 CMIP3 models, averaged over the entire Northeast region for the high (A2) and low (B1) emissions scenarios. Also shown are results for the NARCCAP simulations for 2041-2070 and the 4 GCMs used in the NARCCAP experiment (A2 only). The small plus signs are values for each individual model and the circles depict the overall means.

A key overall feature is that early in the 21st century, the multi-model mean temperature changes are relatively insensitive to the emissions path but late 21st Century changes are sensitive to the emissions path. However, the range of individual model changes is large.

Figure 3.19 shows the mean seasonal changes for each future time period for the A2 scenario, averaged over the entire Northeast region for the 15 CMIP3 models. Temperature increases are largest in the summertime, with means around 3°F in the 2030s, 5°F in the 2050s, and almost 9°F in the 2080s. Wintertime experiences the lowest warming, but the means still increase over time, starting at 2°F in the 2030s and ending just over 6°F in the 2080s.

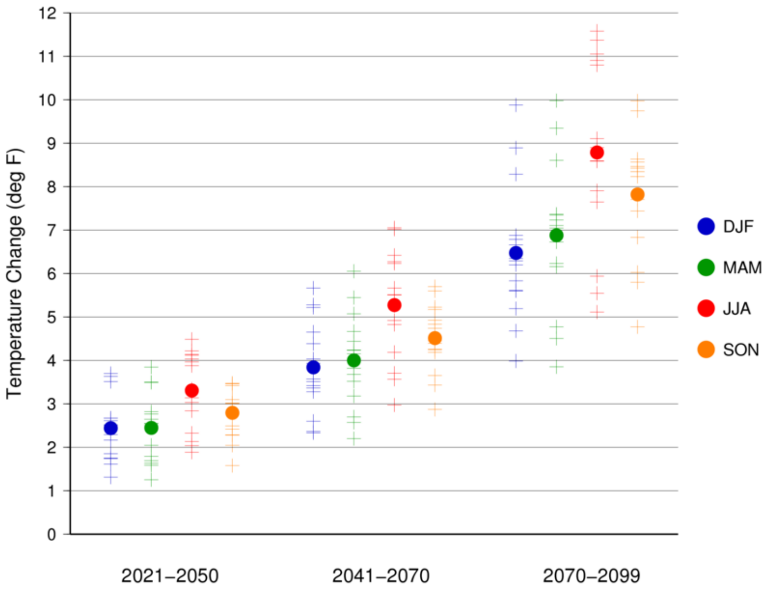


Figure 3.19. Mean seasonal temperature changes (°F) for each future time period with respect to the reference period of 1971-2000 for all 15 CMIP3 models, averaged over the entire Northeast region for the high (A2) emissions scenario. The small plus signs are values for each individual model and the circles depict the overall means.

The distribution of changes in mean annual temperature for each future time period and both emissions scenarios across the 15 CMIP3 models is shown in **Table 3.1**. The range of changes from lowest to highest varies from 1.4°F in the 2030s for the B1 scenario to 10.0°F in the 2080s for the A2 scenario.

Table 3.1. Distribution of changes in mean annual temperature (°F) for the Northeast region for the 15 CMIP3 models.

Scenario	Period	Low	25%ile	Median	75%ile	High
A2	2021-2050	1.6	2.1	2.9	3.3	3.7
	2041-2070	2.7	3.8	4.8	5.0	5.8
	2070-2099	4.5	7.1	7.9	8.4	10.0
B1	2021-2050	1.4	2.1	2.5	2.8	3.3
	2041-2070	1.8	2.9	3.4	3.8	4.4
	2070-2099	2.8	3.7	4.3	5.1	5.9

This table illustrates the overall uncertainty arising from the combination of model differences and emission pathway. For the 2030s, the projected changes range from 1.4°F to 3.7°F and arise almost entirely from model differences. By the 2080s, the range of projected changes has increased to 2.8°F to 10.0°F, with roughly equal contributions to the range from model differences and emission pathway uncertainties.

Extreme Temperature Projections

A number of metrics of extreme temperatures were calculated from the daily NARCCAP and CMIP3 daily statistically-downscaled data sets. Maps of a few selected variables and a table summarizing the results follow. Each figure includes the difference between the the 2050s period (2041-2070) and the climatology reference period (1971-2000), as well as a map of the reference period for comparison.

Figure 3.20 shows the spatial distribution of the NARCCAP multi-model mean change in the number of days with maximum temperatures exceeding 95°F, between the 2050s and the historical reference period. The largest absolute increases of more than 15 days occur in the far south and west of the region where the number of occurrences in the present climate is the highest. Parts of West Virginia and Maryland may see the number of days with maximum temperatures exceeding 95°F per year increase by more than 20. The smallest increases of less than 5 days occur in the northernmost areas of Maine, New Hampshire, Vermont and northern New York, where the general increase in temperature is not large enough to substantially increase the chances for such hot days.

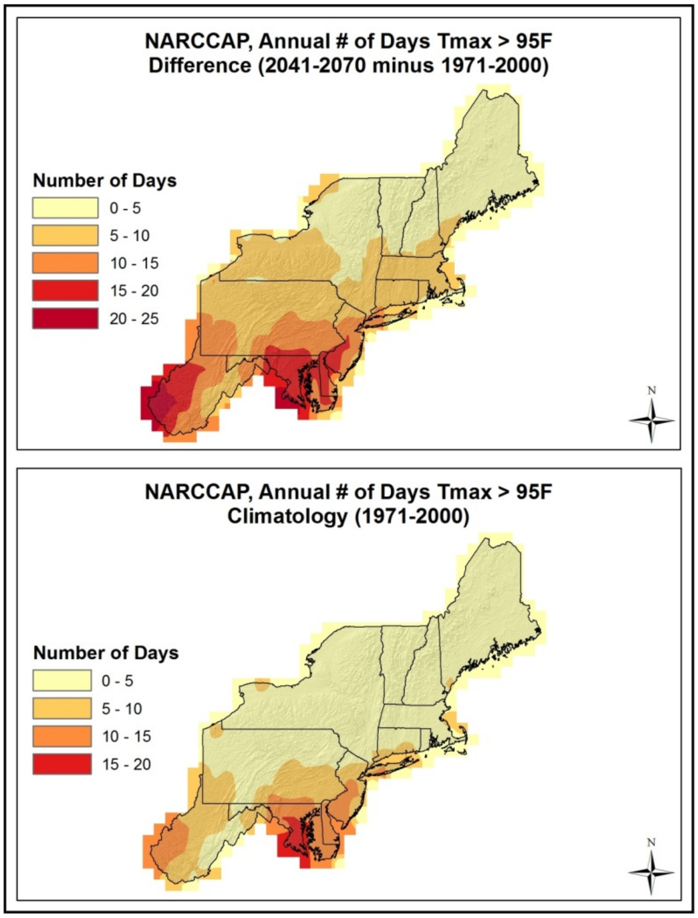


Figure 3.20. Spatial distribution of the NARCCAP multi-model mean change in the number of days with a maximum temperature greater than 95°F between 2041-2070 and 1971-2000 (top). Climatology of the number of days with a maximum temperature greater than 95°F (bottom).

Figure 3.21 shows the spatial distribution of the NARCCAP multi-model mean changes in the number of days with minimum temperatures below 10°F between the 2050s and the historical reference period. All parts of the region are projected to experience a decrease in the number of cold days. The largest absolute decreases occur in the north of the region with some areas decreasing by 20 days or more. The smallest decreases occur in coastal and southern areas where the number of occurrences in the present-day climate is small.

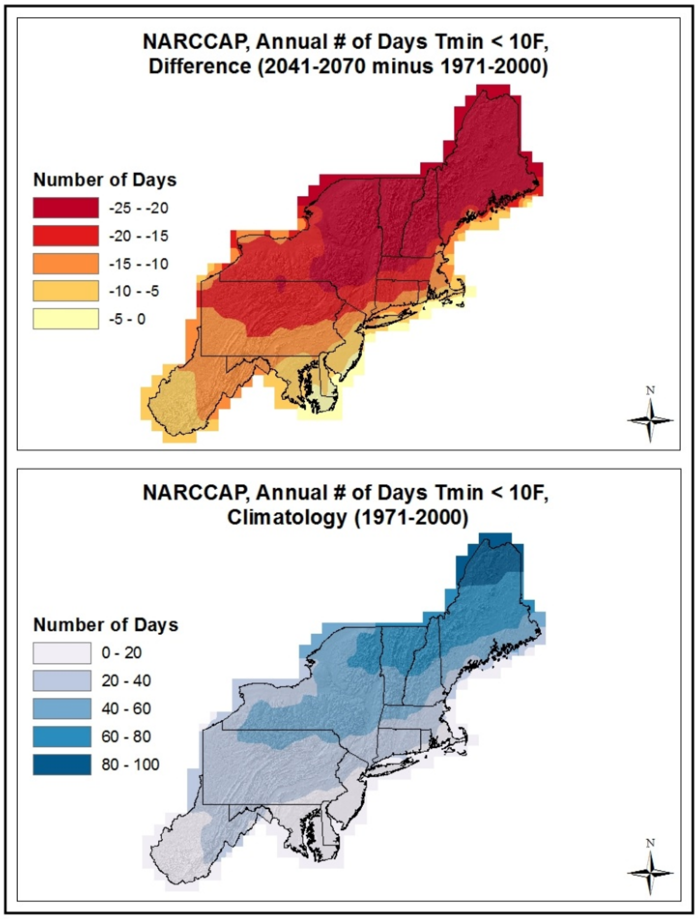
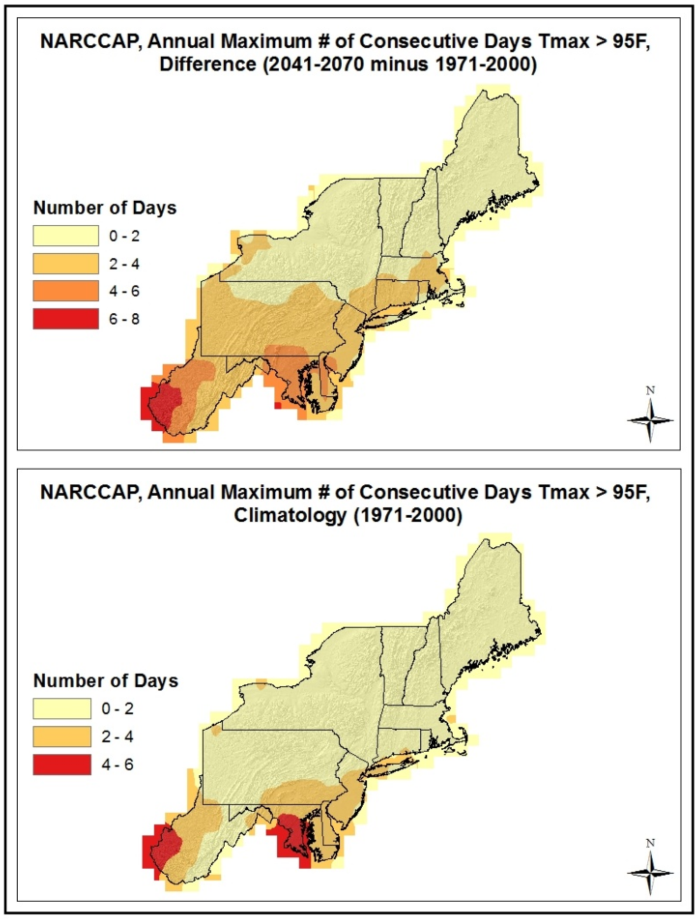


Figure 3.21. Spatial distribution of the NARCCAP multi-model mean change in the number of days with a minimum temperatures below 10°F between 2041-2070 and 1971-2000 (top). Climatology of the number of days with a minimum temperature less than 10°F (bottom).

Consecutive warm days can have large impacts and are analyzed here as one metric of heat waves. **Figure 3.22** shows the NARCCAP multi-model mean change in the average annual maximum run of days with maximum temperatures exceeding 95°F between the 2050s and the historical reference period. The pattern is roughly similar to the change in the total number of days exceeding 95°F for both the difference map, as well as its respective climatology. In most of New York and New England increases are small (less than 2 days), whereas areas further south are generally in the range of 2-6 days. The greatest increases are in western West Virginia where the average annual longest string of days with such high temperature increases by 6 days or more.


NARCCAP, Annual Maximum # of Consecutive Days Tmax > 95F, Difference (2041-2070 minus 1971-2000)

NARCCAP, Annual Maximum # of Consecutive Days Tmax > 95F, Climatology (1971-2000)

Figure 3.22. Spatial distribution of the NARCCAP multi-model mean change in the annual maximum number of consecutive days with a maximum temperature greater than 95°F between 2041-2070 and 1971-2000 (top). Climatology of the annual maximum number of consecutive days with a maximum temperature greater than 95°F (bottom).

The mean changes for selected temperature-based derived variables from the NARCCAP simulations between the 2050s and the historical reference period are summarized in **Table 3.2**. These were determined by first calculating the derived variable at each grid point. Then the spatially-averaged value of the variable was calculated for the present and each future period. Finally, the future-present difference or ratio was calculated from the spatially-averaged values. In addition, these same variables were calculated from the CMIP3 daily statistically-downscaled data set for comparison.

Table 3.2. The mean and standard deviation of changes in selected temperature variables for the NARCCAP simulations. Mean changes from the CMIP3 statistically-downscaled analyses are also shown for comparison.

Variable Name	NARCCAP Mean Change	NARCCAP St. Dev. of Change	Statistically-Downscaled Mean
Freeze-free period	+26 days	5 days	+22 days
#days Tmax > 90°F	+13 days	7 days	+16 days
#days Tmax > 95°F	+8 days	6 days	+5 days
#days Tmax > 100°F	+4 days	5 days	+1 day
#days Tmin < 32°F	-26 days	3 days	-22 days
#days Tmin < 10°F	-17 days	4 days	-13 days
#days Tmin < 0°F	-9 days	4 days	-6 days
Max run days > 95°F	+171%	105%	+338%
Max run days > 100°F	+237%	212%	+940%
Heating degree days	-16%	1%	-17%
Cooling degree days	+99%	32%	+93%
Growing degree days (base 50°F)	+41%	6%	+36%

For the NARCCAP data, the average freeze-free period increases by 26 days by the 2050s. The number of days with daily maximum temperatures exceeding various thresholds increases by 13, 8, and 4 days for thresholds of 90°F, 95°F, and 100°F, respectively. The number of days with minimum temperatures falling below various thresholds decreases by 26, 17, and 9 days for thresholds of 32°F, 10°F, and 0°F, respectively. A measure of heat waves is the run of days exceeding thresholds. The average annual maximum run of days exceeding thresholds of 95°F and 100°F increases by 171% and 237%, respectively, a significant increase in the length of such hot periods. Heating degree days (a climatic metric related to the energy required for heating in the cold season) decreases by 16% while cooling degree days (a climatic metric related to the energy required for cooling in the warm season) increases by 99%. The number of growing degree days increases by 41%.

For the variables calculated from the CMIP3 daily statistically-downscaled data set, the values are mostly comparable. The number of days with the maximum temperature greater than 90°F increases slightly less in the statistically-downscaled data set (+22 days) than in NARCCAP (+26 days). There is, however, a larger increase in the run of days the maximum temperature exceeds 95°F and 100°F in the statistically-downscaled data set. The number of days with the minimum temperature less than 32°F decreases slightly less in the statistically-downscaled data set (-22 days) than in NARCCAP (-26 days).

Projections for other Temperature Variables

Changes in the variability of temperature can magnify or ameliorate the impacts of mean temperature changes. The monthly BCSD time series were used to calculate variability on the interannual and interseasonal time scales. The variability measure is the standard deviation of annual or seasonal mean values of temperature. Changes were calculated as the percent change in standard deviation between the future and present periods. The quantile mapping that constitutes the core of the BCSD methodology will have equal effects on the present and future simulated variability for all anomalies that are within the range of the control simulation. However, if future values fall outside of the control simulation range, an empirical procedure is used to extend the mapping function. There is no assurance that any such extensions will be physically realistic. Since this is likely to affect a small minority of the future simulated values, it is unlikely to affect the sign of any changes, but could add uncertainty to the quantitative value.

Figure 3.23 shows the CMIP3 multi-model mean changes in temperature variability between present and future periods for the A2 scenario, averaged for the entire Northeast region. Annually, there is a small increase in variability at the 2030s and the 2050s, but a small decrease by the 2080s. The winter season indicates a decrease in variability at all future periods, with the largest decrease being 14% for the 2080s. Both small increases and decreases can be seen in spring, whereas fall and summer show only increases in variability, the largest occurring in summer for the last two periods, reaching 17% by the 2080s.

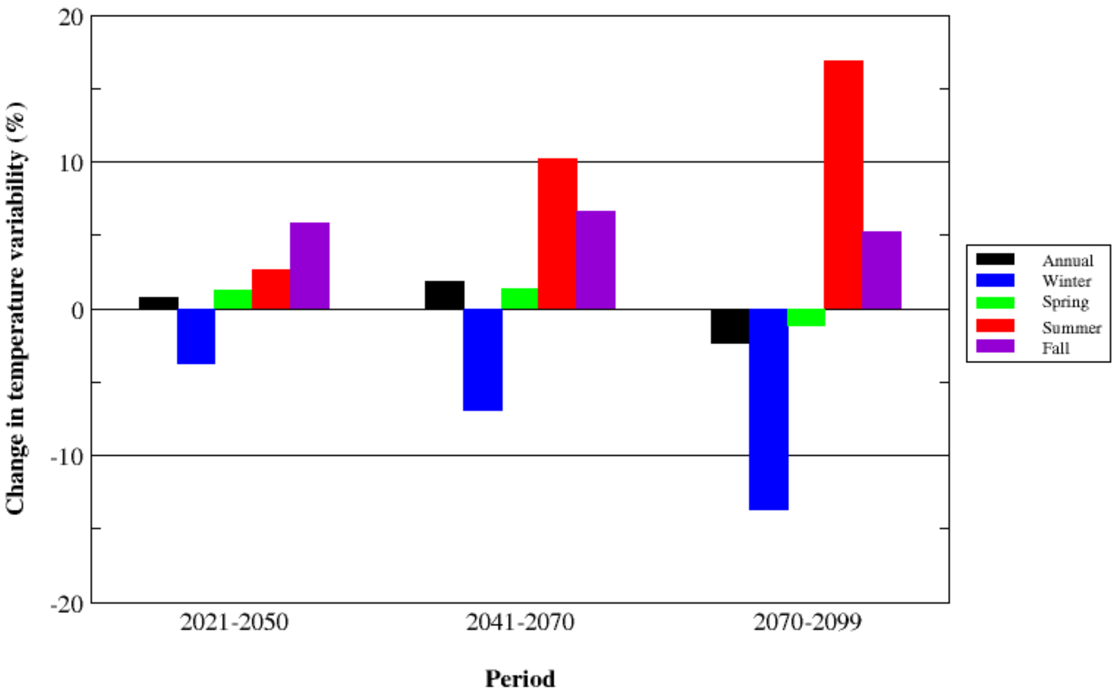


Figure 3.23. Multi-model mean annual and seasonal changes in temperature variability (%) for the 3 future periods with respect to the reference period of 1971-2000 for the high (A2) emissions scenario.

The spatial distribution of the NARCCAP multi-model mean change in the freeze-free season between the 2050s and the historical reference period is shown in **Figure 3.24**. Increases can be seen throughout the region with at least 18 more days in the annual freeze-free season across the region. The largest increases are in high elevation areas, with values of greater than 27 days. Most areas will see increases on the order of 3-4 weeks.

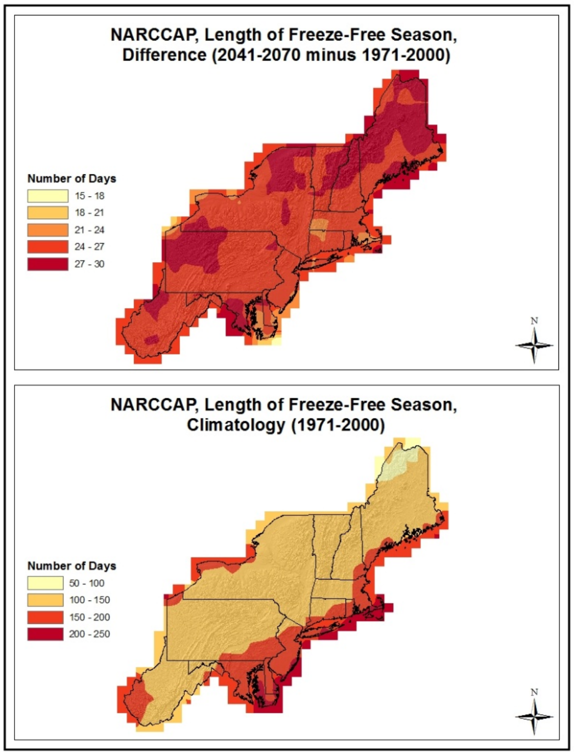


Figure 3.24. Spatial distribution of the NARCCAP multi-model mean change in the length of the freeze-free season between 2041-2070 and 1971-2000 (top). Climatology of the length of the freeze-free season (bottom).

The spatial distribution of the NARCCAP multi-model mean change in cooling degree days between the 2050s and the historical reference period is shown in **Figure 3.25**. In general, the changes are quite closely related to mean temperature with the warmest (coolest) areas showing the largest (smallest) changes. The southernmost areas of West Virginia and Maryland are projected to have the largest increase of cooling degree days per year (up to 700). The furthest north parts of the region, including northern Maine and New Hampshire, will see the smallest increases of less than 200 cooling degree days.

The spatial distribution of the NARCCAP multi-model mean change in heating degree days between the 2050s and the historical reference period is shown in **Figure 3.26**. In general, the entire region is projected to experience a decrease of at least 600 heating degree days per year. Also, the areas expected to have the greatest increase in cooling degree days will have the smallest decrease in heating degree days, and vice versa. The largest changes occur in northern areas, which could see decreases of up to 1,600 heating degree days. Areas south of Pennsylvania and New Jersey are projected to experience the smallest decrease in heating degree days per year.

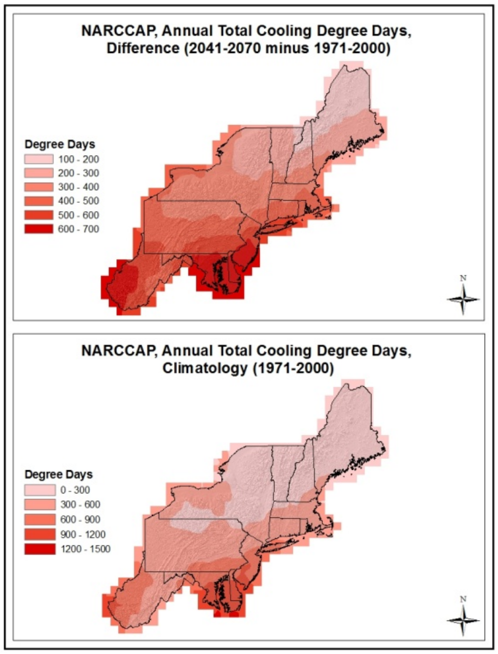


Figure 3.25. Spatial distribution of the NARCCAP multi-model mean change in the number of cooling degree days between 2041-2070 and 1971-2000 (top). Climatology of the number of cooling degree days (bottom).

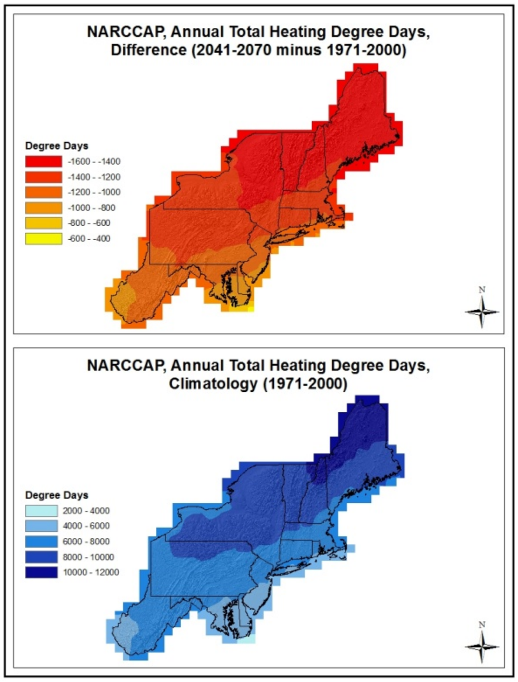


Figure 3.26. Spatial distribution of the NARCCAP multi-model mean change in the number of heating degree days between 2041-2070 and 1971-2000 (top). Climatology of the number of heating degree days (bottom).

Mean Precipitation Projections

The distribution of the CMIP3 multi-model mean changes in annual precipitation is shown in **Figure 3.27**, for the three future periods (2030s, 2050s, 2080s) and two emissions scenarios (A2, B1). The far northern regions show the largest increases while southern and coastal areas show less of an increase. The largest north-south differences are for the A2 scenario in the 2080s, varying from an increase of around 2% in southern West Virginia to an increase of 9% in northern Maine.

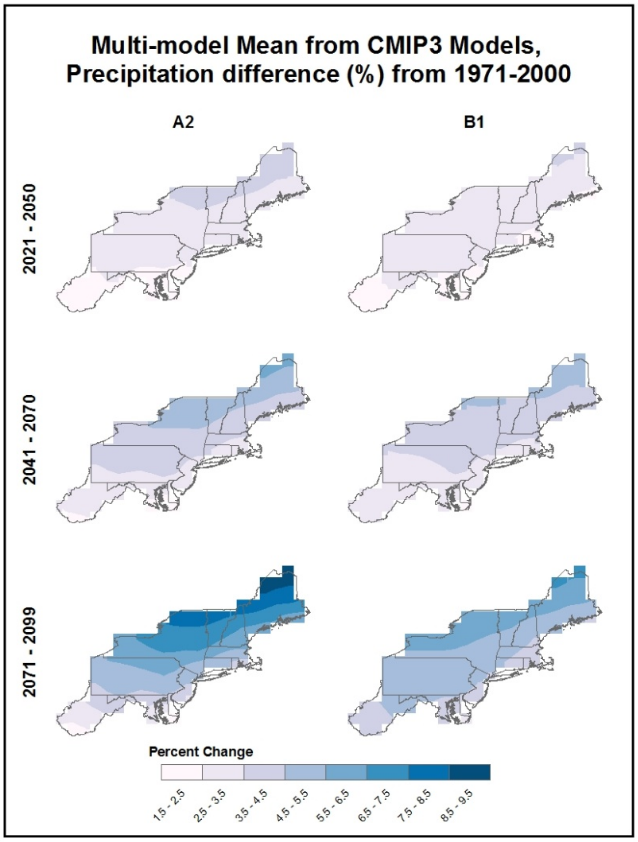


Figure 3.27. Multi-model mean annual differences in precipitation (%) between the 3 future periods and 1971-2000, from the 15 CMIP3 model simulations.

The distribution of changes in mean annual precipitation for each future time period and both emissions scenarios across the 15 CMIP3 models is shown in **Table 3.3**, along with the distribution of the NARCCAP simulations (for the 2050s, A2 scenario only) for comparison. For all periods and both scenarios, the CMIP3 model simulations include both increases and decreases in precipitation. All the median values are zero or positive, but very small (less than 2%).

Table 3.3. Distribution of changes in mean annual precipitation (%) for the Northeast region for the 15 CMIP3 models.

Scenario	Period	Low	25%ile	Median	75%ile	High
A2	2021-2050	-6	-1	0	2	5
	2041-2070	-9	-2	0	3	5
	2070-2099	-13	-5	1	4	9
	NARCCAP	*-1*	*4*	*6*	*6*	*10*
B1	2021-2050	-4	0	2	2	3
	2041-2070	-3	-1	1	3	4
	2070-2099	-2	0	2	4	5

Figure 3.28 shows the annual and seasonal precipitation change between 2041-2070 and 1971-2000 for the A2 scenario, for the 9 NARCCAP regional climate model simulations. The annual changes are positive throughout the region, with small increases of less than 6%. Winter shows the greatest increases of up to 18%, whereas summer changes are mostly negative. Spring and fall changes are mostly positive, generally varying between 0 and 12%. Values in the summertime are negative, ranging up to -12%.

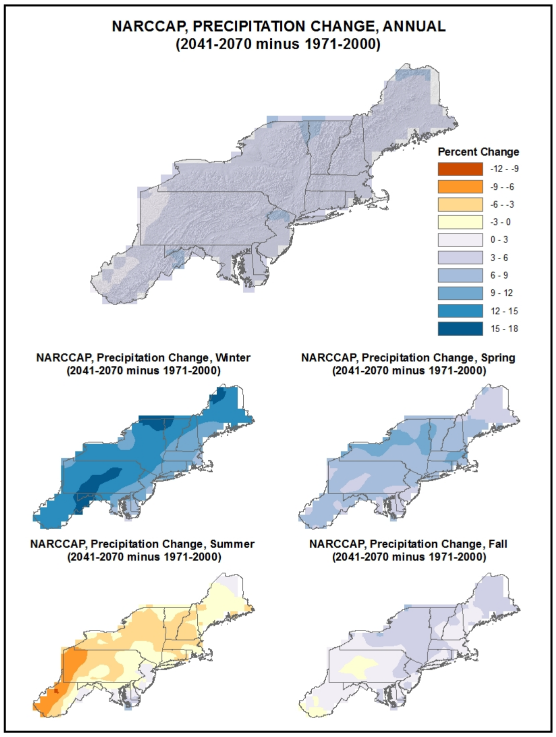


Figure 3.28. Multi-model mean annual and seasonal differences in precipitation (%) between 2041-2070 and 1971-2000, from the 9 NARCCAP regional climate model simulations.

Table 3.4 shows the seasonal distribution of precipitation changes across the 15 CMIP3 models, between 2070-2099 and 1970-2000 for both emissions scenarios. On a seasonal basis, the range of model-simulated changes is quite large. For example, in the A2 scenario, the change in summer precipitation varies from a decrease of 35% to an increase of 13%.

Table 3.4. Distribution of changes in mean seasonal precipitation (%) for the Northeast region for the 15 CMIP3 models.

Scenario	Period	Season	Low	25%ile	Median	75%ile	High
A2	2070-2099	DJF	-5	1	6	10	19
		MAM	-17	-11	0	2	5
		JJA	-35	-17	-2	5	13
		SON	-13	-3	4	8	12
B1	2070-2099	DJF	-3	0	4	6	8
		MAM	-9	0	2	3	8
		JJA	-10	-3	0	5	14
		SON	-10	1	3	6	8

A majority of the models indicate increases in precipitation for all seasons, with the exception of summer in the A2 scenario. In the B1 scenario, the range of changes is generally smaller with a tendency towards slightly wetter conditions (i.e., more models indicate an increase in precipitation than for the A2 scenario). The central feature of the results in **Table 3.4** is the large uncertainty in seasonal precipitation changes.

Figure 3.29 shows the mean annual changes in precipitation for each future time period and both emissions scenarios, averaged over the entire Northeast region for the individual 15 CMIP3 models. In addition, averages for the 9 NARCCAP simulations and the 4 GCMs used in the NARCCAP experiment are shown for the 2050s (A2 scenario only). The small plus signs are values for each individual model, and the circles depict the overall means. The mean changes for the CMIP3 models are both positive and negative, but values are small (less than 2%). For the A2 scenario, the models project average increases of 0.4% by the 2030s, -0.1% by the 2050s, and -0.2% by the 2080s. The B1 scenario shows an increase for each time period, reaching +2% by the 2080s. The mean of the NARCCAP simulations is larger at +4.4%, with the mean of the 4 GCMs used in the NARCCAP experiment being closer to the CMIP3 mean value (+1.8%). The range of individual model changes in **Figure 3.29** is large compared to the differences in the multi-model means, as also illustrated in **Table 3.4**. For all three future periods and for the two scenarios, the individual model range is much larger than the differences in the CMIP3 multi-model means.

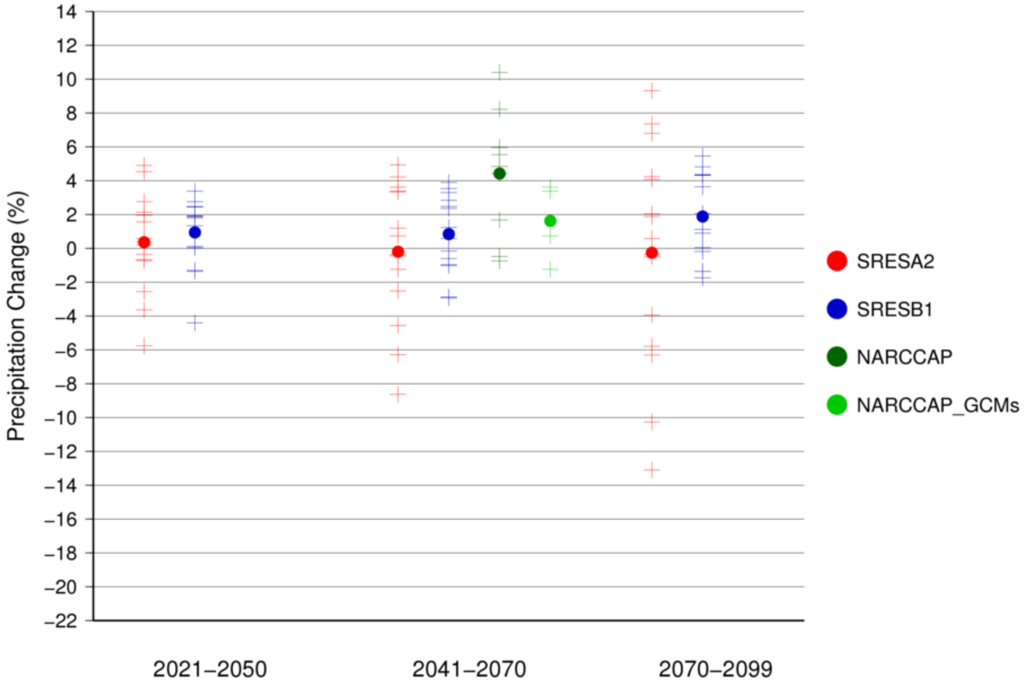


Figure 3.29. Mean annual precipitation changes (%) for each future time period with respect to the reference period of 1971-2000 for all 15 CMIP3 models, averaged over the entire Northeast region for the high (A2) and low (B1) emissions scenarios. Also shown are results for the NARCCAP simulations for 2041-2070 and the 4 GCMs used in the NARCCAP experiment (A2 only). The small plus signs are values for each individual model and the circles depict the overall means.

Figure 3.30 shows the mean seasonal changes in precipitation for each future time period for the A2 scenario, averaged over the entire Northeast region for the individual 15 CMIP3 models, as well as the NARCCAP models for the 2050s. The CMIP3 models project increases during the fall and winter of up to 6%. For spring and summer, precipitation changes are negative (-2 to -7%). The NARCCAP models, which are displayed for the 2050s only, are close to the same as the CMIP3 models for the summer and fall seasons. On the other hand, they appear slightly larger for the winter and spring seasons. The model ranges in **Figure 3.30** are large compared to the multi-model mean differences. This illustrates the large uncertainty in the estimates of precipitation changes derived from these simulations.

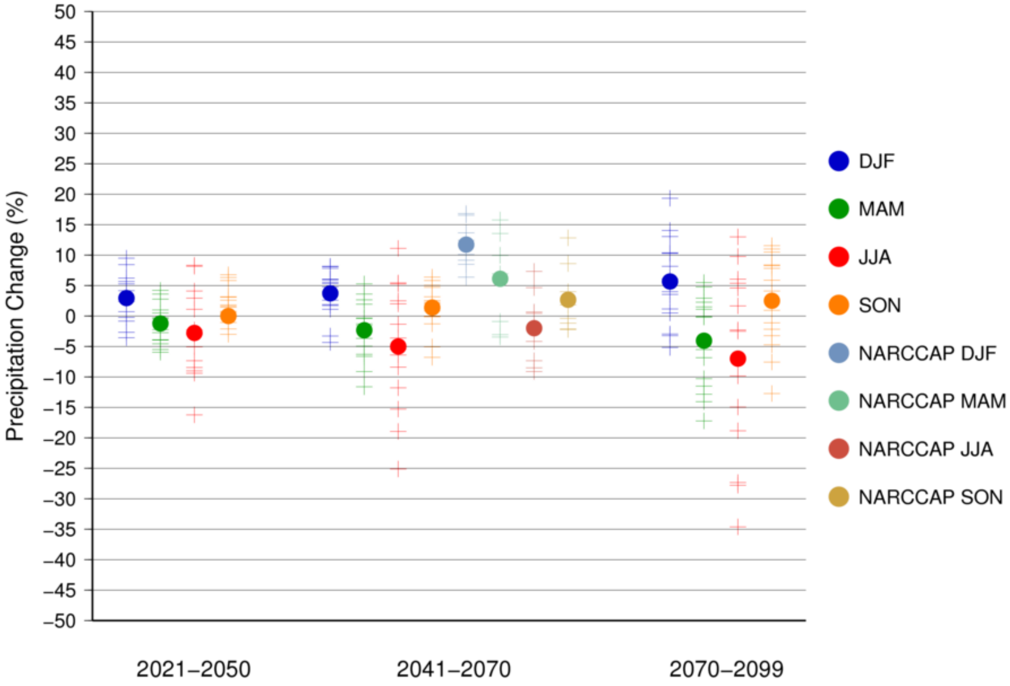


Figure 3.30. Mean seasonal precipitation changes (%) for each future time period with respect to the reference period of 1971-2000 for all 15 CMIP3 models, averaged over the entire Northeast region for the high (A2) emissions scenario. Also shown are results for the NARCCAP simulations for 2041-2070 and the 4 GCMs used in the NARCCAP experiment. The small plus signs are values for each individual model and the circles depict the overall means.

Extreme Precipitation Projections

Changes in the variability of precipitation can magnify or ameliorate the impacts of mean precipitation changes. The monthly BCSD time series were used to calculate variability on the interannual and interseasonal time scales. The variability measure is the standard deviation of annual or seasonal totals of precipitation. Changes were calculated as the percent change in standard deviation between the future and present periods.

Figure 3.31 shows the CMIP3 multi-model mean changes in precipitation variability between present and future periods for the A2 scenario, averaged for the entire Northeast region. Annually, there is an increase in variability for all future periods, ranging from 2.5% in the 2030s to 17.5% in the 2080s.

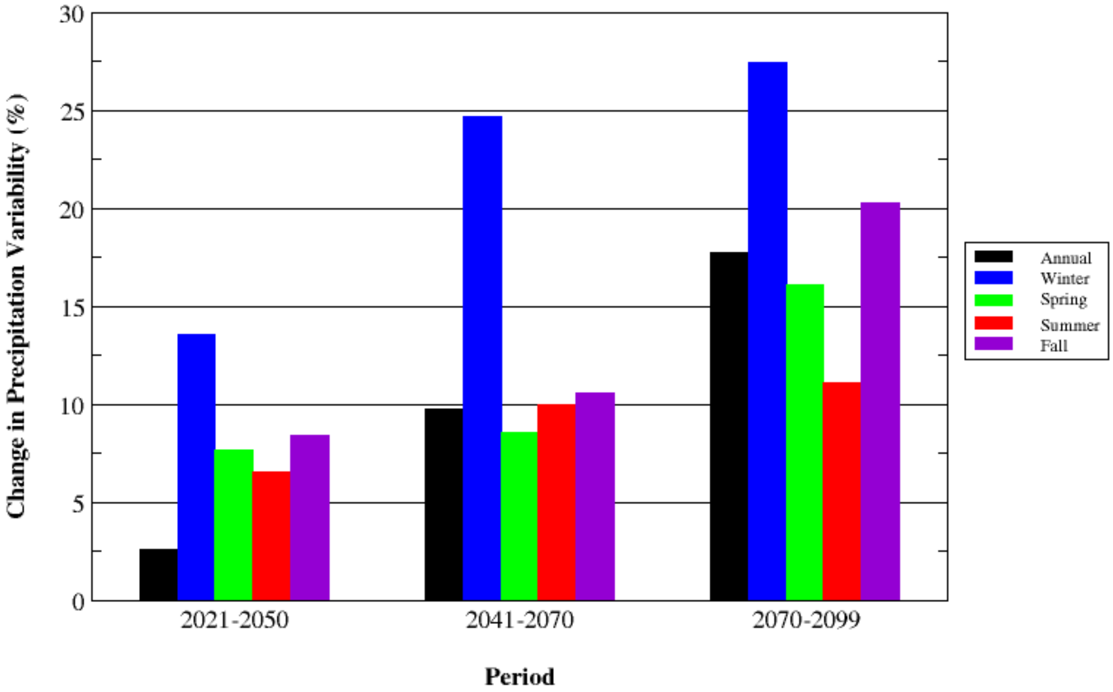


Figure 3.31. Multi-model mean annual and seasonal changes in precipitation variability (%) for the 3 future periods with respect to 1971-2000 for the high (A2) emissions scenario.

There are also increases for all four seasons. Wintertime sees the highest increase (approximately 13% in the 2030s, 24% in the 2050s and 27% in the 2080s). Spring and summer have the lowest increases, but these still reach more than 10% in the 2080s.

The spatial distribution of the NARCCAP multi-model mean change in number of days with precipitation exceeding 1 inch in the 2050s is shown in **Figure 3.32**. The climatology map is also displayed for reference. All areas exhibit increases, the greatest being up to 2.5 days per year in central New York. The smallest increases are in western Pennsylvania (less than 1 day per year).

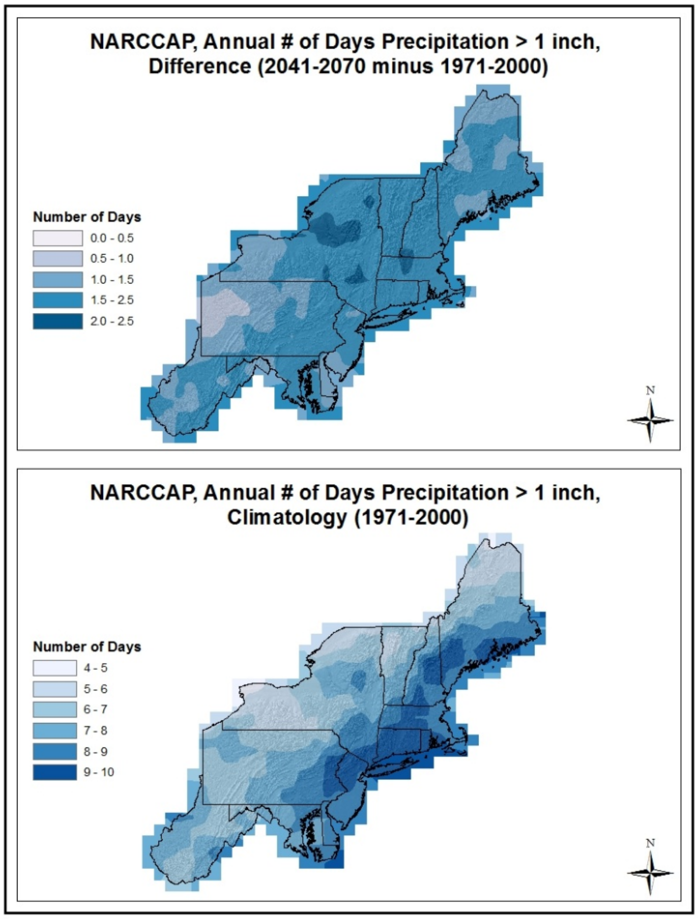
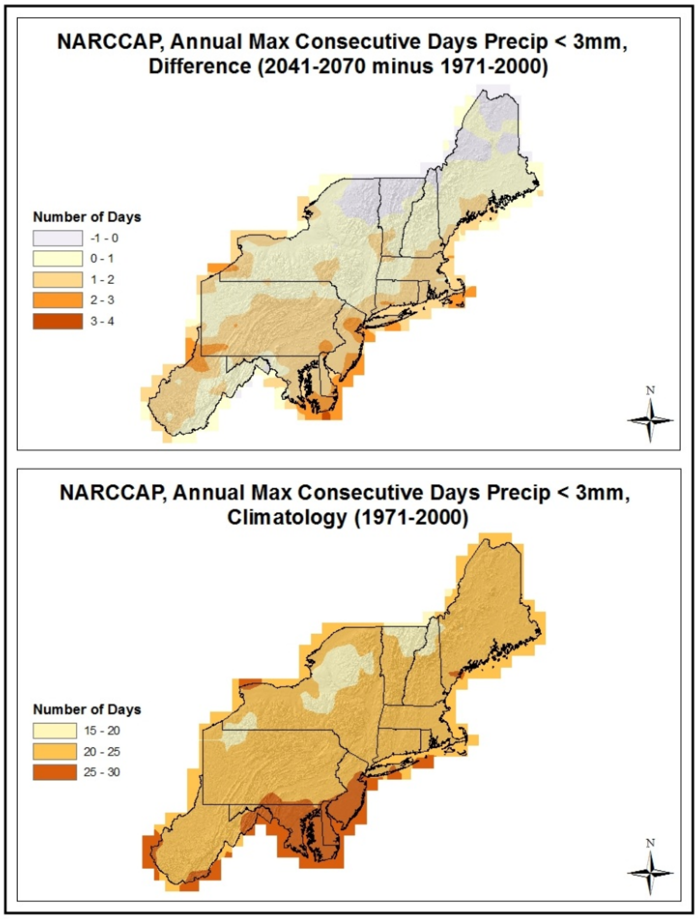


Figure 3.32. Spatial distribution of the NARCCAP multi-model mean change in the number of days with precipitation exceeding 1 inch between 2041-2070 and 1971-2000 (top). Climatology of the number of days with precipitation exceeding 1 inch (bottom).

Consecutive days with little or no precipitation can have large impacts. **Figure 3.33** shows the NARCCAP multi-model mean change in the average annual maximum run of days with precipitation less than 0.1 inches (3 mm). Areas that now have the largest annual values, such as southern Maryland and New Jersey, are expected to see the greatest increases of up to 4 days per year. Most other areas will see smaller increase or no change over time. There are some areas in the north of the region that may see a decrease in days, but these values are relatively small.


NARCCAP, Annual Max Consecutive Days Precip < 3mm, Difference (2041-2070 minus 1971-2000)

NARCCAP, Annual Max Consecutive Days Precip < 3mm, Climatology (1971-2000)

Figure 3.33. Spatial distribution of the NARCCAP multi-model mean change in the annual maximum number of consecutive days with precipitation less than 0.1 inches/3 mm between 2041-2070 and 1971-2000 (top). Climatology of the annual maximum number of consecutive days with precipitation less than 0.1 inches/3 mm (bottom).

The mean changes for selected precipitation-based derived variables from the NARCCAP simulations between the 2050s and the historical reference period are summarized in **Table 3.5**. The same variables from the CMIP3 statistically-downscaled simulations are also shown for comparison. For the NARCCAP data, the number of days with precipitation greater than certain thresholds increases for all threshold values (+21% for 1 inch, +41% for 2 inches, +56% for 3 inches, and +65% for 4 inches). Interestingly, the increases are higher for the more extreme thresholds. The means from the CMIP3 daily statistically-downscaled simulations are higher than their NARCCAP counterparts. The number of days with precipitation exceeding certain thresholds also increases for all 4 thresholds (24% for 1 inch, 54% for 2 inches, 87% for 3 inches, and 120% for 4 inches).

Table 3.5. Mean changes, along with the standard deviation of selected precipitation variables from the NARCCAP simulations. Mean changes from the CMIP3 statistically-downscaled analyses are also shown for comparison.

Variable Name	NARCCAP Mean Change	NARCCAP St. Dev. of Change	Statistically-Downscaled Mean
#days > 1 inch	+21%	7%	+24%
#days > 2 inches	+41%	24%	+54%
#days > 3 inches	+56%	45%	+87%
#days > 4 inches	+65%	70%	+120%
Max run days < 0.1 inches	+1 day	+2 days	+0 days

Acknowledgements

Analyses of the NARCCAP simulations were provided by Linda Mearns and Seth McGinnis of the National Center for Atmospheric Research and by Art DeGaetano and William Noon of the Northeast Regional Climate Center. Analysis of the CMIP3 GCM simulations was provided by Michael Wehner of the Lawrence Berkeley National Laboratory and by Jay Hnilo of the NOAA Cooperative Institute for Climate and Satellites (CICS). Analysis of the BCSD downscaled data was provided by Phil Duffy of Climate Central. Additional programming and graphical support was provided by Laura Stevens, Scott Stevens and Jun Zhang of the NOAA CICS, Greg Dobson of the University of North Carolina-Asheville, and Byron Gleason of NCDC.

3.4 Socio-economic and Land-Use Scenarios and Projections

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This section describes two additional key factors for baseline and scenario planning: data and projections of 1) socioeconomics and 2) land use.

Socioeconomic data and projections

Northeast Climate Assessment

At the federal level, the U.S. Census Bureau[9] has provided available, state level, data and projections for all fifty states and DC based on the 2000 census data showing population projections for 2010, 2020, and 2030, as well as comparison data (percent of change over the time period). Data was available broken down into sex and age comparisons. Projections from the most recent 2010 census are not yet available. More detailed projection data is provided on a state by state basis, with the Census Bureau providing a list of states that offer these services. Downscaled data based on scenarios are available through the EPA National-Scale Housing-Density Scenarios.[10]

County level data was found for all 12 states in the Northeast. Some data is available from state's government websites, and some data is available from other sources including state

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[9] http://www.census.gov/population/www/projections/index.html
[10] http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=203458

universities. Some states have data available at a better resolution than county, such as by city or township; however, county level data was used for the regional maps shown in **Figure 3.34**.

Some states offer very detailed county data, such as figures on sex and age. Some states use high, medium, and low projection figures (based on the SRES emissions scenarios). Once a master list of population projects for 2015 at the county level for each state in the region was compiled, the next step was to join the data to shapefiles so it could be mapped. As the shapefile data include square mileage for each county, projected population density for each county could be calculated and mapped as well. These maps, county level projected population for 2015, and county level project population density for 2015, could then displayed side by side on the same page. From here, additional data regarding major cities was added to showcase where within the counties the populations are concentrated.

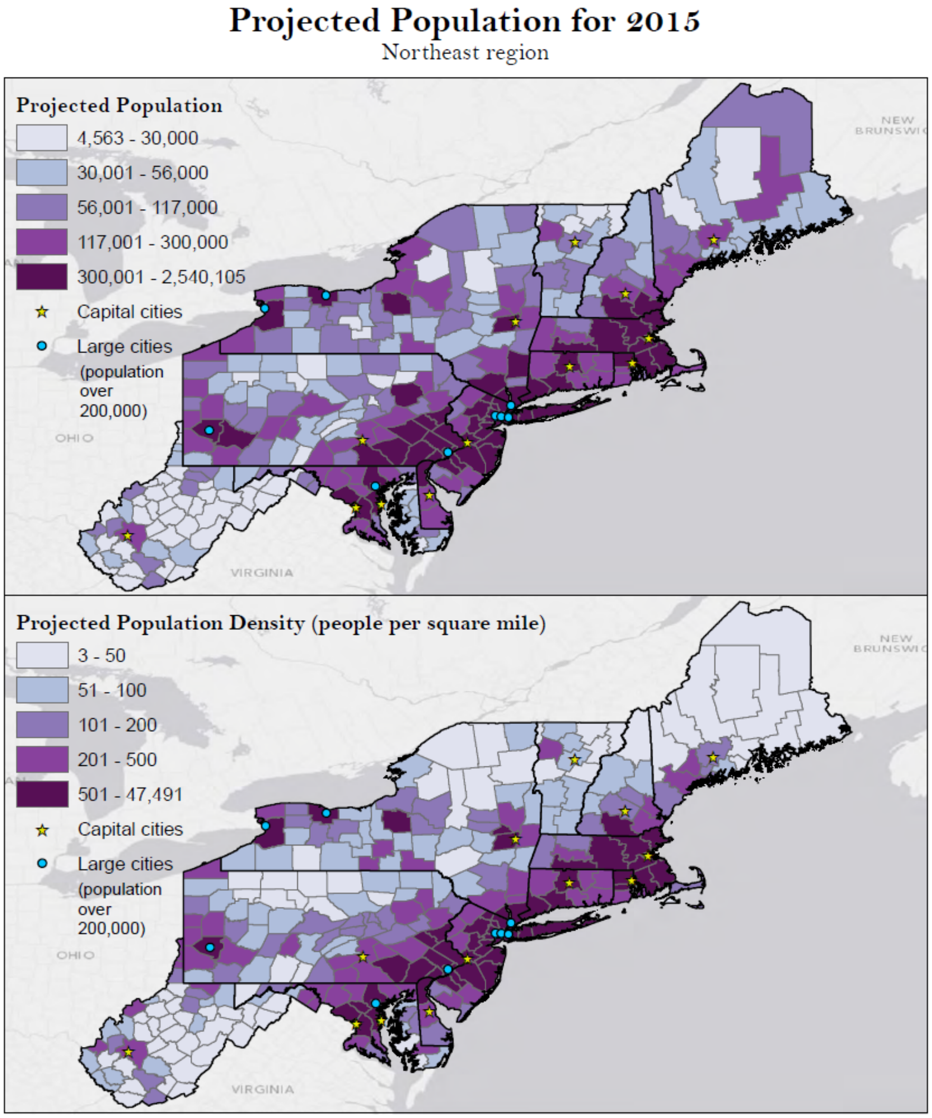

Figure 3.34. Projected Population for 2015 in the Northeast Region. Source: CIESIN.

Land Use

Land cover and land use scenarios are being used from several sources. The National Land Cover Database 2006, includes baseline land cover categories. (Multi-Resolution Land Characteristics Consortium)[11].

National Land Cover Database 2006 (NLCD2006; Fry 2011, Xian 2009) is a 16-class land cover classification scheme available at 30 meter resolution. It is based on Landsat Enhanced Thematic Mapper+ (ETM+).

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[11] http://www.mrlc.gov/nlcd2006.php

4. Climate Change Impacts and Solutions by Sectors and Systems

Coordinating Lead Authors - Lindsay Rustad and Shubhayu Saha

Many sectors and systems within the Northeast have already experienced impacts and will continue to be effected by a changing climate. Vulnerable sectors and systems include; water, forest ecosystems and the carbon cycle, agriculture, coasts and oceans, human health, infrastructure including transportation, telecommunications, and energy, local communities and urban areas, economies, and government. Although each of these sectors/systems faces challenges from climate variability and change, adaptation and mitigation strategies are being implemented.

Each of the seven sections includes: 1) the Northeast context, 2) description of current and potential future climate impacts, and 3) an overview of the many adaptation strategies already underway or in development.

4.1 Water

Lead Authors - Casey Brown, Alan Cohn, Robert Lent, Glenn Hodgkins, Franco Montalto and Raquel Sousa

Water Section Context

The Northeast is a relatively water rich region and there are no expectations for that to change over the 21st century. Large water supply systems have benefited from falling water demand in the last several decades leaving them fairly resilient to small changes in climate. Concerns in the region are largely related to possible increases in excess water events, including flood risk and the management of stormwater. Studies are mixed in terms of changes seen historically, while these events remain among the most difficult to credibly assess with models. Identifying and managing vulnerabilities to current climate variability may be the most effective approach to preparing for the 21st century.

Drinking Water

A large percent of the population in the Northeast, especially in high-density urban areas, is served by surface water systems. In many rural areas groundwater wells are a more common source of supply. Snowmelt runoff is an important component of reservoir and groundwater recharge for parts of the Northeast.

Sixty-seven percent of Northeast drinking water supply is from surface water (**Table 4.1)**. Major surface water users include New York City and Boston, which each have a comprehensive watershed management approach which has allowed them to be amongst the only five major US cities to obtain a waiver from the US EPA's filtration requirement. Other major surface water supplies and their users include the Great Lakes, Lake Champlain (Burlington, VT), the Finger Lakes and Onondaga Lake.

Thirty-three percent uses groundwater, including a large population served by the Magothy aquifer in Long Island, NY (**Table 4.1**). In northern New England (Maine, New Hampshire, Vermont) and Delaware, a majority of drinking water supply comes from groundwater. In New Jersey, half of drinking water comes from groundwater.

Table 4.1. Domestic water use in the Northeast U.S., 2005 (derived from Kenny et al., 2009)

State	Total domestic water use (Mgal/d)	Groundwater water use (%)	Surface-water use (%)
Maine	71.9	62	38
New Hampshire	98.2	64	36
Vermont	39.8	54	46
Massachusetts	528	31	69
Connecticut	263	36	64
Rhode Island	85.4	20	80
New York	1860	26	74
Pennsylvania	704	33	67
New Jersey	605	50	50
West Virginia	183	34	66
Maryland	610	25	75
Delaware	51.1	59	41
Total	5100	33	67

Although there are a wide range of water sources in the Northeast, they are connected hydrologically. Many locations have therefore developed comprehensive protection and sharing agreements, including the Delaware River Basin Commission which includes the cities of New York and Philadelphia, and the cross-border Lake Champlain Basin Program between New York, Vermont, and Quebec, Canada. The latter provides an excellent example of how climate, impacts, and adaptation considerations extend beyond the region.

Vogel et al. (1997) derived sensitivity curves for reservoirs in the Northeast which are dominated by over-year storage. These curves show the impact of changes in precipitation and air temperature on water-supply system yield and resilience.

Flood Risk

Floods in the Northeast are typically caused by two major pathways: tropical depressions and other major convective events that occur during late summer and fall and warm rainfall events on ripe snowpack in the spring, which are especially important in northern parts of the region. The 20th century was marked by major destructive floods in the Northeast followed by the development of infrastructure to protect major urban areas. Since that time, population has continued to expand throughout the Northeast, leading to increasing vulnerability to flood damage in the region, especially in areas not protected by infrastructure. Recent events including

Hurricane Irene in Vermont, New Hampshire, Connecticut and the Delaware River Basin have had major impacts in rural areas and demonstrated clear vulnerability to floods.

Stormwater and Wastewater Management

Stormwater is collected to avoid flooding and reduce impacts of runoff on water quality. Stormwater systems are often separated from sanitary sewer systems, however in older cities these systems are often combined. Combined sewer systems are found in 31 states and DC, with the majority in the Great Lakes and Northeast (EPA, 2008).

Some stormwater systems discharge directly into receiving waterbodies. Others are routed through detention ponds and other facilities that promote physical settling as a very minimal level of treatment. In other cases, stormwater is mixed with wastewater in combined sewer systems. The conveyance capacity of such systems is typically 2-4 times the dry weather flow, meaning that during relatively small precipitation events, most of the combined flow passes through wastewater treatment plants and is treated. However, when the rate of combined flow exceeds this threshold, combined sewer overflows (CSOs) occur, discharging untreated combined sewage directly to receiving waters. CSOs are problematic from both a water quality and public health perspective.

Human Health and Ecology

Management of drinking water, stormwater, and wastewater are strongly tied to preservation of human health and ecological productivity. Drinking water withdrawals and diversions are managed to maintain aquatic ecosystems. There is increasing interest in providing ecologically sustaining streamflows in addition to minimum streamflow requirements. The challenge now facing watershead managers is that static streamflow requirements may not be appropriate for changing climate conditions. The northeast is home to a variety of aquatic species that are at the southern end of their range and sensitive to changes in stream temperature, including brook trout and Atlantic salmon.

The primary water quality concern is pathogen levels, which are linked to gastrointestinal disease through drinking water and recreational uses, and dissolved oxygen levels, which limit ecological productivity. Water quality is a concern especially in regard to algal blooms such as those that occur in Long Island Sound and Lake Champlain.

Drought

Although the region on average has sufficient water, it is nonetheless affected by drought. The drought of record for the entire region occurred during the 1960s and was marked by several years of below-average rainfall that was accompanied by below normal temperatures. Retrospective studies have tied this period to anomalous conditions in the northern Atlantic. The amount of time that has passed since that drought raises the question of how well prepared the region is for the next multi-year drought. Single-year droughts can also be problematic for small systems that have less ability to manage a reduction in flows. The Ipswich River in

Massachusetts, one of the most endangered rivers in the country, has been drained dry in recent years due to over- abstraction during dry summer periods.

Climate-Related Trends and Projected Impacts

The Northeast is famous for unpredictable and changeable weather. Historical trends and climate projections imply that the same may be true of its climate. A consistent message from all climate science is that there is a warming trend and that trend is projected to continue. Warming has important implications for water resources and aquatic ecosystems, especially related to timing of flows affected by snowmelt runoff. There are also indications of possibly increased amounts of precipitation, both historically and in projections. There are possible increases in late summer droughts as well. The generally small magnitude of these changes and their tendency to be counterbalanced suggests that variability and extremes, both difficult to assess, are major concerns for the future.

Engineers and others have typically designed structures (such as bridges) and facilities (such as water supply and waste water treatment plants) to accommodate high or low flows of a defined rarity (such as the 100-year flood). Past designs are based on the concept of stationarity (non-changing flows over very long periods of time). The assumption of flow stationarity has recently been questioned because of the potential effects of global warming on flows (Milly et al., 2008). It is therefore important for engineers and resource managers to understand how flows may change in the future.

An increase in the occurrence of intense precipitation events is projected to accompany a warmer climate and there may be some evidence of this occurring in the Northeast (Trenberth, 2003; see Chapter 3). The result in the Northeast, where there is a high proportion of urban areas and aging infrastructure, is an increase in flash flood events, combined sewer overflows and degraded water quality. Interannual variability of precipitation and possible changes in the frequency of drought are extremely important factors for large reservoir systems like those that supply Boston and New York City. Although the exact nature of future climate is uncertain, there is certainty that current water management operations are based on the historical record and that significant deviations from those expectations may cause difficulties.

Drinking Water

Hayhoe et al. (2007) project increases in the number of short-term droughts in the Northeast by the middle to end of this century based on climate model projections; they also project very small decreases in the lowest annual streamflows. However, the climate models showed limited skill reproducing precipitation trends during the 20th century. During the last half of the 20th century, the lowest annual streamflows increased for many rivers in the Northeast (Lins and Slack, 2005) while temperature was increasing.

The prospect for increasing temperatures raises a concern that the demand for water may also increase in a region where demand has fallen for many years. However, the major concern for drinking water systems related to temperature is the potential loss of the natural storage provided by snowpack in most winters. Surface water systems with limited reservoir storage may find future climate conditions more challenging.

During the last century there have been significant changes in the timing of winter-spring streamflows in the parts of the Northeast that have a substantial annual snowpack (Hodgkins et al., 2003; Hodgkins and Dudley, 2006; Burns et al., 2007). The timing of snowmelt runoff is sensitive to air temperature changes in the late winter (Hodgkins et al., 2003). Snowmelt-related streamflows are projected to continue to become earlier in the next century (Hayhoe et al., 2007)

Sea level rise presents another drinking water concern, notably for river and groundwater sources, due to the possibility of saltwater intrusion and movement of estuarine salt fronts. Intense precipitation can also increase sediment transport in runoff leading to increased reservoir turbidity levels, which has been a challenge in the NYC system. Finally, drinking water managers are faced with decisions about flood management in multi-objective systems and may be increasingly called upon to reduce flood risk if that risk intensifies.

Flood Risk

Changes in flood risk could arise in several ways. A reduction in snowpack could reduce the frequency of "rain on snow" flooding which is a major cause of spring floods flows in the region. Hurricanes and tropical storms are another cause of floods in the region. Studies estimate that the intensity and possibly the frequency of hurricanes may accompany a warming climate, although the implications for the tracking of those storms to the Northeast is largely unknown. If the precipitation intensity increases as theorized, localized flooding and flash flooding in urban areas may become more problematic. Because floods are generally rare events their statistics remain difficult to estimate and consequently, the estimation of flood risk is also difficult. Anticipating how flood risk may change in the future is extremely difficult.

Some rivers in the Northeast experienced increasing annual peak flows in the last 50-100 years (Lins and Slack, 2005; Collins, 2009; Hirsch, 2011). Lins and Cohn (2011) found both significantly increased and decreased peak flows in this region. Higher annual peak flows in recent years cause estimates of flood flows, such as the 100-year flood flow, to increase in some cases (Collins, 2009). Based on their use of climate projections, high streamflows, Hayhoe et al., (2007) estimated to increase in the Northeast in the 21st century.

Stormwater and Wastewater Management

Increases in heavy downpours can lead to increases in flooding (Rosenzweig et al., 2011) Increasing precipitation may lead to an increase in combined sewer overflows and challenge the capacity of wastewater treatment plants. Hodgkins and Dudley (2011) found large increases in summer stormflows in New England in the last 60-80 years. In this same area, the frequency of small floods has increased in recent years (Armstrong et al., 2011).

Sea level rise is another potential challenge for stormwater management and wastewater treatment since it can affect the ability of these systems to discharge into receiving water bodies. Furthermore, coastal and riverine flooding can damage or destroy infrastructure at wastewater treatment plants. A storm in March 2010 wiped out treatment plants in Warwick, RI, and due to regulatory constraints they were required to be rebuilt in the same vulnerable location.

Human Health and Ecology

Climate change can alter the ability of current water management practices and infrastructure systems to balance water quantity distributions and maintain water quality. Furthermore, direct impacts of temperature and precipitation changes may affect pathogen levels and suitability of habitats. Temperature changes can enhance eutrophication and contribute to more frequent algal blooms. Higher stream temperatures may harm native cold water aquatic species. The range of the native brook trout appears to be shrinking due to current temperature increases.

Managing Climate Change and Extremes

Past experience can provide valuable institutional knowledge for managing future extremes, but climate change will likely present challenges outside the realm of experience. Linking water managers with practical knowledge may be an important contribution to preparing for climate change. While very large utilities are often able to access and produce climate information, other medium and small utilities are much less connected. See case study on Connecticut River Knowledge Network in Box 4.1.

Drinking Water

Most utilities have drought management programs in place. Water management decisions are often based on institutional knowledge but some utilities have developed tools for translating information about weather and streamflow into information to support operations (e.g. the NYC Operations Support Tool). Some municipalities are also evaluating the adequacy of existing and proposed infrastructure to manage projected changes in precipitation.

Drinking water quality is also managed through operational and infrastructure approaches. When operational approaches are insufficient to manage individual events, interventions such as alum treatment may suffice. However, if these interventions do not satisfy water quality requirements then treatment facilities may be necessary (NYCDEP, 2008).

The Northeast region has not been affected by a multi-year drought since the 1960s. A key question is whether water systems are currently prepared for an event of that duration and intensity. A study based on the water supply system for Springfield, MA, shows how real options and forecasts may be used to adapt to a changing climate even when the direction of change is uncertain (Steinschneider and Brown, 2012).

Stormwater and Wastewater Management

Stormwater management is based on design storms, usually derived from historical observations of precipitation. Although water resource agencies in some locations updated their design storm definitions, the NOAA Rainfall Frequency Atlases have not been updated for the Northeast US since 1963. Some studies have concluded that many of the design storms used in infrastructure planning may be underestimating the actual volume of rainfall (UNH, 2011; Rosenzweig et al., 2011).

Cities including Philadelphia, Syracuse, and New York are pioneering comprehensive green infrastructure programs to reduce combined sewer overflow events by reducing the generation of urban runoff. These goals are to be accomplished by reducing runoff volumes and rates by reducing overall imperviousness and promoting the capture, infiltration, evapotranspiration, and detention of stormwater that is generated on decentralized management sites. From a climate change adaptation perspective, green infrastructure plans can help to retain more precipitation in and on the land surface, offsetting any potential increase in the frequency of drought, by more regularly replenishing soil moisture. Where green infrastructure includes vegetation, these initiatives can also provide wind barriers and shade, potentially buffering the effects of increasing temperatures on vulnerable urban populations. By directing runoff generated on impervious surfaces to distributed stores (soil pores, depressions, cisterns, etc.), GI will effectively reduce the spatial extent of runoff source areas during wet weather, reducing the likelihood of floods due to runoff concentration. Finally, where harvested runoff becomes a substitute for potable water that would otherwise be provided by drinking water systems, GI can help to extend water supplies.

Some locations are also taking sea level rise and flooding into account when designing new infrastructure or making improvements. Well-known examples include the Deer Island Wastewater Treatment Plant in Boston. The Rockaway Wastewater Treatment Plant in New York City is also proposing to raise equipment as part of its upgrade cycle (NPCC, 2010).

Human Health and Ecology

Ecologists are working to implement strategies to restore waterbodies that will be sustainable in a changing climate. The drinking water, stormwater, and wastewater management communities are intrinsic to ecological management due to the effects of withdrawals and releases. A successful example of coordination between a water utility and ecological restoration groups is found in New York City, where the Department of Environmental Protection is implementing a comprehensive watershed management and restoration plan to reduce and counteract the impacts of stormwater runoff and treated wastewater discharge into the ecologically-sensitive Jamaica Bay (NYCDEP, 2008).

Conclusion

The Northeast is a relatively water rich region and there are no expectations for that to change over the 21st century. Large water supply systems have benefited from falling water demand in the last several decades leaving them fairly resilient to small changes in climate. Concerns in the region are largely related to possible increases in excess water events, including flood risk and the management of stormwater. Studies are mixed in terms of changes seen historically, while these events remain among the most difficult to credibly assess with models. Identifying and managing vulnerabilities to current climate variability may be the most effective approach to preparing for the 21st century.

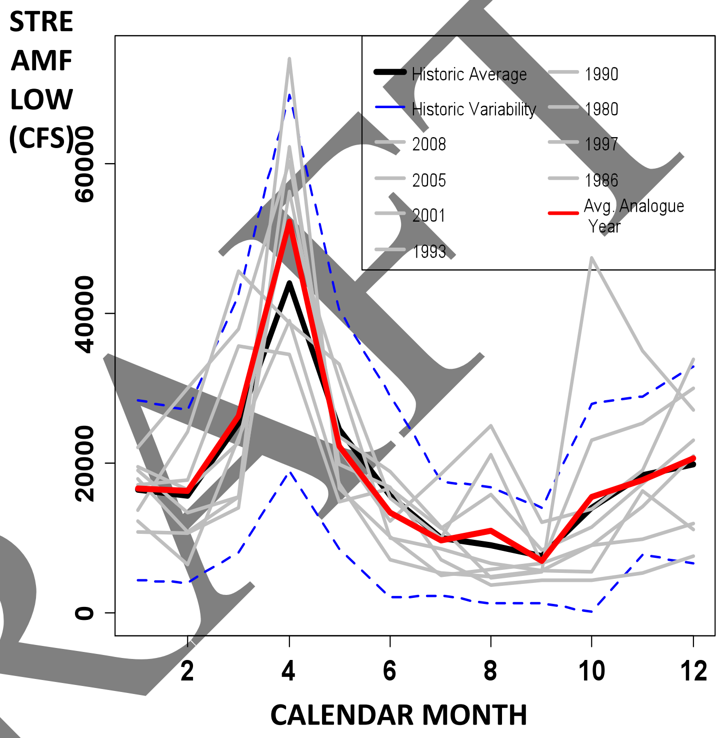
Box 4.1: Connecticut River Knowledge Network - Building a knowledge network for climate adaptation in the Northeast US

Climate variability and change challenge the basic assumptions by which infrastructure and water resource management strategies have been designed and implemented historically. Likewise, the intensification of anthropogenic disturbances, channel modifications, and land-cover changes have complicated our ability to make predictions and provide reliable climate information (Milly et al. 2008). Hydrologic forecasts in water management may be key for adaptation to a nonstationary climate in the future. There have been many studies that describe the advantages of forecast use in water management (Pagano et al., 2001; Pagano et al., 2002; Gong et al., 2010; Kim and Palmer, 1997; Rayner et al., 2005). For example, predictive elements of the El Nino-Southern Oscillation phenomenon (ENSO), which has periodic and inter-annual influence on atmospheric and oceanic circulation patterns, is commonly used in the Pacific Northwest for water resource management; forty percent of the streamflow variability in the Columbia River is closely correlated with this climate signal (Callahan et al., 1999; Meinke and Stone, 2005). In the Northeast US, numerous studies have demonstrated potential skill in predicting seasonal climate variability and streamflow based on the impact of atmospheric-ocean circulation patterns in the Northeast (Bradbury et al., 2002a,b; Kingston et al., 2007; Hartley and Keables, 1998; Steinschneider and Brown, 2011). However, the need for climate information and current use by water managers is largely unknown for the region.

A research project at the University of Massachusetts, Amherst, funded by NOAA’s Sectoral Applications Research Program seeks to fill that gap. The first step was surveying the current use of and need for climate information in the Connecticut River Basin, the largest river in New England. To assess current use of forecasts in the Northeastern United States and test the diffusion of innovations framework, a survey for administration to local water managers in the basin was developed. Specific topics in the survey were designed to investigate water managers’ and stakeholders’ preferences, opinions, and perceptions of forecast information. Questions were based on Rogers’ (2003) diffusion of innovations theory, which focuses on the impacts that temporal scale, trialability, ease of use, and risk assessment have on forecast application. Contrary to the literature on water managers’ use of forecasts in decision-making around the world, managers and stakeholders in the Connecticut River Basin stated common use of climate information and short-term forecasts in their daily operations. Despite their interest in attempts at using forecasts, however, managers’ perceived value of climate information remains low. Survey results indicated that the time scale of information available for use, communication barriers between stakeholders, and the low perceived threat of climate change in the future contributed to ambiguity and uncertainty in forecast use. These responses contribute to a better understanding of the needs and requirements of the water resources community in the Connecticut basin, and encourage the production of more useful and accurate information for them in the future

The survey set the stage for the first Hydroclimate Workshop at the University of Massachusetts Amherst. Representatives from the Farmington Basin, which supplies drinking water to the city of Hartford, CT, New Hampshire regulators that manage Lake Winnipesaukee and over two-hundred other lakes in New Hampshire, the Army Corps of Engineers, who own fourteen flood control dams in the basin, and Trans Canada, which supplies six hundred megawatts of power via its thirteen hydroelectric stations on the Connecticut and Deerfield Rivers (Hachey, 2011) were present at the workshop. Current climate information at the watershed scale was presented at the workshop, illuminating the current state of the basin in an effort to predict possible streamflow conditions in the coming spring season of 2011. (**Box Figure 4.1**). The forecasts of the magnitude of spring flows for 2011 reflected the high snow water equivalent and soil moisture conditions in the basin in late March.

Snow cover has a large impact on the atmosphere, hydrology, and ecosystems of the Northeastern United States. Studies have shown that the timing and magnitude of discharge from rivers is strongly correlated with snow mass coverage and succeeding melt (Yang et al. 2003). Likewise, snowmelt can lead to flooding, and with a changing climate, increased temperatures, and larger storm events as projected with climate change, this could have important implications for water management in the basin. The implications of these efforts are significant, potentially enabling reservoir managers to identify whether basin conditions in a given year are favorable for meeting specific springtime ecological flow targets, ensuring water supply, increasing hydroelectricity efficiency, and managing flood control reservoirs. A follow up analysis of average flows in April confirmed that 2011 flows were approximately 15% higher than average April flows over the historical record at the Thompsonville gage (located at the mouth of the Connecticut River Basin). Furthermore, the highest peak flow in April of this year was 6% higher than the average maximum peak flow in April over the historical record. Seasonal predictions of streamflow may provide water managers with useful information to facilitate in their operational policies and decision making.



Box Figure 4.1. Analogue Forecasts: Monthly Streamflow at Thompsonville, CT.

The workshop and survey established opportunities for better providing relevant climate information for water managers in the Northeast including the potential adaptations for climate change.

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4.2 Forest Ecosystems and the Carbon Cycle

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Climate is a key regulator of terrestrial biogeochemical processes. The magnitude of the climate change that has been observed during the 20th century and that is expected for the 21st century for the northeastern United States (see Chapter 3.2 and 3.3) has had, and will continue to have, profound impacts on the structure, function and biodiversity of the region's forests and on the ability of these ecosystems to store and cycle carbon. A recent synthesis concluded that the changes in climate that are already underway will result in alterations in forest species composition, length of the growing season, and forest hydrology (Rustad et al. 2009, Rosenzweig et al. 2011). Together, these exert significant controls on the health, productivity and sustainability of the region's forests. This chapter focuses first on climate change effects on the assemblages of species in the Northeast (trees, wildlife, and pests, pathogens, and invasives), and then on impacts on forest productivity and the biogeochemical cycling of carbon and nutrients.

As discussed in chapter 3, analysis of long-term climate data sets from the 20th century from the northeastern United States show that mean annual temperature has risen, precipitation has increased, and the onset of spring (based on phenologic indicators) has advanced by ~4 days. Projections for the 21st century, based on a suite of climate models and emission scenarios statistically downscaled for the region, suggest that the onset of spring will advance by an additional 10 to 14 days, river flows will increase during winter and spring but decrease in summer due to increased frequency of short term droughts, and winter ice and snow will diminish or disappear altogether (Huntington et al. 2009; see also Chapter 3). This is a significant increase in growing season length but it must be considered in context with the present variation in northeast growing season length associated with latitude, elevation, and proximity to large bodies of water (**Figure 4.1**). The variability and intensity of weather (i.e., the day-to-day fluctuations in local conditions) is also expected to increase, with more precipitation falling in large events with greater intervening dry spells, and a greater frequency and severity of extreme events, including hurricanes, winter rain, snow, and ice storms, droughts, and heat waves (see Chapter 3 and Huntington et al. 2009).

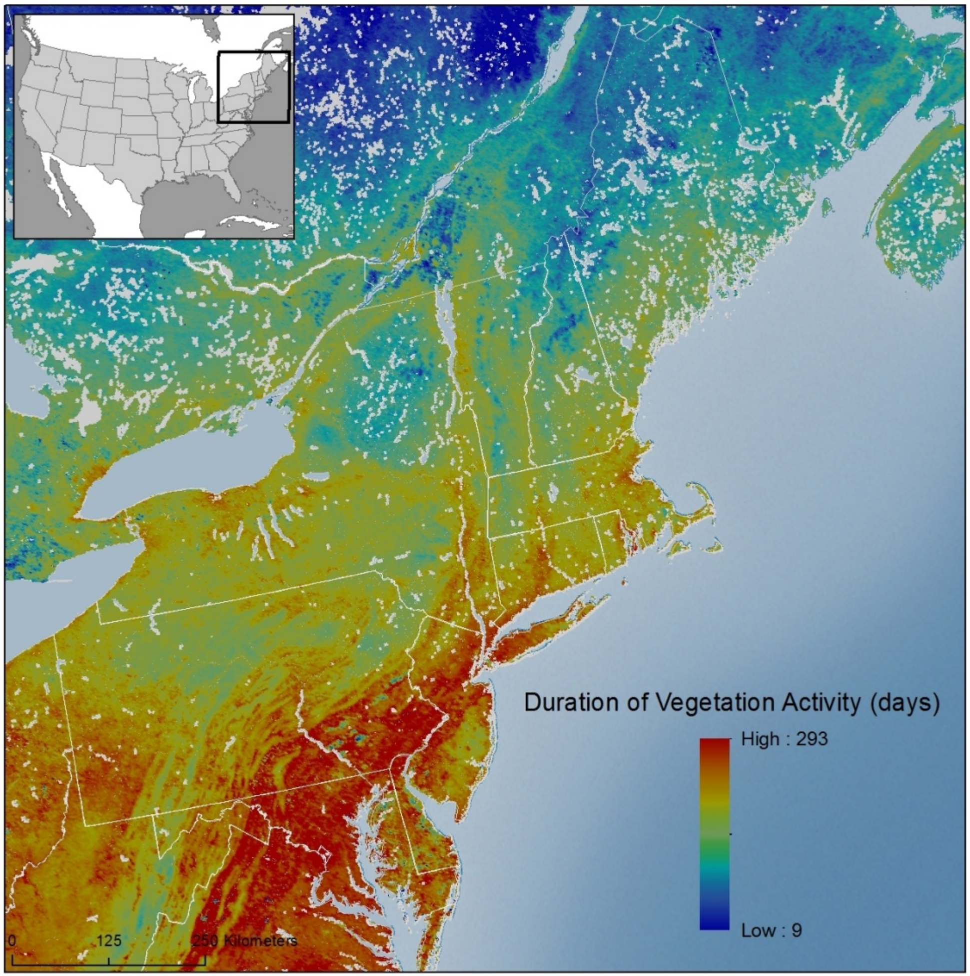

Figure 4.1. Duration of vegetation activity across the Northeastern U.S., averaged for the period 2003-2008. This image was derived from NASA's MODIS phenology products at the Woods Hole Research Center, using data produced at Boston University.

Forest Composition

Forests cover large areas of the land surface in the northeastern U.S., ranging from 59% in Rhode Island to upwards of 89% in Maine (NLCD 2001). These forests are currently dominated by southern hardwoods (oak [*Quercus* spp], hickory [*Carya* spp.]) and pines (*Pinus* spp.) in the southernmost part of the region, northern hardwoods in the central part of the region and at lower elevations throughout (beech [*Fagus grandifolia*], birch [*Betula papyrifera*, *B. alleghaniensis*], maple [*Acer saccharum*, *A. rubrum*]), and boreal-conifer forests to the north and at higher elevations (red and black spruce [*Picea rubra*, *P. mariana*], balsam fir [*Abies balsamea*]). Eastern Hemlock (*Tsuga canadensis*), an important, old-growth shade tolerant species, is currently found throughout the northeast.

Paleoecological data from the region reveal a strong climate signal in current species assemblages, and show that tree species have shifted in response to a gradually changing climate over the past 12,000 years since deglaciation. How species will shift in the coming decades in response to the rapid pace of human-modified climate change remains an enigma, complicated by the longevity of individual trees in the existing forest, robustness of the genetic pool to accommodate adaptation to new climatic conditions, limitations on regeneration and dispersal, and interactions with other vectors of global change such as elevated atmospheric deposition of pollutants (acids, nitrogen, mercury), ozone, land use change, habitat fragmentation, and changes in disturbance regimes caused by prevalence of native and introduced pests and pathogens, and/or fire.

Despite documented changes in regional climate (see Chapter 3b), only limited evidence exists to date to suggest a corresponding shift in tree species. One study in Vermont showed that composition of the forests on the western slopes of the Green Mountains had changed between 1964 and 2004, and as a result, the boundary between northern hardwoods and boreal forest had shifted upslope by 299 to 390 feet (91 to 119 meters) (Beckage et al. 2008). Although the authors suggested that climate warming contributed to this change, other explanations include regional trends in land use, acid rain, and the associated base cation depletion.

In another study, Zhu et al. (2011) examined the USDA Forest Service Forest Inventory and Analysis (FIA) database for evidence of incipient changes in the ranges of 92 eastern U.S. tree species. They reasoned that climate driven change in habitat suitability could be determined by comparing the latitudinal ranges of seedling and adult trees. If the range of a species was expanding northward, for example, they expected to find seedlings of that species in forest plots north of adult trees. They found little evidence that species ranges were expanding northward or otherwise tracking contemporary climate change. Instead tree ranges were generally contracting. These results are concerning because they suggest that as the climate continues to change, trees of a different species or genotype better adapted to the changed conditions will be very slow to move into the area.

Predicting the future occurrence of individual tree species and forest types is challenging. Rather than attempting to predict where actually species will be, scientists use computer models to predict the future shift in *suitable habitat* for individual tree species and forest types. This is commonly referred to as the ‘climatic envelope’ approach. It combines information on current species distributions with climate projections for the future based on an ensemble of global climate models and emissions scenarios, and generates maps of *suitable habitat* for individual species and assemblages of species as forest types. Iverson et al. (2008) used this approach to predict that the center for suitable habitats for 134 eastern U.S. tree species would move up to 800 km to the northeast. In the northeastern states, the result would be a dramatic contraction of suitable habitat for the spruce-fir forest type, substantial decline in suitable habitat for the maple-birch-beech forest type, and marked expansion of suitable habitat for oak-dominated forest types (**Figure 4.2**). Predictions of change in suitable habitat for individual tree species indicate that of the 84 most common species in the Northeast, 23-33 will lose suitable habitat under low and high emission scenarios, 48-50 will gain habitat, and 1-10 will experience no change in habitat. Under a high emission scenario, the tree species predicted to have the most-affected habitat include balsam fir, quaking aspen (*Populus tremuloides*), and paper birch (80-87% *decline* in suitable habitat) and black and white oak (more than two fold *increase* in suitable habitat).

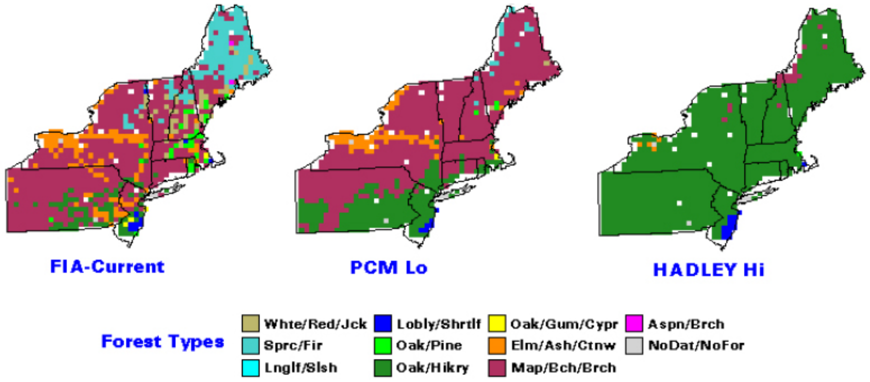

Figure 4.2. Current and Projected Suitable Habitat for Major Forest Types in New England under Different Emissions Scenarios. Suitable habitat for the forest types of New England is expected to shift with changes in climate associated with different emissions scenarios. Source: Mohan et al. 2009.

Wildlife

Climate change has already and will continue to affect the distribution and abundance of many wildlife species in the region through changes in habitat, food availability, thermal tolerances, species interactions such as competition, and susceptibility to parasites and disease (Rodenhouse et al. 2009). Vulnerable species include highly specialized animals, those whose populations are already declining or threatened because of some other stressor, and/or those dependent on range-restricted or isolated habitats (Rosenzweig et al. 2011).

In the northeast, birds are among the most intensively studied taxa (Rodenhouse et al. 2009). Decades of survey data show that migratory birds are arriving earlier and breeding later in response to recent climate change, with consequences for the annual production of young and survival. Among resident birds, 15 of 25 species studied are increasing in abundance, which is consistent with the observation that ranges of these species are limited by winter climate. Of the remaining species, five are declining in abundance, including highly valued species such as ruffed grouse (*Bonasa umbellus*), and five show no change. Significant range expansions have also been observed, with 27 of 38 species studied expanding their ranges in a northward direction.

Using a climatic envelope approach similar to that described for forest tree species, scientists predict (**Figure 4.3**) that future climate change will bring major changes in bird distribution and abundance with substantial differences among species and geographic areas (Rodenhouse et al. 2009). For resident species, twice as many species are expected to increase in abundance as decrease; for migrants (which compose > 85% of the avifauna of the northeast), an equal number are expected to increase as decrease. ‘Winners’ with an increase in abundance include the pileated woodpecker (*Dryocopus pileatus*; +15-50%), the great horned owl (*Bubo virginianus*; +18->200%), and the northern cardinal (*Cardinalis cardinalis*; +20-33%). ‘Losers’ which are expected to decrease in abundance, include the common loon (*Gavia immer*; -76-93%), the winter wren (*Troglodytes hiemalis*; 42-73%), and the rose-breasted grosbeak (*Pheucticus ludovicianus*; -23-71%). A few species that inhabit the cool, high elevation spruce-fir forests of the region, such as the Bicknell's thrush (*Catharus bicknelli*), are uniquely susceptible to climate change, and have already been declining as the climate warms in the White Mountains of New Hampshire (King et al. 2007). Models predict a loss of half the suitable habitat available for this species with even a 1^{o}C change in mean annual temperature (Rodenhouse et al. 2008).

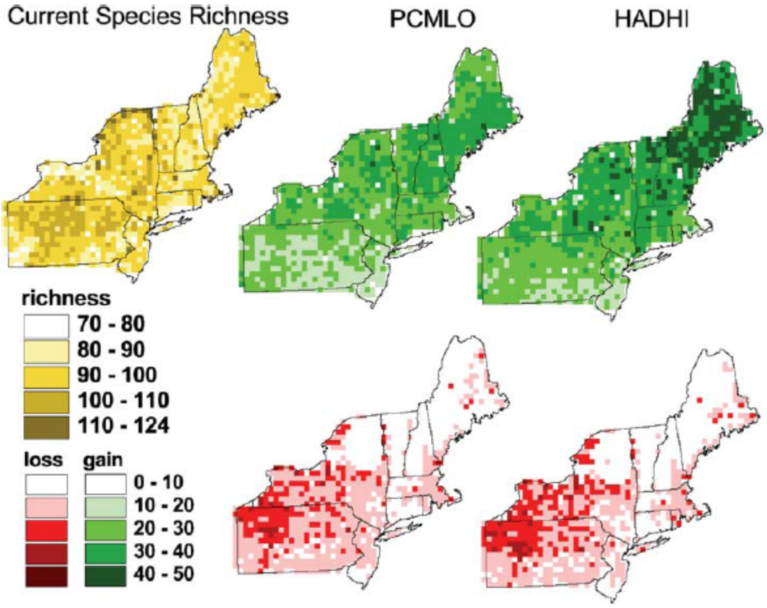

Figure 4.3. Project Gains and Losses in Bird Species Richness across the Northeast Under High and Low Emissions Scenarios. Climate change is projected to affect bird species richness more intensely in some areas of the northeastern U.S. than in others. Source: Rodenhouse et al. 2008.

Pest, Pathogens and Invasive Species

Climate-related historical and future projected changes in native and introduced pest, pathogen and invasive species deserve special mention as these species are among the leading cause of disturbance to northeastern forests, and they seem to be particularly adept at adjusting to changing climatic conditions (Dukes et al. 2009; for common species, see **Table 4.2**). Direct effects of climate change on these species are likely to include summer warming-induced acceleration of reproductive and development rates, winter warming- induced increase in the ability of many of these species to overwinter, and moisture-related changes in survival and fecundity. The prediction for a general increase in extreme minimum winter temperature may be especially important in allowing for the northward migration of many unwanted species. For example, hemlock wooly adelgid (HWA) is distributed in areas where minimum winter temperatures stay above -28.8°C (Skinner et al. 2003). Based on the most recent climate projections, climate warming could allow HWA to spread unimpeded throughout the range of hemlock distribution in North America. The potential impacts of widespread hemlock mortality include changes in forest composition, structure, nutrient cycling, surface water quality and populations of associated wildlife (Dukes et al. 2009).

Table 4.2. Common native and non-native pests, pathogens and invasive species of the northeastern United States (Dukes et al. 2009)

Insect Pests	**Pathogens**	**Invasives**
gypsy moth (*Lymantria dispar*)	chestnut blight (*Cryphonectria parasitica*)	Tree-of-heaven (*Ailanthus altissima*)
balsam woolly adelgid (*Adelges piceae*),	dutch elm disease (*Ophiostoma ulmi* and *O. novo-ulmi*)	*Multifora rose (Rosa multiflora)*
hemlock woolly adelgid (*Adelges tsugae* Annand)	beech bark disease (*Neonectria faginata*	*Wine raspberry (Rubus phoenocolasius)*
emerald ash borer (*Agrilus planipennis* Fairmaire)	white pine blister rust (*Cronartium ribicola*)	*Japanese barberry (Berberis thunbergii)*
Asian longhorned beetle (*Anoplophora glabripennis*)	sudden oak death (*Phytophthora ramorum*)	mustard (*Alliaria petiolata*)
tent caterpillar (*Malacosoma disstria*)	armillaria root rot (*Armillaria* spp.)	mustard (*Alliaria petiolata*)
spruce budworm (*Choristoneura fumiferana*).	white trunk rot (*Phellinus* spp.).	stilt grass (*Microstegium vimineum*)

Forest Productivity

Changes in climate and atmospheric CO_2 concentrations affect forest productivity both directly through effects on physiological processes such as photosynthesis and respiration, and indirectly through effects such as longer growing seasons (Hughes 2000; Saxe et al. 2001). Across large geographical areas or more local elevational gradients, forest productivity generally increases with increasing mean annual temperature and rainfall (Leith and Whittaker 1975), and with increasing growing season length (Baldocchi et al. 2001). Responses however can vary by forest type. In the Northeast, Ollinger et al. (2008) used a physiologically-based forest growth model called PnET-CN to predict changes in net primary productivity (NPP) over the next 100 years. Results showed that NPP in deciduous forests would increase by 52 to 250 percent by 2100, depending on the global model and CO_2 emissions scenario used. The same model projected that current-day spruce forests are likely to exhibit a climate-driven decline in productivity along with a contraction of range.

Climate variability and extremes will also affect forest growth and productivity. Historical data from Mohan et al. (2009) show that extreme weather events such as droughts, extreme cold or heat, and/or wind storms have been directly linked with tree declines, diebacks, and/or periods of below average productivity (Mohan et al. 2009). Future increases in the frequency and severity of extreme weather events will undoubtedly have significant consequences for forests.

Forest Carbon Balance

The USDA Forest Service carries out periodic forest inventories and estimates the amount of carbon in US forest ecosystems and average annual changes in these stocks (USEPA, 2011; Smith et al., 2010). These inventories take into account forest growth, harvesting, and changes in forested land area and show that the carbon in northeastern forests (and the US as a whole) is increasing each year. According to these figures, across the 12 northeastern states there are approximately 34.3 million ha of forested land, representing around 12% of the national total. On average, the forests of the northeast contain about 107 metric tons of non-soil carbon per hectare, somewhat more than the national average of 87 metric tons per hectare. In the northeast, forest carbon stocks have been increasing over the 2001-2010 period by about 0.8 metric ton per hectare per year, about a third more than nationally. Collectively, the northeastern forests have been taking up almost 28 million metric tons of carbon per year, about 16% of the total of all US forests. Based on FIA figures, the net annual rate of forest carbon stock increase (tons C/ha/y) is more than twice as high in the southern states of the region (West Virginia, Maryland, Delaware, Pennsylvania) than in the northern states (Maine, New Hampshire, Vermont). Because of details of the inventory process (only a portion of plots are remeasured each year) and refinements in carbon calculation details (see Smith et al. 2010), the inventory-based estimates are not yet suitable for the detection of trends nor predictions of future carbon uptake or loss.

Climate can affect carbon sinks either through increased productivity and C sequestration in above and belowground plant biomass, plant residues and soil organic matter, or decreased productivity and/or increased rates of soil organic matter decomposition (Davidson and Janssens, 2006).

Land use may either counter or enhance the effects of climatic change on carbon sinks. For example, turn-of-the-century agricultural abandonment and fire suppression led to regrowing forests and caused the Northeast to serve as a global carbon sink for much of the 20th century. Recent data suggest that some of the Northeast (Massachusetts, Connecticut) is, once again, being deforested (Drummond and Loveland, 2010; Jeon, 2011; Thompson et al., 2011). Currently, the legacy of young, growing forests appears to offset the loss of carbon from deforestation for a net carbon sink. This sink is expected to continue for the next 50 years, at least, but if the current conversion rates continue, the future is uncertain. For example, Thompson et al. (2011) suggest that in Massachusetts forest conversion and timber harvest will reduce biomass gains by 18% and 4%, respectively, over the next 50 years, whereas climate change will increase biomass gains by 13.5%, for a net loss of 8.5%.

Controversy exists on how best to estimate carbon sinks. Carbon sinks estimated from changes in land use (or age structure) are generally smaller than estimates based on measurements in forest inventories. For example, Williams et al (in press) reported that recent estimates of *NEP* derived from inventory stock change, harvest, and fire data were twice the *NEP* sink derived from forest age distributions. Possible reasons for these discrepancies include modeling errors and the possibility of climate and/or fertilization (CO_2 or nitrogen) growth enhancements which are picked up by direct inventory methods.

Biogeochemcial Cycling

Changes in climate, hydrology and forest tree species composition will have a cascade of effects on associated biogeochemical processes within forest ecosystems. Warmer temperatures and extended growing seasons will likely increase rates of microbial decomposition, and nitrogen mineralization, nitrification, and denitrification. This would provide increased short term availability of nutrients such as calcium (Ca), magnesium (Mg) and nitrogen (N) for forest growth. However, this would also increase the potential for elevated losses of these same nutrients to surface waters (Campbell et al. 2009). Model results from the Hubbard Brook Experimental Forest, NH suggest that even under a low emission scenario, forests may respond to climate change with significant increases in nitrate leaching from soils to surface waters, with consequences for downstream water quality and eutrophication (Campbell et al. 2009). The potential accelerated loss of the base cations Ca and Mg, especially from sensitive areas that have already experienced loss of these nutrients due to decades of acidic deposition, has important implications for soil acidification as these cations play a pivotal role in buffering acid deposition in the region. Warmer temperatures will also likely increase rates of root and microbial respiration, with an increased release of CO_2 from the soil to the atmosphere.

A major unknown in predicting these warming-mediated biogeochemical responses is the potential interaction with projected future short- and longer-term droughts, which tend to have the reverse impact on microbial processes, with microbes typically reducing activity or going into dormancy during periods of drought stress. Current projections suggest that future summers will be characterized by warmer temperatures and similar total precipitation inputs which will likely occur as larger events separated by longer dry periods. Coupled with potentially higher productivity, the outlook is for increased rates of evaporation and transpiration, resulting in significant reductions in soil moisture and increase in growing season drought conditions, with implications not only for direct effects on biological activity, but also for wildfire frequency.

Extreme Events

Much of the regional discussion on climate change and its impacts on northeastern forests has focused on changes in mean climatic conditions. Human-induced climate change is however also characterized by an increase in the prevalence and severity of extreme events such as heat waves, cold waves, wind storms, floods and droughts (IPCC, 2007; Huntington et al. 2009). There is growing recognition and concern that these types of events can have equal - or greater - impact on natural and managed systems than the more gradual change in means that are typically associated with climate change. In the northeast, legacies of past extreme events such as the hurricane of 1938, the derechos (i.e., long-lived windstorms with winds in excess of 58 mph) of 1995, the ice storm of 1998, and even the most recent tropical storm Irene are readily apparent across the forested landscape of the region. It is imperative for the scientific and land management communities to better understand and anticipate the future occurrence and impact of these extreme events on forest species composition and productivity, biogeochemistry, wildlife, and pests, pathogens and invasive species.

Adaptation

The apparent slow rate of natural vegetation change in response to a changing climate combined with accelerating disturbance and the likely increasing impact of pests, pathogens, and invasive plants, presents a significant challenge to the sustainability and productivity of northeastern forests and the animals within them. A coalition of most organizations involved in land, forest, and animal conservation (including Audubon, The Nature Conservancy, Sierra Club, National Wildlife Federation, Trout Unlimited, and The Wilderness Society) have joined in a call to increase funding to help resource managers at all levels enhance the sustainability of fish, wildlife, and other natural resources in the face of climate change (e.g. http://wilderness.org/content/natural-resources-adaptation-coalition-brief). Federal agencies are now required to manage climate impacts to their missions, programs, and operations (Anon. 2011). However, most forested lands in the Northeast are in private ownership. After identifying likely impacts of climate change, an important next step is to develop cost-effective strategies for adaptation.

Summary

It is evident that the twentieth century climate of the northeastern United States has changed more rapidly than at any time since the last glaciation, and the projections are that this rate of change will continue throughout the 21st century. In the near term, it is likely that productivity of forests has already or will soon increase. However, the unfolding direct and indirect effects of this climate change on forests of the northeastern United States, both alone and in combination with other vectors of change such as acid deposition, N and Hg deposition, ozone, and changes in land use are comprehensive, complex, and not likely beneficial. More research on the direct, indirect, and interacting effects of these changes on forest ecosystems is urgently needed, and aggressive measures to anticipate and adapt to these changes are encouraged.

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4.3 Agriculture and Food Systems

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Agriculture is a significant component of the Northeast economy that includes large wholesale grower-shippers selling product nationally and internationally, a substantial dairy industry, and thousands of small farm operations selling direct retail and providing communities throughout the reion with local, fresh produce. Farmers will be on the front lines of coping with climate change, but the direct impacts on crops, livestock, and pests, and the costs of farmer adaptation, will have cascading effects beyond the farm gate and throughout the Northeast economy (Wolfe et al. 2008: Wolfe et al. 2011a). While climate change will create unprecedented challenges, there are likely to be new opportunities as well, such as developing new markets for new crop options that may come with a longer growing season and warmer temperatures (Hoffman and Smith 2011). Taking advantages of any opportunities, and minimizing the adverse consequences of climate change, will require new decision tools for strategic adaptation. Adaptations will not be cost- or risk-free, and inequities in availability of capital or information for strategic adaptation may become an issue for some sectors of the agricultural economy. Also, adaptation will be made more complex by uncertainties regarding global market forces, and the effects (either beneficial or detrimental) of climate change on competitors and the capacity for adaptation by competing regions.

Along with integrating climate change adaptation into business planning, farmers can play a significant role in climate change mitigation by improving farm energy efficiency, and managing crops, soils, and livestock to reduce greenhouse gas emissions and sequester soil carbon (Wolfe et al. 2011b; American Society of Agronomy 2010). Most mitigation strategies make good business sense given rising energy costs, uncertainties regarding future energy policy, and co-benefits for sustainable soil health and crop productivity (Scherr and Sthapit 2009). The use of farmland and marginal woodlot acreage for biomass fuel crops is likely to become increasingly important in coming years (e.g., see New York biofuels “roadmap”, NYSERDA 2010).

Vulnerabilities

- **Increased frequency of heavy rainfall events and flood damage** is a recent trend and current challenge that is projected to continue. In addition to direct crop damage, wet springs delay planting and subsequently delay harvest dates. This is an issue for agriculture nationally (Hatfield et al. 2011), but particularly for the Northeast (Wolfe et al. 2011a), where the frequency of heavy rainfall events has increased more than any other region of the country (Groisman et al. 2004). For some fresh market vegetable growers, much of their profit is based on early season production so this can have substantial negative economic effects. Use of heavy equipment on wet soils leads to soil compaction which subsequently reduces soil water holding capacity, water infiltration rates, root growth, and yields. Food safety becomes an issue when flooding becomes severe enough for stream overflow into agricultural fields with harvestable crops on the ground, as occurred in the recent (2011) flooding in the Northeast from Tropical Storm Lee.

- **Increased risk of summer drought** (defined here as crop water requirements exceeding water available from rainfall plus stored soil water) was projected to increase for New York in a recent analysis (Wolfe et al. 2011a), due to primarily to increased summer temperatures increasing evapotranspiration without a concomitant increase in summer precipitation. This corroborated a prior climate analysis for the Northeast region by Hayhoe et al (2007). However, compared to some other agricultural regions we may remain relatively water rich because annual precipitation is not expected to decline (Horton et al. 2011). We do not have the same level of certainty regarding projections for future rainfall and drought severity as we do for temperature.
- **Increased frequency of summer heat stress** (i.e., number of days that exceed high temperature thresholds negatively affecting crop yields, crop quality and livestock productivity is projected for the region. Recent modeling analyses for the dairy industry in New York (Wolfe et al. 2011a) and the Northeast (Wolfe et al. 2008) indicate significant milk production declines due to heat stress by mid- to late-century (without adaptation), and the high milk-producing cows being used today are particularly vulnerable.
- **Increased weed and pest pressure** associated with longer growing seasons (allowing more insect generations per season and more weed seed production) and warmer winters (allowing more over-wintering of pests) will be an increasingly important challenge. We already have some examples of earlier arrival and increased populations of some insect pests, such as corn earworm, and model projections of expansion of the aggressive invasive weed, kudzu into the Northeast (Wolfe et al. 2008). Research indicates many of our most aggressive weeds benefit more than crop plants from higher atmospheric carbon dioxide, and become more resistant to herbicide control (Ziska and Runion 2006).
- **Risk of frost and freeze damage** continue, and these risks are exacerbated for perennial crops in years with variable winter temperatures. For example, midwinter-freeze damage cost New York Finger Lakes wine grape growers millions of dollars in losses in the winters of 2003 and 2004 (Levin 2005). This was likely due to de-hardening of the vines during an unusually warm December, increasing susceptibility to cold damage just prior to a subsequent hard freeze (Howell et al. 2000). Another avenue for cold damage, even in a relatively warm winter, is when there is an extended warm period in late winter or early spring causing premature leaf out or bloom, followed by a frost event (Gu et al., 2008).
- **Implications for the broader food system (e.g., storage and distribution)** have not been well-studied, but vulnerabilities range from increased risk of food-borne pathogen outbreaks, increased energy use and costs of refrigeration (Antle 2009).

Opportunities

- **A longer growing season** will open up new opportunities as well as vulnerabilities, such as developing new markets for new crop options. The expansion in the Northeast of the non-native and cold-sensitive European (*Vitis vinifera*) white wine industry over the past 40 years has benefited from the reduced frequency of severe cold winter temperatures over this time period. European red grape varieties such as Merlot could benefit with additional warming, as could other crops such as peaches, watermelon, and tomato (Wolfe et al. 2011a). Some Northeast field corn growers are already experimenting with slightly longer growing-season varieties that produce higher yields. Soybean acreage in New York has increased from about 40,000 acres in 1990 to over 300,000 acres in 2011, associated in part with the climate becoming better suited to this crop (Shackford 2012).

- **Proximity to major metropolitan markets** is an advantage for Northeast farmers, particularly as transportation costs for long distance shippers to the region increase with rising fuel costs. The region is well positioned to meet the demand for a lower carbon footprint food supply, resulting in new job creation and economic development opportunities (Hoffmann and Smith 2011).
- **Competing agriculture regions may be harder hit by climate change.** For example, compared to California, a major competitor with Northeast farmers for sale of high value fruit and vegetable crops, the Northeast will be relatively water rich and summer heat stress will be less severe. The Napa Valley wine grape region of California will be challenged to continue producing high-quality wine grapes (Jones et al. 2005), while European wine grape production in the Northeast may benefit from a longer growing season.
- **There will be many win-win opportunities associated with mitigation** (Wolfe et al., 2011b). Some of these may eventually be applicable to carbon-offset payments in emerging carbon-trading markets. Northeast farmers could:
    - *Conserve energy and reduce greenhouse gas emissions* (increase profit margin and minimize contribution to climate change)
    - *Increase soil organic matter* (this not only improves soil health and productivity, but because organic matter is mostly carbon derived from carbon dioxide in the atmosphere via plant photosynthesis, it reduces the amount of this greenhouse gas in the atmosphere)
    - *Improve nitrogen use efficiency* (synthetic nitrogen fertilizers are energy intensive to produce, transport and apply, and soil emissions of nitrous oxide (a greenhouse gas) increase with nitrogen fertilizer use)
    - *Enter the expanding market for renewable energy using marginal land* (e.g., wind energy, solar, biomass fuels, energy through anaerobic digestion of livestock manures and food processing wastes)
    - *Improve manure management* (reduces nitrous oxide, methane and carbon dioxide emissions; also can be used as renewable energy in anaerobic digesters)
    - *Increase consumer support—from households to large institutional food services—for local food supply*

Adaptations

- ***Improving cooling capacity of livestock facilities*** and increasing the summer use of fans and sprinklers for cooling will be an obvious adaptation strategy for the dairy industry. A recent analyses suggested these low-cost options can pay for themselves and can be effective for moderate heat stress conditions. (Wolfe et al., 2011a) Certainly, new barns should not be designed based on the 20th century climate, but rather for the increased heat loads anticipated in the 21st century.
- ***Chemical and non-chemical control of pests.*** While we can look to more southern regions for control strategies for weeds and pests moving northward, these may not always be directly transferable or desirable for our region, particularly if they involve

substantial increases in chemical loads to the environment. New policies and regulatory frameworks may become necessary, involving good communication among farmers, IPM specialists, and state agencies.

- ***Supplemental irrigation*** will be an obvious adaptation strategy in the Northeast, and investment in expanded irrigation capacity will become essential for those growing high-value crops by mid- to late-century. This assumes that summer droughts do not become so severe as to dry up major surface and groundwater supplies. Since the Northeast does not currently have a significant regional irrigation water supply infrastructure, state-wide investments in such may need to be considered by mid- to late-century.
- ***Adaptations to wet conditions*** include maintaining high soil organic matter and minimizing compaction for good soil drainage. In some cases this will not be sufficient and installation of tile drainage systems will be warranted, a costly adaptation strategy. Shifting crop production to highly drained soils is an effective adaptation, but would then require irrigation for the expected drought periods.

Knowledge Gaps

With timely and appropriate proactive investment in research, as well as support for monitoring and information delivery systems, and policies to facilitate adaptation, the agriculture sector of the Northeast economy will have the necessary tools for strategic adaptation to meet the challenges and take advantage of any opportunities associated with climate change. Below highlights important needs, many of which are discussed in more detail in the recent agriculture chapter of the ClimAID report (Wolfe et al. 2011a).

- **Non-chemical control strategies for looming weed and pest threats** are needed, as well as enhanced regional IPM coordination, and monitoring and rapid-response plans for targeted control of new weeds or pests before they become widespread.
- **New economic decision tools for farmers** are needed that will allow exploration of the costs, risks, benefits, and strategic timing of various adaptation strategies (e.g., the timing of investment in new irrigation equipment) in relation to various climate change scenarios and potential impacts on crops and livestock.
- **Sophisticated real-time weather-based systems for monitoring and forecasting stress** periods and extreme events are needed. Current guidelines for many agricultural practices are based on outdated observations and the assumption of a stationary climate.
- **Crops with increased tolerance to climate stresses** projected for our region, with emphasis on horticultural or other crops important to the Northeast economy but not currently being addressed by commercial seed companies, will be needed and can be developed using conventional breeding, molecular-assisted breeding, or genetic engineering.
- **New decision tools for policy-makers** are needed that integrate economic, environmental, and social equity impacts of agricultural adaptation to climate change.

Regional climate science and modeling research is needed to help farmers discern between adverse weather events that are part of normal variability and those that are indicative of a long-term climate shift warranting adaptation investment. There are some climate factors, such as increased climate variability and increased frequency and clustering of extreme events, that could potentially have severe negative impacts on the agriculture industry, but our current level of certainty about these climate factors is low.

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4.4 Coasts and Oceans

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Introduction

In the northeast United States, many major centers of population, commerce, industry, shipping, as well as private residences and recreational facilities are located near the coast. As sea level rises, this region could face more numerous destructive floods, increased beach and shore erosion, submergence of salt marshes, and saltwater intrusion into estuaries and near-shore aquifers, which in turn would cause significant property damage, more frequent transportation and communication disruptions, and permanent land loss.

Globally, 20th century sea level rose at rates of 1.7-1.8 mm/yr (0.07 in/yr), increasing to ~3 mm/yr (0.12 in/yr) since 1993 (Church and White, 2011; Cazenave and Llovel, 2010). By 2100, sea level could rise at least 18 to 59 cm (7-23 in) (IPCC, 2007), or exceed one meter (3.3 ft) (Vermeer and Rahmstorf, 2010; Horton et al., 2008; Pfeffer et al., 2008; see also *U.S. National Climate Assessment: Sea Level Rise Scenarios*, 2012).

However, global trends are inadequate guides for local adaptation, because of the great variability in local or regional sea level rise due to glacial isostatic adjustments, land subsidence, neotectonics, gravitational changes, and shifts in ocean circulation (Church et al., 2010)[12] (see also Chap. 3.2). In the Northeast, average 20th century sea level trends range between 1.82 mm/yr (0.07 in, Portland, Maine) to 3.44 mm/yr (0.14 in, Annapolis, Maryland) (NOAA, 2009)--somewhat above the global trends. Projected shifts in North Atlantic circulation could raise sea level in Boston, New York City, and Washington, D.C. an additional 20 to 50 centimeters (8 to 20 inches) by 2100 (Yin et al., 2009, 2011), although these changes are considered fairly uncertain.

Extra-tropical cyclones have increased in intensity and storm tracks have shifted northward over the last 50 years (see also Chap. 3.2). Winter storms are expected to strengthen, with higher wind speeds and more extreme wave heights (Karl, et al., 2009, p.38).

Although the total number of tropical cyclones will likely decrease or remain the same, the number of most intense cyclones is expected to increase substantially ((Knutson et al., 2010; Mousavi, et al., 2011). Superposition of elevated hurricane surges on a higher sea level will exacerbate coastal flooding.

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[12] In the Northeast, spatial variations in relative (or local) rates of sea level rise, as measured by tide gauges, come mainly from subsidence due to glacial isostatic adjustments, and in places, excess groundwater extraction. Tide gauge record lengths differ, but generally span much of the 20th century. The Battery, New York City, has one of the longest records in the U.S., dating back to 1856. http://tidesandcurrents.noaa.gov.

Cumulative effects of increased annual and seasonal temperatures (Hayhoe et al., 2007), changes in snow pack and density, and shifts in lake ice-out dates (Huntington et al., 2004; Hodgkins and Dudley, 2006; Hodgkins et al., 2002) could change the timing and magnitude of river flows (Shaw et al., 2011; Collins, 2009; Hodgkins et al., 2003) which would ultimately impact the coastal zone. The increased number of extreme precipitation events in the Northeast (Douglas and Fairbank, 2011; Speirre and Wake, 2010) may have raised groundwater table elevations over the last decade (Weider and Boutt, 2010) (See also Chap. 3.2).

Impacts

Permanent inundation and land loss will accompany higher ocean levels. In the Chesapeake Bay, several historically inhabited islands have been abandoned, disappeared, or are rapidly shrinking (Gibbons and Nicholls, 2006; Mills et al., 2005) [13]. This could presage similar losses elsewhere. The eastern shore of the Chesapeake Bay is particularly vulnerable to impacts of accelerated sea level rise, because of its low topography, hundreds of miles of coastline, and growing population, especially in and around Dorchester County, where half the land area lies below 1.5m of sea level and is already vulnerable to flooding from moderate storms (Cole, 2008). By 2100, about 93 per cent of the tidal marshes and swamps and over 32,000 acres of undeveloped dry lands in the Blackwater National Wildlife Refuge, may be inundated (National Wildlife Federation, 2008; Maryland Dept. Nat. Res., 2008). In New Jersey, for example, a sea level rise of 2 ft (0.61 m) or 4 ft (1.22 m) by 2100 would permanently inundate between 170 and 442 km^2 respectively (corresponding to 1% to 3% of the total land area) (Cooper et al., 2008).

Sea level rise is also likely to exacerbate beach and bluff erosion, shoreline retreat, and migration of tidal inlets (Fitzgerald et al., 2008). Historic shoreline retreat[14] from New England to Maryland has averaged 0.5 m (19.7 in) plus or minus 0.09 m (3.5 in) per year, with the highest average rates on Martha's Vineyard and Nantucket, northern New Jersey, and Delaware (Hapke et al., 2010). Since the 1960/1970s, the regional retreat averaged 0.3 m (11.8 in) plus or minus 0.1m (3.9 in), with 60 percent of the sampled transects eroding.

More frequent coastal flooding is another consequence of rising sea level, even without changes in storm characteristics. In the Northeast, the return period of the 2005 100-year storm flood elevation could shrink to 30 years by 2050, assuming the relatively high A1F1 IPCC SRES emissions scenario (Kirshen et al., 2008a). In Boston and Atlantic City, the 100-yr flood level return periods could shrink to 8 years or less by the 2050s. In New Jersey, a 2 ft (0.61 m) sea level rise would reduce the current 100-year return period to 30 years, and a 4 ft (1.22 m) rise would reduce it to 5 years (Cooper et al., 2008).

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[13] The anomalously high relative (local) sea level rise in Chesapeake Bay is a combination of sediment loading, glacial bulge collapse, groundwater extraction, a buried impact crater, and tectonic crustal downwarping. http://pubs.usgs/fs/fs_102-98/ http://www.ngs.noaa.gov/GRD/GPS/Projects/CB/SUBSIDENCE/subsidence.html ; http://marine.usgs.gov/fact-sheets/fs49-98/

[14] Shoreline changes were measured along open ocean sandy beaches, from the 1800s to the present using nautical charts, topographic maps, aerial photography, and more recently, LIDAR, with mean high water or high waterline as reference datums.

Saltwater will encroach further upstream and into coastal aquifers (Karl et al., 2009; Shaw et al., 2011), and increase the salinity of estuaries, which may show increased variability due to greater expected variability in streamflow (e.g., Najjar et al., 2010). Already, upland areas in Dorchester County, Maryland, on the eastern shore of Chesapeake Bay, are becoming nontidal wetlands, infiltrated with brackish water (Maryland Dept. Nat. Res., 2008).

Boston and New York City, in general, will be more resilient to salinity impacts, because their reservoirs are located far inland. However, with rising sea level the salt front could migrate up the Hudson River to the Chelsea Station water intake station, near Poughkeepsie, NY, particularly during droughts—just when the water is most needed (Buonaiuto et al., 2011). Some other areas potentially affected by encroaching salinity include Philadelphia (Delaware River) and Long Island aquifers (Buonaiuto et al., 2011; Karl et al., 2009).

Vulnerabilities

Current and future exposure to flooding and storm damage depends on various physical and socioeconomic factors such as rates of sea level rise, frequency and intensity of storms, land elevation, dynamic or unstable landforms, such as barrier islands, open coast sandy beaches, estuaries, wetlands, or deltas, and projected changes in population growth and housing density. High-risk populations include the aged, disabled, urban poor, and those lacking transportation during storm evacuation emergencies or access to evacuation routes.

Populations at risk within the 100-year flood zone—present and future

In the Northeast, of the nearly 1.6 million people living within the FEMA 100-year coastal flood zone (2000 census), 63 per cent live in New Jersey and New York (**Table 4.3**) (Crowell et al., 2010).

Table 4.3. Population in the FEMA 100-year flood zone (Crowell et al, 2010).

Maine	33,000
New Hampshire	11,000
Massachusetts	174,000
Rhode Island	55,000
Connecticut	119,000
New York	494,000
New Jersey	496,000
Delaware	46,000
Maryland	148,000
Total	*1,576,000*

Around a third of the land area of Boston and New York City, and 13% of Washington, D.C. lie at or below 6 meters, exposing them to storm surges superimposed on a higher sea level (Overpeck and Weiss, 2009).

Barrier islands constitute an inherently dynamic, high-risk environment. Northeast states with the largest barrier island populations are New York and New Jersey (209,956 and 158,320, respectively) (Zhang and Leatherman, 2011). Regional cities located on barrier islands (entirely, or in part) include Atlantic City, New Jersey, Ocean City, Maryland, and Long Beach, New York.

A recent building boom has accompanied the revitalization of urban waterfronts, such as Boston harbor, New York City, Jersey City and Hoboken, NJ, and Baltimore (**Figure 4.4**). The evacuation of roughly 370,000 New York City residents from homes and high-rise condominiums in Battery Park City, Coney Island, and Rockaway Beach neighborhoods of New York City, in preparation for Hurricane Irene in August, 2011, are a harbinger of the growing population potentially vulnerable to storm surges (Barron, 2011). Planned re-development of the Brooklyn waterfront (NYC-DCP, 2011) could expose additional population and property to storm risks.

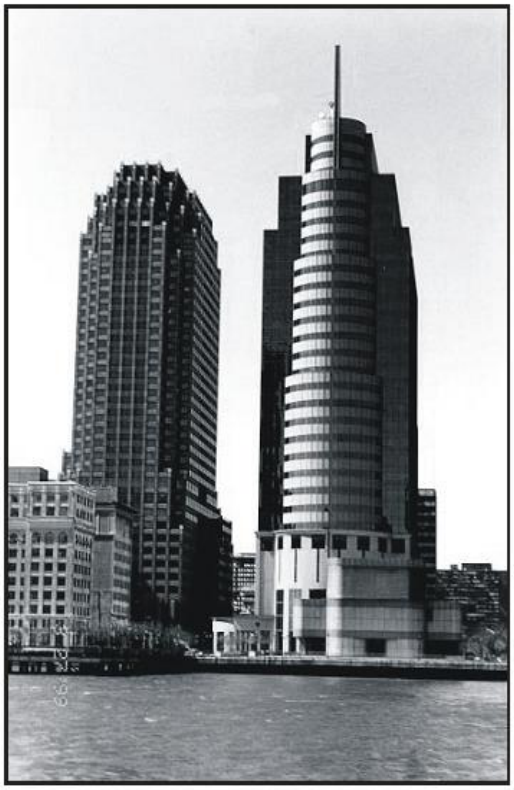
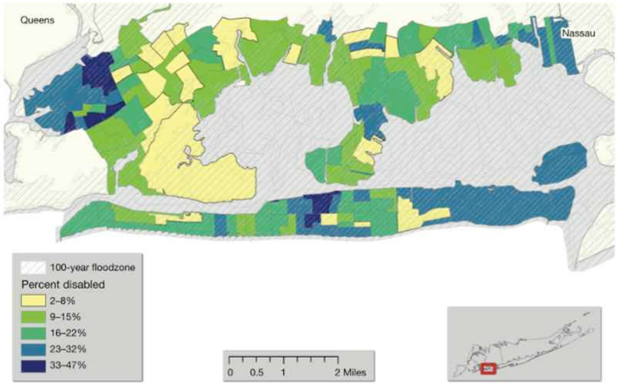
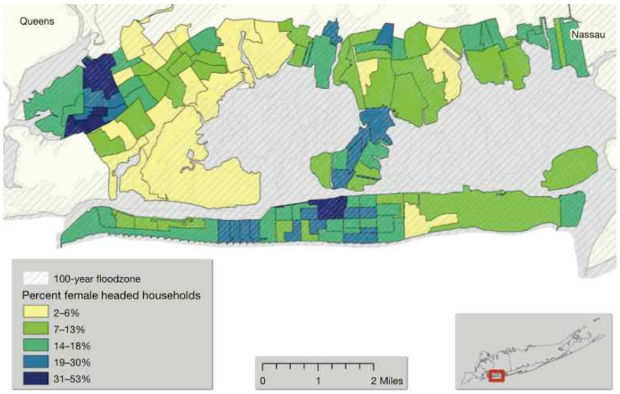


Figure 4.4. Waterfront re-development, Jersey City, New Jersey. Photo: V. Gornitz.

Box 4.2: Case study - Long Beach, NY.

Long Beach Barrier Island, off Long Island, New York encompasses the towns of Long Beach, Atlantic Beach, and Lido Beach, and along with adjacent sections of coastal communities on the mainland, falls within the FEMA 1-in-100 year flood zone. Whereas diverse income groups within the flood zone share a comparable risk to coastal flooding their ability to cope with disaster will differ markedly (Buonaiuto et al., 2011). Although Long Beach is predominantly middle class, clusters of low income, renters, and/or disabled populations within the 100-year floodplain may be less able to cope with the impacts of storm floods (**Box Figure 4.2a and 4.2b**). Only three bridges connect the barrier island to Long Island and during an emergency, the elderly, handicapped, or those lacking vehicles may be unable to evacuate in time. Hurricane Irene (downgraded to tropical storm), which passed directly over the island on August 28, 2011, illustrates the exposure of the island to severe coastal storms. Despite evacuation orders, most residents chose to remain on the island, which fortunately escaped with only minor street flooding and beach erosion.





Box Figure 4.2a. Percent of disabled population in Long Beach area, by census tract (US Census 2000). [Fig. 5.12 in Buonaiuto et al., 2011)].
Box Figure 4.2b. Percent of female-headed households in Long Beach area, by census tract (US Census 2000). [Fig. 5.13 in Buonaiuto et al., 2011)].

Assets at Risk

Vulnerability of property to sea level rise or storm surge depends on the rate and extent of rise, the storm flood level, location within the flood zone, building type and age, and existing protective structures.

New York City, New Jersey, Boston, Philadelphia, Wilmington, and Baltimore represent major U.S. Northeast seaports. In addition to port facilities, other types of critical infrastructure potentially at risk include schools, hospitals, transportation routes, oil tanks and refineries, power stations, and wastewater treatment plants. The vulnerable location of some of these assets may expose them to wave damage, salt water corrosion, and groundwater intrusion at times of higher flood levels.

Coastal Ecosystems at Risk

Extensive coastal wetlands remain around Chesapeake Bay, Delaware Bay, New Jersey, Long Island, and Cape Cod. In addition to providing important habitat for migrating birds, fish and other aquatic life, coastal wetlands provide recreational opportunities, such as birding, boating, fishing, and protection against storm surges and waves. Furthermore, salt marshes store carbon in thick peat deposits (Elsey-Quirk et al., 2011, Mudd et al., 2009, and Chmura et al., 2003).

Salt marshes can withstand moderate rates of sea level rise given an adequate sediment supply. However, they are unlikely to survive rates exceeding 10-20 mm/yr, except in places with high sediment deposition and/or tidal ranges (Kirwan, et al., 2010; Cahoon et al., 2009, Reed et al. 2008). In New Jersey, for example, a sea level rise of 2 ft (0.61 m) and 4 ft (1.22 m) would submerge nearly 17% and over 32% of the state's coastal wetlands, respectively (Cooper et al., 2008). On the other hand, Rhode Island marshes with present accretion rates of 1.5 to 1.7 times that of local sea level rise are quite likely to keep pace with rising sea level over the next century (Bricker-Urso et al., 1989). However, other mid-Atlantic marshes do not show comparable rates (Chmura et al. 2003). While short-term accretion data are being collected throughout the coastal Northeast[15], results to date are still too preliminary to anticipate future marsh extents (Cahoon, D.R. and Lynch, J., 2011). In many places, aerial photo analysis indicates a progressive erosion of marshes along their seaward edge and limited inland migration (e.g., Jacobs et al. 2010). In spite of greater regulation to minimize development and land clearing since the 1970s, wetland deterioration and losses of 1-2 % per year have occurred thereafter (e.g., Hartig et al., 2002). Dredging for navigation channels has inadvertently increased the tidal range, which may have exacerbated marsh submergence (Swanson, 2008), and climate change is creating additional stresses. Where neither development nor steep slopes restrict inland marsh migration, high marsh is converting to low marsh (Hartig and Gornitz, 2005, Donnelly and Bertness 2001).

Box 4.3: Case study - Chesapeake Bay

Chesapeake Bay is the largest estuary on the U.S. Atlantic Coast. Home to around 15 million people, Chesapeake Bay is a major link in the Atlantic flyway estuary and boasts over 3,600 species of wildlife, including over 350 species of finfish. Commercial harvesting of finfish and shellfish yield about $200 million annually (USACE, 2008).

A 2°F increase in Chesapeake Bay water temperatures since the 1930s, as well as historic sea level rise, has intensified coastal flooding, conversion of wetlands to mudflats, and has caused changes in salinity. The temperature increase has adversely affected the eelgrass, which provides habitat for blue crab and other marine organisms (Maryland Dept. Nat. Res., 2011; Najjar et al., 2010). Water pollution, habitat losses, and over-exploitation have also stressed aquatic ecosystems. Tidal freshwater marshes in Chesapeake Bay are especially vulnerable because of the low salinity tolerances of the vegetation. To preserve the economic and ecological resources of Chesapeake Bay, the State of Maryland recommends a number of strategies, among which are restoration and protection of high quality natural habitats to foster resilience, reduction in impervious surfaces by planting vegetation, removal of impediments to habitat connectivity, enforcement of tougher pollution standards, prioritization of preservation programs, and restoration of critical bay and aquatic habitats to enhance their resilience to climate change (Maryland Department of Natural Resources, 2011) (see also Saving Blackwater National Wildlife Refuge, below). Other ongoing efforts include multi-agency USGS, NOAA, FWS, and NMFS collaboration with local parks managers to collect data on marsh accretion rates (see the Chesapeake Bay Watershed FY 2011 Action Plan).

Fish and Shellfish in the Northeast

Commercial and sport fisheries are major food and recreational resources along the Northeastern coast. As coastal waters in the Northeast continue to warm, fish and shellfish have and will

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[15] Using Surface Elevation Tables and feldspar marker horizons.

continue to respond in various ways. Freshwater – marine migratory (anadromous) fishes that make spawning runs up their natal rivers may become extirpated, experience changes in their life cycle and migration phonologies, or colonize rivers that becomes inhabitable because of favorable thermal changes. Marine species may respond by shifting their distributions, by experiencing altered spawning success, or through changing interactions with other species within their ecological community.

Box 4.4: Freshwater-marine migrating fish

Spawning runs up rivers of anadromous fishes cue to water temperatures and flow. Significant temperature increases over the 20th and 21st centuries have been observed in Northeastern rivers, including the Potomac, Patuxent, and Delaware, Hudson, and Hubbard Brook, New Hampshire (Kaushal et al. 2010). Seekell and Pace (2011), for example, found a 0.945^{0}C increase between 1946 and 2007 in the Hudson River at Poughkeepsie, with many of the warmest temperatures recorded over this period's final 16 years. Changes in annual and seasonal discharges in Northeastern rivers (Hayhoe et al. 2007) may affect runs anadromous fishes.

Rainbow smelt, *Osmerus mordax*, a boreal species that ranges southward into north temperate waters, has shown the most dramatic response of Northeastern fishes to date. Smelt ceased spawning migrations in the Delaware River circa 1900, but continued to appear in the Hudson River system after that. However, the last significant tributary runs on the Hudson occurred in 1979 (Rose 1993), and recreational net fisheries have since disappeared. While Hudson River utilities survey data did not show a decline between 1974 and 1990 (Rose, 1993), since 1995, rainbow smelt essentially disappeared from the Hudson River and they have not been seen in other surveys.

Simultaneously, anadromous smelt were also disappearing from Connecticut and Massachusetts waters, where they once supported recreational and commercial fisheries. Sampling in about a dozen Connecticut rivers and streams in 2003 and 2004 captured only nine smelt, from the Mystic River, in 2004 (Fried and Schultz 2006). Another boreal anadromous fish with similar temperature requirements, Atlantic tomcod *Microgadus tomcod*, also appears to be retreating northward. The Hudson population is showing a long-term decline, and the species has become scarce in Connecticut and Rhode Island (Fried and Schultz 2006). This pattern of progressively northward declines and disappearances of both smelt and tomcod are strongly consistent with thermal stress.

A shift in species' range and colonization pattern may be another indicator of warming waters. Gizzard shad, *Dorosoma cepedianum,* is a euryhaline (tolerates fresh to marine salinities) herring that enters the sea but is more commonly seen in fresh and brackish waters. Found in brackish waters from New York southward over than a century ago, a few individuals were detected in New York Harbor in the 1930s (Breder, 1938). Gizzard shad were unknown from the Hudson River until 1973, when 674 specimens were caught (George, 1983). Since then gizzard shad have become common in the Hudson. They also appeared near the mouth of the Connecticut River by 1976, in Massachusetts waters of the Connecticut River, and to the east in Niantic Bay by 1985 (O'Leary and Smith 1987). In October 1985 a single specimen was captured in the Merrimack River, in Lawrence, Massachusetts (O'Leary and Smith, 1987). Subsequently, gizzard shad have been caught in Maine as far north as the Kennebec River (Daniels et al., 2005). The progressive northward expansion of range of this southern temperate fish is consistent with warming.

Another consequence of warming is an apparent shift in the phenology (annual timing) of anadromous fishes towards earlier spawning runs. In Maine, the median capture date for Atlantic salmon *Salmo salar* in the Penobscot River advanced by 1.3 days per year between 1986 and 2001, and by 1.2 days per year between 1983 and 2001 for alewife in the Androscoggin River (Huntington et al., 2003). Similarly, critical temperatures that characterize the timing of alewife *Alosa pseudoharengus* runs into streams into eastern Connecticut have advanced by almost two weeks between the 1970s and 2007 (Ellis and Vokoun, 2009). While the full consequences remain unknown, the rapidity of the change has the potential to disrupt these fishes' established ecological relationships at various life history stages.

Box 4.5: Marine Fish and Shellfish

The marine waters of the Northeast include portions of two thermally contrasting zoogeographic provinces, the colder Acadian Province (north of Cape Cod) and the warmer Virginian Province (south of Cape Cod). Although many species occur in both provinces (often in different seasons), fish diversity is much higher in the Northeast. For instance, 326 fish species occur in New York's marine and estuarine waters (Briggs and Waldman, (2002). This high diversity is due in part to the great variety of habitats (e.g., estuaries, coastal bays, tidal straits, ocean beaches, continental shelf) and to pronounced seasonal temperature changes (Briggs and Waldman 2002).

The longest available coastal sea-surface temperature time series (Woods Hole, Massachusetts, 1886-2002) showed variations consistent with recent warming (Nixon et al. 2004). The temperature record showed no significant trend for the first 60 years, but some cooling occurred during the 1960s, followed by significant warming from 1970–2002 at an annual rate of 0.04°C. During the 1990s, annual mean temperatures averaged approximately 1.2°C warmer than on average between 1890 and 1970; winter (December, January, and February) temperatures were 1.7°C warmer and summer (June, July, and August) temperatures were 1.0°C warmer.

In the New York Bight, Buonaiuto et al. (2011), modeled sea surface temperature changes for the 2050s in comparison with a 1980s baseline under two emissions scenarios. Substantial future increases for near-shore waters ranged between 1.0 to 1.4 °C , depending on the particular model and emissions combination. The projected temperature increases between Long Island and waters to its south correspond to current water temperatures between the southern tip of the Delmarva Peninsula and Delaware Bay. Thus, the present-day fish community of this more southerly region provides a glimpse of what the ichthyofauna of New York may resemble in 2050 (Buonaiuto et al., 2011).

In Narragansett Bay, Rhode Island, annual mean water temperature has risen 1.7 °C in 30 years (Fulweiler and Nixon 2009). The modest increases in water temperatures there and in other temperate coastal waters have caused large ecological shifts that favored macrocrustaceans (e.g., crabs) and southern pelagic fishes at the expense of boreal demersal fishes (Oviatt (2004). Temperature increases have altered growth and nutrient dynamics between winter flounder

Pseudopleuronectes americanus early life stages and predatory sand shrimp *Crangon septemspinous*, which may have contributed to the sharp decline in winter flounder in Narragansett Bay (Taylor and Collie, 2003).
Declines in an important macrocrustacean, American lobster *Homarus americanus,* at the southern edge of its range in New York, have been likely linked to warming waters (Howell et al. 2005). Warming has favored three alien sea squirts over native forms in Long Island Sound (Stachowicz et al. 2002), potentially affecting community structure.

Warming will also impose complex and difficult-to-forecast shifts in the relationships between freshwater and saltwater habitats. American eel *Anguilla rostrata* has evolved to capitalize on the transport and nutrient resources of the Gulf Stream. However, observed declines of eels in freshwaters may be related to recent effects of climate change on this current (Wirth and Bernatchez 2003).

In summary, fishes of the Northeast face a litany of stresses, including overfishing, pollution, and habitat alteration. To these may be added evidence of considerable effects of warming. Moreover, it is likely that more subtle and complex climate effects have gone largely undetected. Additional warming may induce greater effects as thresholds of tolerances are exceeded and as community interactions are further perturbed.

Broader scale effects in the Northeast also are likely with additional warming. The relative abundances of anadromous vs. coastal shelf-spawning fishes in Chesapeake Bay varied on a scale of a decade or longer, most likely with the phases of the North Atlantic Multidecadal Oscillation (AMO), which affect precipitation (Wood and Austin, 2009). Wetter phases enlarge low-salinity estuarine nursery areas for anadromous fishes, whereas drier phases create higher-salinity estuarine nursery areas for coastal spawners. Climate changes that affect the AMO directly, or freshwater runoff, would also affect Chesapeake Bay fishes.

One challenge in discerning climate-driven changes in marine fish distributions is that the signal may be masked by noise from other factors. Fish distributions are not static even when environmental conditions remain nearly constant. Fish populations occupy the most optimal habitats under low abundances but also disperse into less optimal habitats at high abundances (MacCall 1990). Thus, mainly mid-Atlantic species that only rarely occur in New York waters may appear there largely as a function of density dependence and not because of favorable temperatures. Tracking changes in runs of anadromous fishes may provide a clearer signal of warming in that nearly all anadromous species return to natal rivers to spawn, thereby fixing one potential variable, geography, but not phenology.

Adaptation

Adapting to sea level rise generally involves implementing measures to minimize inundation risks and also helps to mitigate the present-day risk of storm surge flooding. Specific adaptation actions can follow three basic pathways: 1) shoreline protection, 2) accommodation, and 3) managed relocation (retreat).

Shoreline Protection

Building new or reinforcing existing engineering structures and restoring natural coastal landforms are two major approaches to shoreline protection. Raising existing seawalls, dikes, and levees and strengthening bulkheads, revetments, and adding breakwaters offers extra protection against higher surge levels and waves. Such structures are well suited to protect highly developed areas (e.g., Kirshen et al., 2008b), but need to be appropriately designed in order to prevent undermining of embankments, which would increase the flood risk. Other defense structures include proposed tidal barriers for New York City (Hill ed., 2011), similar to the Thames Barrier, London, or the Maeslant barrier, the Netherlands.

Beach nourishment and widening are extensively used to buffer against storm surges and also provide recreational space. Other “soft” protective methods include dune and wetlands restoration, and replanting of native vegetation (**Figure 4.5**). However, coastal wetland buffer zones many kilometers wide may be needed to substantially reduce storm surge impacts, and predicting the exact attenuation, which depends on topography and duration of storm surge, is difficult (e.g., Wamsley et al, 2010).

Figure 4.5a. Dune revegetation in Atlantic City. Photo: Jon K. Miller, Research Assistant Professor, Stevens Institute of Technology.
Figure 4.5b. Dune restoration, Ocean City, New Jersey. Photo: Tom Herrington, Stevens Institute.

Coastal wetland restoration, similar to beach nourishment, involves adding sediment and replanting with salt marsh species. In Chesapeake Bay, Maryland and Jamaica Bay, New York, sandy material dredged during harbor deepening projects was stockpiled and then placed on former marshlands and replanted with salt marsh species (U.S. Army Corps of Engineers, 2008a, 2011, 2012).

Box 4.6: Saving Blackwater National Wildlife Refuge

Called the “Everglades of the North”, Blackwater National Wildlife Refuge, 12 miles south of Cambridge, Maryland, is home to endangered Delmarva fox squirrels and the largest population of American bald eagles north of Florida (U.S. Fish & Wildlife Service, 2010). The Blackwater watershed contains one-third of Maryland’s tidal wetlands, and thus plays an important role in maintaining the region’s biodiversity and productivity. Since the 1930s, the refuge has lost over 8,000 acres (3,240 hectares) of salt marsh to rising sea level, subsidence, increasing salinity, and invasive species predation (**Box Figure 4.3**). To prevent further losses and preserve the unique estuarine ecosystem, the Mid-Chesapeake Bay Marshland Restoration Project developed by the U.S. Army Corps of Engineers, the U.S. Fish and Wildlife Service, the Maryland Port Administration, the Maryland Department of Natural Resources, and the University of Maryland will use material dredged from shipping channels to expand and restore several Bay islands and help return wetlands in Dorchester County and the Blackwater Refuge to 1930s-era conditions (U.S. Army Corps of Engineers, 2008b; U.S. Fish & Wildlife Service, 2010). As an added benefit, the restored marshes will provide storm protection for nearby towns, including Cambridge, Maryland.

Box Figure 4.3. Blackwater National Wildlife Refuge. Left: Stressed salt marsh (brown); healthy marsh (green). Right: submergence of marsh (U.S. Fish & Wildlife Service, http://www.fws.gov/blackwater/restore.html (last updated Sept. 30, 2010).

Accommodation

Various strategies to live with rising waters and lessen flood damages can be adopted, some of which are becoming more common. Building codes can make structures more storm-resilient. Buildings can be raised above the FEMA 100-year flood zone, constructed on stilts, or ground floors used for non-residential purposes, such as business, parking, or recreation. For example, the Deer Island Wastewater Treatment Plant in Boston Harbor was elevated 1.9 feet (0.58 m) in 1998 above its original height to accommodate projected sea level rise through the 2050s--the planned lifespan of the facility (Feifel, 2010).

Neighborhoods can be designed around “floating” buildings and houseboats (e.g., Sausolito, Seattle, Rotterdam, Bangkok (Dircke et al., 2012). Innovative multifunctional flood defenses (such as dikes) combine surge protection with housing, parking, parks, and commercial activities. Multi-purpose examples from Dordrecht, the Netherlands, Hamburg, Germany, and Toyko, Japan can serve as models for Northeast coastal cities (Stalenberg, 2012) (**Figure 4.6**).

Figure 4.6. Raising and strengthening the levees in Scheveningen, the Netherlands. Notice the buildings on top of the structure. (Photo: V. Gornitz)

Box 4.7: Rural African-American communities along the Eastern Shore of Chesapeake Bay.

Paolisso et al. (2012) evaluated adaptation options for Smithville and Bellevue, Maryland, two small, poor and aging communities along the Eastern Shore of Chesapeake Bay. The two towns are examples of *invisible communities* because of their overall geographic isolation, small size, and dispersed population. While residents' scientific understanding of climate change was limited, their experience in surviving a series of severe blizzards in early 2009 that made roads impassable and assistance or evacuation impossible gave them intimate familiarity with impacts of flooding and extreme storm events. Therefore, members of both communities were highly motivated to learn more about their options for adapting to climate change impacts. Community-based education, support, and assistance efforts could significantly improve their adaptive capacity. Information on state and county adaptation plans as well as environmental and human impacts would provide people with the knowledge and understanding to engage the community in adaptive programs. As is true throughout the Eastern Shore, local churches provide a social institution that motivates, organizes, and mobilizes individuals to work toward common goals. Thus, church-based networks could become a key component in facilitating future adaptation plans in this region. Schools are another community-based institution that can disseminate information and help organize adaptation planning.

Heavy rainfall accompanying severe coastal storms, such as Nor'Ida (Nov. 13-14, 2009) and Hurricane Irene (Aug. 22-29, 2011) (Chapter 3.2), frequently produces extensive river flooding.

Therefore, urban water management needs to plan for both inland and coastal flooding, inasmuch as coastal storms frequently produce heavy inland precipitation (Chapter 4.1). Creating more urban "green infrastucture" or "green roofs", expanded park space and curbside tree plantings will help increase soil infiltration and reduce runoff.

Other accommodation strategies include building canals and slips, and artificial offshore islands to dissipate wave energy. A reduction in seaward slope and planting of saltmarsh vegetation, or salt-tolerant shrubs can also dampen wave energy and surge impacts (Nordensen et al., 2010; Aerts, et al., 2011).

Managed relocation (retreat)

While shoreline protection and accommodation may lessen the effects of near future sea level rise and storm surges, these measures may be insufficient against accelerated sea level rise and exacerbated flooding. A point may be reached where the frequency and severity of flood damages may necessitate relocation further inland. The relocation (or retreat) can be phased in over time through buyout programs, erosion setbacks that include sea level rise, rolling easements, relocation of individual structures inland, and land use zoning. Existing regulations vary by state and locality, and are often weakly enforced (Titus, 2009; Higgins, 2008). A retreat option may be more appropriate for less developed and/or environmentally sensitive areas (e.g., Kirshen et al., 2008b).

Box 4.8 Adaptation to sea level rise in New York City

As a consequence of an anticipated 1 to 2 foot (30 to 58 cm) sea level rise (possibly up to 3.4-4.6 ft [1 to 1.2 m], in the less likely event of more rapid ice melt[16]) by the 2080s, New York City faces more frequent and extensive flooding of streets, residences, businesses, wastewater and sewage treatment facilities, power plants, and other critical infrastructure, with serious economic implications (Buonaiuto et al., 2011; Rosenzweig, C. and Solecki, W., 2010). In response to this potential threat, the New York City Panel on Climate Change (NPCC) has outlined an eight-step "flexible adaptation pathway" which includes inventorying infrastructure and assets at risk, linking adaptation strategies to capital and rehabilitation cycles, and periodically re-adjusting adaptation plans to the latest climate projections (Rosenzweig et al., 2011; Rosenzweig and Solecki, 2010; see also NCA Urban, Infrastucture, Vulnerability and Climate Change; Section 3.1.1). While originally developed for New York City, the proposed adaptation plan can be readily modified to serve the needs of other urban areas in the Northeast.

Meanwhile, the City is incorporating the NPCC climate and sea level rise projections into its planning and is updating FEMA's flood insurance rate maps (e.g., **Box Figure 4.4**) with LIDAR data (NYC DCP, 2011; see also Duell et al., 2011). In addition, the City is expanding its green infrastructure, embarking on wetlands restoration, and creating "soft edge" waterfronts to dampen oncoming wave energy.

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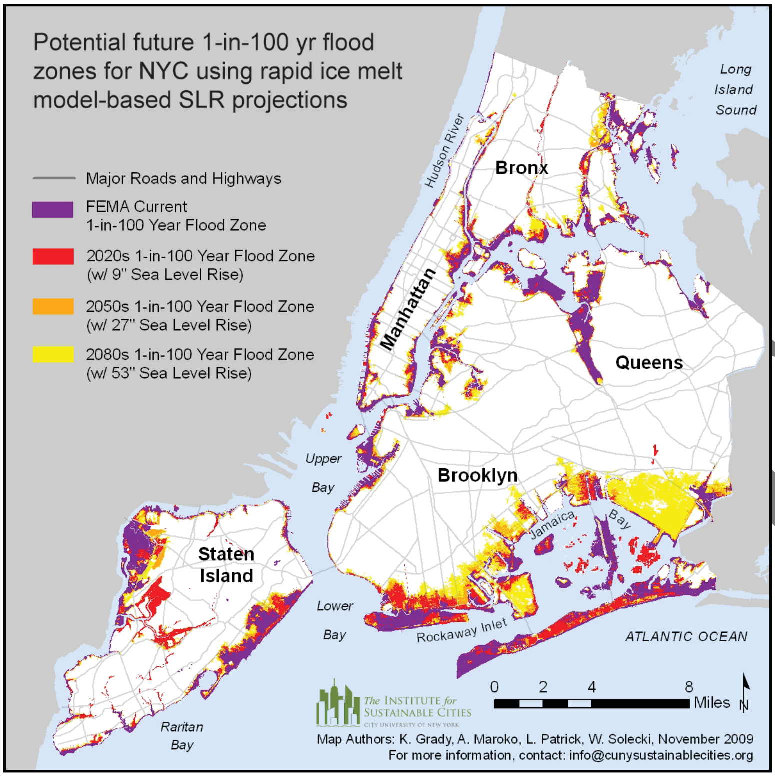
[16] See Horton et al., 2010, in: Rosenzweig, C. and Solecki, W., eds. 2010. Climate Change Adaptation in New York City: Building a Risk Management Response. *Annals of the New York Academy of Sciences*, 1196, 354p.



Note. This map is subject to limitations in accuracy as a result of the quantitative models, datasets, and methodology used in its development. The map and data should not be used to assess actual coastal hazards, insurance requirements or property values or be used in lieu of Flood Insurance Rate Maps issued by FEMA.

Interpretation. The floodplains delineated above in no way represent precise flood boundaries but rather illustrate three distinct areas of interest: 1) areas currently subject to the 1-in-100 year flood that will continue to be subject to flooding in the future, 2) areas that do not currently flood but are expected to potentially experience the 1-in-100 year flood in the future, and 3) areas that do not currently flood and are unlikely to do so in the timeline of the climate projection scenarios used in this research (end of the current century).

Box Figure 4.4. The potential 100-year flood zones for New York City with sea level rise—rapid ice melt scenario (Fig. 3 in Solecki et al., 2010).

Other options include adapting emergency evacuation plans (such as those implemented during Hurricane Irene; see Chap. 3.2) to changed climatic conditions, raising critical infrastructure, elevating flood walls, re-zoning to lower building density, multifunctional land use development, flood-resilient construction, open space preservation, and greening of the waterfront (Major et al., 2012; NYC-DEP, 2011). Construction of storm surge barriers represents a large-scale adaptation approach (Hill, 2011).

Conclusions

Significant sections of major Northeast cities, seaports, commercial, industrial, and recreational facilities are located near the coast and face growing risks associated with accelerated sea level rise, including land submergence, increased frequency of coastal storm flooding, exacerbated beach erosion, wetlands losses, and saltwater incursion. Changes in near-shore ocean and stream temperatures have already begun to affect regional fish communities. Over 1.6 million people in this region live within the FEMA 100-year flood zone and the coastal population will mount as development continues. However, communities can take steps to lessen potential adverse effects. Adaptation to a rising sea assumes multiple approaches. Among these are strengthening shoreline protection by building new engineering structures or reinforcing existing ones, restoring and re-vegetating beaches and coastal wetlands, constructing more flood-resilient buildings, and establishing appropriate land use zoning, erosion setbacks, and rolling easements linked to sea level rise. Local, state, and regional planners are beginning to assess the impacts of sea level rise and consider means of adaptation. However, a need exists for greater inter-agency cooperation and coordination, information sharing, and incorporation of the latest scientific data on climate change into the planning process.

- Recent high-end sea level rise scenarios (Vermeer and Rahmstorf, 2009; Horton et al., 2008) imply heightened exposure of Northeast coastal cities and natural ecosystems to more frequent storm surge flooding and other adverse effects (Rosenzweig and Solecki, 2010; Kirshen et al., 2008a). Low-lying and subsiding areas will be the most affected.
- Changing ocean currents could enhance sea level rise and also affect marine ecosystems in the Northeast to a greater extent than in other parts of the country (Hu et al., 2011; Yin et al., 2009, Yin et al., 2011).
- Coastal managers, decision makers, and stakeholders should begin planning for adaptation to future sea level rise (Rosenzweig et al., 2011; Major et al., 2012).
- Inasmuch as climate change will likely exacerbate existing socioeconomic inequities, augmenting adaptive capacity for resource limited communities will be instrumental in enabling these communities to adapt (Douglas et al., 2010; Paolisso et al., 2012).

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4.5 Human Health

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This section identifies some of the health–exposure pathways likely to affect people living in the Northeast region, assembles current knowledge on the associated public health burden, and highlights strategies to adapt to and reduce such impacts. The federal interagency working group on Climate Change and Health has conducted a comprehensive assessment of potential public health impacts from climate-sensitive environmental exposures for the nation as a whole (Portier et al., 2010).

Impacts and Vulnerabilities

A combination of retrospective data analysis and predictive models has been used in environmental epidemiology to determine the public health burden attributable to climate change. This section gleans from the recent literature to highlight some of these estimated health impacts and vulnerable populations.

Extreme Heat

There is a growing evidence base linking elevated summer temperature to excess mortality (Kovats and Hajat, 2008) and morbidity (Ye et al., 2011). In the United States, deaths associated with extreme heat are the primary cause of weather-related mortality (Luber and McGeehin, 2008). Metzger et al. (2010) tracked each death in New York City between 1997 and 2006 during the months of May to September and found a sharp increase in the frequency of death above a 95°F heat index (a measure of how hot it feels when relative humidity is combined with actual air temperature). Exposure to excessive heat for a single day and for prolonged periods (e.g. a heat wave lasting several days) was both associated with increased mortality. For the Northeast in general, Anderson and Bell (2011) found that a 1°F increase in average daily temperature during a heat wave (successive days of extremely high temperatures) was associated with a 4.39% increase in the relative risk of non-accidental mortality, while the corresponding national estimate was 2.49%. Given that a large proportion of the population in the Northeast is elderly, the region will have high health vulnerability during prolonged episodes of intense summer temperature.

Shao Lin et al. (2009) found that at temperatures above a certain threshold, cardiovascular and respiratory hospitalizations increased among the residents of New York City. Collating daily data on hospitalization, temperature and humidity for the summer months of 1991-2004, the study found that hospital admissions due to respiratory and cardiovascular complications increased by 1.4% and 3.1% respectively for each °C above a threshold of 32°C in the average apparent temperature (an index combining temperature and relative humidity) three days prior to the admission.

While such retrospective analyses help ascertain the current public health impact attributable to anomalous increase in ambient temperature, predictive models combining health and temperature have produced estimates of the future health burden related to extreme heat. In a review of the literature, Huang et al (2011) find most studies predicting an increase in future heat-related mortality. Knowlton et al. (2007) simulated mean daily temperatures using a global-to-regional climate modeling system for years between 1990 and 2050 in the New York City metropolitan area. The simulations represented IPCC SRES scenarios A2 and B2, and were designed to account for acclimatization and adaptation that could dampen the adverse impact of extreme heat on health (e.g., increased use of air conditioning, gradual physiological adaptation). The study projected an increase of 47% to 95% in heat-related mortality in 2050s compared to the baseline of 1990, depending on assumed future scenarios (B2 with acclimatization and A2 without acclimatization respectively).

Table 4.4. Projected Summer Regional Mean Daily Temperatures (°F) and Associated Heat-Related Premature Mortality, Aggregated Across the New York City Metropolitan Region, in the 1990s vs. the 2050s (Source: Kinney et al. 2011; Knowlton et al. 2007)

Year, Scenario, Assumptions	Mean Summer Daily Temperature (SD)[a]	Total Regional Heat-Related Premature Deaths
1990s	72.9 (5.68)	1418
2050s A2[b]	76.7 (5.51)	2764
2050s A2 with acclimatization	76.7 (5.51)	2376
2050s B2[c]	75.8 (5.67)	2421
2050s B2 with acclimatization	75.8 (5.67)	2087

[a] Mean county-specific decadal summer daily temperature in °F (mean SD). Note that the same summer daily temperature simulations were applied in mortality risk assessments with and without acclimatization assumptions.

[b] A2 scenario assumed rapid human population growth, relatively weak environmental concerns, and a lack of aggressive greenhouse gas regulations.

[c] B2 scenario assumed more-moderate population growth and increased concerns about environmental sustainability, with more aggressive greenhouse gas regulations, compared with A2.

Air Quality

There is a substantial body of evidence linking adverse health outcome to exposure to poor air quality. Ozone and pollen concentrations in the air could potentially have a significant adverse public health effect in the Northeast.

Pollution. Air pollution can be affected adversely in a variety of ways by climate change (Kinney 2008). A paper by Shao Lin et al. (2008) finds that chronic exposure to ambient ozone increases the risk of asthma admissions among children in New York State. According to Sheffield et al. (2011), increased ground level ozone due to climate change could increase regional summer ozone-related asthma emergency department visits by 7.3% in the New York metropolitan area by the year 2020. Earlier work by the New York Climate and Health Project reported increasing risks for exposure to ozone and associated acute mortality (Hogrefe et al., 2004; Knowlton et al., 2004).

Pollen. Changes in temporal distribution of temperature, precipitation and carbon dioxide could affect the species distribution and growing seasons of plants with allergenic potential and poses a challenge for public health. Dellavalle et al. (2012) followed a cohort of children with asthma living in Connecticut, Massachusetts and New York and found that ambient pollen increased asthma symptoms and preventive medication use. Sheffield et al. (2011) identify a strong association between tree pollen concentration and allergy medication sales in New York City. Using daily airborne pollen concentration data for genera of tree pollen, peak days of concentration for each year between 2003 and 2008 were identified. The study found a 141% increase in the over-the-counter sales of allergy medication on and after 7 days from the peak dates of pollen concentration.

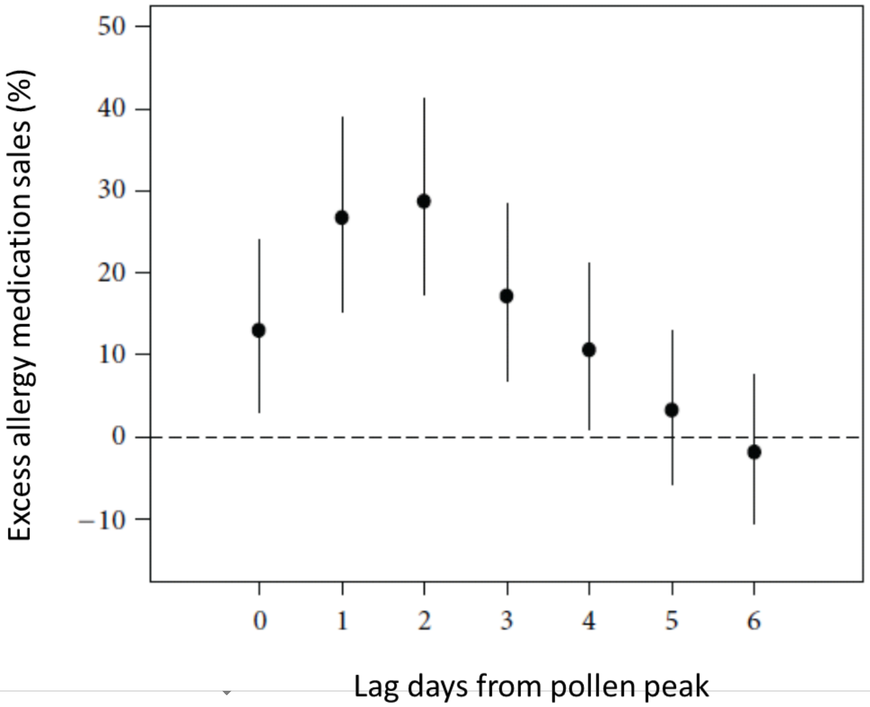

Figure 4.7. Estimated impacts of the tree pollen peaks on the percentage change in the mean allergy medication (Source: Sheffield et al. 2011)

According to Ziska et al. (2011), warmer summers and milder winters related to global warming may be associated with flowering phenology and pollen initiation (Rosenzweig et al., 2011) which could explain the increase in ragweed pollen season by 13 to 27 days at latitudes above

44°N, encompassing much of the Northeast region. New York, Pennsylvania, Vermont and West Virginia are among the states that the National Wildlife Federation report identifies at risk of high increases in allergenic tree pollen. According to the Behavioral Risk Factor Surveillance Survey (BRFSS, 2010), prevalence rates of self-reported lifetime asthma among adults is higher than the national average in all northeastern states except New Jersey and Maryland. Assuming that trends for allergic asthma are similar, this makes the population in the region vulnerable to pollen-related allergies and respiratory complications.

Lyme Disease

Health surveillance data on reported cases of Lyme disease shows that the Northeastern states had the highest rates across the United States (Bacon et al., 2008). While Connecticut had the highest rate of incidence of Lyme disease (76.3 cases per 100,100 people) among all states, 87% of all reported cases in the United States between 2000 and 2010 were from the Northeastern states (CDC, Lyme Disease Data).

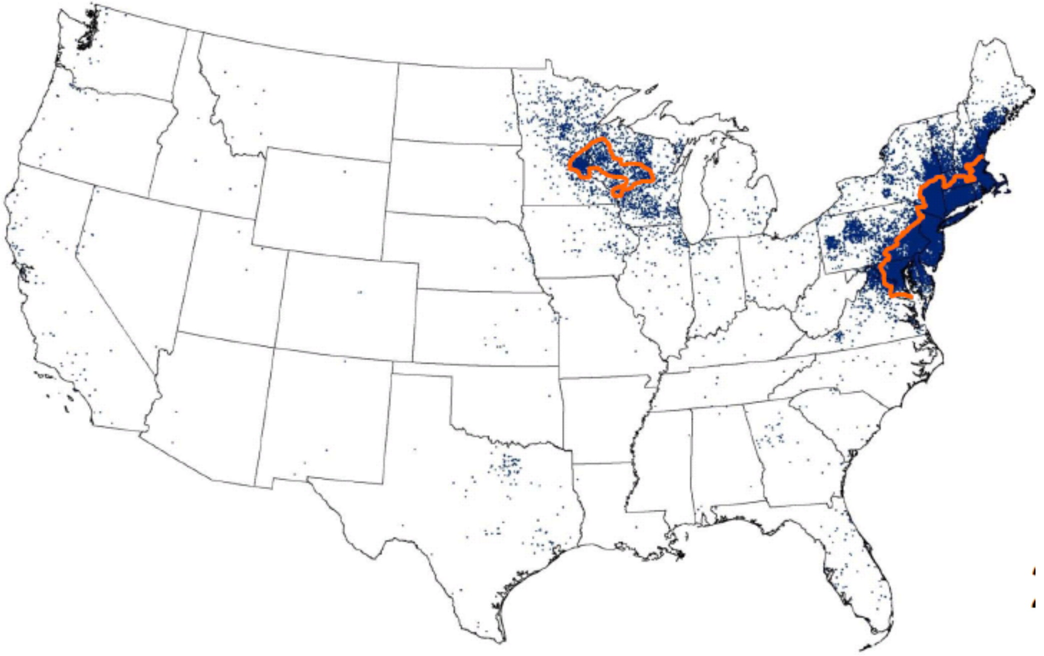

Figure 4.8. Expanding spatial distribution in the reported cases of Lyme disease in the Northeast; the red line shows the spread in 1998. [source: modified from map available at http://www.cdc.gov/lyme/stats/maps/map2010.html]

The combined effect of changes in weather patterns and landscape features can influence the geographic range of vector borne diseases such as Lyme disease, the most commonly reported vector-borne disease in the United States. Using a global circulation model, Brownstein et al. (2005) predicted the spatial distribution of habitat for *Ixodes scapularis*, the principal vector for Lyme disease. While their model predicts a significant northward shift in suitable vector habitat into Canada, the northeastern states are predicted to remain stable habitats for the vector.

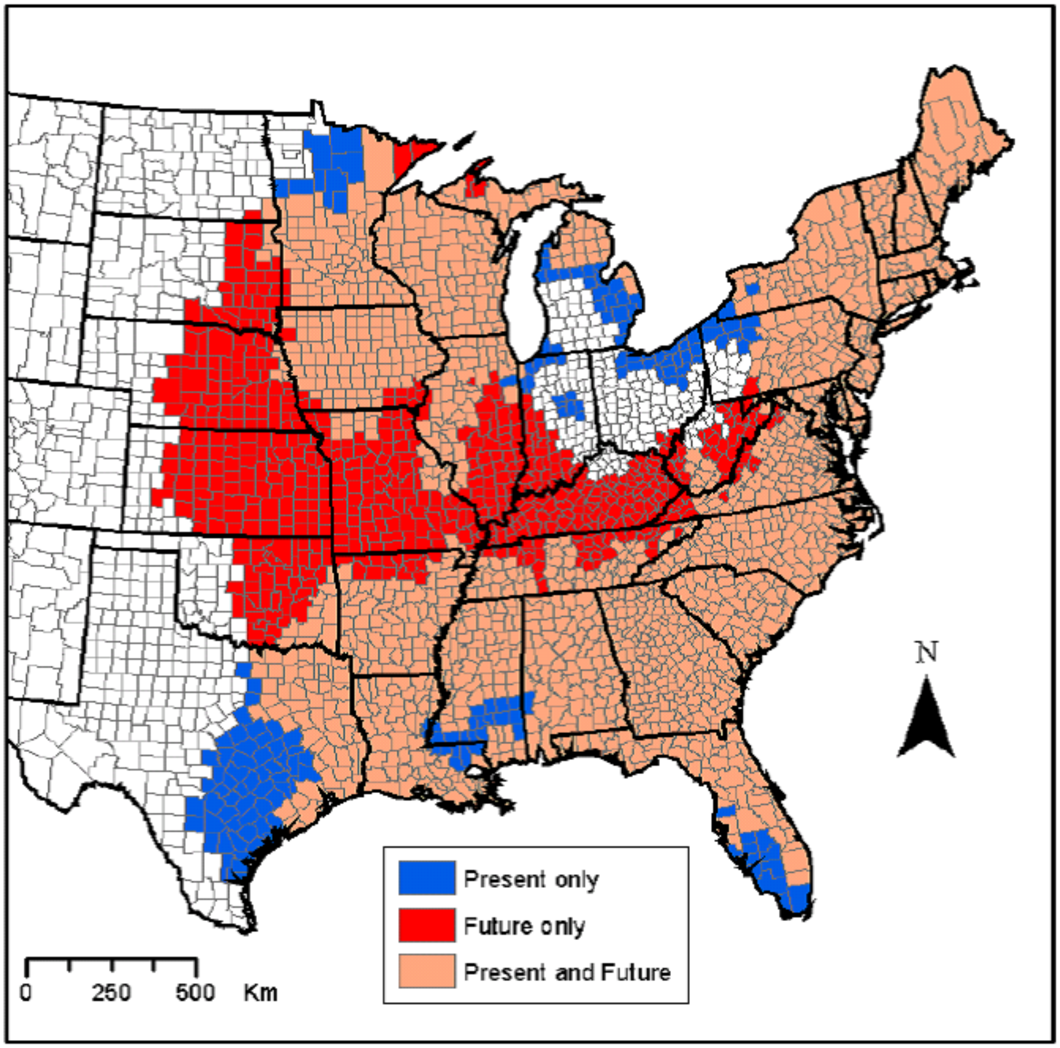

Figure 2.9. Change in county-based distribution of *Ixodes scapularis* from present to the 2080s. The future distribution based on climate change data, which considers the effects of both greenhouse gas and sulfate aerosols, was overlaid on the current predicted distribution. The map reveals future suitable (in red) and unsuitable (in blue) counties. Most areas in the Northeast are shown to remain suitable over time (in pink). (Source: Brownstein et al., 2005)

Waterborne Disease

Based on climate projections of increasing levels of seasonal precipitation and variability in the Northeast (see Chapter 3, Section 3), there could be potential impacts on waterborne disease. While there is growing evidence connecting waterborne disease incidence to recreational water use (Patz *et al.*, 2008) and consumption of contaminated seafood (Iwamoto *et al.*, 2010), there remains a paucity of such studies conducted in the Northeast. In Connecticut, the risk for contracting a stomach illness while swimming significantly increased after a 1” precipitation event (Kuntz and Murray 2009). High concentrations of toxins from the harmful algal bloom (*Alexandrium fundyense*) halted coastal shellfish harvesting from Maine to Massachusetts

(Anderson *et al.*, 2005). Studies have found associations between diarrheal illness among children and sewage discharge in Milwaukee (Redman et al., 2007). Since EPA estimates four combined sewage overflow events per year for the Great Lakes region and New England (U.S. EPA, 2008), this raises public health concerns in communities served by the combined sewer systems that collect and co-treat storm water and municipal wastewater.

Adaptation Efforts

Much of the adverse health impacts related to climate-sensitive environmental exposures are preventable. Adaptation strategies range from implementing individual / community-level intervention plans to capacity-building across health care agencies (Huang *et al.*, 2011). Integration of health concerns into climate action plans developed in other sectors (transportation, urban planning, water supply, sewage management etc.) will also produce co-benefits from adaptation planning by reducing adverse health effects to environmental exposures (Kinney *et al.*, 2011).

Health messaging and air conditioner use.

Among individual-level interventions, NYC Department of Health undertook a multi-pronged initiative to prepare for and prevent adverse heat-related health outcomes among residents of New York City. This included distribution of education materials, media communications and air-conditioners as part of the Cooling Assistance Programs (Graber *et al.*, 2011). The effectiveness of these intervention programs are yet to be rigorously examined, particularly the air conditioner distribution program given the high cost of energy use that may prevent its use by poor households on one hand (Kinney *et al.*, 2011), and the contribution to greenhouse gas emissions from its functioning on the other.

Cooling shelters.

In situations of extreme heat, local agencies have been coordinating efforts to direct individuals at risk (often the elderly and economically disadvantaged) to cooling shelters. While no explicit cost-benefit studies exist for operationalizing such cooling shelters, many people have taken advantages of such services.

Heat alert warning systems.

Kalkstein et al. (2004) estimated the potential lives saved though issuing early warnings before extremely hot days and concluded that such warning systems could be highly cost-effective based on the economic benefits from averting premature deaths. However, there exists no gold standard in approaches to predict heat events in order to plan public health emergency response (Hajat *et al.*, 2010), and appropriate warning methodology would require better assimilation of contextual climate and population characteristics.

Public health workforce development.

As part of developing a comprehensive public health response to climate change, there is a need to train and build capacity at public health agencies at state and local levels. As part of the 'Climate Ready States and Cities Initiative', a flagship effort launched by the Climate and Health program at the Centers for Disease Control, the states of New York, Maine and Massachusetts and New York City are being funded to assess potential environmental changes from climate change, the associated public health vulnerabilities and prepare adaptation strategies to reduce such adverse impacts.

It is also expected that hospital emergency departments (EDs) will see an increased demand for services as climate-related illnesses increase in the future. Those who are more vulnerable to the health impacts of climate change – the elderly, the very young, and socioeconomically disadvantaged – rely disproportionately on EDs for medical care. In addition, many conditions that are particularly sensitive to climate changes are often seen in the ED, such as heat-related illnesses and respiratory diseases (Hess *et al.*, 2011). Such increased demand will need to be considered as part of a comprehensive plan for workforce development.

Conclusions

With a changing climate, current epidemiologic understanding suggest an increase in the adverse health effects associated with direct impacts of extreme heat events, and the combined effect of increased air pollution and temperature. With changing patterns in precipitation and temperature, changes in the distribution of disease vectors, as in the case of Lyme disease, would also pose a threat to public health. A major public health challenge ahead will be to improve health surveillance programs to assess health vulnerability, both in terms of places and people, to environmental exposures that will be affected by a changing climate. There are infrastructure issues related to energy supply that could affect public health. Studies have found excess mortality and hospital admission associated with the power outage of 2003 in New York City (Lin *et al.*, 2011; Andersen and Bell, 2012)). As the public health science grows, building greater adaptive capacity in local health departments, promoting institutional learning, developing integrated tools across disciplines and better coordination among other agencies will be critical to mitigate some of the adverse health impacts (Hess et al., 2012).

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4.6 Infrastructure: Transportation, Telecommunications, and Energy

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This section outlines projected climate change impacts to human created infrastructure networks in the Northeast, with a focus on transportation, telecommunications, and energy systems. It also gives an overview of some adaptation strategies being developed to make this infrastructure more resilient.

Transportation Systems

Climate change can have significant impacts on transportation systems that were built based on now changing underlying climatic assumptions. The Northeast region is crisscrossed with a dense network of roads, rail lines, airports, and ports that are relied on for the safe and efficient movement of people and goods. The region has over 470,000 miles of roads, including almost 7,000 miles of interstate highway (FHWA, 2011). Over 77,000 bridges and large culverts are integrated into these roads, and countless smaller culverts accommodate water and wildlife passage through the roadway beds (FHWA, 2010). Over 4,000 miles of commuter rail (half the Nation's total) and about 1,250 miles of light rail and heavy passenger rail carry passengers in the metropolitan areas (FTA, 2010). The Northeast is home to three of the top 20 U.S. ports for containers: the ports of New York and New Jersey; Baltimore; and Wilmington, DE (RITA, 2012). The region hosts 76 airports, including major airports in low-lying coastal areas: LaGuardia and John F. Kennedy airports in New York, Liberty Airport in Newark, and Logan Airport in Boston.

Climate Risks for the Northeast Transportation Sector

Climate change presents significant risks to transportation infrastructure and operations in the Northeast. These risks will vary by the type and location of the infrastructure, as well as its underlying condition. For example, sea-level rise, tropical storms/hurricanes, and storm surges are major concerns in coastal areas. Impacts of climate changes on coastal infrastructure include periodic or permanent inundation and erosion of coastal roads and railways and increased frequency of infrastructure repair after events (Titus et al., 2009). Other climate change effects, such as increased variability in temperature extremes and changes in precipitation patterns, including more severe precipitation events, are not confined to coastal areas and will likely be experienced more broadly across the region with significant impacts ranging from increased pavement deterioration on roads to overwhelming of stormdrain systems and stormwater management facilities to short-term flooding and compromised safety. Many of the impacts of climate change on the transportation system could affect the functioning of other sectors, including public health, security, and commerce.

Sea level rise and storm surge risks to transportation infrastructure**.** Coastal transportation systems in the Northeast including roads, rails, ports, and airports are at risk from sea level rise and storm surge (TRB, 2008). With the rising sea level, the coastline will change, leaving highways that were not previously at risk to storm surge and wave damage more exposed. This in turn could lead to the erosion of the road base and bridge foundations. Sea level rise also amplifies the effect of storm surge, causing more severe storm surges that may result in the loss of evacuation routes. Many of the airports in the Northeast are located in coastal areas, and their facilities and runways are particularly vulnerable to sea level rise.

Box 4.9: Planning for Sea Level Rise in Delaware and Maryland

In July 2011, The Wilmington Area Planning Council (WILMAPCO), the Metropolitan Planning Organization (MPO) for Cecil County, MD and New Castle County, DE completed a study to identify transportation infrastructure in the region at risk from sea level rise (WILMAPCO, 2011). The study used locally developed inundation scenarios to assess the potential impacts of sea level rise on existing roads, bridges, railways, marinas, ports, and airports in the region and found that sea level rise would present a challenge to key components of the local transportation network. For example, in the 0.5 meter sea level rise scenario, 117 bridges and overpasses as well as all 33 area marinas would be at risk. The study is being used to assess which infrastructure under threat from sea level rise is most critical, as well as to evaluate planned projects that may be impacted. A number of WILMAPCO policy recommendations have emerged from the study, including incorporating climate change policy into the next Regional Transportation Plan (RTP), continually monitoring sea level rise impacts to planned projects, improving climate change public outreach, and supporting ongoing climate change adaptation and mitigation efforts.

Risks to transportation infrastructure from increases in heavy precipitation.. Intense precipitation can have significant impacts on roadways, including causing weather-related traffic disruptions, flooding of evacuation routes, and road washouts. In addition, increased peak streamflow could affect scour rates and influence the size requirement for bridges and culverts (FHWA, 2010). For transit systems, the most disruptive near-term impact is likely to be intense rainfall that floods subway tunnels and low-lying facilities, bus lots, and rights-of-way (FTA, 2011). For example, in New York, heavy rainfall shut down 19 major segments of the subway, incapacitating the electrical systems, and affecting two million customers in 2007 (MTA, 2007).

Box 4.10: Case Study - New Jersey

The New Jersey Department of Transportation (NJDOT), in partnership with the three New Jersey MPOs (NJTPA, DVRPC, and SJTPO), and other state agencies developed an inventory of their transportation assets and used climate change models to perform a risk assessment of their transportation infrastructure vulnerable to climate change. The research involved coastal and inland study areas and looked at sea level rise, storm surge, temperature, precipitation, and inland flooding impacts on their roadways, bridges, rail, airports, and port and marine assets. The study found that under a middle scenario for inland flooding in 2100, 81 miles of roadways and over 138 rail miles could be impacted. With just over 1 meter of relative sea level rise in 2100, almost 14 miles of roadways, 1.4 miles of NJ Transit lines, and over 14 miles of major freight rail lines could be impacted in the Central Study Area. The Coastal Study Area, under the same sea level rise scenario, may see 31 total rail miles (passenger and freight) and over 48 miles of roadways impacted (NJTPA, 2011)..

Heat risks to the transportation system. Increases in very hot days and heat waves can result in pavement deterioration and rutting, causing possible degradation and short-term loss of public access. (FHWA, 2010) More extreme heat events in the northeast could cause buckling of airport runways and rail lines (TRB, 2008).

Adaptation and Mitigation Solutions

Given the extent and long design life of transportation infrastructure, accounting for climate change throughout the transportation system will take decades. In the near term, changes in operations can help manage some climate change effects. Transportation systems serve a crucial role in emergency evacuations related to extreme weather events. Improvements in emergency response coordination and collaboration such as between emergency managers and transportation providers, and through the integration of weather and emergency management functions at Transportation Management Centers, can improve transportation system preparation for, and performance during, extreme weather events. DOTs can also recognize emergency management as a distinct functional responsibility (TRB, 2008).

In the longer term, modifications to existing structures and adjustments to some original design inputs may be necessary. Some transportation agencies have begun to retrofit current transportation systems to better handle future climate conditions. For example, the New York Metropolitan Transportation Authority (MTA) has raised many of its sidewalk level ventilation grates to prevent water from infiltrating its tunnels from sidewalks (**Figure 4.10**) (FTA, 2011).

Figure 4.10. Raised Ventilation Grates in New York City. Source: MTA New York City Transit.

Design modifications that have been implemented for reasons unrelated to climate can have a co-benefit of increasing resiliency to climate changes. After Hurricane Irene, Vermont Department of Transportation (VTrans) found that whereas over 1,000 culverts were undermined by the floods, culverts that had been designed to better accommodate aquatic organism passage (AOP) were mostly unscathed (Vermont, 2012 ; Gram, 2011). An AOP culvert is designed to simulate a range of flow conditions that occurs in the natural stream and can usually accommodate a higher peak flow than a traditionally-designed culvert can. In an evaluation of its infrastructure vulnerability to climate change effects, the Port Authority of New York and New Jersey (PANYNJ) discovered that some of the recent improvements the agency had made for other reasons had climate adaptation co-benefits. For example, recently constructed security barriers could also serve as storm surge protection, and improved pavements designed to withstand heavy truck traffic also perform well at a much higher temperatures than traditional pavements (McLaughlin et al., 2011).

> "The toll Irene took on Vermont's transportation infrastructure is now clear. On the combined town and state network, Irene washed out more than 2,000 roadway segments, undermined more than 1,000 culverts and damaged more than 300 bridges. Rebuilding everything will cost hundreds of millions of dollars. Understanding that our climate is changing and that the frequency and intensity of storm activity will likely be greater during the next 100 years than it was during the last 100, it is prudent that as we rebuild we also adapt. But doing so successfully will not be easy." Richard Tetreault, Chief Engineer, VTrans (State of Vermont, 2012).

Some agencies are updating design assumptions to account for climatic conditions 50 or more years from now. For example, PANYNJ issued design criteria for all new construction and major rehabilitation projects calling for the use of specific climate projections for the 2080's (Buchsbaum, 2009). A project to modernize the LaGuardia Airport terminal will use the new guidelines (McLaughlin et al., 2011).In addition, the U.S. Army Corps of Engineers has issued guidance on accounting for projected future sea level rise across the project life-cycle for all Army Corps civil works activities in areas with tidal influence (U.S. Army Corps, 2011).

As precipitation increases in the Northeast region, existing culverts may become undersized, potentially leading to catastrophic failures. Culvert management systems can assist in identifying and prioritizing needed culvert improvements.

Box 4.11: Assessing the Vulnerability of Culverts in New Hampshire

Planners and researchers undertook a study in the NH Oyster River Watershed to evaluate stormwater capacity under future climate change and population growth scenarios. They inventoried all major culverts in the watershed and then estimated projected peak flow under future climate and population scenarios. The project team developed cost estimates for replacement culverts that would accommodate the flows, and they ranked the culverts based on vulnerability and potential hazard to the community. The resulting information was provided to decision makers to be used as a guide for prioritizing culvert upgrades and directing low impact development ordinances (Stack et al., 2010).

Conclusions

The Northeast region contains some of the oldest infrastructure in the country. Yet this infrastructure continues to serve some of the largest population concentrations. Like much of the infrastructure in the Northeast, the transportation system was built to withstand the historically expected range of climatic conditions. Because future sea levels, temperature and precipitation patterns are expected to deviate from these historical experiences due to climate change, much of this infrastructure could be at risk. However, as this aging infrastructure is rebuilt or upgraded, there are opportunities to take into consideration the changing climate and to strengthen this infrastructure to meet these future challenges.

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Telecommunications

The telecommunications sector is a pillar to any modern economy. Technically, it comprises land and mobile telephone and fax services, satellite, cable, the Internet, TV and radio, specialized closed telecommunication links (government, financial, public security and emergency services, dedicated microwave links, etc.). The northeastern US, as defined in this report, and especially the coastal urban corridor from Boston / New York / Philadelphia / Baltimore to Washington D.C. is not only the most densely populated of the US, but also the one with the highest density of infrastructure (**Figure 4.11**), including telecommunications (FCC 2008). The region has a vast concentration of data- and telecommunication-intensive businesses and institutions (financial services, media, communication, and academic research).

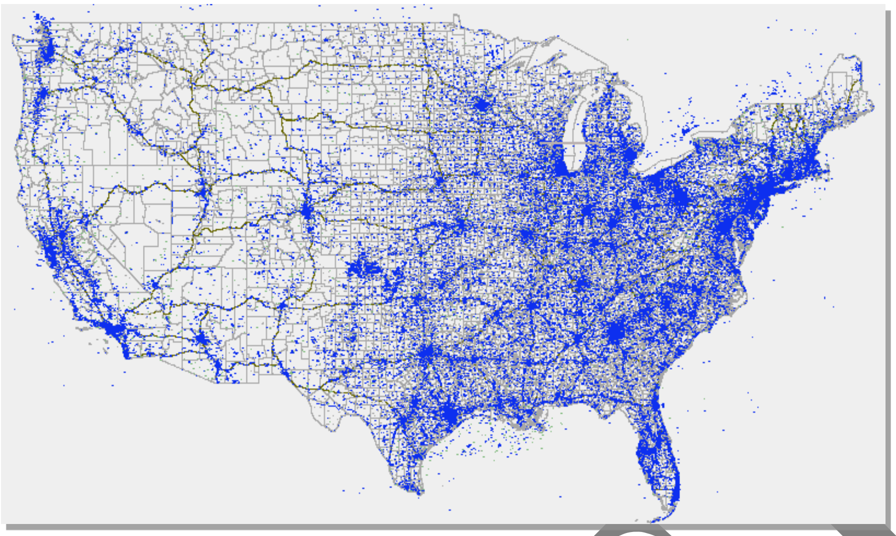

Figure 4.11. Dot map of cell phone towers in the US. Note high density of towers in the urban concentrations near the Atlantic coast of the northeastern US. Source: Source: http://lewishistoricalsociety.com/wiki2011/tiki-read_article.php?articleId=6

Globally, nationally and regionally telecommunication is in a mode of rapid expansion and perpetual technological change. The introduction of the Internet, fiber optics, hand-held devices, distributed computing, telecommunication satellites, and "cloud" data management are only a few examples of this rapid change and constant development.

Telecommunications is almost entirely privately owned. It is in a state of fierce internal competition. It is relatively lightly regulated (federally by the FCC, and on the state level by public service commissions). The telecommunications industry is staunchly regulation-averse. While largely privately owned, telecommunication performs an important public function, for public safety, security and during emergencies. Telecommunication has a large economic multiplier effect and without its reliable functioning a modern, highly developed market economy is unthinkable and unworkable. Telecommunication's reliable functioning is closely tied to the reliability of the electric grid.

Climate Trends, Hazards, Vulnerabilities and Impacts

Wind, snow, icing from freezing rain, lightning, and river, coastal and urban flooding are the most common primary extreme-weather related threats to telecommunication. Secondary threats to telecommunications stem from falling trees and electric power outages that are themselves often caused by extreme weather events. Therefore the reliable functioning of different types of infrastructure is highly correlated and interdependent. To the extent that climate change tends to increase severity and frequency of the extreme weather events, the chances of telecommunication outages, are likely to increase, and thus related economic losses are likely to mount, especially as society tends to ever more rely on telecommunication as a backbone of its functioning.

In the northeastern US, from mid-Atlantic to New-England states, from the Atlantic coast to the Great Lakes, several major and occasionally long-lasting telecommunication outages have been associated with severe weather events, foremost from tropical storms during hurricane season (July to October); and from extra-tropical nor'easter winter storms (November to April). Of course not all storms fit these two categories; any storm system that combines excessive wind with excessive precipitation, whether as rain, freezing rain or snow, respectively poses a hazard to the sector. A history of winter storms, especially those associated with heavy snow and/or severe icing conditions interrupting electric and telecommunication services, is given by Jones and Mulherin 1998, and has been updated by Chagnon 2003, Chagnon and Karl 2003, and for a portion of the northeastern US by Jacob et al. 2011.

A severe winter storm causing damage from intense icing and/or wet snow occurred in Pennsylvania, New York and the New England states on December 11-12, 2008. More than 1.4 million customers lost power in six states, and nearly a week later 100,000 customers still had no power. The numbers for customers without phone or cable services are less well documented, but the press reported widespread and persistent outages (Jacob et al. 2011), often because restoration of downed wires for the telecommunication utilities typically cannot occur until the electric wires are restored first. Two storms in 2011 with wide-spread outages in the northeastern US, of both electric and telecommunication services, have not yet been fully scrutinized, but their impacts have been reported in the media and trade publications, largely based on FCC and some utility press releases[17]. They were:

- Hurricane *Irene* (downgraded to a tropical storm during the more northern portion of passage through the subject area) which occurred in late August 2011, causing damage from coastal storm surge flooding, river flooding and high wind; its effects were amplified by a second storm, *Lee*, following on *Irene's* heels and dumping more rain on already saturated grounds, causing a second wave of floods in many parts of the northeastern US, but especially in Pennsylvania, New Jersey, New York and the New England states. According to initial reports[18] 1,400 cell towers and cell sites were damaged or disrupted by *Irene* -- mainly in Virginia, New Jersey, New York (and North Carolina). In addition to cellular service disruptions from power outages or other problems, land line phone service and other forms of communication were also affected: 132,000 wired voice subscribers had lost service on the

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[17] Detailed, region-specific telecommunication outages attributable to specific service providers are generally not released to the public by the Federal Communications Commission (FCC), nor by the states' Public Service Commissions. The federal and state regulators receive such data generally under confidentiality agreements with the industry. Nor are the outage reporting requirements uniform between landline-, wireless phone, and cable services, nor are they always equitably enforced. This scarcity of publicly accessible, reliable outage data leaves customers for the most part in the dark about competitive performance and relative reliability. The confidentiality is commonly justified to the public by concerns about protecting the security of telecommunication operations, especially during emergencies. This protection occurs, however, mostly at the expense of the customers who find it difficult to make informed long-term business choices to mitigate their own exposure and vulnerabilities, and plan and invest accordingly in true redundancies to minimize their own business interruptions.

[18] http://www.computerworld.com/s/article/9219556/Irene_takes_out_cell_towers_disrupts_communications and

http://spectrum.ieee.org/tech-talk/telecom/wireless/hurricane-irene-tests-resilience-of-communication-networks first day, while 500,000 cable customers lost service, mostly in Virginia. After the initial FCC reports on wired voice subscribers and cable customers, the agency increased the numbers for the East Coast a day later to 210 000 and 1 million, respectively. The reports also cited that 6,500 cell sites were down along the East Coast, and that Vermont had 44 percent of its cell sites down—a higher percentage than that in other states.

- An early snowstorm occurred in October 2011 that brought many trees down since it occurred when the foliage was still on the trees, causing the snow to more readily accumulate and thus making the loads on branches excessive. The falling branches and trees, in turn, brought down power and communication lines. The snow caused power outages from Maryland to Maine, affecting almost 3 million customers.[19] This included about 40,000 customers in Maine; 640,000 in Massachusetts; 285,000 in New Hampshire; at least 6,400 in Vermont; 800,000 in Connecticut; 300,000 in New York; 600,000 in New Jersey; 250,000 in Pennsylvania; and at least 11,000 customers in Maryland. Snowfall was highest in western Massachusetts measuring 27 inches. A total of 11 fatalities were attributed to it and state emergencies were declared in New Jersey, Connecticut, Massachusetts and parts of New York. In general, no telecommunication outage numbers have been provided to the public for this storm. The outage numbers for telecommunications are most likely lower, and are often delayed by a few hours until batteries either at the customers' devices run down, or diesel fuel tanks of back-up power generators at the service providers' facilities (cell towers, central offices) are exhausted, typically within less than ½ day. The State of Connecticut commissioned a special study regarding the October 2011 snowstorm power restoration (Witt Associates 2011). It states:

> 'The Attorney General's Office called for the investigation [of electric power restoration] to be broadened to include telecommunications and cable services as well';

and recommends:

> 'In addition to electricity, communications also are critical during large-scale outages. The state should review the restoration efforts of major telecommunications providers as well as cable providers upon which Connecticut citizens and businesses are increasingly dependent for voice-over-internet phones and internet-services.'

This indicates, at least indirectly and only for Connecticut, that telecommunications were severely affected and restoration was slower than the public expected.

Managing Vulnerabilities / Adaptation Options

Given the seemingly rising vulnerabilities of electric and telecommunications utilities, and the likely increase in extreme weather events driven by climate change (see Section IIIc), the question of how to manage these vulnerabilities and adapt to possibly more frequent and more severely inclement weather events becomes more urgent.

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[19] http://blog.al.com/wire/2011/10/power_outages_from_east_coast.html

One opportunity for the telecommunications industry is, that because of expected continues turnover in technologies, climate resilience can be built into the upgrades when new technologies are periodically introduced, often on a decadal time scale or less. But many parts of the telecommunication infrastructure have longer lifetimes and may have to be retrofitted for a changing climate. Some options for managing the risks, both on the provider and consumer side, are (Jacob et al. 2011):

- Move overhead lines to underground cables where possible and economically feasible. This applies to wire and fiber optic cables alike.

- Tree trimming, where applicable, more often in rural and suburban than urban areas, to avoid or reduce downed lines during wind, snow and ice storms.

- Shortening extreme weather-related outage times by planning ahead of storms to mobilize additional field crews, and having stored sufficient supplies of replacement poles, cable, other critical hardware, and fuel for back-up power.

- Educate customers how to prepare for short and extended electric grid outages. This, for instance, may imply installing at least one hard-wired instead of only wireless handsets in homes; storing a charged spare battery for the central fiber-optic home terminal; and/or recharging options for batteries of mobile phones by either using car-based, photovoltaic or other chargers; charging from small power generators (only an outdoor option and rarely applicable in cities with high-rise and apartment buildings; there, community-based recharging “posts” could be organized, or provided by emergency first responders).

- Increase fuel supply for back-up power generators at cell phone towers, central offices, and radio/TV antennas, to sustain communication options during extended electric grid outages. At roof-mounted wireless antennas providing mobile phone services in city neighborhoods, battery packs, potentially combined with photovoltaic charging devices, could provide interim power to bridge electric grid outages.

- Raise (or otherwise flood-prove) key telecommunication infrastructure, at flood-prone central offices, fiber optic repeater stations, power supplies; and fortify cell phone towers against failure from ice, wind, and flooding.

- Increase redundancy and general robustness of backbone networks (Internet; broadband high-speed links and nodes), especially where vulnerability to flooding or other climate hazards has been identified.

- To the extent possible, decouple the vulnerabilities of the telecommunication networks and infrastructure from the vulnerabilities of the electric grid.

To achieve some of these adaptation measures may also require changes in policy and regulations and may need to take into account the larger economic context in which the reliability of critical infrastructure systems, including telecommunication, must be seen. The costs for adaptations may have to be equitably shared between industry and customers, and hence ought be scrutinized by public service commissions on state levels where public service commission regulate both performance and the rates that customers can be charged. The telecommunication industry has its own technical minimum performance standards[20], but may want to more aggressively revise these in the light of recent actual performance outcomes.

Conclusions/Recommendations.

- Telecommunications in the northeastern US has proved to be vulnerable to extreme weather events under current climate conditions.
- It is likely that extreme weather conditions will become more frequent and more severe as a consequence of the predicted climate change. Especially along the Atlantic coast and tidal estuaries, where the exposure to coastal storm surges increases with sea level rise, any near-shore facilities at low elevations will be ever more vulnerable, unless relocated, raised, or otherwise hardened or protected. Increased flooding along inland rivers, partly driven by land use, partly by climate change, may also pose increased threats. Snow and freezing-rain storms are not expected to decrease in the foreseeable future (Horton et al. 2012; Liu et al. 2012).
- Telecommunications has a unique opportunity to build-in climate robustness as it replaces part of its infrastructure when periodically introducing new technologies. Remaining older systems may need to be retrofitted, or in some cases relocated.
- Regulations and standards of performance may need to be raised, internally by the industry on a voluntary basis, but also by stricter federal and state regulations.
- Telecommunications, while largely privately owned and operated, has a major public safety function before, during and after emergencies; telecommunications outages can have dire consequences for lives and livelihoods. Governments may be able to do more to ensure that this public function can be adequately and reliably performed.

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Energy[21]

Energy systems are a fundamental and vital form of infrastructure, supporting basic commerce and quality of life needs across the Northeast and United States as a whole. Although energy systems are designed to operate under a range of weather and supply and demand conditions, climate change may stress the system in ways that damage equipment, disrupt critical fuel supply chains, or otherwise exceed current design limits, increasing the risk of breakdown (Hammer et al., 2011). By almost any measure, energy use and the resources to support it have been increasing over the past century.

Key Vulnerabilities and Risks

Climate change variables directly impacting the urban energy system in the Northeast include temperature change, precipitation, and sea level rise. Other climate change-related factors that may affect the energy system include water temperature, ice and snow, wind, cloudiness, humidity, stream flow rates and levels (Ebinger & Vergara, 2011), and extreme weather events. How these factors will manifest themselves, and the corresponding energy system impacts, will vary significantly by locale. Some effects may be very localized, affecting a single power line, transformer, or power plant in or near a particular city. Others may have ripple effects that carry across a much broader region, reflecting the highly interconnected nature of today's energy system.

Key Impacts

Climate change risks will affect both energy supply and energy demand.

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[21] The energy subsection presented here is adapted from Stephen A. Hammer's submission for the *Technical Report on U.S. Cities and Climate Change: Urban, Infrastructure, and Vulnerability Issues* submitted in support of the U.S. National Climate Assessment

Supply impacts are of particular concern because of the long-lived nature of most energy system assets. Power-generating facilities are built to last many decades, while transmission or distribution assets may last even longer. Repairing or replacing these systems can be extremely costly and logistically challenging, particularly in urban areas, because the repair or replacement process can take some time and be highly disruptive. In New York City for example, the city's electricity transmission system consists of over 90,000 miles of underground cables, making wholesale upgrades to the system prohibitively complex and expensive.

Demand-related impacts relate to both heating and cooling demand. On a net basis, climate change may either increase or decrease overall energy use in a specific city or region, depending on the level of climate change-related temperature change, and whether that locale experiences its peak energy demand in the winter or summer. For much of the Northeast, more energy is devoted to winter heating than summer cooling, but for some urban areas peak demand is associated with summer cooling.

Impacts of rising temperatures. Temperature changes may affect both fossil and renewable-based forms of energy. In the case of fossil fuel stocks, access is the primary consideration, as warmer temperatures may ease harsh weather conditions or ice cover that currently limit access to those resources, such as those found under the polar ice cap. Conversely, in the case of Alaskan oil and gas fields and pipelines constructed on permafrost, warming conditions may force the shutdown of these facilities as the ground becomes less stable (Bull et al., 2007). The effects of these changes on the Northeast will tend to be indirect, as supply chain impacts ripple across regional, national, or global energy markets.

Rising temperatures may cause power lines to sag or fail (Hewer, 2006), while heat waves can force equipment to operate beyond its rated performance capacity, leading to breakdowns. Heat waves led to the failure of thousands of transformers in 2006, as the equipment was unable to cool down sufficiently at night before demand spiked again the next morning. More than one million customers around the state eventually lost power (Miller et al., 2008; Vine, 2008). Warmer temperatures may also extend the growing season for plants and trees, increasing the need for tree trimming programs to ensure falling trees or tree limbs do not damage transmission and distribution assets (Hammer et al., 2011).

Climate impacts on the supply of energy available from fossil fuel-fired, nuclear, and biomass-based thermal power plants are generally linked to cooling water requirements and the efficiency of a given facility's generation cycle under changing climate conditions. Cooling water is potentially problematic if drought decreases water availability (Bull et al., 2007; Feeley et al., 2008; NETL, 2009), or if the temperature of the water entering the plant exceeds design or government imposed operating permit limits. Climate change may also increase the risk that cooling water exiting the plant will raise the temperature of receiving waters to a higher-than-allowed level. There have been several instances in the US and Europe when nuclear power facilities were forced to scale back or halt operations because of this water temperature problem (Letard et al., 2004; Jowit and Espinoza, 2006; Flessner, 2010; Kopytko and Perkins, 2011), imposing price or supply impacts in cities and regions heavily served by these facilities.

Thermoelectric power plant production levels may also be affected by climate change. As temperatures rise, air density declines, increasing energy consumption in the compressor and decreasing power output (ICF, 1995; Schaeffer et al., 2008). Impacts are relatively modest, however, compared to output level changes already occurring at power plants resulting from normal variations in seasonal temperatures.

The most significant demand impacts associated with climate change are likely to occur in energy demand for heating or cooling services, taking the form of a U-shaped demand curve. At low temperatures heating demand is high; energy demand drops as temperatures moderate, but then rises (in the form of increased demand for cooling services) as temperatures increase (Ebinger & Vergara, 2011). On a net basis, the impact of climate change on total energy use will depend on whether a city or region is winter or summer peaking. Nationally, changes in winter-related demand are expected to outweigh cooling-related demand increases, resulting in a net decline in total energy use (Wilbanks et al., 2008). Because of differences in how seasonal energy demand is typically satisfied (e.g. natural gas or liquid fuels for heating versus electricity for cooling), impacts may fall disproportionately on certain energy sectors or household or company budgets.

Looking solely at electricity demand, climate change may result in different impacts depending on whether the focus is on total annual demand (e.g. in MWh or GWh) or peak demand ($\mathrm{MW_{p\ or}}$ $\mathrm{GW_p}$) as they may highlight important differences in the adequacy of a region's energy supply network. A city or region's existing supply will generally be capable of handling warmer nighttime temperatures and a longer cooling season because demand during these time periods is typically lower than peak demand on summer afternoons, meaning there is excess capacity available in the supply network. Increases in peak daytime demand, by contrast, may exceed this supply capacity, raising the prospects of more frequent blackouts or brownouts (Miller et al., 2008; Hayhoe et al., 2010).

A key variable affecting summer cooling demand is the baseline level of air conditioning units deployed in a city or region. Areas with low levels of current deployment or use may see more significant demand growth than areas where most buildings already have air conditioning installed (Wilbanks et al., 2008). Much of the Northeast fits this category.

There is a sizable amount of research examining the relationship between temperature change and energy use in buildings (Amato et al., 2005). Wilbanks et al (2008) summarize many older studies which found that a 1°C upward temperature increase results in a decrease in heating-related energy demand of roughly 1.5-10% in residential buildings and 1.5-16% in commercial buildings. The same report also noted that national studies found cooling-related energy demand increases 5-22% per 1°C temperature increase, with regional studies finding even more significant gains.

There is less research exploring the link between climate change and energy demand, although one study in New York did seek to project the impacts of climate change on electricity demand for the period 2011-2039. The effects were found to vary widely across the state. For example, in New York City, climate change may increase peak power demand in the summer by up to 497 $\mathrm{MW_p}$ (or 4%) beyond current peak demand levels. In western and northern parts of the state, peak demand increases are lower but nonetheless sizable, collectively totaling nearly 340 MW_p in the cities of Rochester, Buffalo, and Syracuse (Hammer et al., 2011).

Industrial power demand is generally considered less temperature sensitive, as a much smaller fraction (~6.8%) of sectoral energy use is associated with space conditioning (US EIA, 2007). More research is necessary, however, to fully understand climate change impacts on other forms of this sector's energy use (Wilbanks et al., 2008).

Changes in Precipitation Patterns. The amount of water available for hydropower varies each year, due to localized weather patterns, local hydrology, and the need to accommodate competing uses for the water (Wilbanks et al., 2008). Precipitation falling as snow can extend the hydropower season, as the snowpack 'banks' the water until it is completely melted. Warmer temperatures may result in higher winter rainfall levels, affecting winter hydropower output levels.

Location may also play an important role, as retention dams often have different operating rules depending on their elevation and function (e.g. water storage, flood control, or hydropower production), factors that dictate whether water is stored or released.

In the Great Lakes region, a series of studies, most dating back 10-20 years, have attempted to forecast how future precipitation, runoff, and lake evaporation levels will change as a result of climate change, with some analyses projecting minor lake elevation declines, depending on which GCM scenarios are employed (c.f. Quinn, 1988; USEPA, 1989; Mortsch and Quinn, 1996; Chao, 1999; Lofgren et al., 2002; Croley, 2003; Fay and Fan, 2003). Even minor lake change levels can have sizable impacts on hydropower production, however, with strong regional supply and price consequences. The New York Power Authority has estimated that a 1-meter decrease in the water level of Lake Ontario could reduce power output at their St. Lawrence/FDR hydropower facility by 280,000 megawatt-hours per year (Hammer et al., 2011).

The transmission and distribution of electricity, gas, and other fuels can be also affected by changes in precipitation patterns. The energy transmission and distribution system is already subject to stresses from high winds, snow, ice, flooding, landslides, and siltation and erosion (Ebinger & Vergara, 2011). Snow and ice storms regularly damage electricity transmission towers, distribution poles, pole-top transformers, and wiring. In some cases, damage can run into the billions of dollars, and take months to repair (Ostendorp, 1998), creating extensive service disruptions for customers. Climate change may either increase or decrease the incidence of this damage on a localized basis, as snow, ice, and heavy wind events become more or less prominent.

Changes in Wind Patterns. Shifts in either the distribution or variability of wind patterns may occur as a result of climate change (Pryor and Barthelmie, 2010). One study estimated wind speeds could decline 1-15% over the next century (Breslow and Sailor, 2002), although other studies argue the evidence for such significant decline is less conclusive (Pryor and Barthelmie, 2011). Seasonal differences in wind power output could be particularly prominent (Edwards, 1991; Segal *et al*., 2001; Breslow and Sailor, 2002). These changes could affect both existing wind farm locations, and lead to changes in areas sought for future wind technology deployment.

To the extent extreme weather events become commonplace, high winds may result in short-term increases in power output levels, although if wind speeds are too high, wind turbine damage can occur (Soto, 2010). Such damage may point to wind speeds that exceeded the design specification of the equipment or deficiencies in construction or equipment manufacturing practices (Chou and Tu, 2011).

There is little experience to date with wave and tidal energy in the U.S., so impacts may partly depend on the extent to which this sector develops. Wave formation is directly linked to wind levels, with Harrison and Wallace (2005) concluding a 20% increase in wind speed will raise wave power levels by 133%. The link between wave height and climate change is generally unclear. No references have been found detailing the relationship between climate change and tidal energy.

Changes in Solar Levels. There is little research thus far that has focused on potential impacts on solar power production resulting from climate change. Cutforth and Judiesh (2007) suggest climate change will change atmospheric water vapor content and cloudiness levels, with Pan et al (2004) estimating these impacts could cut seasonal solar resources in the Western U.S. by as much as 20%.

Extreme Weather Events. Almost all energy facilities are affected by extreme weather through the movement and impact of wind and water. Natural gas price spikes attributable to tropical storm damage extended in recent years all the way from the Gulf Coast to New York State (New York State Energy Planning Board, 2009). High winds can also impact power plants that use air cooling towers, forcing the facilities to shut down during storms to avoid damage.

Adaptations

Adaptation strategies appropriate for the Northeast will vary. Some may have a temporal focus (e.g. short vs. long term); be proactive or reactive; and be structured as a no-regrets, low-regrets, or win-win strategy. They can also be market or policy-led, and have a localized or systemic focus (Ebinger and Vergara, 2011). Wilbanks et al (2008) emphasize the role that enhanced knowledge can play in driving adaptive capacity, arguing that data gaps reduce public or policymaker understanding of the need for adaptation initiatives. Because the energy system relies heavily on mechanisms that balance energy supply and demand, power production dispatch orders and pricing signals may also depend on improved data monitoring or forecasting ability (Troccoli, 2010).

In general, adaptation responses can be categorized as technological, behavioral, or structural (Ebinger and Vergara, 2011).

Technological change. Technological responses focus on the hardening of existing system assets to reduce their vulnerability to climate change risks. Dikes, enhanced pumping capacity, or salt-water resistant transformers all reduce potential impacts from sea level rise or storm-induced flooding (Mansanet Bataller et al., 2008). Smart grid technology may allow damaged networks to recover faster by rerouting power around damaged areas. Smart grid technology may also allow for increased integration of distributed generation technology, reducing the load on system assets stressed by heat waves or other extreme weather events. Such load reductions can reduce the incidence of blackouts or brownouts.

Behavioral change. Behavioral strategies may involve the relocation of critical energy system assets away from risk-prone areas (Ebinger and Vergara, 2011). This can include changing the methods of fuel storage or increasing the elevation of new power generation facilities to reduce flooding risks (Hammer et al., 2011). Changes in emergency planning procedures can also facilitate faster response times to problems, or avoid them altogether. Tree trimming programs reduce the likelihood that falling trees or limbs will be a problem during ice or snow storms, or high wind events (Hammer et al., 2011). Energy efficiency and peak demand management programs can also reduce the amount of energy needed for base and peak loads, offsetting some of the increases in demand expected from higher temperatures.

Structural change. Structural changes promoting adaptive capacity may include changes to fundamental energy market rules to create demand response programs that incentivize power load reductions during heat waves. Utilities and local authorities can also pursue citywide building efficiency upgrade or tree planting programs that reduce solar gain in buildings during summer, thus reducing demand for air conditioning. Policy strategies that promote energy supply diversification can also reduce the risk of supply shortfalls due to drought, flooding, or breakdowns associated with extreme heat events. In particular, on-site distributed generation can enhance energy security for individual buildings as well as providing systemwide load relief (Vine, 2008).

Overcoming Barriers and Stimulating Innovation

In the Northeast, many cities especially are highly dependent on power supplied by power generation facilities (thermal power plants, hydroelectric dams, wind farms, etc.) located far from the city. High voltage transmission lines import power from these facilities to distribution networks serving the city. These power plants and transmission and distribution systems form the nucleus of single or multi-state wholesale energy markets, where prices are set based on demand levels and supply availability.

The nature of this system design means that parts of the region may feel the impacts of climate change even if certain climate changes are not observed locally. Drought or excessive precipitation in regions producing hydropower have ripple effects over the regions they serve, both in terms of supply and price.

Climate change may have significant impacts on urban energy systems in the Northeast, depending on the type of risk, the design of the energy system, and the consumption patterns of local energy users. Although energy systems are designed to operate under a range of weather and supply and demand conditions, climate change may stress the system in ways that disrupt critical fuel supply chains or otherwise exceed the system's current design limits, increasing the risk of breakdown.

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4.7 Community/Urban; Local Economy and Government

Lead Authors - Carl Spector and Jeffery Raven

Significance of Urban Centers in the Northeast

The Northeast is highly urban. About 23 percent of the region's total population of 65 million resides in the 27 cities with populations over 100,000. (U.S. Census Bureau, 2012a) Including their suburbs (the Census Bureau's metropolitan statistical areas) raises the proportion to over half.[22] Northeastern cities include concentrations of businesses, educational, health care, and cultural institutions, and government. The predominance of cities in economic terms is indicated, for example, by the ratio of weekday daytime population to residential population. The unweighted average ratio for the 27 largest cities is 1.17, with a range of 0.84 (Yonkers, a bedroom suburb of New York) to 1.72 (Washington, D.C.). (U.S. Census Bureau, 2012b) This ratio understates the influence of cities, because the influx into urban centers occurs throughout the day and night. Some large cities estimate that their "day-long" populations at least double (Boston Redevelopment Authority, 1996); and this pattern can persist down to much smaller municipalities. (Lamb, 2011)

Table 4.5 Populations and poverty rates of the most populous Northeast cities

City	Residential population (2010)	Daytime/Residential population (2000)	Family poverty rate (%) (2009)
New York	8,175,133	1.07	15.8
Philadelphia	1,526,006	1.06	19.9
Baltimore	620,961	1.14	17
Boston	617,594	1.41	11.9
Washington	601,723	1.72	14.6
Pittsburgh	305,704	1.41	15.5
Newark	277,140	1.22	21.2
Buffalo	261,310	1.16	26.9
Jersey City	247,597	0.97	13.6
Rochester	210,565	1.35	26.2
Yonkers	195,976	0.84	10.5
Worcester	181,045	1.12	15.2
15 more cities over 100,000	1,920,296	1.14[23]	
Total	15,141,050	1.17[24]	

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[22] This rough calculation uses the national average ratio of suburb/city of 1.5. A more careful calculation would have to note, for example, that Yonkers has been double-counted..

[23] Unweighted average

[24] Unweighted average

Sources: U.S. Census Bureau, 2012a, 2012b, 2012c.

Significant Urban Risks

Northeastern cities are vulnerable to climate change through all of the sector vulnerabilities discussed in this chapter. The particular risks for cities arise from the interactions of those vulnerabilities with the density and complexity—physical, economic, and social—of urban life.

Urban density means that relatively small changes can affect many people and much valuable property. Most of the largest cities in this region are vulnerable to sea-level rise or increased riverine flooding. A global rise in sea level of 0.5 m (1.5 ft) could expose an additional $6 trillion worth of property to coastal flooding in the Baltimore, Boston, New York, Philadelphia, and Providence metropolitan areas. (Lenton et al., 2009) The prevalence of basement apartments, a common result of population density and the demand for housing, creates a typically urban vulnerability to increased levels of flooding due to climate-change. (Levy 2011) The urban heat-island effect—whereby the mass of city buildings, roads, and other infrastructure absorbs heat during the day and releases it at night, an effect often exacerbated by the challenges of natural ventilation in dense, compact communities—will magnify the risks from increased frequency and intensity of heat waves.[25] Increased mechanical cooling and its waste heat then intensifies the urban heat island. Density of settlement has influenced how cities have taken shape, particularly in some coastal or riverine cities, where the value of land has led to the filling of wetlands or other low-lying areas. In downtown Portland, Maine, for example, the land most vulnerable to increased flooding as a result of sea-level rise is just those areas that were filled in during the 19th century. (National Resources Council of Maine, 2012)

Big cities are dependent on large, complex systems for energy, food, water, sewage, telecommunications, and transportation. (Rosenzweig et al., 2011) This infrastructure is necessary to bring in resources from great distances—a concept now quantified as ecological footprint. (Wackernagel et al., 2006) The water supply of New York City stretches almost 200 km (120 mi) from the city; the treated waste water from Boston is transported through a pipe 9 km (5 mi) out to sea; a portion of the Northeast's electricity is imported from hydroelectric facilities in Canada; and food comes from all over the world. Centers of finance, telecommunication, education, insurance, law, and trade, are dependent on complex infrastructure systems for routine business activities as well as for the "delivery" of their employees by mass transit systems. Other trades and businesses are reliant on delivery of raw materials or finished goods for distribution. The geographical vulnerability of cities to climate change extends as far as their resource base.

Urban infrastructure takes characteristic forms. Infrastructure that elsewhere remains on the surface—road and rail, electric and telecommunications cables, parking lots—goes underground in cities, becoming more vulnerable to the increased risk of coastal or riverine flooding. Utility poles, where they stand, carry multiple lines, so that the failure of one can affect many systems. Buildings are bigger, higher, and closer together, contributing to the urban heat-island effect and the loss of permeable surfaces; and the loss of permeable surfaces from all sources—buildings,

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[25] See Section 4.5. Human Health.

streets, and sidewalks—increases the vulnerability to flooding. Also, in Northeastern cities, many of them established by European settlers in the 17th or 18th century, infrastructure can be old or built on old foundations, particularly water and sewer systems. (Kessler, 2011) Already failing or inadequate systems will face increased stress from climate change. The age of Northeastern cities also invokes historic preservation laws that complicate any change to protected structures.

Social and economic structure can heighten climate change risks. Poverty rates in cities are, in general, higher than the national average. In 2009, the national rate for poverty by family was 10.5 percent. (U.S. Census Bureau, 2012c) Most of the large cities in the Northeast have rates that are considerably higher (see Table IV.g-1). These segments of the population will be more vulnerable to some climate-change risks with fewer resources for adaptation; for example, their homes may not have air-conditioning to cope with heat waves,[26] and they are more likely to suffer from asthma, which makes them more sensitive to the poor air quality associated with heat waves. (Garg *et al.*, 2003) In Northeastern urban areas, poorer households are frequently non-white, non-English-speaking, or immigrant, which may pose additional burdens on adaptive capacity and further implicates adaptation in the issues of environmental justice. (Environment Protection Agency, 2012)

Municipal Responses and Challenges

As the level of government closest to local residents and businesses, municipalities are acutely aware of risks arising from climate change. Just as cities across the United States, including many in the Northeast, were leaders in the development of climate mitigation plans, so are they at the forefront of adaptation. Plans range from those focused directly on adaptation, such as Keene, New Hampshire's 2007 plan, one of the earliest, *Adapting to Climate Change: Planning a Climate Resilient Community*; to New York City's *PlaNYC*, which includes climate adaptation as one piece of a comprehensive, long-term development strategy. (City of Keene, 2007; City of New York, 2012; Rosenzweig and Solecki, 2010) Whatever the structure, city governments have employed several basic strategies.

Reduced reliance on remote resources

Reducing the need for remote resources may reduce a city's vulnerability to climate-influenced disruptions of distant resources and their transport infrastructure. Energy efficiency programs and renewable energy programs are prominent features of climate mitigation plans of most cities, but they also serve an adaptive purpose. The overlap of mitigation and adaptation strategies is an important feature of many climate action plans, creating both a sense of efficiency and a soft introduction to adaptation, which has been considered more difficult to address. Urban agriculture and local-food movements are burgeoning, with much support from local

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[26] See Section 4.5. Human Health.

governments.[27] Conversely, many adaptation strategies have mitigation benefits, especially those that reduce vulnerability to extreme heat.

Strengthening infrastructure

Previous sections discuss ways to reduce the climate vulnerability of existing infrastructure, and many cities are starting to engage in that process. This is often fruitfully done in the context of normal operations, for example, by including adaptation elements in standard long-term capital planning. (Boston Water and Sewer Commission, 2010) The ability of cities to do so, however, is often limited by constraints on geographical or political authority. For example, although the airport and ocean port of Boston lie within the city's geographical boundaries, political authority for their management is retained by a regional authority that is a political subdivision of the Commonwealth of Massachusetts.

Expanding multi-purpose green infrastructure

Green infrastructure—trees, rain gardens, green roofs, and so on—is an effective tool for climate adaptation, because it can simultaneously address many problems, current and projected—stormwater management, urban heat-island effect, and air quality—and brings mitigation and social and esthetic benefits as well. In particular, green infrastructure has the potential for making public spaces more attractive, which can increase street presence and economic activity. Not least in its attractiveness is its lower cost relative to grey infrastructure. Integrating natural systems into the urban fabric can produce desirable micro-climates within compact, pedestrian-friendly built environments. Philadelphia's recent green stormwater plan exemplifies many of these characteristics. (Philadelphia Water Department, 2012)

Land-use planning and building codes

(Sussman and Major, 2010; Major and O'Grady, 2010) Land-use planning, through zoning codes and other measures, are traditional municipal tools for managing development. These powers, which vary by state, may also include formal project reviews, a variety of permitting processes, and control and enforcement of building codes. Some cities are modifying or expanding their definitions of flood plain or buffer zones to account for projected sea-level rise or change in precipitation patterns, or imagining ways that rising waters could be welcomed into the city. (U.S. Climate Change Program, 2009; Museum of Modern Art, 2010) Other cities, without creating new rules, have incorporated climate-change projections into their environmental review of new projects. A key challenge is to employ these regulatory tools without deterring economic development, especially in light of the revitalization that many Northeast cities have experienced in the past 30 years. A concomitant difficulty, common to both adaptation and mitigation, is that it is easier to regulate new development than to determine—and require and fund—changes to existing structures, especially private property. A related potential obstacle is the historic and architectural preservation rules that many municipalities have put in place to prevent or deter changes to buildings and neighborhoods.

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[27] The mayors of Boston and Baltimore are leading the U.S. Conference of Mayors' new Food Policy Task Force, announced January 20, 2012. See http://www.cityofboston.gov/news/Default.aspx?id=5461. See also section 4.3 Agriculture and Food Systems, above, for a discussion of food sheds.

Strengthening emergency preparedness

Emergency preparedness is a core responsibility of municipal government. Climate change will increase the frequency and intensity of many previously identified natural hazards, and perhaps introduce new ones. Most emergency planning in the Northeast is conducted under guidelines, structures, and processes developed by the Federal Emergency Management Agency (FEMA). Although existing emergency planning protocols rely primarily on historical data (Federal Emergency Management Agency, 2008), cities are finding ways to introduce climate projections, particularly for hazard mitigation plans, updates of which are required every five years for a city to remain eligible for FEMA project funding. This federal program is a receptive vehicle for climate adaptation, because, as FEMA states, "Hazard mitigation is any sustained action to reduce or eliminate the long-term risk to human life and property from hazards," and it comes with pre-established protocols and potential funding streams.

Leadership and community engagement

Climate action in many Northeast cities has included extensive community engagement (City of Burlington, 2012), and adaptation is receiving increasing attention. Important stakeholders include the public at large, the private sector, especially private utilities and the real-estate development community, and major institutions such as universities and hospitals. Because of the technical nature of much adaptation planning, involvement from scientists at universities and other institutions has been critical. The participation of the business sector has been no less important. Cities do not want to alienate existing businesses and discourage new development that is critical to their economic well-being. The business sector, in turn, makes clear the constraints that it faces; for example, the relatively short time-frame employed in financial analyses and the corresponding disincentive for incorporating climate change in their planning. Engagement with the wider community ensures that the community understands and supports potentially significant long-term changes in city structures and policies and that equity issues are thoroughly addressed. The latter include the differential impacts of climate change or climate adaptation measures on various geographic sections and socio-economic sectors of the city and their resources for adapting. In some cities, equity goals go even farther, for example, stating, "Implementation of the climate action recommendations should not exacerbate existing social and economic inequalities and should, whenever possible, contribute to reducing those inequalities." (City of Boston, 2010) Leadership from local officials, whether it starts with a mayor or city council, is an important element of community engagement, and "leading by example" is essential. (City of Boston, 2010)

Engagement with other levels of government

The jurisdictional limitations of municipal governments in dealing with climate vulnerabilities, already discussed, make cooperation with state and regional authorities essential for cities. In some cases, engagement is structural. For example, a city may have one or more designated seats on a regional transportation or water authority—though this does not guarantee accommodation of a particular city's concerns.[28] In other cases, such engagement may depend upon the

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[28] See discussion of Delaware River Basin, in Section 4.1. Water, above.

willingness of political leaders to actively facilitate cross-jurisdictional discussions. Such cooperation may require reaching from municipal to state and federal authorities.

Gathering resources

To the extent that city governments can incorporate incremental climate adaptation within existing municipal processes, climate adaptation may not require large amounts of new funding; for example, by incorporating adaptation measures into the long-term capital plan of a water or transportation authority with existing funding streams. Similarly, using adaptation criteria in the evaluation of private development pushes the cost into the marketplace and with, theoretically, a long-term amortization. Because much municipal infrastructure relies on federal funding, cities will be looking to federal agencies that fund capital projects to explicitly allow or require adaptation planning as part of federal design.

Large-scale protective measures

Where incremental steps will be insufficient in the long term, cities are starting to discuss large-scale protective measures (for example, storm-surge barriers) against the effects of climate change. For the most part, these discussions are at a theoretical stage, though discussions of engineering challenges are becoming more common. (American Society of Civil Engineers, 2009) Municipal government are engaged in these discussions, but are far from committing to such massive projects, which are likely to require resources beyond municipal capabilities.

National and international networks

Cities have always profited from each other's experiences. Northeastern cities are using existing national, regional, and international networks (for example, U.S. Conference of Mayors, ICLEI) and developing new ones (for example, New England Municipal Sustainability Network, Urban Sustainability Directors Network) to share information and exchange ideas on adaptation. (ICLEI, 2012) Within these various frameworks, Northeastern cities are finding ways to collaborate on research projects, often with NGO and academic partners, and search for replicable adaptation strategies.

Conclusions

Physical, social, and economic density and complexity, as well as age and geographic reach, multiply the vulnerability of Northeast cities to the entire range of climate-change risks. Many Northeast cities have begun to address climate adaptation, frequently linking it to existing planning or infrastructure-improvement processes.

Municipal governments can draw on a wide variety of local governance tools for adaptation—including zoning, permitting, planning, stakeholder engagement, and leading by example—but face limitations of authority, geographical jurisdiction, and resources that will require effective engagement with other levels of government.

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5. Climate Change and Regional and Local Identities: New England, Mid-Atlantic and the Urban Northeast Corridor, and Central Appalachia

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The Northeast contains a diverse set of ecoregions, built environments, and cultures. The characteristic weather variability shapes not only these environments, but also the local communities who reside in them. The Northeast region supports a multitude of lifestyles, from urban city dwelling to subsistence farming and hunting. This chapter discusses three regions within the Northeast: New England, the Mid-Atlantic and Urban Northeast Corridor, and Central Appalachia. It presents each region's unique local identities, environment features, climate risks, and challenges from climate change.

5.1 New England

Lead Author- Ellen Douglas

The natural environment of New England is characterized by its variability. In fact, Mark Twain aptly remarked, "One of the brightest gems in the New England weather is the dazzling uncertainly of it." New England's location halfway between the equator and the North Pole and sandwiched between the Appalachian Mountains and the Atlantic Ocean makes its weather more variable than most other places on Earth. The New England culture, environment, and economy are fundamentally integrated with the seasonal changes that traditionally have served up resplendent summers, crisp autumns with spectacular fall foliage, snow covered landscapes accompanied by a variety of winter sports, and the eternal hope of spring.

New England is beloved for its variety and its citizens have adapted to changing economic and climatic conditions to keep New England states consistently ranked near or at the top for quality of life[29] ratings. The New England landscape ranges from the remote, mountainous, forest covered regions of northern Maine, New Hampshire and Vermont to the heavily populated and highly altered landscapes of the coastal flatlands along the southern and southeastern coastal areas of Massachusetts, Rhode Island and Connecticut. The character of the New England coastline varies considerably from rocky headlands in coastal of Maine (upon which stands the iconic New England lighthouses) to low-lying sandy beaches along Cape Cod, Massachusetts. The New England climate is known for its variability, too. The winters are harsh and the snowpack deep in the northern regions and the summers are mild and reasonably long in the southern areas. The change of seasons is pronounced, especially in the autumn, during which New England is known around the world for its vibrant fall colors. The fact that New England offers the best of all seasons is what makes it a year round tourist destination, bringing sun bathers in summer, skiers in winter through mid-spring and "leaf peepers" by the droves in the fall. Arguably, it is the very character of New England, including the stark contrasts and sudden changes that make it beloved by so many as a place to live. But it is the very character of New England that is at risk as average temperatures rise and weather extremes become more pronounced and destructive.

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[29] Data from CNBC surveys: http://www.cnbc.com/id/43344770

Because of its variable nature however, New England is especially vulnerable to the impacts of climate change. New England's climate has experienced substantial changes over the past half century[30]. Over this period, the northeastern United States has experienced a region-wide winter warming trend of almost 4°F. The number of days with snow on the ground has decreased an average of one week. Winter activities such as pond hockey, ice fishing and sled dog racing have been impacted as ice breaks up on the lakes more than a week earlier than it used to. Peak snowmelt runoff in the spring now occurs 7-10 days earlier in northern New England rivers. Increasing extreme rainfall events and flooding, rising seas, and an influx of pests (Lyme disease bearing ticks at the top of the list) have emerged as the latest and potentially most serious challenges to the New England quality of life.

New Englanders are accustomed to extreme weather events. Recently however, New Englanders have endured a sequence of severe storm that have resulted in devastating floods and debilitating power outages across the region. In New Hampshire alone, federally declared disasters cost $3.5 million per year between 1986 and 2004; from 2005 to 2008, they cost an average of $25 million per year[31]. In addition, power outages that used to last a day or two now commonly extend over a week or two in some communities. Perhaps the most insidious change has been relative sea level, which has risen seven inches during the past century and is projected to rise from 3 to more than 6 feet in the coming century. This means more coastal flooding as storms move onshore, especially when a coastal storm occurs at high tide.

Current Climate of New England[32]

The factors that dominate New England climate are its latitude (essentially half-way between the North Pole and the equator), its coastal orientation, the dominant weather patterns, and its terrain. Because of its latitude, New England is often a place where warm-moist air from the south clashes with cold dry air to the north. Frontal systems often traverse the region one after another. Northern New England has a long and highly complex coastline along its eastern boundary, which is dominated by a cold water current while southern New England's coastline bounds its southern extent and is dominated by a warm water currents. The interaction between the land and the sea create sea breezes in spring and summer, particularly along the east coast, which tend to ameliorate thunderstorms along the coast while bringing relief from scorching temperatures in the peak summer heat. In winter, the coastal waters remain warm relative to the land, influencing snow-rain transitional boundaries. Predominant westerlies bring drier continental airflow to New England; hence, despite its coastal orientation, New England climate is not maritime as is experienced on the west coast of the United States. The mountainous topography of New England also influences weather patterns. Increases in elevation lead to cooler air temperatures and increased precipitation, especially on the windward (western) side. In fact, the Mount Washington Observatory, located at the top of New England's highest peak, is known as "Home of the World's Worst Weather"[33]. The combination of these four factors in a small geographical region (relative to other regions of the US) create New England's notoriously variable and

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[30] Additional information at Carbon Solutions New England: http://carbonsolutionsne.org/

[31] Values in 2009 dollars

[32] Summarized from Keim, B., June 1999. Current Climate of the New England Region. Prepared for the New England Regional Assessment, 2000.

[33] http://www.mountwashington.org/

sometimes extreme weather. An oft repeated colloquialism in New England is, “If you don’t like the weather, just wait five minutes!”

Average annual temperatures in New England range from about 40°F in the north to about 50°F along the southern coast. Cooler temperatures prevail at higher elevations, for instance, the average annual temperature at the top of Mount Washington is 26°F. Both daily and seasonal temperature ranges are smaller along the coast, because of the moderating influence of the ocean, and larger inland. Absolute extreme temperatures in New England have been as high as 107°F and down to -50°F (see Table 5.1). The region is also plagued with a great abundance of freeze-thaw cycles. The average annual rainfall across New England ranges from about 35 inches in the north to near 55 inches in the south. Elevation tends to enhance precipitation totals; Mount Washington averages nearly 99 inches of “liquid equivalent” precipitation per year. Across New England, there are subtle differences in the seasonal distribution of rainfall. The region has experienced extreme rainstorms that would rival those in the Southeast (**Table 5.1**).

Table 5.1. Maximum recorded values for precipitation and temperature in New England (Source: National Climatic Data Center http://www.ncdc.noaa.gov/extremes/scec/searchrecs.php)

State	24-hr Rainfall (in)	24- hr Snowfall (in)	Snow depth (in)	Max Temp (°F)	Min Temp (°F)
Maine	13.32	40.0	84	105	-50
New Hampshire	11.07	49.3	164	106	-50
Vermont	9.92	42.0	149	107	-50
Massachusetts	18.15	29.0	62	107	-35
Rhode Island	12.13	30.0	42	104	-28
Connecticut	12.77	30.0	55	106	-36

Snowfall is highly variable across New England both spatially and temporally, generally lowest in Southern New England and highest in Northern New England. The White and Green Mountains average well over a 100 inches per year; Mount Washington averages 254 inches of snowfall per year. Extreme events in the region come in every form: snowstorms, hurricanes, tornadoes, heavy rains, high winds, ice storms and more. Time series of these extremes over the past 100 years suggest subtle changes, but a signal is not clear. Hurricane and tropical storm frequencies in New England show almost no change over the past century, with the most powerful landfalling hurricanes occurring in the middle part of the 20th century. Tornado frequencies are difficult to interpret because of changing population densities and overall public awareness and reporting, but it does seem clear that the past couple of decades have seen a reduction in frequency as compared to the 1950s, 1960s, and the early 1970s. There does appear to be an increase in extreme precipitation events in recent decades.

Recent Climate Change Assessments for New England

Three assessments of climate change impacts in New England have been completed since the year 2000. A summary of these assessments and their key findings are included in Appendix A. Previous assessments found strong evidence that increased average and minimum temperatures have already been observed in New England, especially in the last several decades of the 20th century. These increased temperatures have impacted winter more than summer, and have shifted the timing of spring and fall by a week or more. The most quantifiable impacts have been observed in a higher proportion of winter precipitation as rain rather than snow, a reduction in winter snow pack extent and snow depth, and in retreating dates for lake ice-out and peak river flows. Future climates are projected to have average temperatures well above those that have been experienced in New England's past, suggesting not just a shift in climate but in the New England landscape, ecology and regional character. The northward migration of suitable habitat for forest species will continue, with spruce/fir habitat completely disappearing under both scenarios by 2100. Destructive insects such as the Hemlock Wooly Adelgid will likely continue their northward march. Suitable habitat for native marine fish species is projected to shift northward as well. Precipitation is projected to increase by as much 30% (but more likely 10 to 20%), with a greater proportion of rainfall occurring as high intensity events. The frequency of short-term (one to three month) droughts is also projected to increase. Some of the biggest impacts on human health are related to heat stress (due to a sharp increase in extreme heat days), air quality degradation (due to increased ground level ozone), and the overwintering of mosquitos and ticks which carry Lyme disease, West Nile Virus and Eastern Equine Encephalitis. The warming New England climate will likely have negative impacts on the agriculture, fishing and tourism, important economic sectors that are already struggling under current economic conditions

Recent Observations of Climate Variability and Change in New England

In New England, increases in annual and seasonal temperatures continue to be documented (Hayhoe et al., 2007). Changes in snow pack and snow density (Huntington et al., 2004; Hodgkins and Dudley, 2006), and shifts in lake ice-out dates and the timing and magnitude of river flood flows (Hodgkins et al., 2002; 2003; Collins, 2009) have been observed. The link between the earlier snowmelt, diminished snowpack and the resulting hydrologic response (advances in the timing of peak flows and attenuation of spring flow) was verified by Campbell et al. (2011) who performed a modeling study using long-term historical hydroclimatic data collected at the Hubbard Brook Experimental Forest (HBEF) in northern New Hampshire. They identified increasing trends in precipitation, which have led to increased annual water yields within the HBEF watersheds, and significantly decreasing evapotranspiration over the period of record. Using downscaled projections from a general circulation model, Campbell et al report that projected increases in evapotranspiration due to warming temperatures are likely to offset increased precipitation, resulting in little projected change in streamflow. Weider and Boutt (2010) found heterogeneous water table fluctuations across New England in response to precipitation over the last 60 years. However, they report evidence of increasing groundwater table elevations over the last decade, perhaps in response to observed increases in New England precipitation (Speirre and Wake, 2010).

Rivers have shaped the landscape and ecology in New England; river flow integrates the influence of both meteorological and terrestrial changes. Hence, the river systems in New England represent a complex but useful indicator of climate change. In order to understand how observed hydrologic changes are related to climate change, however, it is important to first understand the drivers of hydrologic variability in the region. A cluster analysis performed on stream gages in New England rivers by Kingston et al. (2011) distinguished 14 rivers in northern New England (NNE) from 6 rivers in southern New England (SNE), with high hydrologic homogeneity and high correlation (0.74 and 0.90, respectively) within each group. NNE rivers showed minimum flows in January to March (water storage in snowpack) and dramatic peak flows in April through June (water released during snowmelt) and lower flows in August and September. A secondary peak of about one-third the magnitude of spring flows occurred in November and December. In SNE rivers, springtime peak flows were about two-thirds of the magnitude of peak flows in NNE river. In contrast to NNE, SNE rivers remained high from December through February, and instead had annual minimum flows in late summer. The distinctive influence of snowpack in the NNE river flows is being attenuated by warming temperatures and decreasing snowpack depth and density (as noted above) and is likely to reduce the distinction between northern and southern New England rivers, with as yet unknown impacts to New England hydrology overall.

Factors that Confound Climate Change Attribution in New England

New England is characterized by high variability in its topography, its climate and in how humans have altered its landscapes. Alone and in combination, such large ranging natural variability makes it difficult to identify a climate change signal. Two of the biggest confounding factors are long-term variability and human alteration, as explained below.

Long-term climate variability. One of the most difficult tasks is distinguishing the influences of climate variability (due to long-term fluctuations in global-scale phenomena such as the El Niño -Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO) from the influence of recent anthropogenic climate change. Hirsch et al. (2001) reported a marked increase in East Coast winter storms during El Niño winters, but there appears to be no clear link between ENSO and New England climate (Bradbury et al., 2002). Lins (1997) found coherent modes of variability in New England rivers in winter (November through January), April (due to snowmelt) and August (due to frequent frontal and cyclonic storms). He noted that storms that affect northern New England (Maine, New Hampshire, Vermont, and Massachusetts) often do not impact southern New England (Connecticut, Rhode Island). Kingston et al. (2007) analyzed large-scale climatic controls on monthly high and low river flow in New England for 1958–2001. Preliminary analysis showed links between streamflow and the NAO, but further inquiry suggested that river flow was more closely linked to the East Coast trough (rather than the Icelandic low and Azores high), and that air temperatures in New England were linked to NAO-related sea surface temperatures. Balling et al. (2011) found correlations with the 315K isentropic surface in New England that suggest long-term enhance moisture flow into the region.

Human alteration and ecosystem adjustment. River flow integrates geographic, biotic and social influences which interferes with the ability to detect an impact due to climate change (Jones, 2011). Most trend studies limit their analysis to gages in ‘unregulated’ (minimal flow regulation, dams or water withdrawals) rivers or segments of rivers. In fact, the US Geological Survey has developed a database of stream gages called the Hydroclimatic Data Network (HCDN; Slack et al., 1993) for just this purpose. However, in many cases these “unregulated” gages are located in low-order, headwater drainage basins often far removed from human populations. In highly urbanized regions such as the Northeastern US, it is difficult, if not impossible, to find flow records that do not reflect some level of human alteration. Additionally, climate-related changes may be overwhelmed by vegetation responses to past disturbances, or ecosystem adjustments to climate variability. For instance, it is well known that logging operations denuded much of northern New England in the 19th century; the recovery of these forests has been cited as a testament to ecosystem resilience. Unfortunately, the recovery of these forests during the 20th century coincides with most flow records (which began in the early 20th century or later) and hence, our observations of stream flow variability and change integrate, to a largely unknown degree, the signals of human flow alterations and of forest recovery. Thus, “all records of streamflow reflect some combination of factors that may confound interpretations of climate change effects” (**Figure 5.1**; Jones 2011). As a result, hydrologist often have to rely to synthetic flow time series as a surrogate for natural flow time series. For example, Tu (2009) used a modeling study to surmise that in eastern Massachusetts rivers, increased monthly flows in late fall and winter and decreased summer flows can be attributed mainly to climate change, while changes in nitrogen loading in the same rivers was attributed to both land use change and climate change.

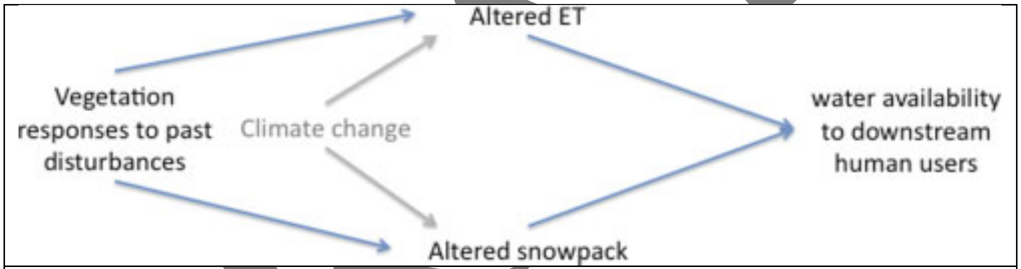

Figure 5.1. Confounding interactions of vegetation and climate change in streamflow. (Source: Jones, 2011; used with permission).

Extreme Events

Just about every type of extreme weather event known to humankind occurs in New England from time to time, including hurricanes, tornados, severe thunderstorms, hailstorms, blizzards, ice storms, floods and droughts. In fact, two of the top-rated U.S. weather events during the 20th century (1938 Hurricane and the Blizzard of 1978) took place in New England and two others (the Superstorm of 1993 and great El Niño episodes of 1997-8) brought devastation to parts of New England[34]. Since the beginning of the 21st century, New Englanders have endured a sequence of extreme events that have resulted in devastating floods and debilitating power outages across the region on an almost yearly basis. It began on October 8 and 9, 2005, when southwestern New Hampshire experienced damaging flooding as a result of a storm that produced over 7 in. (180 mm) of rain in a 30-hr period. The heavy, intense rainfall resulted in runoff and severe flooding, especially in regions of steep topography that are vulnerable to flash

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[34] Weatherwise Magazine (www.weatherwise.org). Top weather events were rated by Weatherwise contributors and by the National Oceanographic and Atmospheric Administration (NOAA).

flooding[35]. Five counties were later declared a federal disaster area. The second event (commonly referred to as the Mother's Day storm) occurred May 12–16, 2006, resulting from a strong low pressure centered over the Great Lakes region at 500 mb and a nearly stationary occluded surface front situated off of the southern New England coast. During this record-breaking event, rainfall totals exceeded 13.8 in. (350 mm) over the five-day period in a relatively concentrated area along the northern Massachusetts, New Hampshire, and southern Maine coastlines. Within four months of this event, state and federal assistance to Massachusetts alone exceeded $70 million. Parts of Massachusetts and New Hampshire were declared a federal disaster area. New England experienced a third extreme storm event less than a year later, on April 15–17, 2007. Known as the Patriot's Day storm, it was one of the largest springtime storms to hit New England in memory[36]. The storm dropped over 6–8 in. (150–200 mm) of rainfall in southern Maine and New Hampshire[37] and heavy snowfall to northern areas and caused flooding of many rivers throughout the region. The storm also packed hurricane-force winds that caused storm surge and flooding in coastal areas. Floods resulting from both the 2006 and 2007 storms had recurrence intervals greater than 100 years[38]. Once again, parts of central New Hampshire and southern Maine were declared federal disaster areas. In mid-December 2008, an ice storm caused widespread damage in eastern Massachusetts, southeastern New Hampshire and southern Maine and left nearly one million people without power[39]. For most New Englanders, the outage lasted several days, but for those in more remote locations, it would be two to three weeks before power was restored. A relatively quiet spell during 2009 was abruptly ended by a blizzard that hit New England on February 25-27, 2010, becoming known as a "snowicane" because along with heavy snow in the interior and flooding rains in coastal areas, this storm brought sustained hurricane force winds to the region[40]. In March of the same year (2010), coastal New England experienced three extreme rainstorms in as many weeks. At the Blue Hill Observatory (BHO) in Milton, Massachusetts, March 2010 became the wettest month in a 120-year record, exceeding the previous record (August 1955) by 0.03 inches[41].

In 2011, a year when the entire US experienced an exceptional number of record breaking events (and more "billion dollar disasters" than ever before[42]), New England experienced its share of exceptional events as well. On February 3, the aftermath of the "Groundhog's Day Blizzard" hit New England, leaving behind a foot of snow and causing buildings in Connecticut and Massachusetts to collapse[43]. A month later, a late season snow storm hit between March 5th and 7th dumped 25.8 inches (65.5 cm) of snow in Vermont, the largest single-storm accumulation on record during March[44]. On June 1st, a cold front associated with a low pressure center over eastern Canada moved into very warm and moist conditions, spawning three tornadoes in western Massachusetts, one rated as an EF-3. Prior to the cold front, temperatures records were

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[35] http://pubs.usgs.gov/of/2006/1221/pdf/OFR2006-1221.pdf

[36] http://www.fema.gov/about/regions/regioni/ora/externalaffairs/patriotsdaynoreaster.shtm

[37] http://www.erh.noaa.gov/gyx/patriots_day_storm_2007.htm

[38] http://pubs.usgs.gov/fs/2009/3049/pdf/fs_2009-3049.pdf

[39] http://www.boston.com/news/local/massachusetts/articles/2008/12/13/ice_storm_paralyzes_parts_of_new_england/

[40] http://en.wikipedia.org/wiki/February_25%E2%80%9327,_2010_North_American_blizzard

[41] http://www.bluehill.org/climate/pre2010.gif

[42] http://www.ncdc.noaa.gov/img/reports/billion/timeseries2011.pdf

[43] http://www.ncdc.noaa.gov/sotc/snow/2011/2

[44] http://www.ncdc.noaa.gov/sotc/snow/2011/3

broken across the state. The path of the EF-3 tornado was the second longest in the state's history. The tornado was responsible for three fatalities in Springfield, and up to 200 injuries over its entire track[45]. In late August, Hurricane Irene brought torrential rain and storm surges of 3–4 feet, causing significant river flooding across eight states, including New York, Vermont, and New Jersey. The flood waters are considered to be one of the Northeast's worst flood disasters. The storm itself was unusually large, with a 500 mile (805 km) diameter, and tropical force winds which extended nearly 300 miles (483 km) from its center[46]. Between October 29th and 31st, a powerful, early season extratropical cyclone brought heavy snow to the Rockies and Great Plains of the US before moving off the Atlantic Coast, where it rapidly intensified into a Nor'easter and dumped over a foot of snow over interior regions of the northeast. Over 30 inches of snow were reported across western Massachusetts and southern New Hampshire. In Concord, Maine, 22.5 inches (57.2 cm) of snow accumulated between 3pm on the 29th and 7am on the 30th, setting the second greatest 24-hour snowfall on record for the city[47]. In sharp contrast, winter 2011-2012 has so far (as of Feb 27, 2012) been one of the warmest and least snowiest winters in New England. Records at the BHO, kept continuously since 1885, show this winter to be the second least snowiest; February so far has been the driest on record and the second warmest and this winter may prove to be the warmest on record.

Is this rash of extreme events in New England part of natural cycle or is it a harbinger of things to come? A few studies have begun to shine some light on this question. Brown et al., (2010) evaluated in 17 temperature and 10 precipitation indices at 40 stations across the Northeast (New England plus New York, Pennsylvania and New Jersey) over three time periods—1893–2005, 1893– 1950, and 1951–2005—and over 1870–2005 for the available longer-term stations. Consistent with climate model projections, strong increases in the frequency of warm events (e.g., warm nights and warm summer days) and decreases in the frequency of cold events (e.g., ice days, frost days, and the cold spell duration indicator) were observed. A decreasing trend in frost days since 1870 was observed, with the strongest trends over the latter part of the 20th century. The growing season has been increasing over the same period of record. Maximum temperatures indices showed strong warming trends over the period 1893–1950, and minimum temperatures showed increases since 1950. Precipitation indices suggested a tendency toward wetter conditions, although few significant trends were found. Some of the variability in the 27 indices over the second half of the 20th century was explained by variability in the North Atlantic Oscillation, Pacific decadal oscillation, and Pacific–North American patterns, however, these patterns showed little influence on the 27 indices over the entire 20th century.

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[45] http://www.ncdc.noaa.gov/sotc/tornadoes/2011/6
[46] http://www.ncdc.noaa.gov/sotc/tropical-cyclones/2011/8
[47] http://www.ncdc.noaa.gov/sotc/snow/2011/10

Spierre and Wake (2010) reported an increasing trend in regional average annual precipitation of 0.73 ± 0.27 inches/decade from 1948-2007 across the Northeast. Increasing trends in seasonal precipitation totals was also found, with fall showing the greatest increases, following by spring, summer, and then winter. Significant increasing trends in days with 2-inch or greater precipitation were found at some stations in Massachusetts, Vermont and Eastern New York, and days with 4-inch or greater rain were generally increasing, but the statistical significance could not be assessed. Douglas and Fairbank (2011) evaluated trends in annual maximum precipitation (MAXP) and the number of days with 2 inches of rain or greater (GT2in) at stations throughout Maine, New Hampshire and Massachusetts. MAXP was found to be stationary (no trend) from 1954-2005; however, an increasing trend in GT2in was found at some stations. The majority of stations in southern New Hampshire and eastern Massachusetts showed evidence of trends in MAXP for the time period 1970–2008 (see Figure 5.2), suggesting that annual maximum precipitation in northern coastal New England has increased by 1 to 2 inches since 1970 (Douglas and Fairbank, 2011). Furthermore, extreme precipitation events of longer than one-day duration have caused large-scale flooding in the region over the last decade. The magnitude of longer duration storms (particularly two-day storms) may also be increasing, calling for engineered infrastructure that can accommodate increases in both storm magnitude and duration. Collins (2009) found evidence of increasing 100-year flood flows in unregulated river throughout New England. In addition to the impacts of increased precipitation and river flow, densely populated coastal communities in the Northeast are highly vulnerable to coastal flooding. Kirshen et al. (2008) evaluated the effect of sea level rise on the so-called “100 year coastal flood” at coastal cities in the Northeast. Under the higher emissions scenario, by 2050, the elevation of the contemporary (circa 2005) 100-year coastal flooding event may be equaled or exceeded at least every 8 years or less. Under the lower emissions scenario, by 2050, the elevation of the contemporary 100-year event may be equaled or exceeded every 30 years or less.

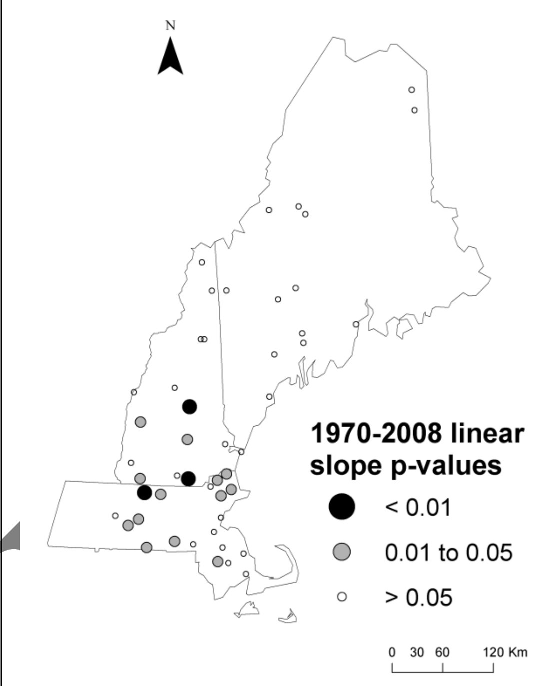

Figure 5.2. Significant increasing trends in annual maximum precipitation in Northern New England (Douglas and Fairbank, 2011).

Changes in Terrestrial Resources

Warming temperatures will likely have substantial affects, both positive and negative, on terrestrial ecosystems in New England. Ollinger et al. (2007) found that increased growth was predicted across deciduous sites under most future climate conditions, while growth declines were predicted for spruce forests under the warmest scenarios. Both climate and rising CO_2 contributed to predicted changes, but their relative importance shifted from CO_2-dominated to climate-dominated from the first to second half of the 21st century. Tang and Beckage (2010) project that regional warming will result in the loss of more than 70% (possibly 100%) of boreal conifer forest and a 26% decrease in northern deciduous hardwood in New England by the late 21st century. Over the same timeframe, mixed oak-hickory forests will shift northward by 100-200 km and will increase in area by 149-431%. However, they note that when rising atmospheric CO_2 concentrations is considered, losses of boreal conifer forest in New England is reduced. Thompson et al. (2011) used model simulations to compare the impacts of forest growth, forest conversion and climate change on above ground biomass. They found that continued forest growth and succession had the largest effect on above ground biomass (AGB), increasing stores from 49% to 112%. Compared to simulations with no climate or land use, forest conversion reduced gains in AGB by 18% over 50 years and timber harvests reduced gains in AGB by 4%, while climate change increased gains by 13.5%. Hence, the increase in growth rates from climate change will be more than offset by forest conversion. Pucko et al. (2011) found evidence that climate change is also affecting the distribution of forest species at the community scale. In response to a 0.49 degrees C per decade warming between 1964 and 2006, they found changes in elevational distribution and community composition across a 600-meter elevational gradient on Camels Hump Mountain, Vermont, USA. In some cases, species responses were individualistic at some elevations, but similar at other elevations. While they attributed these responses mostly to climate change, other factors such as invasive earthworms and prolonged exposure to acid deposition may have also contributed.

Evans and Purschel (2009) suggest that forest management strategies that take into account the impacts of climate change can help make forests more resilient and can increase carbon storage to help mitigate these impacts. Mellilo et al. (2011) investigated the impact of soil warming on carbon storage in New England forests and found that soil warming resulted in carbon losses from the soil and stimulated carbon gains in the woody tissue of trees because of additional nitrogen released from soil-warming enhanced decay of organic matter. After seven years, warming-induced soil carbon losses were nearly compensated for by plant carbon gains in response to warming.

Changes in Marine and Coastal Ecosystems

Salt marshes are prominent features along the New England coastline. They have long been thought to be dynamic and resilient, able to thrive despite threats from human and natural disturbances, but how climate change will impact saltmarshes is still unclear. Charles and Dukes (2009) performed manipulative experiments in two saltmarshes in Massachusetts and found that salt marsh communities may be resilient to modest amounts of warming and large changes in precipitation. They report that moderate daytime warming increased biomass production in *Spartina alterniflora* but not in *Spartina patens-Distichlis spicata* communities and that drought increased biomass in both communities. Decomposition was enhanced by increased precipitation and reduced by drought. These results suggest that warming due to climate change could help salt marshes keep pace with sea-level rise as long as they are not inundated by sea-level rise. Experimental warming was found Gedan and Bertness (2010) to impact *Spartina patens,* a foundation species in saltmarshes, by increasing biomass production but had little impact on the ecological role of this grass or on the saltmarsh community as a whole. However, Geden and Bertness (2009) note that warming could reduce plant diversity in New England salt marshes and

Gedan et al. (2011) report that the combination of accelerating sea level rise and salt marsh die-off may overwhelm the natural compensatory mechanisms of salt marshes and increase their vulnerability to drowning.

Warming temperatures may have more complex effects on marine organisms. Harley (2011) found that climate change may affect organisms, not only physiologically, but by changing predator-prey relationships. In this study, warming was found to reduce predator-free space on rocky shores, resulting in a disappearance of reproducing communities in some cases. Alewives are anadromous fish that have returned to New England rivers to spawn for thousands of years. However, alewife populations have plummeted during the last two centuries due to dams, pollution and overfishing[48]. Where alewives do still exist, warming stream temperatures may be changing their behavior. Ellis and Vokoun (2009) reported that alewife runs have occurred about 12 days earlier on average than in 1970, which has implications for water supply management for rivers in southern New England. Lucey and Nye (2010) confirmed a shift towards species that prefer warmer waters in four distinct subregions off the northeast coast (Mid-Atlantic Bight, Southern New England, Georges Bank, and Gulf of Maine) resulting in current species assemblages that are similar to the historic assemblages in the subregion to the south. They report that these shifts have occurred in response to a combination of both fishing and climate, and current reductions in fishing pressure may not be adequate to return the system to a more historic species assemblage.

Recent Climate Change Assessments and Adaptation Initiatives in New England

Adaptation is generally defined as taking proactive steps to improve the resiliency of both the natural and built environments to the impacts of climate change. Compared to many other planning processes, the major challenge of adaptation planning is the wide range of uncertainty associated with projecting future climates as well as uncertainties in other drivers such as population growth, land use change, and technological innovation. Because of additional uncertainties in the timing of impacts, adaptation strategies themselves must dynamic and adaptive (Kirshen et al., 2011). Although the United States government has not been able to come to an agreement on an approach to either mitigation or adaptation strategies related to climate change, many state and local governments are beginning to take steps in that direction. **Table 5.2** outlines some of the climate change assessment and adaptative planning that are underway or are being considered across New England. While not exhaustive, this list offers insight into the many aspects of climate change impacts and adaptation strategies being considered.

Table 5.2. Summary of climate change assessments and adaptation planning in New England States and communities.

Maine	In 2009 the University of Maine released “Maine’s Climate Future: An Initial Assessment” giving a general overview of the possible climate change impacts in the state of Maine with the interest of assessing possible opportunity for adaptation.

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[48] http://www.fws.gov/GOMCP/pdfs/alewife%20fact%20sheet.pdf

	http://climatechange.umaine.edu/files/Maines_Climate_Future.pdf
	In 2009 there was an assessment of the effects of climate change in the Casco Bay region of Maine "Climate Change in the Casco Bay Watershed: Past, Present, and Future" showing a need for adaptation projects to begin development. http://www.cascobay.usm.maine.edu/pdfs/Climate_Change_in_Casco_Bay.pdf
	In 2010 the Maine State Legislature passed LD 460, a "Resolve, To Evaluate Climate Change Adaptation Options for the State" giving climate change adaptation a governmental mandate to assess options for future climate change adaptation projects. http://www.mainelegislature.org/legis/bills/bills_124th/billtexts/SP016301.asp
New Hampshire	New Hampshire has several studies that involve climate change adaptation in progress. A pilot program in Keene, New Hampshire, sponsored by the International Council for Local Environmental Initiatives (ICLEI) has been developed to assess possible climate change adaptation strategies and increase the overall resiliency to climate change effects of Keene on a local level. http://cbtadaptation.squarespace.com/storage/KeeneSummary_ICLEI_FINAL2.pdf http://www.icleiusa.org/action-center/learn-from-others/ICLEI_case%20study_Keene_adaptation.pdf http://www.ci.keene.nh.us/sites/default/files/Keene%20Report_ICLEI_FINAL_v2_0.pdf
	The Piscataqua Region Estuaries Partnership (PREP) has published a management plan in 2010 that includes planning ahead for climate change impacts "with the awareness that climate change impacts must be factored into all aspects of watershed management activities." http://www.prep.unh.edu/resources/pdf/piscataqua_region_2010-prep-10.pdf
	"The Oyster River Culvert Analysis Project" report was released in 2010 through the EPA's Climate Ready Estuaries (CRE) and is a complete analysis of storm water capabilities in the Durham area complete with cost of upgrading or replacing current systems as well as adding other abatement strategies (especially Low Impact Development (LID) methods. http://www.cakex.org/sites/default/files/oyster_river_culvert-prep-10.pdf
Rhode Island	Rhode Island is presently in the middle of an ambitious project of coastal management. The Rhode Island Ocean Special Area Management Plan (Ocean SAMP) was started in August of 2008. The project, led by the Rhode Island Coastal Resources Management Council (CRMC) supported by the University of Rhode Island (URI) and the Rhode Island Sea Grant (RISG) has been placed in charge of "submerged areas" as well as key coastal areas. As part of the Ocean SAMP, the CRMC has begun zoning coastal and oceanic areas in Rhode Island for evaluation, usage restriction and continuing research. The CRMC is evaluating potential areas to build wind turbines to help mitigate future carbon emissions. R.I. has set the goal of harvesting 15% of their needed electrical energy from coastal wind turbines. The CRMC also is establishing usage regulations including coastal development with a focus on safe building zones and practices as well as natural inundation barriers. http://coastalmanagement.noaa.gov/news/archivedmtgdocs/2009neregmtg/boyd.pdf;http://seagrant.gso.uri.edu/oceansamp/documents.html

	The Brown University Center for Environmental Studies released an evaluation in 2010, “Summary: Preliminary Assessment of Rhode Island’s Vulnerability to Climate Change and its Options for Adaptation Action”, an assessment of the possible threats to Rhode Island due to climate change as well as potential adaptation strategies. http://www.cakex.org/sites/default/files/Rhode%20Island%20Climate%20Change%20Adaptation.pdf
Vermont	Vermont has completed its comprehensive climate action plan, focusing on public health issues and economic effects as well as effects on water resources. http://www.anr.state.vt.us/anr/climatechange/Adaptation.html
Connecticut	Another ICLEI local pilot project with assessment and suggested adaptive strategies, “A Report to the Town of Groton and Communities throughout New England” through ICLE and the Connecticut Department of Environmental Protection. http://www.groton-ct.gov/depts/plandev/docs/Final%20Report_Groton%20Coastal%20Climate%20Change%20ProjectJP.pdf
Massachusetts	A 2011 assessment of adaptive strategies in Massachusetts from the Executive Office of Energy and Environmental Affairs. http://www.mass.gov/eea/docs/eea/energy/cca/eea-climate-adaptation-report.pdf
	In March 2009, Mayor Thomas M. Menino formed the Boston Climate Action Leadership Committee and Community Advisory Committee. The charge to the committees was to give recommendations to the Mayor on the next set of goals, policies, and programs that Boston should establish for itself as it confronts the risks and opportunities of global climate change. Adaptation plans for the city can be found at http://www.cityofboston.gov/climate/adaptation/
	A vulnerability assessment through the EPA’s Climate Ready Estuaries program, “Vulnerability Assessments in Support of the Climate Ready Estuaries Program: A Novel Approach Using Expert Judgment, Volume II: Results for the Massachusetts Bays Program (External Review Draft)” is available for review only. **Warning**: this report is still under review. http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=237920#Download
	Storm surge visualization with freeboard recommendations for Hull, MA and further assessment. http://www.mass.gov/czm/stormsmart/resources/hull_inundation_report.pdf http://www.nbwctp.org/programs/CCdocs/PowerPoints/Panel_Planning%20for%20Community%20Climate%20Change%20Adaptation_Hull,%20MA_Anne%20Herbst.pdf Draft plans from the Cambridge, MA Climate Protection Action Committee. http://www2.cambridgema.gov/cdd/et/climate/clim_adaptation_rec.pdf

Box 5.1: Sunapee Watershed Infrastructure Project, Lake Sunapee New Hampshire

The Lake Sunapee Protective Association (LSPA) Watershed Steward, Robert Wood, is a principal investigator for a project in which a team of investigators will assess the adequacy of stormwater infrastructure within the 50 square mile Sunapee watershed. A team of scientists from Antioch University New England and Syntectic International of Portland, Oregon will study and prepare the Lake Sunapee watershed for increased stormwater runoff expected from climate change. The Lake Sunapee watershed has experienced an unusual and ongoing period of extreme rainfall events that significantly diverge from the historical climate pattern. Previous New England studies by the team found that portions of existing drainage systems are currently undersized as a result of already-changed rainfall patterns. "Recent experience and scientific studies are clear," said Michael Simpson, director of Antioch University New England's Resource Management and Conservation program. "Storm patterns are worsening and it is no longer prudent to delay action. We will never have perfect science; however sufficient science is available now. This project will protect the community with adequately reliable, local-scale information to support informed decisions." By encouraging the participation of community members, the project will empower citizens to choose adaptation plans that are best for their towns. For example, Low Impact Development methods can minimize runoff and significantly reduce the need for more expensive drainage system upgrades. The project team hopes to catalyze similar work nationwide, reducing further loss of life and damage from worsening storms. By demonstrating a practical protocol for action, this work provides urgently needed decision-support to leaders seeking to maintain historical protection levels in their communities. (http://www.lakesunapee.org/templates/infrastructure.html)

Box 5.2: Obstacles and incentives to climate change adaptation in metropolitan Boston, Massachusetts

A team of researchers, led by Dr. Ellen Douglas of the University of Massachusetts Boston, explored the possible future impacts of increased coastal flooding due to sea level rise and the potential adaptation responses of two urban, environmental justice communities in the metropolitan Boston area of Massachusetts. East Boston is predominantly a residential area with some industrial and commercial activities, particularly along the coastal fringe. Everett, a city to the north of Boston, has a diversified industrial and commercial base. While these two communities have similar socioeconomic characteristics, they differ substantially in the extent to which residents would be impacted by increased coastal flooding. In East Boston, a large portion of residents would be flooded, while in Everett, it is the commercial/industrial districts that are primarily vulnerable. Through a series of workshops with residents in each community, the study found that the target populations do not have an adaptation perspective or knowledge of any resources that could assist them in this challenge. Furthermore, they do not feel included in the planning processes within their communities. However, a common incentive for both communities was an intense commitment to their communities and an eagerness to learn more and become actively engaged in decisions regarding climate change adaptation. The lessons that can be applied to other studies include 1) images are powerful tools in communicating concepts, 2) understanding existing cultural knowledge and values in adaptation planning is essential to the planning process and 3) engaging local residents at the beginning of the process can create important educational opportunities and develop trust and consensus that is necessary for moving from concept to implementation.

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5.2 Mid-Atlantic and the Urban Northeast Corridor

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Overview

One of the defining features of the mid-Atlantic is the positioning of major cities along the coast from the southwest to the northeast including Washington DC, Baltimore, Philadelphia, Newark and New York City. This sub-region is home to more than 48 million people (NJ (8.8M), NY (19.5M), PA (12.7M), DE (907K), MD (5.8M), D.C. (618K)) (U.S. Census Bureau, 2011) which represents approximately 15 percent of the population of the United States (312M). The vast majority of the people, infrastructure and wage are situated along the Atlantic coast or major estuaries and rivers. For this reason, the Mid-Atlantic corridor coupled with greater Boston is currently responsible for an estimate 20 percent of gross domestic product in the U.S and is expected to add an additional 18 million people by 2050 (Regional Planning Association, 2006). This corridor also hosts a $2 trillion economy, many of the top research universities, three of the world's busiest airports (LaGuardia, JFK, Newark) and the headquarters of 162 of the Fortune 500 companies (Bloomberg and Rendell, 2011). With just two percent of the land mass of the United States, this area often referred to as the Northeast Corridor or "megaregion" has the highest population concentration, economic prosperity and urbanized landscapes in North America (Cox et al., 2006).

Population Census

Population estimates from the U.S. Census Bureau (2010) indicate that the greater New York City/New Jersey metropolitan area represents one of the most density settled areas in the country with over 11.8 million (cumulative total for Nassau (1.3M), Suffolk (1.4M), Westchester (949K), Queens (2.2M), Kings (2.5M), Richmond (469K), New York (1.6M), and Bronx (1.4M) Counties) and an additional 4.3 million in New Jersey (cumulative total for Hudson (634K), Bergen (905K), Essex (784K), Union (537K), Middlesex (810K) and Monmouth (630K) Counties) for a total of 16.1 million people. Other metropolitan areas in the Mid-Atlantic sub-region include Philadelphia County (1.5M) with an additional 513,000 across the Delaware River in Camden County, NJ, Baltimore City, MD with 621,000 (2010) and Washington, D.C. with 618,000 (2011). New Castle County, DE had 538,000 (2010) with 71,000 in the City of Wilmington.

Land-Use and Geographic Features

Land-use characteristics vary across this sub-region from highly developed in the northern portions (Long Island and New York City, greater New York/New Jersey) including other major cities to the agriculture, forested, and wetlands through southern New Jersey, Delaware, and eastern Maryland (i.e., Delmarva Peninsula). The Mid-Atlantic sub-region is represented by two ecoregion provinces that meet approximately at the Delaware state line; 221 Eastern Broadleaf Forest (Oceanic) and 232 Outer Coastal Plain Mixed (Bailey, 1995). These include the inner and outer coastal plain and piedmont (Rogers and McCarty, 2000). Landform characterization of the

Outer Coastal Plain is gentling sloping with local relief of less than 300 feet. Higher elevations up to 1000 feet in the Piedmont Plateau are typical to the west and north (Bailey, 1995). The major watersheds of the Mid-Atlantic sub-region include the Raritan Bay (New York/New Jersey), Long Island Sound (New York), Delaware River and Bay (Pennsylvania, New Jersey, Delaware) and the Chesapeake Bay (Pennsylvania, New Jersey, New York, Maryland, Delaware). Long Island, New York, large section of New Jersey, and the Delmarva Peninsula are characterized by smaller coastal watershed directly exposed to the influences of the Atlantic Ocean. Within these watersheds, extensive coastlines exist at the interface with the Atlantic Ocean and along estuaries, bays and inlets that total 8,128 miles in length (MD (3,190 miles), NY (2,625), NJ (1,792), DE (381), PA (140)) (NOAA, 2011). Along this coastline are 1,000 of miles of coastal beaches and barrier islands interspersed with estuaries, embayments and river drainage systems including seven National Estuary Programs (Long Island Sound, Peconic Estuary, New York-New Jersey Harbor, Barnegat Bay, Delaware bay, Delaware Inland Bay, Maryland Coastal Bays), twenty-one National Wildlife Refuges, four National Estuarine Research Reserves, two National Sea Shores (Assateague Island, MD; Fire Island, NY), and countless state, county, municipal, and private parks and protected lands. These coastal, riverine, and upland ecosystems provide critical ecological value and function that help to sustain recreational and commercial fisheries, attract and retain tourism revenue, and define the quality and cultural characteristics of the Mid-Atlantic.

The climate of the two ecoregion provinces in the Mid-Atlantic sub-region is generally a humid continental climate with variable annual temperature ranges between the two. In the southern states of this sub-region (Maryland and Delaware) the average annual temperatures range is 60 to 70^{O}F while in the northern states (New York) the average temperatures range from 40 to 60^{O}F. Annual precipitation is variable across this sub-region ranging from 35 to 60 inches in the north and 40 to 60 inches in the south. Precipitation patterns tend to be well distributed throughout the year in the south with increased rainfall during the late spring and summer months in the northern part of the sub-region (Bailey, 1995).

Transportation and Commerce Networks

The transportation and commerce networks in the Mid-Atlantic are will be impacted by a climate altered future due to the principal dependence on a single major corridor and the close proximity on that corridor to the coast. The Mid-Atlantic is linked via a robust transportation network of ports, rails, and roadways that run predominantly southwest to northeast between the major cities from Washington D.C. through Baltimore and Wilmington/Philadelphia to New York City (The Northeast Corridor). The almost continuous network of suburban towns linked to major cities from Washington D.C. clear up to Boston has resulted in the term “megalopolis” (Gottmann, 1961) and more recently the “Northeast megalopolis” (**Figure 5.3**). Major arteries such as the 118 mile length of the New Jersey Turnpike and supporting bridges were constructed after WWII (1950-1952) to accommodate the increase in vehicle congestion and American’s penchant for travel. At the center of the transportation network, New Jersey Transit hosts what is known as the third largest public transportation system by ridership in the nation connecting New York City to Philadelphia and points south. The birth of the rail system in the Mid-Atlantic and perhaps the Nation can be traced to Baltimore in 1827 with the advent of the Baltimore to Ohio Railroad (B&O) as the City struggle to compete with New York City (i.e., Erie Canal) and

Philadelphia to provide commerce to the western expanses (Woody, 1827). This initial system quickly connected to Washington D.C. and eventually spawned the network of rail lines and telegraph (i.e., commerce, goods, and communications) between the cities and towns of the Mid-Atlantic. Today, the rail system in the Mid-Atlantic accommodates approximately 259 million passengers annually along with 14 million car-miles of goods (Bloomberg and Rendell, 2011). It is important to note however that since many of these rail beds were put in place in the early to mid-1800s, global sea levels have risen substantially. Here in lies both a major risk to modern day transportation and commerce and an unavoidable cost for the Mid-Atlantic at some point in the future.

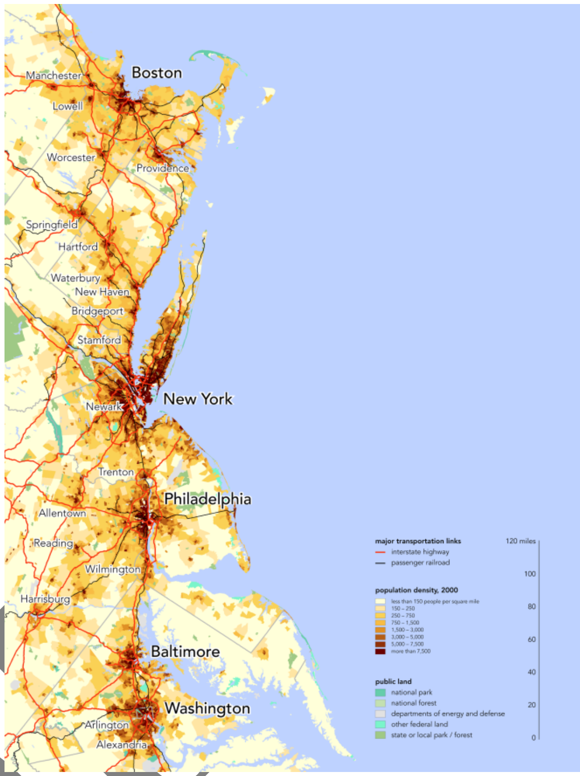


Figure 5.3. Northeast megalopolis from Washington D.C. to Boston through the Mid-Atlantic. Source: Bill Rankin

Ports

Many of the larger port facilities in the US are aggressively planning for expansion to increase capacity and access for larger vessels traffic expected in 2014 with the expansion of the Panama Canal (Logistics Management, 2011). This includes four ports in the Mid-Atlantic sub-region that consistently have ranked as the largest by volume in the United States; New York/New Jersey (646,621 Twenty-foot Equivalent Unit (TEU) Q1 2011), Baltimore (73,267 TEU), Philadelphia (38,049 TEU), and Wilmington (31,168 TEU) (Zepol Corporation, 2011). The on-going engineering and design in many ports includes dredging, improving access through major infrastructure projects (i.e., “Raising the Roadway of the Bayonne Bridge" – Port Authority of New York and New Jersey) and the expansion of existing facilities (i.e., Global Container Terminal in Jersey City, NJ). The incorporation of expected increases in flooding from storm events and sea level rise into Port expansion plans will likely create a competitive edge and avoid future costs of re-engineering facilities and navigation lanes in the Mid-Atlantic sub-region. This is especially critical for the New York/New Jersey Port Authority given that it is the single largest East Coast "ocean cargo gateway" accommodating an estimated 31 percent of all container traffic along the Atlantic coast (Logistics Management, 2011) and was ranked as the 20th and 22nd largest in the world in 2008 and 2009, respectively (US Department of Transportation, 2011). This Port is rivaled by only the Ports of Los Angeles and Long Beach in the United States.

Tourism

According to data from the US Department of Labor's Bureau of Labor Statics, the "Professional and Business Services", "Education and Health Services" and "Government" sector typically provide the largest number of jobs in the Mid-Atlantic sub-region. "Leisure and Hospitality" ranks high amongst all the sectors for sub-regional states employing approximately 750,000 in New York (Dec. 2011), 336,000 in New Jersey (Dec. 2011) and 230,000 people in Maryland (Dec. 2011). Recent estimates of revenue generated by tourism range from $54 billion annually in New York and $36 billion in New Jersey to $21 billion (140 million visitors) in Pennsylvania (Investopedia, 2010). One of the key characteristics and features that continue to draw tourists is the availability and access to coastal areas (beaches and ocean) and supporting facilities (restaurants, hotels, events, gambling). Atlantic City, NJ stands out as an example of a premier past and current tourist attractions in terms of relative visits and revenue within the Mid-Atlantic. The history of Atlantic City has been punctuated by hazard events including the loss of two famous piers (Steeplechase and Heinz 57) during The Great Hurricane of 1944.

Fisheries

Revenue derived from commercial fisheries in both estuaries and at sea in the northeast (New England and Mid-Atlantic) was approximately $1.2 billion in 2004 (Fogarty *et al.,* 2007). Commercial fisheries revenue (prices paid prior onshore handling) in 2003 was estimated at 226.4 million for the four states reporting in the Mid-Atlantic sub-region (51.6M (NY), 120.6M (NJ), 5.2M (DE), 49M (MD)) (NOAA/NMFS 2004). Major ports (10M annually) in the sub-region are confined to New Jersey and New York include Cape May/Wildwood, NJ (42.7M in 2003), Point Pleasant, NJ (22.8M), Atlantic City, NJ (20.8M), Long Beach/Barnegat Light, NJ (16.3M), and Montauk, NY (11.0M). The port facilities that support these fisheries are subjected to immediate impacts from coastal storms and sea level rise longer term. Of most concern to the industry and managers in the Mid-Atlantic is the potential for "poleward shifts" of economically importance fish and shellfish due to increased water temperatures (Fogarty et al*.,* 2007).

Defining Catastrophic Events

Large storm events such as tropical storms and hurricanes and extratropical storms have driven the formation and continued development of the coastlines in the Mid-Atlantic. Hurricanes stand out as the most dramatic hazard (i.e., coastal and inland flooding, wind) experienced in this sub-region and can reshape coastlines, increase wetland loss and beach erosion, damage private and public structures, interrupt business, displace people and result in loss of life. The Mid-Atlantic region has had several period of increased hurricane activity including from 1876 to 1904, 1933 to 1966, and from 1995 to present (Schwartz, 2007). One of the most significant was the Great Atlantic Hurricane of 1944 (September 14) with gusts up to 100 miles per hour and estimated 35 foot storm surge in coastal New Jersey. This Hurricane caused more damage in New York City than the Great Hurricane of 1938 (September 21), also known as "The Long Island Express". This hurricane produced winds that reached over 186 miles per hour, generated 15 foot breakers, overwashing approximately one half of coastal areas in Long Island, New York, and created 12 new inlets (Donnelly et al., 2001). Nationally significant precipitation events associated with hurricanes include a 22 inch deluge over a 10 hour period in Ewan, New Jersey near Philadelphia in September 1940 (Schwartz, 2007). Of greatest concern however is the repeat of a hurricane in 1821 which passed through all the major population centers from Washington, D.C. to the greater New York/New Jersey metropolitan area. Economic and public health impacts from a repeat of the 1821 hurricane event have the potential of surpassing even Hurricane Katrina as the nation's most costly natural disaster (Ashton et al., 2007).

Key Climate Implications: Exposure, Sensitivities, and Vulnerability

Sea Level Rise

While the degree of impact from sea level rise on urban and suburban communities in the sub-region depend on the position of populations, infrastructure, and natural resources, the projected rise coupled with storm surge represent both an immediate and long-term challenge. Across the Gulf and Atlantic Coasts of the United State, 3 of the states in the top ten for most vulnerable (total acres and percentage of land below 1.5 meters) to sea level rise are in the Mid-Atlantic sub-region; Delaware, Maryland, New Jersey (The Maryland Commission on Climate Change, 2008; Titus and Richman, 2000). This has important implications across many sectors and facets of the ecological, social, and economic livelihoods of this sub-region.

Projected relative sea level rise rates for the Mid-Atlantic sub-region are significantly higher than global averages (1.7 ±0.5 mm/yr) and surpass the majority of other areas of the United States due principally to continued land subsidence from isostatic rebound from the Wisconsin Ice Age (CCSP, 2009). For example, the CCSP (2009) reports a rate of sea level rise of 3.98 mm/yr (± 0.11) for Atlantic City, NJ, 3.12 mm/yr (±0.16) for Baltimore, MD, 3.53 mm/yr (±0.13) for Annapolis, MD, 2.75 mm/yr (±0.12) for Philadelphia, PA, and 3.13 mm/yr (±0.21) for Washington, DC. This range of relative sea level rise (2.75 – 3.98 mm/yr) is likely a low estimate with a more realistic range between 11 and 12 mm/yr for the Mid-Atlantic as contributions for continental ice sheet melt to the world's oceans are considered (CCSP, 2008).

Population

Estimated impacts based on the 2000 US Population Census suggest that between 450,310 to 2,310,550 people (excluding Chesapeake Bay Watershed) are at potential risk from a 1 meter sea level rise in the Mid-Atlantic (CCSP, 2009). Associated implications of a 1 meter rise are most pronounced in the New York Harbor and Raritan Bay watersheds (as defined by CCSP, 2009) with dramatic impact estimates as high as 269,420 owner-occupied residences, an additional 178,790 renter-occupied residences, and 21,090-acres of developed lands inundated (CCSP, 2009). High impact estimates for Delaware Bay and River watersheds (CCSP, 2009) include 113,320 owner-occupied residences, 38,640 renter-occupied residences, and 12,720-acres of developed lands (CCSP, 2009). This will result in both temporarily and permanently displace citizens including "at-risk" populations; elderly, young and low income communities.

Infrastructure

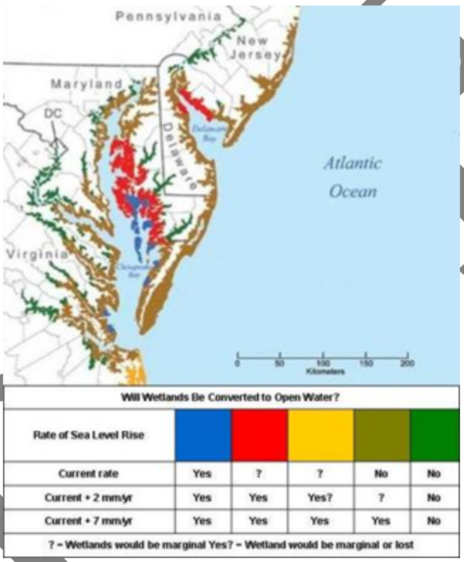
Potential impact estimates by the US. Department of Transportation (2008) indicate that for Maryland approximately 67-miles of roads and 27-miles of rail will be "regularly inundated" under a 59 cm sea level rise scenario (IPCC, 2007). Although the total number of impacted miles of Maryland's roads and rail is a small percentage of the overall system, repeated and regular interruptions along the network could have far reaching and lasting effects for commerce over time. Impacts from permanent and temporary flooding (with 59 cm sea level rise) for infrastructure in New York are estimated at 212 miles of roads, 77 miles of rail, 3,647-acres of airport facilities, and 539-acres of runways (US DOT, 2008). The total land area flooded permanently (69,031-acres) and temporarily flooded (62,289-acres) in New York is estimated at 131,319-acres. The total land area flooded by a 59 cm sea level rise in New Jersey (325,403-acres) and Maryland (474,552-acres) is much larger than New York, Delaware (140,737-acres), Pennsylvania (8,271-acres) and Washington, D.C. (2,392-acres) (US DOT, 2008) due to the lower lying coastal plain and overall land mass of each state.

Of greater concern are the projections of impacts to ports in Maryland (principally Baltimore, MD) with an estimated permanent and temporarily flooded area of 298-acres or 32% of the overall port facilities in the state (US DOT, 2008). Other important port facilities including those in New York (110-acres and 26% of overall port facilities), New Jersey (344-acres and 13%), Pennsylvania (89-acres and 25%), Delaware (126-acres and 39%) (US DOT, 2008) will experience impacts from sea level rise and storm surge. These impacts have potentially significant economic ramifications across the sub-region; for example over 50,200 jobs, $3.6 billion in personal income, $1.9 billion in business revenues, and $388 million in state/county/municipal tax revenues were generated by the Port of Baltimore in 2006 alone (Maryland Port Administration, 2008). In comparison, the New York/New Jersey port industry supported 232,900 jobs, $12.6 billion in personal income, $5.8 billion in total tax revenue with a cumulative 100 million tons of cargo through the terminals in 2004 (New York Shipping Association, 2005).

Ecosystems

Potential adverse impacts to ecosystems in the Mid-Atlantic sub-region due to climatic changes will likely be driven through interaction with other factors identified as current stressors. Existing fragmentation of forest systems due to development will prevent the migration of certain species and decrease the resilience of existing populations. Freshwater systems will be required to accommodate increased surface runoff and higher flows. This may be particularly problematic in urban settings where stream channels have been channelized or otherwise altered (Rogers and McCarty, 2000). In addition, the increased intensity, frequency, and duration of precipitation events may elevate the delivery through surface runoff of pollutants to freshwater, coastal and estuarine systems.

Inland and coastal wetlands in the Mid-Atlantic sub-region have experienced a loss of acreage in the last few decades primarily due to development and redevelopment through filling and altering drainage systems. For example, between 1992 and 2007, a net loss of 3,126-acres of wetlands has been documented in Delaware with the greatest impact in forested wetlands on the Delmarva Peninsula (DDNREC, 2011). Many of the existing coastal wetlands in the Mid-Atlantic sub-region will be exposed further to increasing conversion due to sea level rise and in situ alteration due to warming sea temperatures in estuaries and embayments. Sea level rise scenarios in the 11-12 mm/yr range will result in extensive conversion to open water and loss of coastal marsh which will have societal and business implications in throughout the Mid-Atlantic sub-region (CCSP, 2009, **Figure 5.4**).



Will Wetlands Be Converted to Open Water?					
Rate of Sea Level Rise	🟦	🟥	🟨	🟫	🟩
Current rate	Yes	?	?	No	No
Current + 2 mm/yr	Yes	Yes	Yes?	?	No
Current + 7 mm/yr	Yes	Yes	Yes	Yes	No

? = Wetlands would be marginal Yes? = Wetland would be marginal or lost

Figure 5.4. Conversion of existing wetlands to open water under three sea-level rise scenarios in the Mid-Atlantic. “Current +7 mm/yr” represents a 11-12 mm/yr rise (110-120 mm by 2100). Source: CCSP 2009.

Adaptive Capacity

In many of the states in the Mid-Atlantic sub-region there are on-going assessments of exposure and vulnerability to climate change. In some cases, these assessments build on the awareness of risk and explore the capacity needed to reduce overall vulnerability and adapt to climate change. The following (**Table 5.3**) is a summary of prominent adaptation related reports and efforts by state in the Mid-Atlantic sub-region that provide information either directly or indirectly on adaptive capacity, respectively.

Table 5.3 Mid-Atlantic Sub-region Adaptation Reports and Initiatives

State	Mid-Atlantic Sub-region Adaptation Reports/Initiatives
New York	The ClimAID Integrated Assessment for Effective Climate Change Adaptation: This report provides impacts and adaptation assessment and case studies across eight sectors in New York State (Rosenzweig *et al*., 2011). Climate Change Adaptation in New York City: Building a Risk Management Response: This report by the New York City Panel on Climate Change (2010) provides climate projections, vulnerability assessments, adaptation strategies, and recommendations on resilience programs for the NYC.
New Jersey	Coastal Community Vulnerability Assessment Protocol: A GIS-based approach to assessment community vulnerability with visual tools developed by the New Jersey Coastal Management Program (2011a., 2011b.). Getting to Resilience: A Coastal Community Resilience Evaluation Tool: A questionnaire developed by the New Jersey Coastal Management Program (2011a., 2011b.) designed to guide an assessment of how a community has incorporated hazard and sea level rise mitigation in to planning documents.
Delaware	Delaware Department of Natural Resources and Environmental Control's Sea Level Rise Initiative: This Initiative consists of vulnerability assessments, pilot implementation projects, stakeholder engagement and training, and informed policy development in Delaware (Delaware Coastal Program, 2011).
Pennsylvania	Pennsylvania Climate Adaptation Planning Report: Risks and Practical Recommendations: This report by the (2011) represents the first statewide effort to provide "practical" strategies for individual and cross-cutting multiple sectors; infrastructure, public health and safety, natural resources, and tourism and outdoor recreation. Climate Change in Pennsylvania: Impacts and Solutions for the Keystone State: This report by the Union of Concerned Scientists (2008) provides an overview of potential impacts and solutions for the state of Pennsylvania.
Maryland	Climate Action Plan: This plan prepared by the Maryland Commission on Climate Change (2008) provides a vulnerability assessment, early recommendation items, and the identification of priority policy options for further review.

Box 5.3: Green and Gray Infrastructure: "Designing the Edge"

Coastal communities in the Mid-Atlantic sub-region have a long history of trying to maintain their coastlines using a variety of traditional structural mechanisms, including jetties, groins, seawalls, beach replenishment and construction of bulkheads. In many cases, this coastal armoring or hard engineering approach has had detrimental impacts on natural resources and ecosystems by modifying required geomorphic and sediment processes such as erosion, transportation and deposition. In recent years there has been a growing recognition in the Mid-Atlantic sub-region that natural resources can and should be factored in as a viable approach and potential alternative to traditional hard engineering methods. What has emerged in a few states is a deliberate science-based examination and implementation of coastal zone management that both enhances the natural benefits from coastal ecosystems (i.e., wave attenuation, storm buffering, filtration, storage) and also meeting societal needs through engineered solutions along the coastal and riverine edges (e.g., green or bio-walls vs. steal bulkheads). A central theme to greater long-term success in coastal management implementation is providing greater flexibility in design to accommodate future uncertainty from climatic change. Regardless of what structural approach is used in a given location there is a universal need to incorporate the best available projections regarding sea level rise and storm surge often with longer structural and planning horizons (i.e., 30-50 years). In addition, there is a universal need for state regulatory agencies to accept and issue permits to enable alternative approaches and improve current and future management flexibility in the face of climatic change along the coast and rivers.

As an alternative to the steel bulkheads that currently line the Harlem River in New York City, a collaborative partnership between The New York City Department of Parks and Recreation, the Metropolitan Waterfront Alliance, Harlem River Park Task Force, New York Department of State's Division of Coastal Resource, and community groups is in the process of replacing degraded structures with alternative shorelines that increase recreational opportunities, improve fish and wildlife habitat, and enhance public access to the river. Through a multi-disciplinary planning effort starting in 2007 by the Harlem River Design Team (i.e., architects, planners, engineers, ecologists, artists) with other stakeholders, a phased planning to implementation effort emerged in the Harlem River Park (132nd to 145th St.) called "Design the Edge" (NYC Parks and Recreations & MWA, 2010). This initiative was developed through a community engagement process whose principle objective was to replace the traditional "urban edge" of the Harlem River with an improved approach that provides both improved recreational and ecological benefits. With an estimated grant total of $14.3 million, the project is completing two phases of construction that were preceded by extensive testing of potential design ideas and elements in wave tanks that simulated flow and velocity for the project site.

The project originated from the realization that typical approaches to shoreline stabilization in heavily urbanized setting are not conducive to supporting fish and wildlife, limit access and recreational opportunities effective cutting the adjoining community off from the river, reflect and magnify wave energy creating a hazard for small vessels, prone to eventual corrosion and release of contained material, and limit the storage capacity for storm surge and increasing sea levels. In response to these drawbacks the design team identified several key remedies that epitomize a progressive approach to alternative shoreline management in the urban setting of the Mid-Atlantic sub-region. These elements included reduction in the erosion of material into the river, encourage "multi-use waterfront pathways" with access to the river (i.e., school groups, jogger, small boats), and improve both the habitat availability and ecosystem functions at the river/upland interface. In addition, the project recognized that alternative approaches need to be cost competitive with traditional bulkhead approaches. For all the alternative porous shoreline approaches examined the price per linear foot ($6,057 to $6,995) was less than a traditional steel bulkhead ($8,000 – 10,000/LF). Despite the complexity of the site due to constraints from adjoining highway infrastructure, access by supply trucks at off-peak hours, and the need to construct underwater the final bids for "porous alternatives" where significantly less than traditional steel bulkheads.

The "Deign the Edge" project provides an important example of the potential for alternative shoreline design in the Mid-Atlantic sub-region that achieve multiple objectives including increasing the ability to adapt to sea level rise in urban environments. The project provides 10 guiding principles to consider in other effort of this nature 1) "install surfaces that support estuarine life", 2) incorporate filter-feeders (i.e., shellfish) as a "living water filtration system", 3) reduce the reflectance of wave energy through terraced or sloped banks, 4) minimize flow velocities through irregular shorelines, 5) utilize native vegetation in structure, 6) incorporate porous and vegetative spaces for bioremediation, 7) use structural materials that can resistant to tidal conditions, 8) increase access for recreational boats, 9) improve ability to accommodate larger boats, and 10) create structures that enhance safe public access to the resource.

Box 5.4: Philadelphia, Pennsylvania Emergency Plans for Excessive Heat

Excessive heat events are a growing concern in the United States due to the threat to the public particularly in urban environments where mortality and "nonfatal adverse health" effects and the sensitivity of certain segments of the population (i.e., elderly, children, poor) are disproportionately at risk (EPA, 2006). In the Mid-Atlantic sub-region, older cities such as Philadelphia have suffered heat-related mortality disproportionately due to relatively high poverty levels (1 in 5 persons) coupled with old building stock and aging infrastructure (Union of Concerned Scientists, 2008). Projections by the Union of Concerned Scientist (2008) indicate that under high emission scenarios Philadelphia will experience more than 80 and 25 days over 90^{O}F and 100^{O}F by late century, respectively. This represents a significant change from recent history with less than 1 day above 100^{O}F per year from 1961 to 1990.

As part of a comprehensive emergency planning response the Philadelphia Managing Director's Office of Emergency Management (2010) launched the "Citywide Excessive Heat Plan". The Plan was developed and benefits from continued input and coordination amongst a broad stakeholder base within the City of Philadelphia. Triggered by heat-related notifications by the National Weather Service the annually updated plan provides roles and expectation for action teams (City managers, first responders, NGOs) during excessive heat events. The Plan's Operational Strategies calls for "Education and Preseason Preparedness" to maintain readiness and help reduce needs during events, "Public Notification and Warning" systems and networks to alert and provide procedures for effected populations, "Excessive Heat Response" that operationalizes the City and partners response during an event, and "Utilities" which restricts the ability of public utilities to turn off power for non-payment.

The full extent of the response strategy speaks to the breath of the effected communities ranging from declaring a heat emergency and activation of public cooling centers/swimming pools and deploying mobile public health team and outreach to homeless persons to operating a recreational sprinkler program by the Philadelphia Fire Department across the City. As part of this Plan the City has developed a web-based interactive mapping service that provides evacuation route from any address with back-up routes and the location of all emergency facilities along with a dedicated Office of Emergency Management blog. The City of Philadelphia's Excessive Heat Plan is recognized by the National Weather Service as the first of its kind in the United States and will serve as a model for other urban areas around the globe.

This Plan can also be envisioned as an important part of a larger comprehensive climate action approach for the City of Philadelphia (Chastain *et al*., 2011) and as an example for other urban areas seeking to increase resilience to climatic change. The comprehensive nature of this plan complimented by an engaged and purposeful network of organizations and departments has provided the City of Philadelphia with increased adaptive capacity to handle current and future increases in excessive heat events in a highly urban center of the Mid-Atlantic sub-region.

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5.3 Central Appalachia

Lead Author - Brent Yarnal

To the west of the Northeast's megalopolis stands an area of great natural and human contrasts known collectively as the Appalachians. In its eastern parts are rolling hills, steep, narrow ridges, and confined valleys; in its western reaches are the rugged hills and hollows of a highly dissected plateau. The rolling hills and valleys of the east have rich, thick agricultural soils; forested ridges and plateau hilltops have poor, thin soils. The combination of topography and geology leads to periodic severe flooding. The human backdrop of the Appalachians is also strikingly diverse, with agrarian, industrial, and postindustrial economies cohabiting the region (Yarnal, 2009). This section will describe first the biophysical landscape of the Appalachians and then the socioeconomic setting, highlighting those elements of both the biophysical and human landscapes important to the climatic impacts and vulnerabilities of the region.

The Appalachian Mountains are a system of mountains and plateaus that extend from the Canadian Maritimes to northern Alabama. They formed through a series of Paleozoic era continental collisions starting about 480 million years ago and ending about 260 million years ago. Following the last mountain-building episode, the region eroded quickly under the heavy rains and heat of its near-equatorial location forming a nearly flat plain by the Mesozoic era at 225 million years. Subsequent uplift, erosion, and deposition of the region throughout the Cenozoic era starting roughly 50 million years ago led to today's familiar landscape (Poag and Sevon, 1989). The resulting Appalachian Mountains can be divided roughly into three north-south sections: the northern Appalachians, which extend from Newfoundland south to the Hudson River of New York; the Central Appalachians, with the southern border at the New River in southern West Virginia; and the southern Appalachians, covering the remaining southward portion of the mountains. This report focuses on the Central Appalachians.

Moving from east to west, the north-south trending Central Appalachians are diverse geologically, possessing several physiographic provinces (**Figure 5.5**). The eastern foothills are called the Piedmont, a rolling landscape of low hills and relatively gentle swales. The Piedmont is bounded to the west by the steep, crystalline Blue Ridge, which runs the length of the mountain chain exposing few gaps from the Hudson River into the southern Appalachians. Immediately to the west, a broad linear valley — called Great Valley in the northern parts of the region and Shenandoah Valley in the south — mirrors the Blue Ridge. Immediately to the west of the Great Valley is the complex folded structure of the Ridge and Valley system, highlighted by alternating narrow ridges and valleys, each extending north and south for tens of miles. Although the ridges are primarily tough sandstone, the valleys are either shale or limestone with pockets of anthracite coal, especially in eastern Pennsylvania (Shultz, 1999).

The Allegheny Plateau (sometimes called the Appalachian Plateau) forms the westernmost part of this region in a broad northeast to southwest swath that extends from southern New York to the New River and beyond. It is really a series of interlocking uplifted and warped plateaus, each with slightly different geological and geomorphological characteristics. Although a topographic map reveals that the highest elevations are about the same height, thus identifying this area as a plateau, the heavy dissection gives the appearance of a mountainous landscape — hence, West

Virginia's nickname as "The Mountain State." Thick beds of high-sulfur bituminous coal are laced throughout the Allegheny Plateau (Shultz, 1999).

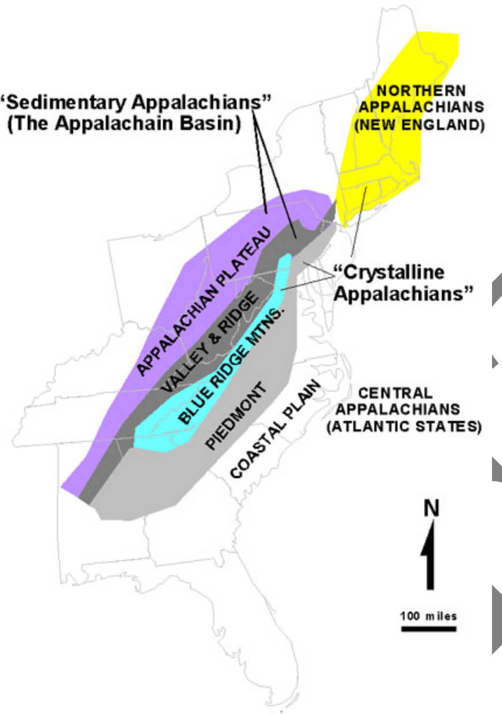


Figure 5.5. Regions of the Appalachian Mountains.
Source: http://3dparks.wr.usgs.gov/nyc/images/fig51.jpg

The Central Appalachians have a humid continental climate that varies from warm to cool, with lower elevation, southerly sites classified as warm, and higher elevation or northerly sites classified as cool. The annual precipitation of cool sites tends to be distributed somewhat evenly throughout the year with an average of roughly 50 inches. Annual precipitation of warm sites tends to have a summer maximum and slightly higher average totals. Locations immediately downwind of the Great Lakes receive significant lake-enhanced precipitation — falling primarily as snow — during winter months, but total annual precipitation is offset by much cooler summers and related decreased rainfall. Average annual temperature is approximately 50 ºF, with summer mean temperatures around 65-75 ºF and winter mean temperatures roughly 25-35 ºF. There are striking variations in weather between the ridges and valleys, however, with the ridges having lower temperatures, stronger winds, heavier precipitation, and more snowfall than the valleys. The region tends to be overcast, with more than sixty percent of all days having greater than six-tenths cloud cover, especially in winter because of the region's position downwind from the Great Lakes. The average frost-free period is about 140 days, with the lower, more southerly Piedmont have a longer growing season and northerly and high-elevation sites having a considerably shorter growing season. Severe winter weather in the form of heavy snow and ice storms is commonplace, and severe summer thunderstorms are also typical. Tornadoes and tropical systems make irregular visits to the region (Yarnal 1989; Yarnal 1995).

The hydrology of the region varies with the physiographic province. Well-integrated dendritic stream networks occupy the Piedmont and the Allegheny Plateau. In the intervening Blue Ridge, Great Valley, and Ridge and Valley, trellis stream networks are found in those areas where shale covers the valley bottoms. In valleys with limestone (karst) geology, however, few surface streams exist because networks of sinkholes and caverns channel the waters underground. Mature, graded, meandering streams with floodplains form in few places in the Central Appalachians because of the geology and physiography. The steep slopes and relatively high elevation of the Allegheny Plateau promote deep incision into the landscape; the sandstone and crystalline ridges of the Ridge and Valley and Blue Ridge foster rapid runoff to the valleys below; and the receiving areas of the limestone valleys have no streams. Only the shale valleys and Piedmont have the potential to form mature floodplains (Shultz, 1999).

Consequently, a large proportion of the Central Appalachians is prone to severe, rapid flooding, with the region being home to many of the nation's deadliest and most costly floods. Several mechanisms generate these damaging floods, including rain-on-snow events (Yarnal et al. 1997; Yarnal et al. 1997), tropical systems, and several types of severe convection (Yarnal et al., 1999). Heavy rains falling on deep snowpacks and accompanying conditions conducive to rapid snow melt and ice jamming resulted in widespread severe floods in 1936 and 1996 (Yarnal et al., 1997). Sluggish tropical systems moving over already saturated soils and high streams caused record floods in 1972 from Hurricane Agnes (Bailey et al., 1975) and again in 2011 from Tropical Storm Lee (Brown, 2011). Severe convection associated with a variety of mesoscale convective systems — including isolated convective storms, squall lines, and mesoscale convective complexes (MCCs) — have resulted in numerous flashfloods in Pennsylvania, such as the infamous Johnstown floods (Hoxit et al., 1978) and the numerous floods of summer 1996 (Yarnal et al., 1999). The convergence of these severe-flood-generating mechanisms over the Central Appalachians causes the region to rank first in the eastern United States in terms of deaths, damage, and number of floods (LaPenta et al., 1995)

Ecoregions

There are primarily three ecoregions provinces in the Central Appalachians (**Figure 5.6**; see (Bailey, 1995). The most northerly is the Laurentian Mixed Forest Province, located in southern New York and northwestern and north-central Pennsylvania. It is transitional between the boreal forest to the north and the broadleaf deciduous forests to the south. It consists of mixed stands of coniferous and deciduous species, with the former being primarily pine and the latter being mainly a mixture of sugar maple, birch, beech, and a few other species. Favorable habitats with good soils produce deciduous forest, whereas less favorable habitats with poor soils result in coniferous forest. To the south at lower elevations, with warmer conditions and more summer rainfall, is the Eastern Broadleaf Forest Province, which dominates the Piedmont and lower elevations of the Allegheny Plateau. This highly diverse forest occupies moist, well-drained sites and has two to three dozen deciduous species, including American beech, yellow poplar, several basswoods, sugar maple, red oak, and white oak. Cooler, moister sites promote the coniferous eastern hemlock. Chestnut was the dominant species in the Eastern Broadleaf Forest, but was wiped out in the early 20th century by chestnut blight. The third ecoregion province is the Central Appalachian Broadleaf-Coniferous Forest Province of the Ridge and Valley and higher elevations of the Allegheny Plateau. Either the White Oak Association or the Black Oak

Association, each with roughly a dozen species, dominates at lower elevations and warmer sites within this province. At higher elevations is the Northeastern Hardwood Forest Association, which consists of mainly deciduous birch, beech, maple, elm, red oak, and basswood with some coniferous hemlock and white pine.

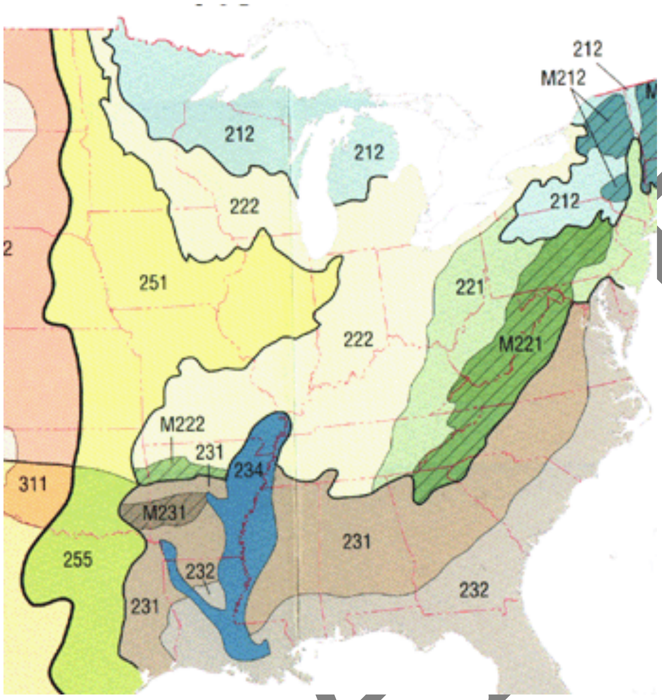


Figure 5.6. Ecoregions of the eastern United States. The three ecoregions covering the Central Appalachians are Region 212–Laurentian Mixed Forest Province, Region 221–Eastern Broadleaf Forest Province, and region M221–Central Appalachian Broadleaf-Coniferous Forest Province (Bailey, 1995). Source: http://www.museum.state.il.us/muslink/forest/htmls/intro_il.html.

Cultivated areas of the Central Appalachians are geographically intermittent because of variable soil quality depending on the soils' parent strata. The Piedmont is renowned for its thick, well-developed soils. The broad valleys of the Ridge and Valley also tend to have thick, rich soils, with the better ones found in those areas dominated by limestone and lesser ones found in shale valleys. In stark contrast, upland areas in both the Ridge and Valley and Allegheny Plateau have thin soils with low nutrient status. Narrow stream valleys in the Allegheny Plateau tend to have better soils, but little total area is available for agriculture. The moist climate and relatively moderate to cool conditions mean that irrigation is not important to regional agriculture (Miller, 1995).

Human Landscape

The human landscape of the Central Appalachians is also diverse, with three stages of development — agrarian, industrial, and post-industrial (Kates et al., 1990)— existing in the region. The evolution of this patchwork human landscape helps explain many of the vulnerabilities to climate change (Yarnal, 2009). Early agrarian settlers started filtering into the area prior to the American Revolution, with the Anabaptist Amish and Mennonite gaining a solid foothold alongside the non-Anabaptist "English" populations in the Piedmont and valleys of the Ridge and Valley. Deforestation of the Piedmont and valley bottoms resulted from this initial round of agrarian development. Industrial development started with the integrated transportation networks and mechanized resource-extraction industries that came to the area in the form of rivers, canals, and railroads that supported iron furnaces, forestry and pulp and paper operations. Railroads also supported the anthracite coalmines in the Ridge and Valley of eastern Pennsylvania followed by the bituminous coalmines in western Pennsylvania and West Virginia. Two rounds of tree cutting deforested the ridges of the Ridge and Valley and the Allegheny Plateau of Pennsylvania and New York, started first by the iron industry in the mid-19th century and completed by pulp and paper operations in the early 20th century. Coal mining stimulated massive steel operations in metropolitan Pittsburgh, which in turn spurred increased bituminous strip mining and various support industries and services throughout much of the Allegheny Plateau, further devastating the landscape and populating this area (Harrington et al., 2009). This large, entrenched industrial society contracted dramatically in the 1970s and 1980s with the export of steel manufacturing to cheaper overseas locales and, in the wake of clean-air legislation, the mining of low-sulfur coal reserves in Wyoming and other western states. Coal mining and ancillary manufacturing and service industries struggle to survive in western Pennsylvania and West Virginia today. In contrast, Pittsburgh — which lost all of its signature steelmaking — has reinvented itself as a post-industrial city dominated by high-tech, institutional, and service industries (Streitfeld, 2009).

Today, agrarian, industrial, and post-industrial societies live side by side in the Appalachians (Yarnal, 2009). Agrarian Anabaptist populations thrive in the Piedmont and valleys of central Pennsylvania, with some toeholds in the Allegheny Plateau. Population growth is so great and good land so limited that many Anabaptists are turning to off-farm employment, and significant emigration of Anabaptists to the Midwest and West is taking place (Kraybill, 2001). Alongside the Anabaptists, most "English" farm families derive a substantial proportion of their income from off-farm employment, and increasing numbers of non-Anabaptist farmers are leaving the farm altogether, selling prime farmland to housing developers. Farmland preserves are slowing down this selloff, but not before the loss of some of the region's most-productive agricultural land to urbanization (Houseal, 1989-90). Industrial elements of Appalachian society are also under siege. Countless small coal-mining towns and hamlets are remnant communities, with spectacular population losses during the past several decades because of the collapse of coal and steel. Remaining working-age people commute long distances each day for low-paying service and construction jobs in larger towns and cities. Most high school graduates leave home for larger urban settings, often outside the region (Eller, 2008).

Impacts of Climate Change

Climate change will be affecting this biophysical and socioeconomic backdrop increasingly during the 21st century. This section will summarize these climate changes and identify some impacts of concern to the natural and human systems.

No analysis of past climate or projected future climate has been conducted specifically for the Central Appalachians. A climate change impact assessment was conducted for the entire mid-Atlantic region (Fisher et al., 2000a; Fisher et al., 2000b; Polsky et al., 2000) including all of the

Central Appalachians except portions of southern New York State. Two climate change impact assessments of Pennsylvania were conducted recently (Union of Concerned Scientists, 2008; Shortle et al., 2009) thereby covering a significant proportion of the Central Appalachians, including all three ecoregion provinces discussed above. These studies assessed not only the impacts of climate change, but also 20th century historical climate change and 21st century climate change projections. The following summary of climate change and its impacts is based on these three reports, especially the more recent ones. For clarity these three reports will not be cited unless they disagree. Other sources will be cited as appropriate.

During the 20th century, Pennsylvania temperature rose more than 0.5 ºF somewhat uniformly across the state. Precipitation also increased by 5 to 20 percent depending on location, with greatest increases occurring since 1970. Average statewide precipitation grew from 38 inches to 44 inches over the century, which is a significant increase over a broad area with many reporting stations. Snowfall has changed even more markedly, with all Pennsylvania areas of the Central Appalachians observing significant decreases in average snowfall during the century, with greatest decreases occurring since the 1970s.

An average of 14 general circulation models (GCMs) reproduced these observed climate changes well, thus suggesting that an average of this group of GCMs would produce reasonable projections of 21st century Pennsylvania climate (Shortle et al., 2009). It is important to note, first, that no single model did as good a job reproducing the climate as the average of all models did and, second, the averaging process damped the modeled extremes so that they were not as great as the observed extremes. In contrast, Union of Concerned Scientists (2008) climate projections were more extreme than those of Shortle et al. probably because they only used 3 GCMs and the mathematical likelihood of greater variation was therefore greater. We use the more conservative projections of Shortle et al. here. These authors used a high-emissions and a low-emissions scenario and, when relevant, we will report both scenario's projections.

Climate change under either high- or low-emissions scenarios will be indistinguishable for the next 20 years. After that, climate change will become much more extreme under the high-emissions scenario as the century progresses. None of the 14 GCMs projected cooling under either scenario, so it is very likely that the region will warm throughout the century. The average warming is 7 ºF under the high-emission scenario and only about half that under the low-emissions scenario. As a result of this warming, the growing season will increase by 5 weeks (3 weeks) under the high- (low-) emissions scenario; the number of frost days will correspondingly decrease by 6 (4) weeks. It is also likely that precipitation will continue to increase in all seasons with the most certainty that winter precipitation will increase over the 21st century. Median annual average precipitation increase is 10 percent and 6 percent, respectively, under high- and low-emissions scenarios; winter projections are 15 and 8 percent. It is likely that precipitation climate will become more extreme, with more intense precipitation and longer dry periods — in other words, more floods and droughts. Nonetheless, there is much uncertainty about whether future tropical and extratropical storms will become more or less frequent, or more or less intense.

The impacts of these climate changes will be felt in the central Appalachian's hydrology and water resources, aquatic flora and fauna, forests, agriculture, human health, and tourism and outdoor recreation. For hydrology and water resources, overall runoff is likely to increase due to the higher winter runoff, but it could decrease in summer because the small increases in summer rainfall coupled with higher temperatures and higher evapotranspiration would draw down water tables and streams in that season. Higher evapotranspiration would mean a decrease in summer and fall soil moisture, which would translate into the likelihood of more short- and medium-term droughts. These droughts could be offset, at least in spring and perhaps early summer, by greater groundwater recharge because of reduced frozen soils and increased winter precipitation when plants are inactive and evapotranspiration is low. Although droughts could become more frequent, floods could become more frequent because of increased heavy precipitation events in all seasons. Rain-on-snow floods could decrease, however, because of the significant decrease in snow cover. Water quality is likely to decline because of increased heavy-precipitation events and increased stream temperature, which is certain to increase in most places.

These water quality decreases from increased water temperature and hydrologic variability are almost certain to have significant impacts on aquatic ecosystems and fisheries in the Central Appalachians. Coldwater communities and highly prized species, such as the Eastern Brook Trout, will decline and be replaced by warm water assemblages and especially by invasive species. Wetlands are also likely to experience changed habitat structure. Today's streams and wetlands are already degrading because of invasive species, modified hydrology, and increased nutrient loads resulting from development and agriculture; climate change will combine with these stressors to place an even greater burden on these ecosystems and their species.

Two to three centuries ago, the Central Appalachians were almost completely covered by forests. Today, the region is still dominantly forest-covered. In the intervening period and continuing into the future, assaults by multiple rounds of clear-cutting, fires, invasive plants, insects, diseases, pollution, and heavy deer browsing have produced forests unlike those virgin forests. Climate change will exacerbate many of these problems and cause many more.

The changing climate is making the Central Appalachians increasingly unsuitable for many tree species. The Laurentian Mixed Forest Province is under the greatest climatic stress, and many trees of this province — especially species of birch and aspen — are likely to be eliminated even under low-emissions scenarios (Iverson et al., 2008). Other species associated with this mixed forest are likely to decline significantly, including several maples, American beech, black cherry, white ash, American basswood, eastern hemlock, and eastern white pine. Species of the Eastern Broadleaf Forest and Central Appalachian Broadleaf-Coniferous Forest would invade the Laurentian Mixed Forest and in some areas replace this forest altogether. The two more southerly forest provinces would nonetheless experience a change in the species mixes in their present ranges. For example, common oaks in these provinces, such as northern red oak and chestnut oak, are projected to decline under high-emissions scenarios and to be replaced by southern species of oaks and hickories. The region will also become increasingly suitable for other southern species such as loblolly pines and red mulberry. It is important to note that some studies suggest that more favorable growing conditions and CO_2 fertilization will increase overall forest biomass, but most experts think increased mortality rates will offset any gains from these effects.

The net effect of climate change on central Appalachian farm revenues is difficult to estimate. Without knowledge of the impact of climate change on global production and prices, it is impossible to know whether a fall (rise) in yields would be offset by higher (lower) prices. Still, even with technological interventions, some elements of agriculture will necessarily decline or leave the region while others will increase or enter the region. Fruits and vegetables adapted to cooler conditions such as apples, American grapes, and potatoes are already declining, while warm-weather crops such as sweet corn are becoming more important. Nursery stock and seed types will need to change to landscaping products better suited to a warmer climate. Milk yields in the dairy industry will fall with increased heat stress. Production costs will change for dairy and beef herds as pasture and feed quality changes; these costs are likely to go up for dairy producers but are uncertain for the beef industry. Climate control costs will change for hog and poultry producers, going up in summer months and down in winter months; lower total costs relative to those of southern states will make the Central Appalachians attractive and will likely attract new hog and poultry producers to the region. Producers will need to tackle increasing numbers and new types of pests, weeds, and diseases. In the end, agriculture will survive and continue to be profitable in the region because the industry and individual producers constantly adjust to technological, market, climatic, and other conditions, so the challenges posed by climate change is already accounted for by the nature of the industry.

Climate change will have many impacts on human health in the Central Appalachians. On the one hand, increased summer maximum and minimum temperatures coupled with higher humidities will certainly increase heat stress and will cause more heat-related deaths, especially in the lower elevations and more southerly parts of the region. Humans adapt to heat, however, through physiological and behavioral changes such as increased adoption of air conditioning. On the other hand, higher winter temperatures will mean fewer direct deaths from cold and indirect deaths from causes such as automobile accidents on icy roads as snow cover and ice decreases in the region. Air quality will decrease and health impacts will increase, with ozone concentrations reaching unsafe levels more frequently as temperatures rise. Ozone concentrations in the Central Appalachians are already very high because of the region's geographic position downwind of the Ohio River Valley, Texas, and Michigan/Ontario, where the precursors of ozone are generated in large quantities (Comrie, 1990). Vector-borne diseases may become more prevalent with climate change because warmer, wetter conditions could improve overall conditions for the disease vectors, lengthen the active season of these vectors, and increase the amount of time people are outdoors and consequently their exposure to the vectors. West Nile virus and Lyme disease are common in lower elevation and southerly parts of the region and could spread upslope and northward as conditions favorable to their vectors improve with climate change. Projections suggest that increased temperatures coupled with more frequent intense thunderstorms will increase flashy storm runoff and the likelihood of water system contamination by infectious pathogens. Giardiasis is already a problem in the Central Appalachians and cryptosporidiosis is occasionally detected in the region.

Climate change will have mixed impacts on outdoor recreation and related tourism. Recreation based on snow and ice such as downhill skiing, cross-country skiing, and snowmobiling are already significantly affected throughout the Central Appalachians and will certainly be even more severely affected in the future. Seasons will be shortened and many winters will not support these activities whatsoever; by the end of the 21st century, it is unlikely that these industries will be viable in all but a handful of locations in the Central Appalachians. Under all climate scenarios, increased temperatures will have significant impacts on sport fisheries. Severely reduced numbers of central Appalachian streams will support trout populations; streams lost to trout will see replacement by warm-water fish. Total demand for fishing may still increase because of longer warm seasons and greater desire to be by water during very hot weather. The impact of climate change on central Appalachian hunting is unclear: the affect of ecosystem change on wildlife abundance is difficult to project, and changes in hunter behavior with warmer conditions and shorter winters are also difficult to predict. For other recreational uses of the forests, hiking and camping seasons will certainly lengthen, but the impact of forest health and composition changes on these activities and the affect of very high temperatures on midsummer hiking and camping in an area with relatively few lakes and reservoirs is uncertain. Certainly, where there is water, demand for swimming and boating will rise dramatically. Demand for other outdoor sports such as golf, tennis, and biking will also increase considerably.

Sensitivities to Climate Change

Vulnerability can be considered a function of exposure, sensitivity, and adaptive capacity. Exposure describes what the system or entity is vulnerable to, and sensitivity helps explain why the system or entity is vulnerable to that exposure. The impacts of climate change specified in section above imply the exposures to be experienced in the Central Appalachians. Among other climate changes, the region will be exposed to higher temperatures, increased total precipitation, more intense precipitation events, and increased evapotranspiration. Summers will be longer and hotter; winters will be shorter and warmer. Growing seasons will be longer; snow and ice will be much reduced in time and space. Exposure to these climate changes will have impacts on water resources, aquatic flora and fauna, forests, agriculture, human health, tourism and outdoor recreation and many more sectors not covered in this and other assessments. How significant those impacts are is determined by the sensitivities of those sectors.

This subsection discusses two examples of natural and human sensitivities to these exposures in the Central Appalachians: hydrology and water resources, and aquatic and terrestrial species in forest ecosystems. Adaptive capacity is then covered in the following subsection on potential adaptation strategies.

Hydrologic sensitivities are inherent in the biophysical system, but water resource sensitivities are the result of variations in the human system. Hydrologic health is sensitive to the nature of the bedrock, aquifer, soil moisture-holding capabilities, and other biophysical factors in combination with weather and climate, thus determining natural water quality and quantity. Water resource health is sensitive to the status of such human factors as infrastructure, user status, management, and government regulation. In the Central Appalachians and other humid regions of the United States, hydrologic health is usually a lesser issue, and given the projected climate changes for the region, it should continue to be secondary to water resource health in the future (Neff et al. 2000). For instance, in a series of related studies, (O'Connor et al., 1999; O'Connor et al. 2005; Yarnal et al., 2006; Dow et al., 2007; Yarnal 2009) demonstrated that in the community water systems of the Central Appalachians, water source — that is, groundwater or surface water — tends to be an important hydrologic determinant of sensitivity to weather, climate variation, and climate change. Simply, all other things being equal, groundwater sources are less sensitive because they are insulated from the elements. More significant issues revolve around human factors that modify the importance of source and cause water systems to be sensitive. The condition and upkeep of infrastructure (e.g., the age, type, and condition of well casings, pumps, pipes, and filters) can turn a plentiful, safe groundwater supply into an unreliable, unsafe resource. User status (e.g., the wealth, education, and politics of the population) can result in insufficient funding for the system, thus causing it to be unable or unwilling to replace decaying infrastructure. Good management is essential, and systems with a poor management structure or inexperienced or untrained managers are more sensitive to weather, climate variation, and climate change. Government regulations that protect water quality and quantity and subsequent enforcement of regulations can help turn a sensitive system into one that is much less vulnerable. In the end, except for the most major weather and climate excursions, water managers find that dealing with the hydrologic sensitivity of a water system is easier than negotiating the system's human sensitivities.

Assessing the sensitivity to climate change of terrestrial and aquatic species in forest ecosystems entails different emphases. (Byers and Norris, 2011) assessed the vulnerability of West Virginia's flora and fauna to climate change. They based exposure to climate stress on projected temperature rise and potential net drying of habitats during the next 50 years. They derived sensitivity from 15 intrinsic species-specific factors, another four factors accounting for species-specific responses to climate change, and six additional geographic factors and human responses to climate change. They found that mobility was a major factor in vulnerability: amphibians are at highest risk from exposure to climate change, followed by fish, mollusks, and rare plants. In contrast, birds and mammals are less vulnerable, as are common and widespread plants. However, cave invertebrates, which are practically immobile, have the strongest resistance to climate change impacts because they are essentially insulated from the elements. Thus, their assessment suggests that, although temperature and moisture change are very important to climate change vulnerability, of more importance to most species are natural and human barriers to species movement. Important natural barriers include low-elevation barriers for mountaintop species (which cannot move upward to avoid warming) and watershed barriers for aquatic species (which cannot move upward over watershed divides to reach cooler watersheds). Anthropogenic barriers of importance in their assessment include dams, roads, and powerlines. In sum, this study shows that key aspects of flora and fauna sensitivity to climate change in the forests of Central Appalachia are the relationships among the intrinsic traits of the species, the expression of climate change, and the geography of the area (i.e., natural and anthropogenic barriers to migration). The results of this study can be extended throughout all three forested ecoregions of the Central Appalachians.

These examples of sensitivity to climate change in the Central Appalachians make two important points. First, the sensitivities of the system or entity under study — and therefore its vulnerabilities — depend on a combination of inherent natural sensitivities to climate change and sensitivities engendered by the human socioeconomic system. In the case of community water systems, in most instances managers can handle all but the most catastrophic weather and climate dislocations, but have more difficulty controlling curves thrown by customers, local government, Federal regulation, and other human elements. In essence, the water systems are more sensitive to socioeconomic stresses than climatic stresses. In the case of West Virginia's flora and fauna, the species inherent limitations (i.e., their mobility) in combination with natural and human barriers (i.e., physical and human geography) suggest that the fundamental sensitivities are natural. Second, because a wide spectrum of sensitivities exists, ranging from primarily natural to primarily socioeconomic with unique combinations in between, each system requires study to understand where it lies on this spectrum. Future assessments of the Central Appalachians must address the particular sensitivities of forests, agriculture, human health, outdoor recreation, and a host of other regional sectors and activities potentially affected by climate variation and change, if we want to understand why these sectors and activities are vulnerable to climate change. Little research has systematically tackled this task.

Adaptive Capacity and Adaptation

Understanding what climate exposures are creating vulnerability and why a system or entity is sensitive to those exposures makes it possible to assess adaptive capacity. In other words, how can the strategic application of risk-management techniques — such as private insurance or government policy — build the capacity to decrease exposure or reduce sensitivity, and to diminish overall vulnerability, lessen the impacts of climate change, and consequently adapt to climate change? This subsection explores this question.

The two cases used in the previous subsection present good examples of the potential for building adaptive capacity. The instance of community water system management suggests many ways to decrease exposure and especially to reduce sensitivity (Yarnal, 2009). Decreasing exposure of a surface water system to weather extremes and climate change could be as straightforward as switching from the surface source to a groundwater source. In places where an aquifer with sufficient yield or quality is absent, it could be possible to develop agreements with a nearby groundwater system to share the resource in times of weather or climate stress. However, more vulnerability reduction measures rely on reducing sensitivity. In a system where aging infrastructure is causing significant water loss and essentially reproducing the symptoms of drought, upgrading that infrastructure can decrease leaks in the system and enable more efficient water use. In areas where ideologies oppose taxation, overcoming political disputes could make it politically feasible to replace infrastructure; alternatively, educating the public about the necessity of upgrading the system and saving money in the short term could pave the way to new infrastructure. Hiring well-trained water managers or retaining experienced managers help overcome many system deficiencies. Good local water regulation or enforcement of Federal and state water regulations can ensure a safe and sometimes plentiful water supply. The capacity of a water system to decrease sensitivity by improving infrastructure, or political, social, or economic conditions affecting water-related decision-making, or management structures and personnel, or government water regulation and enforcement therefore determines its ability to adapt to weather and climate. If it has this capacity, it is resilient and will be able to adapt; if it does not, it lacks resilience and will not be able to adapt. Thus, much of the adaptive capacity of a community water system in the Central Appalachians depends on such variables as local politics and political ideologies, government and management structure, economic status of the community, and educational opportunities and communication channels.

The vulnerability assessment of West Virginia's terrestrial and aquatic species also presents an opportunity to examine adaptive capacity. Byers and Norris (2011, pp. 23-24) suggest the following ten ways of reducing exposure or sensitivity:

- Increase habitat connectivity
- Manage for ecosystem function and habitat integrity
- Protect natural heritage resources and refuges
- Aim for representation, resiliency, and redundancy in these resources and refuges
- Protect water quality and streamflow
- Consider innovative and unconventional risk reduction strategies and management options
- Reduce existing natural and anthropogenic ecosystem stressors
- Monitor and adaptively manage wildlife and habitats
- Forge new interagency and public-private partnerships
- Mitigate the causes of climate change

In this case, building adaptive capacity focuses on smart management of natural systems more than management of human systems. Still, building adaptive capacity in each of these cases necessarily involves human decision-making and capacities of the system to make the right decisions.

These examples suggest that traditional impact assessments of climate change are good places to start investigating potential harms, but are insufficient for managing climate change. Impact assessments not only tend to focus on exposures, but also are inclined to confound exposures, sensitivities, and adaptive capacities. Understanding the risks and risk-reductions strategies needed for developing adaptation strategies therefore requires formal vulnerability assessment in which exposures, sensitivities, and adaptive capacities and their complex relationships are explicitly articulated. Doing so gives a clearer idea of exactly what the climate exposure is, why the entity or system is sensitive is to that exposure, and how risk-management interventions can reduce exposures or sensitivity and therefore help facilitate adaptation to climate change.

To now, climate change research in the Central Appalachians has focused on climate impact assessment (i.e., Fisher et al., 2000a, 2000b; Union of Concerned Scientists, 2008; Shortle et al., 2009), and coverage of the entire region is incomplete with little attention being paid to climate impacts in West Virginia. Moreover, other than the two studies presented here, little systematic climate change vulnerability assessment has taken place in the Central Appalachians. To take the region to the point where firm recommendations for climate change adaptation are possible, it will be necessary for vulnerability assessment of important sectors and locales to take place.

Box 5.5: West Virginia University Listening Session

Author: Kaitlin Butler

Intro and Rationale

On February 16, 2012, contributors to the Northeast Technical Input Report held the first of several listening sessions, in Morgantown, West Virginia. The rationale behind these sessions is to initiate a proactive, participatory process of information gathering, which puts an emphasis on collaboration, learning, and the promotion of information flow amongst a variety of groups. These listening sessions provide a forum for capturing resident voices (e.g. experts, decision makers, community organizations, etc.) about climate and extreme weather related issues at the local and regional scale. We envision several potential benefits from this and future listening sessions, particularly in areas where there is a dearth of systematic climate impacts and vulnerability assessment research, such as Central Appalachia, and specifically West Virginia. The objectives of these listening sessions are: (1) To solicit suggestions regarding key risks, impacts, vulnerabilities, adaptations, and data/information gaps from local sources; (2) To establish and facilitate a dialogue of information sharing with other groups in the Northeast; and (3) To begin an inclusive, iterative process that could continue after the submission of the Northeast Region National Climate Assessment Report. The hope is that these listening sessions will provide an environment for the co-production of knowledge and, perhaps more importantly, the co-identification of information gaps and areas for collaboration. If participation is supported and sustained, there is potential for more robust learning for all groups involved.

Format

The listening sessions are designed and conducted as a facilitated discussion to engage participants in an open dialogue. To set the tone of the session, an overview of what is currently understood about regional climate impacts is provided, followed by an open dialogue guided by 22 +/- pre-drafted questions. The 22 questions are organized were organized into four themes: (1) Climate and extreme weather risks and impacts, (2) Vulnerability, (3) Preparedness, and (4) Data and Information gaps.

Proceedings

The first listening session, reported on here, focused on West Virginia and was held at the University of West Virginia in Morgantown, WV. Eleven people participated in the session, which was guided by Dr. Brent Yarnal, Professor of Geography, Penn State, and Dr. Radley Horton, Associate Research Scientist, Columbia University. An overview of past National Climate Assessments was provided, followed by specific information on the 2013 National Climate Assessment, including guidance and requirements, followed by an overview of the Northeast Technical Input Report. Dr. Horton then presented an overview of the Northeast climatology and outlook under A2 and B1 IPCC scenarios for temperature and precipitation change, followed by an example of remote sensing products and decision support tools from NASA that may be useful in Central Appalachia. The remainder of the listening session was lead by Dr. Yarnal and devoted to participant comments on the following discussion topics: most important extreme weather risks, most important climate variability risks, observed impacts of extreme weather, observed impacts of climate variability, impact change over time, most exposed economic sectors and services, regions or communities, and groups, ability of sector or service, regions or communities, and groups to prevent loss or recover, examples of preparedness actions, barriers to planning or implementation, current data/information use, current source of data/information, collaboration with climate information sources, and data/information gaps (including needs, potential collaborations, and barriers to collaboration).

Discussion Overview

There were several common themes that emerged during the session, nearly all of which echoes the observed and expected impacts described in this chapter. The participants identified 1) hydrology and water resources, and 2) aquatic and terrestrial species as being critical impacts. The group discussed flood impacts on limited and aging infrastructure, farming, sewage and water treatment, and residential areas. Participants noted that the flood risk is due to both topography and anthropogenic contributions such as land use and the built environment. It was noted that multiple factors magnify vulnerability in the region. For example, it was noted that the rural poor are also those living in flood plains or near river bottoms, and usually in inadequate housing such as trailers or mobile homes. With regards to aquatic and terrestrial species, the discussion centered mostly on evapotranspiration impacts on existing wetlands, seasonal shifts in first and last frost, and species domain shifts. It was noted that West Virginia is home to many rare species associated with unique habitats--such as regional ice meadows - which are at risk due to warmer temperatures and invasive species. There are also potential opportunities. One participant noted that West Virginia has several relatively undisturbed corridors, and therefore room for species to move and adapt, which could serve as a future refuge for a range of species.

The participants raised several topics that have not been captured in existing literature. For example, one potentially vulnerable group mentioned was the “Ginsangers”, people who collect and sell wild Ginseng. A participant pointed out that it is a popular practice in the area, and potentially vulnerable to impacts of climate variability and change. A far larger population may be vulnerable through reliance on subsistence farming, and widespread hunting. Lastly, the complex relationship with the coal mining industry was discussed, with one participant pointing out that policy restrictions on the coal mining industry would have damaging economic impacts on the area. The most salient need echoed by nearly all of the participants was for straightforward and explicit education material demonstrating potential regionally-specific impacts.

In summary, the West Virginia listening session provided an opportunity for experts in the area to participate in the National Climate Assessment process and unite around a common goal of increasing involvement and exposure to climate information. The input from the participants reveals a rich resource of opportunity for further collaboration and knowledge production.

Box 5.6: Marcellus Shale: Impacts and Intersections with Climate Change

Case Study Authors: Eleanor Andrews and Arielle Hesse

Introduction

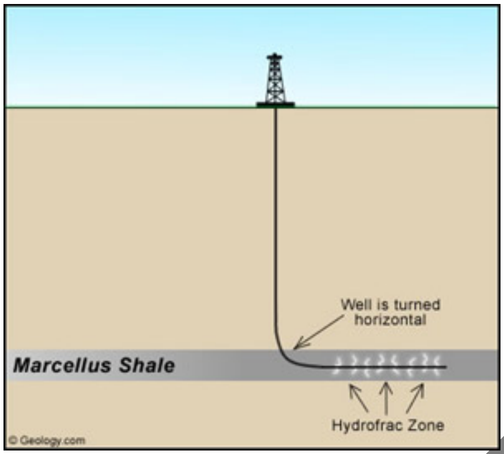
Shale gas development across the United States has blossomed in the Appalachian foothills with the extraction of natural gas from the Marcellus Shale. The extent of the drilling and the rapidity of its onset have kindled many debates, but few more important than its intersection with climate change (See for example, Howarth et al. 2011a). Natural gas is characterized as a “bridge fuel” to cleaner, more renewable sources of energy; it emits approximately 30% less carbon dioxide (CO_2) than fuel oil and half the CO_2 of coal, with fewer byproducts of combustion (DOE, 2009).

Because of this end-use advantage, natural gas can be expected to expand into the power and transportation sectors in the coming decades (Deutch, 2011). However, the cumulative social and environmental impacts of the production and end use of shale gas are unknown, and will be far from uniform across the regions of development. Indeed, the consequences of development for local social and ecological vulnerability will depend on diverse practices in varied contexts. This discussion outlines some potential intersections of shale gas with climate change and human and environmental health.

Box Figure 5.1 Geographical extaent of the Marcellus Shale (American Association of Petroleum Geologists). Source: http://oilshalegas.com/marcellusshale.html.

Background

The Marcellus Shale formation lies 4000-8500 feet below New York, Ohio, Pennsylvania, and West Virginia, with limited reach into neighboring states (**Box Figure 5.1**). Nearly all of the approximately 5,000 wells drilled since 2003 are in Pennsylvania (PA DEP, 2012). Estimates of recoverable resources (methane gas) range from 84 to 141 trillion cubic feet, and another 3.4 billion barrels of natural gas liquids, including ethane, butane, and propane (USGS, 2011; EIA, 2012). Projections of the long-term impacts of Marcellus development vary, but its contribution will be felt over many decades. Shale gas exploration has been driven by rapidly rising natural gas prices and technological innovations, namely high-volume, slick-water hydraulic fracturing and horizontal drilling (**Box Figure 5.2**) (DOE, 2009).



Box Figure 5.2 Horizontal drilling (Geology.com). Source: http://www.dec.ny.gov/energy/46288.html.

Hydraulic fracturing (often called "fracking") is a process whereby water, combined with sand and a small amount of chemical additives, is injected underground at high pressures to force open fissures in the shale, releasing gas (DOE, 2009).

Environmental impacts of production

The overall environmental impact of Marcellus Shale development is hotly contested. The impacts to land, water, and air examined here are those that intersect most visibly with the local effects of climate change. First, shale gas production and its associated infrastructure (including roads, well pads, pipelines, and water treatment facilities) require extensive forest and farmland removal and contribute to habitat fragmentation. This land use may compound the impacts of climate change by limiting local agricultural activities, stressing animal populations, and cutting off migration corridors.

Second, both water quantity and quality may be at risk. Hydraulic fracturing requires between two to nine million gallons of water per well stimulation, which is only a small percentage of daily consumptive use in the Marcellus region (Soeder and Kappel, 2009; Abdalla and Drohan, 2009). Links between water quality and quantity are also increasingly important. Discrete instances of spills and insufficient treatment of produced water have contaminated surface water; indeed, the extraction of heavy metals, radioactive materials, salts, and other hydrocarbons from the shale poses a challenge for disposal (Volz et al., 2011; Howarth et al., 2011b). Broader debates over whether there are inherent risks of hydraulic fracturing to groundwater are inconclusive (e.g., through methane contamination of nearby water wells; Osborn et al., 2011; Davies, 2011). Under climate change scenarios of high precipitation, any contaminants may be diluted, whereas in climate change-enhanced droughts, they will be concentrated.

Finally, the emissions related to the production and transportation of natural gas are significant. Although some studies suggest that production practices may offset the reduction in emissions from using natural gas in lieu of other fossil fuels, significant disagreement persists (Howarth et al., 2011b). Given the heterogeneity of industry practices, individual sites emit different amounts of greenhouse gases, volatile organic compounds, and hazardous air pollutants. In particular, methane's potency as a greenhouse gas amplifies concerns over gas leaks from wellheads and pipelines (Jiang et al., 2011). Evolving regulations and new industrial technologies should be able to reduce environmental disruptions such as habitat fragmentation, water use, and emissions, all of which exacerbate environmental changes when coupled with broader climatic shifts.

Socioeconomic dimensions of production

Marcellus development has transformed the areas with the most drilling activity. Many communities are divided over how to capture the benefits and whether they make up for the costs of development. Projected direct, indirect, and induced benefits are staggering — an influx of billions of dollars from leasing and royalty payments, hundreds of thousands of jobs, infrastructure renewal, tax revenues, and a general revitalization of aging communities (Considine et al., 2009; 2011). The most optimistic predictions, however, have not been borne out, and economic data continue to suffer from a lack of data and disagreement over appropriate economic indices (Alter et al., 2010; Kelsey et al., 2011; Christopherson, 2011; Brundage et al., 2011). Overall, increased assets are associated with greater resilience to environmental stressors, but the distribution of those assets is far from uniform, particularly in boomtown economies. Long-term economic prospects are also unknown, given the non-renewable nature of the gas. Indeed, questions about the overall economic impact and its implications for the vulnerability of people in areas of production remain unanswered.

Conclusions

Natural gas can slow climate change when it replaces the combustion of other fossil fuels. However, projections of greenhouse gas sources at varying timescales differ in regards to natural gas's role in the future, and cannot anticipate new technologies for production or the expansion of natural gas in the national energy portfolio. Unanswered questions include: when the risks of drilling and hydraulic fracturing are minimized, do the expected impacts of industrial development still pose unacceptable trade-offs? Is the economic boon enough to offset increased vulnerability of local populations? Might shale gas, as an inexpensive, domestic energy source, hamper the progress of new clean energy technologies (Jacoby et al., 2012)? It is clear that shale gas development will have uneven impacts on vulnerable groups and areas throughout the region. Thus, as exploration for new and promising energy sources continues, economic drivers fluctuate, technologies evolve, and government establishes new regulations, more biophysical, socioeconomic, and policy research is needed to understand the costs and benefits of ongoing energy development.

Box 5.7: The Nature Conservancy's Central Appalachian Whole System Program
Case Study Author: Thomas Minney

Whole system conservation

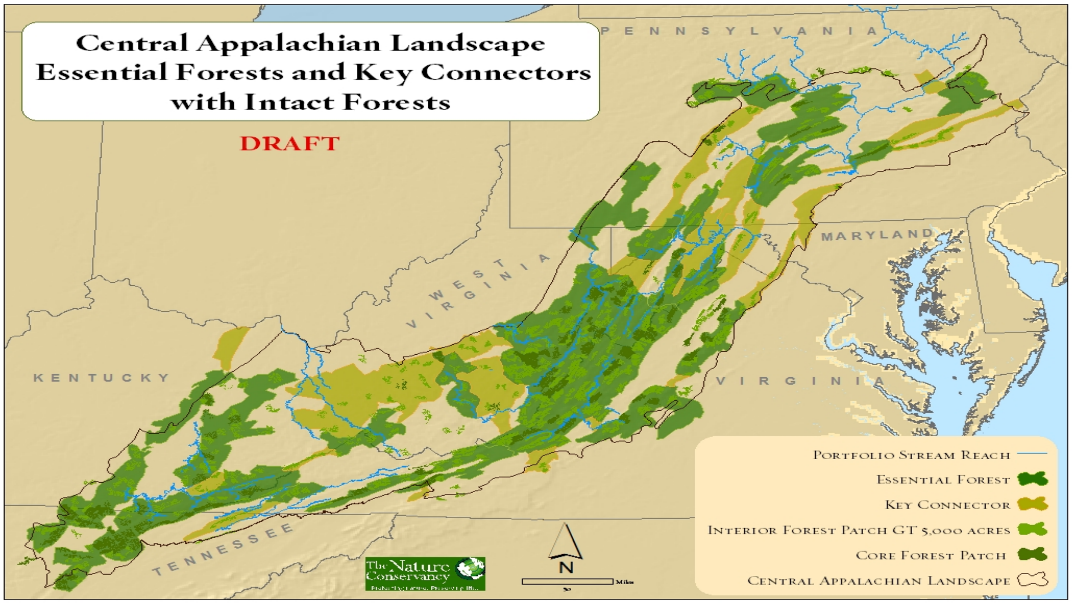
For nearly 60 years, The Nature Conservancy has successfully worked to protect important places harboring rich species and habitats. Despite its many notable accomplishments, the conservation challenges posed by climate change suggest that the Conservancy will need to modify its project-by-project and site-based focus and adopt a whole system approach to conserve nature and its benefits in the future. Addressing these challenges will be difficult. Although climate observations and models are beginning to show the probable scope, scale, and trend of change, exactly how particular ecological systems and ecological functions are changing and at what rate they are changing remain unclear, thus creating uncertainty and making management decisions difficult. Compounding this problem, organizational and political structures focus actions within state boundaries and are thus poorly suited to developing appropriate plans, strategies, and actions to deal with threats that are playing out across larger regions. In sum, scientific uncertainty combined with traditional boundaries and customary spheres of influence mean that The Conservancy must develop a new approach to conservation.

Through its whole system approach (Ward et al., 2011), The Nature Conservancy has begun to develop the organizational structure and partnerships needed for regional conservation efforts, such as the Central Appalachians Whole System Program. The increasing changes wrought by climate change and the expanding footprint of traditional and renewable energy development helped catalyze the Central Appalachian effort by impelling the Conservancy's chapters in Pennsylvania, West Virginia, Maryland, Virginia, Kentucky, and Tennessee to strategize about how they could address regional-scale challenges together and build partnerships with agencies, industries, and other stakeholders across state borders. The design of the Central Appalachians Program area aims to identify the ecological drivers that create the high levels of biodiversity in the Central Appalachians by capturing similar ecological systems and geophysical features. Importantly, decisions on project boundaries go beyond ecological and geophysical considerations to account for the footprints and ownership of partner projects.

The Program identifies both place-based and project-based priorities for the Central Appalachians, yet it develops work plans that coordinate and integrate The Conservancy's regional and global conservation strategies and actions. The Program ensures a mechanism for quickly identifying threats, making decisions, and communicating strategies and actions across the Program area. It articulates common policy goals and approaches, develops cross-boundary partnerships with public agencies and private industries, and monitors progress towards project goals.

Building a Conservation Network for Climate Change

Uncertainty about how species and habitats will respond to climate change and how managers will deal with the complex, interactive responses of the large suite of species and habitats is leading to paralysis in conservation decision-making and action. The Central Appalachians Whole System Program is looking to overcome this paralysis by focusing on the factors that underpin the richness of biodiversity and the long-term persistence of species and habitats across whole systems. The concept of "Saving the Stage," which seeks to map key geophysical settings and evaluate them for landscape characteristics that buffer against harmful climate impacts, makes it possible to identify the most resilient places in the landscape (Anderson and Ferree, 2010; Beier and Brost, 2010). Through this concept, the Program is providing a vision for the long-term conservation success of the Conservancy and partners by identifying a resilient and connected network around which managers can assess threats and impacts and provide for investment prioritization — even in the face of climate change uncertainty.



Box Figure 5.3. Essential forests and key connectors that help buffer ecosystem impacts of climate change (original figure by The Nature Conservancy).

The Nature Conservancy's Eastern Division Science office has mapped geophysical diversity and underlying factors across the eastern United States and used those mapped factors to develop a regional scale map that helps to identify a network of connected and resilient sites (Anderson et al., 2012). If conserved, these sites would maintain the full spectrum of natural environments that can safeguard lasting species and habitats. The Central Appalachians Whole System Program has used this information to design an Essential Forests and Key Connectors Network map (**Box Figure 5.3**) to shape and drive conservation strategy development and investment within the Central Appalachians. The Program is using this new map to help build partnerships with the U.S. Forest Service, U.S. Fish and Wildlife Service, Appalachian Landscape Conservation Cooperative, and Appalachian Mountain Joint Venture, as well as state governments, industries, and landowners.

Conclusions

The challenges to conservation presented by climate change are playing out at scales that require society to think beyond current organizational structures and to look to collaborative efforts across human borders and boundaries. Though it will remain, uncertainty about climate change and its impacts does not need to be an impediment to taking actions. By focusing on the persistent drivers of diversity and ecological function, The Nature Conservancy has designed a resilient, connected, and adaptive conservation network that can be used to develop conservation strategies and conservation actions to protect diversity and ecological function under current and future climates.

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Appendix 5.A. Previous climate assessment in New England

First U.S. National Climate Assessment (NCA) 2000: Northeast region[49]

The purpose of the NCA was to synthesize, evaluate, and report on what was known at the time about the potential consequences of climate variability and change for the US in the 21st century. It sought to identify key climatic vulnerabilities of particular regions and sectors, in the context of other changes in the nation's environment, resources, and economy. Significant variability in weather and extreme events, particularly floods, droughts, heatwaves, and severe storms, have characterized the history of the Northeast US. But the incidence of these events may be increasing. For example, seven major tropical storms crossed the mid-Atlantic region between 1986 and 2000 and six of last 20 years prior to 2000 were characterized by significant drought. It is possible that climate change will result in a decrease in the frequency of some types of weather extremes, while increasing others. The warming projected by climate models over the next several decades suggests possible increases in rain events over frozen ground or rapid snow melting events that can increase flooding.

Key findings of the NCA 2000: Temperature increases of as much as 4°F (2ºC) over the last 100 years have occurred along the coastal margins of the Northeast from the Chesapeake Bay through Maine. Precipitation has generally increased, with trends greater than 20% over the last 100 years occurring in much of the region. Precipitation extremes appear to be increasing while the amount of land area experiencing drought appears to be decreasing. For the Northeast as a whole, the period between the first and last dates with snow on the ground has decreased by 7 days over the last 50 years.

Future projections from the NCA 2000: Future warming was projected to be lower in the Northeast than in many other regions of the US. Winter minimum temperatures were projected to increase from 4-5°F (2-3°C) to as much as 9°F (5°C) by 2100, with the largest increases in coastal regions. Maximum temperatures are likely to increase but at a lower rate than minimum temperatures, with the largest changes in winter. Model projections of future changes in precipitation varied from roughly 25% increases to little change or small regional decreases by 2100. However, the precipitation variability in the coastal Northeast was projected to increase. Models projections for changes in the frequency and intensity of winter storms were inconclusive.

New England Regional Assessment of Potential Climate Variability and Change (NERA), 2001[50]*.*

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[49] http://www.globalchange.gov/publications/reports/scientific-assessments/first-national-assessment/470

[50] http://www.globalchange.gov/images/AssessmentReports/NERA/rockbookexec.pdf

Figure 5.A.1. average temperature changes between 1895 and 1999 (Source: NERA, 2001).

The New England Region Assessment (NERA) was initiated in September 1997, with the *New England Climate Change Impacts* Workshop, held at the University of New Hampshire (UNH). Additional Sector-specific Workshops were held in 1999. The New England Region includes the six New England states (CT, MA, ME, NH, RI, and VT) and upstate New York. The NERA effort focused on the analysis of existing results rather than initiating new studies.

Key findings of the NERA 2001: The following key findings became clearly evident during the NERA:

The Regional Climate Has Warmed over the Past Century. NERA participants found that the regional weighted average temperature across New England and New York has increased by 0.74° F between 1895 and 1999, however warming was not uniformly experienced across the region, as shown in see **Figure 5.A.1.** Similar to NCA 2000 results, warming in winter months was found to be greater than warming in summer. Regional precipitation increased a modest 4% over the same time period, but as with temperature, changes were not uniform across the region.

Human Activities are Affecting Climate. NERA attributed much of the global warming experienced in the last half of the 20th century to human factors including the build-up of greenhouse gases in the atmosphere; this attribution was consistent with a link between accumulating greenhouse and climate change.

Future projections of NERA 2001: Consistent with the NCA 2000 assessment, the following projections for future impacts of climate change in New England and New York follow.

Box 5.A.1: 1998 Ice Storm Damage

In January of 1998, a series of devastating ice storms hit northern New York and New England, along with portions of eastern Canada, causing extensive damage to forests, energy and transportation infrastructure, as well as impacting human health, and in general, disrupting life in the region in a number of significant ways. While it is not uncommon for the region to suffer from such ice storm events, the extensive area of impact (37 counties were declared Federal disaster areas) was very unusual, and the storm has been referred to as at least a 100-year event.

Climate Models Project Significant Warming Over the 21st Century. The Hadley and Canadian climate models projected 6 to 10°F warming in annual minimum temperatures and 10 to 30% increases in precipitation, punctuated by periodic long-term droughts by 2090. These temperature increases would be greater than any climate variation experienced by the region in the past 10,000 years and would result in a profoundly different climate in the New England Region that is currently experienced. For instance, if Boston's average temperature increases by 6°F, it will have the same average temperature as Richmond Virginia. If it increases by 10°F, it will be like Atlanta GA.

Box 5.A.2 Lyme Disease.

Regional Air Quality May Worsen. Hot, dry summer months accelerate the conversion of automobile exhaust (NOX) and volatile organic compounds into ground-level ozone. The same conditions cause power plant emissions (SOX) to form sulfate haze. Both SOX and NOX combine with atmospheric water vapor to produce acid clouds and acid rain. Hence warmer summer months in the future will likely lead to degraded regional air quality and acid rain problems. Degraded air quality was the most frequently identified regional concern.

The spread of Lyme disease is dependent on deer tick population dynamics, which is in turn dependent on the severity of wintertime minimum temperatures, landuse changes, the population dynamics of deer and whitefooted mice, as well as the production of acorn crops across the region. The highest number of cases reported in the United States for Lyme disease in humans centers on the New England region, where the highest number of cases reported for 1998 were in New York and Connecticut. Massachusetts is ranked fifth in the number of cases reported in 1998.

Projected Warming Trends Would Profoundly Change the Sectors. Human health will be impacted by air quality concerns and the expansion of vector-borne disease such as Lyme and West Nile Virus. Forests were already under stress, but were considered to be most adaptable. Increased frequency of droughts and/or flooding would have profound impacts on regional water quality and warming coastal waters will experience species shifts and toxic algal blooms. Sea-level rise will become a significant problem for low-lying coastal regions. An increase in winter temperatures will extend the range of infection disease vectors such as mosquitoes and ticks as well as invasive plants and pests (such as the Wooly Adelgid, which is destroying native Hemlocks).

The Northeast Climate Impacts Assessment (NECIA), 2007[51]

The NECIA was a collaborative effort between the Union of Concerned Scientists and a team of independent experts to develop and communicate a new assessment of climate change and associated impacts on key climate-sensitive sectors in the northeastern United States, which included New England states plus New York, Pennsylvania, and New Jersey.

Key findings of NECIA 2007: Since 1970, average temperatures in the Northeast US have been increasing at a rate of nearly 0.5 °F per decade. Winter temperatures have risen at a faster rate of 1.3°F per decade over the same time. This warming was correlated with other climate-related changes across the region, including more frequent daily maximum temperatures above 90°F, longer growing seasons, a higher proportion of winter precipitation falling as rain, reduced snowpack and increased snow density, earlier breakup of winter ice on lakes and rivers and earlier spring snowmelt resulting in earlier peak flows.

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[51] Union of Concerned Sciences Northeast Climate Impact Assessment (http://www.climatechoices.org/assets/documents/climatechoices/confronting-climate-change-in-the-u-s-northeast.pdf)

Figure 5.A.2. Average annual temperature change projections relative to 1961-1990 average temperature for two emissions scenarios (Source: NECIA, 2007).

Future Projections of NECIA 2007: Because of the inherent uncertainties in assessing the impacts of future climates, NECIA chose a “lower-emissions” (IPCC SRES B1) scenario and a “higher-emissions” (IPCC SRES A1Fi) scenario to compare potential impacts on the region (see figure 3). Using these two scenarios, climate model projections suggest that over the next several decades, temperatures across the Northeast will rise 2.5°F to 4°F in winter and 1.5°F to 3.5°F in summer regardless of the emissions scenario. However, after mid-21st century, temperature change projections diverge substantially (**Figure 5.A.2**), resulting in starkly different climate futures. By late 21st century, under the higher-emissions scenario, winters in the Northeast could warm by 8°F to 12°F and summers by 6°F to 14°F above historic level; the length of the winter snow season could be cut in half across northern New York, Vermont, New Hampshire, and Maine, and reduced to a week or two in southern parts of the region; cities across the Northeast, which today experience few days above 100°F each summer, could average 20 such days per summer; cities such as Hartford and Philadelphia could average nearly 30 days above 100°F; short-term (one- to three-month) droughts could occur as frequently as once each summer from the Catskills northward; hot summer conditions could arrive three weeks earlier and last three weeks longer; and extreme coastal storms in some coastal cities could occur a few times per decade rather than once per century. NECIA investigations found that the magnitude of change was about half under the lower emissions scenario.—typically, about half the change expected under the higher-emissions scenario.

6. Climate Change Decision Support Tools and Resources

Coordinating Lead Authors - Robi Schlaff and Ellen Mecray

Climate decision support includes a continuum of activities from exploratory scientific, legal, and planning efforts to place-based or problem-focused research and assessment to the development of specialized or tailored information tools and services. This chapter highlights the essential ingredients needed for localized action to plan and implement adaptation strategies for a changing climate. The chapter sections include a discussion on terminology, specific examples of climate decision support from the Northeastern US, indicators and monitoring, legal and insurance sectoral requirements, and a section on real-time evaluation of decision-support techniques for optimizing resources for the desired adaptive management outcome.

6.1 Decision Support and Best Practices

Lead Authors - Robi Schlaff, Ellen Mecray, and Adam Parris

Climate decision support as a separate field of research and practice is still an emerging concept in the United States and the Northeast specifically (Moser 2009, NRC 2009, NRC 2010a, NRC 2010b). However, decision support in the context of risk and hazard management in other sectors sensitive to climate is better established. Water managers and farmers, for example, consistently factor weather and climate into their decision-making, and many examples of decision support exist within these sectors. The concept of decision support has often been thought of as data, tools or information. More recently, a broader definition of climate decision support has emerged from a synthesis of "lessons learned" or best practices for developing knowledge "readily usable by policymakers attempting to formulate effective strategies for preventing, mitigating, and adapting to the effects of global change" (U.S. Congress 1990). "Climate-related decision support involves organized efforts to produce, disseminate, and encourage the use of information that can improve climate-related decisions." (NRC 2009).

Implicit in this broader definition is the concept, illustrated in this chapter, that climate decision support includes a range or continuum of activities from exploratory scientific, legal, and planning research to place-based or problem-focused assessment to the development of specialized or tailored information tools and services. This broader definition arose from an in-depth analysis of federally-funded programs supporting climate decision support at the local, state, and regional level including, among others, the Global Change Research Program of the Environmental Protection Agency (EPA) (in particular, its ongoing Great Lakes Regional Assessment); the Regional Integrated Sciences and Assessments (RISA) Program and Science Applications and Research Program (SARP) at the National Oceanic and Atmospheric Administration (NOAA); and the Forest and Agricultural Extension Services at the U.S. Department of Agriculture (USDA) (NRC 2006, Pulwarty et al 2009). The definition of climate decision support is critical because the few examples of evaluation of climate decision support, and the many examples from other fields, illustrate the importance of comparing and contrasting the products and outcomes of a particular effort against the goals and objectives.

For almost a decade, climate decision support has revolved around producing knowledge and information that decision makers view as coming from a credible source and/or legitimate process, salient (or relevant) to their problem or place, and timely enough to incorporate into their actions (Cash et al 2003, NRC 2009, NRC 2010a, NRC 2010b). The National Research Council recently identified six basic principles of effective climate decision support: (1) begin with users' needs; (2) give priority to process over products; (3) link information producers and users; (4) build connections across disciplines and organizations; (5) seek institutional stability; and (6) design processes for learning. In addition to these principles, recent analysis from the NOAA RISA community and from the National Science Foundation's (NSF) Decision Making Under Uncertainty (DMUU) groups illustrate that not all decision support activities can or should meet all of these basic principles.

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6.2 Clarifying the Communication of Climate and Climate Change

Lead Authors - Lesley-Ann Dupigny-Giroux and Amanda Stevens

The climate of the U.S. Northeast is inherently variable over time and space, primarily as a function of its latitudinal extent, topography and proximity to water bodies. The Northeast also lies in the exit region of jet streams over the continent, and is strongly influenced by a number of teleconnections such as the North Atlantic Oscillation (NAO), Tropical/Northern Hemisphere (TNH) pattern and Pacific North American (PNA) pattern. Weather and climate vary markedly over short distances, making a clear understanding of the differences among local (about 1 km in extent) to synoptic scale (on the order of 1000 km in extent) processes critical. As decision makers weigh current and future courses of action in response to weather or climate events to reduce their vulnerability to impacts of weather and climate events, an understanding of key atmospheric terminology and methodology is also needed.

Key Definitions

The first key distinction to be made is among the terms weather, climate, the climate system, climate variability and climate change. **Weather** refers to the "short-term (minutes to days) variations in the atmosphere" of such variables as "temperature, humidity, precipitation, cloudiness, visibility, and wind" (American Meteorological Society's Glossary of Meteorology, 2000). **Climate**, on the other hand, refers to

> "The slowly varying aspects of the atmosphere–hydrosphere–land surface system. It is typically characterized in terms of suitable averages of the climate system over periods of a month or more, taking into consideration the variability in time of these averaged quantities." American Meteorological Society's Glossary of Meteorology (2000)

Thus, like weather, a region's climate is also quantified by its precipitation, temperature, winds, humidity, cloudiness and pressure, but over longer temporal and spatial scales. The IPCC's AR4-WG1 report (IPCC, 2007) expands the temporal definition of climate to a "period of time ranging from months to thousands or millions of years". The World Meteorological Organization (WMO) mandates that climate variables be averaged over a consecutive period of 30 years. These 30-year statistical averages are also called climate normals. A misconception that only 30 years of data are needed to define climate or that climate is only relevant to the last 30 years, may have arisen from the layperson's use of the term 'normal' -- meaning "the expected value" or "according with, constituting, or not deviating from a norm, rule, or principle" (Merriam-Webster Dictionary, 2012). In the Northeast where precipitation and temperature time series display trends over time (Frumhoff et al., 2007; Hayhoe et al., 2007; Jacobson et al., 2009; Spierre and Wake, 2010), the notion of using traditional 30-year statistical averages to describe current and future conditions in long-term decision-making, is currently being scrutinized (Arguez and Vose, 2011; Livezey et al., 2007; Rosenzweig et al., 2011).

The **climate system**, on the other hand, refers to the processes occurring in the Earth's spheres, as well as the interaction among them that determine a region's climate. These spheres are the atmosphere, hydrosphere (lakes, rivers, oceans), cryosphere (which is of less importance in the Northeast), biosphere (vegetation on land and marine biota in the oceans) and the lithosphere (crustal matter). Processes of interest include the exchange of heat, light and water among the spheres as well as biogeochemical functions such as carbon cycling. The interconnectedness of the climate system suggests that a systems-based approach be applied to understanding and quantifying climate processes around the Northeast. Trenberth et al. (2002) outline a climate systems approach to better respond to the needs of the human system (water resources, tourism, infrastructure, agriculture etc.) on varying timescales from short-term weather prediction to longer-term climate scenario projections.

Climate variability, as defined by the IPCC AR-4 WG1 report (IPCC, 2007)

> "refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability)."

Such variations are observed as fluctuations in precipitation and temperature patterns, storm tracks, and frequency over time and space. For example, a southward shift in winter storm track over the Northeast leads to greater snowfall accumulations in southern New England, New Jersey and Virginia with reduced totals across northern New England. Evolving patterns of population growth, land use practices and economic development around the Northeast, all compound the investigation of the impacts from extreme atmospheric events in the light of climate variability (Dupigny-Giroux, 2002). Finally, it is important to note that climate variability differs from the concept of uncertainty, and should not be interpreted as the level of confidence of current climate knowledge.

In November 2011, the IPCC (2011) updated its definition of the term **climate change** to

> "A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use."

Of particular note in this definition is that changes in the statistical properties of climate variables must occur over several decades in order to be considered as a climate change. Changes over shorter time frames, especially from one year to the next, are considered to be examples climate variability. The second important element of the new IPCC definition is the highlighting of land use changes (e.g. deforestation and urbanization) in addition to atmospheric changes such as greenhouse gas modifications. The IPCC (2011) document also notes that its

> "definition differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), where climate change is defined as: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global

> atmosphere and which is in addition to natural climate variability observed over comparable time periods." The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes."

These two definitions highlight the need for clarification in using the term climate change. Climate change can be viewed as the *driving processes* involved, the *impacts* that result and finally the *strategies* that may be employed to either mitigate or adapt to the altered climate regimes. Driving processes behind a climate change can be either anthropogenic in nature or due to internal changes in the climate system, solar activity or Earth's orbital characteristics. Anthropogenic factors include increasing atmospheric concentrations of greenhouse gases, as well as the land use changes such as agricultural land degradation, deforestation, urbanization and the creation of artificial lakes. These land use changes modify the surface albedo (the amount of solar radiation reflected), alter hydrological processes and can lead to variations in wind patterns, humidity, soil moisture, cloud cover, precipitation and temperature. Observable climate change *impacts* include sea level rise, phenological changes (e.g. in bird migrations, maple sugaring season lengths), streamflow and snowpack modifications and changes in the length of the growing season. Finally, the response to both climate change driving processes and climate change impacts, include both *mitigation and adaption strategies* at varying political administrative and agency scales.

The term **uncertainty** should not be misinterpreted as climate variability. Uncertainty "can range in implication from a lack of absolute sureness to such vagueness as to preclude anything more than informed guesses or speculation" and can result from informational gaps to "disagreement about what is known or even knowable" (Moss and Schneider, 2000). The challenge of working with climate change uncertainty involves "being responsive to policymakers' needs for expert judgment at a particular time, given the information currently available, even if those judgments involve a considerable degree of subjectivity" (Moss and Schneider, 2000). One of the best known sources of uncertainty in climate change science is the role of cloud forcing. The presence of clouds affects the Earth's radiative energy balance by reflecting shortwave solar radiation while absorbing and re-emitting longwave terrestrial radiation. The magnitude of these cloud effects varies with cloud type, thickness, height and other optical properties and is not well parameterized in global climate models.

Resiliency can be described as the "ability of social systems, be they the constituent element of a community or society, along with the biophysical systems upon which they depend to resist or absorb" impacts, "to rapidly recover from those impacts and to reduce future vulnerabilities through adaptive strategies" (Peacock et al., 2008). Thus, the notion of **vulnerability** can be applied to both the built environment and the damage that can accrue there, as well as to human individuals and social systems' capacity to "anticipate, cope, resist and recover from the impacts" of a given change (Blakie et al., 1994 and Heinz Center, 2000 in Peacock et al., 2008). Policymakers and other decision-makers are faced with creating and implementing strategies to increase the resiliency of populations, infrastructure and socioeconomic systems, while reducing vulnerability to extreme weather events and climate change. Successful strategies take into account not only the characteristics of the physical environment (e.g., road infrastructure, utilities and telecommunications), but also human systems components such as governance issues, economic livelihood and well-being, as well as individual and community-based coping mechanisms. Resilience and vulnerability planning should be conducted for all populations, including daycare facilities, the elderly, home-bound, homeless and disabled whose access and care needs may differ from other populations being served. In this context, adaptive governance has been proposed by Brunner and Lynch (2010) as an “emerging pattern of science, policy and decision-making” that allows for the testing of “thousands of policies for adapting to those climate changes we cannot avoid, and for mitigating those we can.”

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6.3 Planning Tools

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Introduction

There are many different dimensions of decision support. As stated by the National Research Council (2009), "Decision support–that is, organized efforts to produce, disseminate, and facilitate the use of data and information in order to improve the quality and efficacy of climate-related decisions–is essential for developing responses to climate change. The information that is needed is not only about climate, but also about changes in social and economic conditions that interact with climate change and about the state of knowledge and uncertainty about these phenomena and interactions."

Development of tools to support decision making related to climate change adaptation is an active field of endeavor. However, decision support in the context of risk and hazard management in sectors sensitive to climate is better established. Water managers and farmers, for example, consistently factor weather and climate into their decision-making, and many examples of decision support exist within these sectors. Determining the goals for decision support is critical for evaluation and for discussion of best practices. For the purposes of this discussion, "best practices" include activities that support decisions on the ground that increase resilience or adaptive capacity.

Generally, decision support tools consist of software or documented methods to assist in data collection and/or management, modeling and analysis of environmental or socio-economic systems, illustration or analysis of the consequences of management decisions, facilitation of stakeholder involvement, or project management. Some tools are in the public domain, others must be purchased or licensed, and the degree of technical training required to operate them varies considerably. Often a combination of tools are used together to provide for a complete planning process.

Adaptation planning processes include methods that are qualitative and those that are quantitative, from informal panels of experts to software tools that are intended to aid in risk-based adaptation planning. Many tools used in the context of adaptation planning were not developed specifically to assist in climate change adaptation but are drawn from other disciplines (e.g., land-use planning, environmental monitoring). This section will address tools designed to generate and deliver actionable information to assist states and communities in assessment of climate change vulnerability and risk, quantification of effects, and identification of adaptive strategies in the context of adaptation planning across inter-annual/seasonal and multi-decadal time scales, as used in the Northeast region as defined by the U.S. National Climate Assessment.

Planning approaches vary, but any adaptation planning process must include the following:

- Knowledge of the probable change in a climate variable (e.g., precipitation, temperature, sea level rise) over time or that the climate variable will attain a certain threshold deemed to be significant;

- Knowledge of intensity and frequency of climate hazards (past, current or future events or conditions with potential to cause harm) and their relationship with climate variables;
- Assessment of climate vulnerabilities (sensitive resources, infrastructure or populations exposed to climate-related hazards);
- Assessment of relative risks to vulnerable resources;
- Identification and prioritization of adaptive strategies to address risks.

Comprehensive Adaptation Planning

Comprehensive climate change adaptation planning is undertaken to ensure that all significant vulnerabilities are identified and that local knowledge and values are used in assessing risks and selecting adaptive strategies. The participative planning process used by King County, Washington (Center for Science in the Earth System, 2007) has served as a model for development of local comprehensive climate adaptation plans and for incorporating climate considerations into existing planning processes. ICLEI makes its Local Government Climate Change Adaptation Toolkit available free of charge (ICLEI Oceania, 2008). This toolkit follows a process similar to that used in King County but modified for use by Australian municipal councils. Both include worksheets and templates that can serve as useful models for communities. Recently, ICLEI released its Adaptation Database and Planning Tool (ADAPT), an online tool that guides local governments through ICLEI's Five Milestones for Climate Adaptation (ICLEI). ADAPT is available to ICLEI member local governments through subscription.

State-level adaptation planning in the Northeast has generally relied on qualitative vulnerability assessments by expert panels and stakeholders (e.g., Connecticut Adaptation Subcommittee, 2010; New York State Climate Action Council, 2010), although some states have undertaken initiatives to develop statewide databases to support vulnerability assessments by local governments and state agencies, e.g., Maryland's Coastal Atlas and Wilmington, Delaware's sea level rise (SLR) inundation map (Maryland Department of Natural Resources, NOAAa).

Planning Integration

Increasingly, states and local governments are attempting to account for climate change in master or comprehensive (City of Albany, 2011), local waterfront revitalization or natural hazard mitigation plans, and in plans focused on specific assets or issues such as public health, capital or economic development and redevelopment, open space, and stormwater or wastewater management. Integration of climate change adaptation with more conventional planning processes (also known as "mainstreaming") may be undertaken pursuant to, or independent of, a more general adaptation plan. In a growing number of cases, adaptation is being considered in concert with mitigation and sustainability, for example Philadelphia, PA (Chastain et al., 2011).

Adaptation Planning Tool Information and Resources

Many organizations are developing decision-support tools to assist in adaptation planning. The Ecosystem-Based Management Tools Network (EBMTN) is a source for information about their use, including best practices for using adaptation planning tools. EBMTN resources include a very useful matrix of adaptation planning tools (Ecosystem-Based Management Tools Network).

The National Oceanic and Atmospheric Administration's (NOAA) Digital Coast program provides a framework and tools for identifying coastal vulnerabilities, projecting extent of SLR and storm surge, and predicting coastal wetland migration. The Digital Coast Habitat Priority Planner also provides a process and tools to assist in habitat conservation, restoration and land-use planning by providing a means of obtaining critical habitat analyses that are consistent, repeatable, and transparent. Digital Coast provides an access point and the Roadmap for Adapting to Coastal Risk, a process and tools for conducting risk and vulnerability assessments to help identify people, property, and resources that are at risk of injury, damage, or loss from hazardous incidents or natural hazards. Tools include the Nature Conservancy's Coastal Resilience, which visually links flood scenarios (SLR and/or storm surge) with socio-economic, infrastructure and natural resource layers to assist with adaptation of vulnerable resources and populations in New York and Connecticut. (NOAA, The Nature Conservancy).

The U.S. Environmental Protection Agency's Climate Ready Water Utilities program provides tools, training, and technical assistance for the water sector to develop and implement long-range plans that account for climate change effects. The program's Climate Resilience Evaluation and Awareness Tool (CREAT) is a software tool to assist drinking water and wastewater facility operators in assessing risks, evaluating potential climate change effects and evaluating adaptive options. (U.S. Environmental Protection Agency, 2012)

Matrix of Tools by Sector, Planning Step, Other Factors

To assist with identifying and improving awareness of currently available tools and process a Planning Tool Matrix can be used. This matrix has been compiled from several sources including NOAA's Digital Coast and Ecosystem-Based Management Tools Network and includes information by sector, planning step and tool type. Northeast region examples of applications of the tools are also cited. See the full Planning Tool Matrix in Appendix 6.A.

Case Studies from the Northeast Region of the U.S. National Climate Assessment

To date, most adaptation planning in the Northeast has focused on hazards posed by SLR, enhanced storm surge, heat exposure, shoreline erosion and riverine flooding. The risks to valuable resources, cost of protecting at-risk resources and the opportunity cost of avoided shoreline development likely demand more rigorous planning processes than are currently being used to plan for other climate hazards. Communities in the Northeast already face significant risk from these hazards and are more likely to perceive them as immediate and direct threats. The following are case studies that reflect the use of adaptation planning tools and processes in the Northeast. The case studies selected are by no means an exhaustive list and were selected to be instructive as well representative of the current work on adaptation across this region.

Box 6.1: Delaware, Maryland, and New Jersey

At least three states, Delaware, Maryland and New Jersey, have provided tools or processes to facilitate adaptation planning in coastal communities, and piloted these resources in one or more communities. These pilots have used tools developed specifically to assist with climate change adaptation in combination with tools from other disciplines (e.g., land-use planning) and to assist in assessment of vulnerabilities and communication with stakeholders. More advanced tools to assist in prioritization of adaptation efforts, by quantifying risk, and formalizing identification, selection and development of adaptive strategies, have not been typically used at the local level.

Maryland

The Maryland Department of Natural Resources (MDDNR) provides a toolbox of adaptation planning and implementation resources for counties and towns through its Coast-Smart Communities Initiative. Decision support tools provided include the Coastal Atlas, an online mapping and planning tool, developed using ArcGIS for Flex. The Atlas includes three mapping applications: Ocean, Shorelines and Estuaries. Potential adaptation applications include identification of high-erosion areas, visualization of potential future shoreline positions, areas vulnerable to storm inundation, and floodplain and emergency management. Data for the Atlas have been downloaded from NOAA's Digital Coast and incorporated into the Atlas. The Coastal Atlas is included in Maryland's iMap program, which provides access to coastal data and visualization tools. Datasets included in the Coastal Atlas include effects of SLR on coastal wetlands (Sea Level Affecting Marshes Model output) shoreline erosion, storm surge inundation areas, SLR economic assessment, and high-risk SLR areas. (Maryland Department of Natural Resources).

Box Figure 6.1. Screenshot from Maryland's Coastal Atlas, showing sea level rise vulnerability and erosion vulnerability assessment layers, http://www.dnr.state.md.us/ccp/coastalatlas.

Under the Coast-Smart Initiative, Maryland undertook pilot projects in three coastal counties: Dorchester, Worcester and Somerset. In the case of Worcester County, MDDNR and USGS developed a detailed Light Detection and Ranging (LiDAR) dataset and a topographic elevation model, and modeled SLR for 2025, 2050 and 2050, under three SLR scenarios: steady state, average accelerated and worst case. The increase in hurricane storm surge was depicted for the steady state and average accelerated scenarios. Modeled inundation zones were used in conjunction with geographic information system (GIS) based local land-use, infrastructure and ecosystem data to identify projected effects. (Cole, 2008; Maryland Department of Natural Resources, 2008).

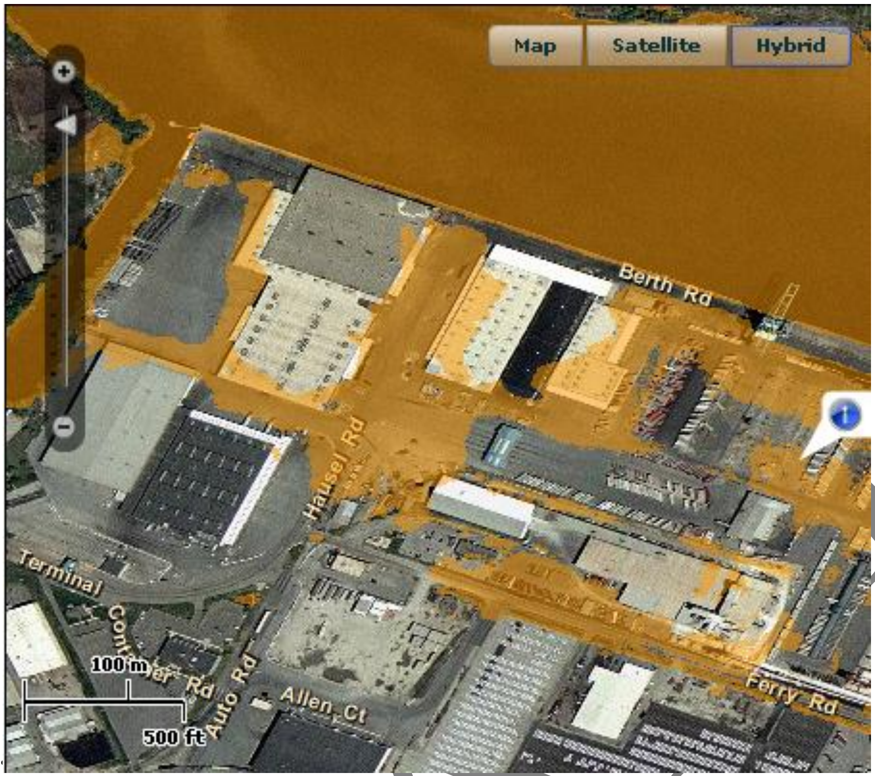
Delaware

The Delaware Department of Natural Resources and Environmental Control's (DNREC) SLR Initiative consists of four components: 1) Provide data for vulnerability assessments and policies (hydrology/sediment movement study, sediment accretion rate study, monitoring gap analysis, storm history, development of coastal inundation maps, Tidal Marsh Vulnerability Index, sediment elevation tables); 2) Design pilot implementation projects; 3) Provide tools, training, and information to stakeholders; and 4) Inform policy development through a SLR Adaptation Plan. (Delaware Coastal Programs, 2011).

Pilot planning processes have begun in the Town of Bowers Beach and the City of New Castle. The two pilot projects are supported by an interactive, online SLR inundation coverage map provided for the entire state of Delaware. The maps are based on a simple model to show possible inundation under three SLR scenarios (0.5, 1.0 and 1.5 m) at constant elevations, relative to local mean higher high water, a technique often referred to as "bathtub modeling." (Delaware Coastal Programs, 2011).

The DNREC also used the Sea Level Affecting Marshes Model (SLAMM) to examine potential SLR effects on marshes within the National Wildlife Refuge System in Delaware, including Prime Hook National Wildlife Refuge. These maps have proved useful for visualizing the extent and potential effects of SLR inundation and have formed the basis of a department-wide SLR adaptation policy for Delaware's DNREC that will guide future decisions about development in Delaware's coastal zone. In addition to improving community resilience and assessing vulnerability, the maps will also be used for land use planning and zoning, developing emergency management plans, assessing economic and ecological impacts, protecting recreational areas, developing future plans for infrastructure, and managing agricultural practices. (Scarborough, 2009).

In addition, DNREC, NOAA and USGS produced an interactive tool to depict current storm tide flood levels at Wilmington, DE as a "proxy" for predicted SLR (NOAA).



Box Figure 6. happens only during storm events but provides a proxy for sea level rise inundation at Wilmington, DE http://www.csc.noaa.gov/de_slr/index2.html.

New Jersey

The New Jersey Coastal Management Program (NJCMP) obtained coastal LiDAR elevation data for three counties on the Delaware Bay at near mean low-water and has developed a GIS-based Coastal Community Vulnerability Assessment Protocol (CCVAP). The protocol is a composite model incorporating six geospatial inputs: geomorphology, slope, flood-prone areas, SLOSH output, drainage and erosion to identify high-hazard areas. Incorporation of SLR scenarios into storm surge models allowed visualization of landward shifts in high-hazard areas over time. To date, the protocol has been piloted in four communities: Cape May Point, Greenwich, Little Silver and Oceanport. (New Jersey Department of Environmental Protection, 2011b; Wood et al., 2010).

Upon completion of vulnerability mapping for each of the four pilot communities, NJCMP invited each community to participate in community adaptation planning. To guide this planning, NJCMP developed the *Getting to Resilience* questionnaire. The questionnaire is intended to guide a facilitated community assessment of how well the community has incorporated hazard and SLR mitigation into its land-use, hazard mitigation, post-disaster redevelopment and other plans. (New Jersey Department of Environmental Protection, 2011a, 2011b; Wood et al., 2010).

Box 6.2: Coastal Resilience - New York and Connecticut

Coastal Resilience (The Nature Conservancy) is a framework driven by extensive community engagement and uses spatial information on storm surge, SLR, ecological, and socio-economic variables to identify options for reducing the vulnerability of human and natural communities to coastal hazards. The framework (tools and process) includes five critical elements:

- Assemble data: Develop integrated databases on social, economic and ecological resources critical to communities;
- Assess risk: Assess risk and vulnerability to coastal hazards including alternative scenarios for current and future storms and SLR with community input;
- Identify choices: Identify choices for reducing vulnerability focusing on joint solutions across social, economic and ecological systems;
- Provide decision support: Provide decision support including web-based guidance, mapping, scenario and visualization tools, and databases;
- Support action: Help communities to develop and implement solutions.

These resources are provided to communities and practitioners through a variety of products, including a website that explains the approach, methods, decision-support tools and strategies for addressing coastal hazards. The project partners include The Nature Conservancy, the Center for Climate Systems Research (CCSR) at Columbia University and the National Aeronautics and Space Administration's (NASA) Goddard Institute for Space Studies, Association of State Floodplain Managers (ASFPM), the Pace Land Use Law Center, NOAA's Coastal Services Center (NOAA-CSC) and the Department of Geography and Geology at the University of Southern Mississippi (USM). The team examined current ecological, biological, socioeconomic, and management information alongside locally relevant, downscaled coastal flooding and inundation scenarios developed from widely accepted climate and hazard models (Ferdaña et al., 2010).

Data Analysis

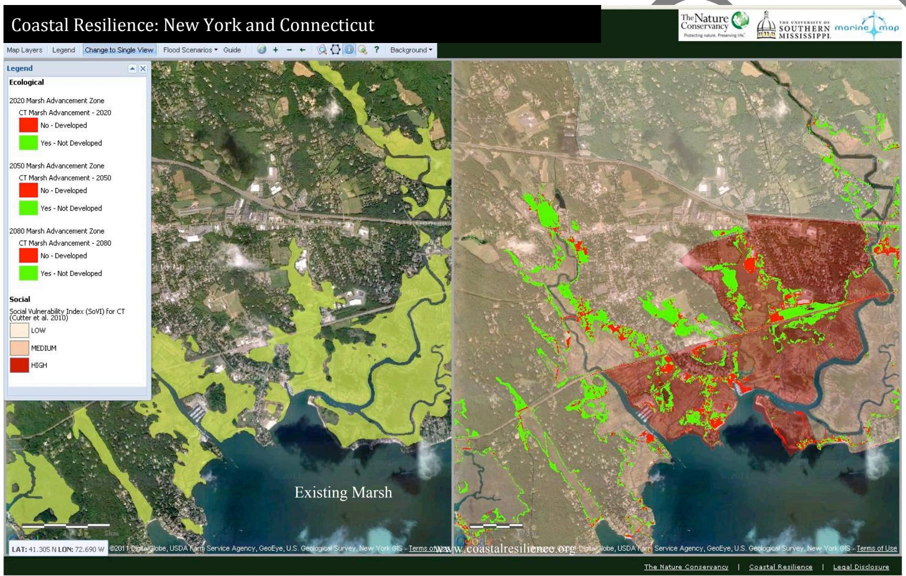
Collection and analysis of geographic information system (GIS) data is a core component of this project, allowing visualization, exploration, and analysis of multi-layered issues influencing coastal resilience. The elevation data used for mapping SLR and storm surge scenarios came from LiDAR-based digital elevation models. Estimates derived from SLOSH estimates storm surge heights and winds resulting from historical, hypothetical, or predicted hurricanes by taking into account atmospheric pressure, size, forward speed, track, and winds were used. From the model's outputs, the maximum envelopes of water (MEOWs) for Category 2 and 3 hurricanes, corresponding to storm surges with estimated 40- and 70-year return periods, respectively, were mapped.

Future SLR scenarios (2020s, 2050s, 2080s) were calculated under different emission scenarios (IPCC – A1b, A2, A2 plus ice sheet melt) with several different global circulation model (GCM) simulations run by Columbia University's Center for Climate Systems Research/NASA. Scenarios incorporated global variables (thermal expansion of the oceans due to global temperature increases and changes in the ice mass, including Greenland, Antarctica, and glaciers) and variables such as local land subsidence and differences in mean ocean density (see

Horton et al., 2010). A bathtub fill approach was used to model inundation from SLR (see Poulter and Halpin, 2008). Hydrologically enforced inundation modelling is most accurate (Gesch, 2009), but was beyond the scope of the current project.

Ecological Analyses

Data and analyses on critical coastal ecosystems, especially vulnerable species and habitats and services, continue to be updated. Coastal wetlands and marshes as well as on the piping plover, barrier island habitats, and submerged aquatic vegetation are emphasized. Intertidal habitats, including wetlands, require adjacent non-developed space to migrate over time to keep pace with rising sea levels. The project team modelled potential marsh advancement zones with SLR based on variables of accretion, erosion, land use/cover, elevation, and projected sea level (Hoover et al., 2010).



Box Figure 6.3. Screenshot from The Nature Conservancy's Coastal Resilience: New York and Connecticut showing existing salt marsh (left screen) and social vulnerability with salt marsh advancement zones (i.e., marsh migration areas) under three decadal time steps (2020s, 2050s, 2080s) derived from downscaled sea level rise projections (right screen), http://www.coastalresilience.org.

Social Vulnerability

Socioeconomic information was analysed and incorporated to better evaluate the consequences of SLR and storm surge hazards on human populations and infrastructure. The U.S. Census Bureau (2000) was used to depict these distributions and to create various census block group level indices based on demographic attributes such as age, income, and access to critical facilities such as hospitals. In addition, a Social Vulnerability Index (SOVI) (Cutter et al., 2003) based on published risk and vulnerability assessment methodologies were utilized. Additional analyses based on the Community Vulnerability Assessment Tool (CVAT) and the AGSO Cities Project (Granger, 2003) was included.

Economic Risks

Census block-level demographic data were combined with economic data to forecast the potential economic damage of future SLR and floods based on the present-day economic landscape. Economic exposure and losses from flooding of infrastructure, including housing, transportation, and commercial structures were calculated. Economic loss represents the full replacement value of commercial and residential structures. Loss calculations were the result of geographic analysis using the Hazards US Multi-Hazards (HAZUS-MH) tool developed by the Federal Emergency Management Agency (FEMA). HAZUS-MH uses GIS software to estimate potential economic losses from earthquakes, hurricanes, and floods. To further understand resources at risk, data was added on hardened shoreline structures, land use, and critical facilities locations (e.g., hospitals and fire stations).

Coastal Resilience is being used in Connecticut and New York by local entities to inform decision making regarding natural resources and community land-use and policy planning. At the municipal level, many communities are incorporating the SLR and storm surge projections into their natural hazard mitigation plans along with specific identification and prioritization of at-risk neighbourhoods, infrastructure and coastal wetlands. Town planners and emergency managers across the coast of Connecticut are using the storm surge projections to reconsider evacuation route and refuge locations in the face of increased storm activity. The risk information is also being connected to sustainability efforts in the greater Bridgeport Area for transportation (bus and rail) assessments and contingency planning in densely populated portions of the project area. In addition, the information is being used for detailed vulnerability assessments and reconsideration of zoning restrictions elsewhere on future growth in future flood and inundation areas. The Town of East Hampton, N.Y. is using the tool to evaluate revetment applications.

State and federal agencies are using the “advancement zone” analyses as a guide to rebalance management objectives directed at acquisition, restoration and habitat conversion of salt marshes for private preserves and national wildlife refuges and management areas. Several national estuary programs are utilizing Coastal Resilience towards providing decision support to communities in the USEPA’s Peconic National Estuary Program (NEP) and Long Island Sound NEP. Coastal Resilience is part of NOAA CSC’s Digital Coast efforts to inform communities about the risks posed by coastal inundation.

Box 6.3: Coastal Adaptation to Sea Level Rise Tool

The Coastal Adaptation to Sea Level Rise Tool (COAST) enables a three-dimensional view and alternatives assessment of economic impacts (cost-benefits analysis) to infrastructure, critical facilities and private structures due to sea level rise and storm surge scenarios. COAST allows decision makers the ability to visualize avoided costs, multi-decade tallies of expected damage, and narrative and presentation-based interpretation of alternative adaptation actions that can protect vulnerable assets in coastal communities. The tool was developed with support from the

U.S. EPA by the New England Environmental Finance Center, housed at the Muskie School of Public Service, University of Southern Maine. It is currently being integrated into climate change adaptation efforts in Portland, Maine and Hampton/Seabrook, New Hampshire.

For single-event visualization, the approach overlays polygons of anticipated extreme weather events onto vulnerable assets (e.g., real estate) selected by the user community. Tables representing values of these assets, such as parcel maps and assessors' data, are then merged with a "depth-damage function" that specifies how much of the asset's value is lost at different depths of inundation. These expected damages are extruded out of the landscape in a topographic portrayal of risk for that scenario.

In Portland Maine, residents are experiencing regular inundation even from high tides, as with the pictured "king tide" in Back Cove, from October 2011. The COAST approach is helping understand the cumulative cost of taking no adaption action over a set time period versus the cost of constructing a levee system and hurricane barrier that might protect vulnerable real estate in this area.

A sample extrusion map is below for cumulative a no-action scenario of lost real estate values from now through the year 2100, suggesting cumulative expected damage to private property from a storm surge event (a 100-year storm, with 180 cm of sea level rise, at high tide). Damage expected from storm surge is represented with blue polygons, and damage from sea level rise is represented with red polygons.

For multi-decade tallies, probabilities of a range of storm surge events are combined with probabilities of different sea level rise scenarios, and cumulative expected damage tables are produced that help identify adaptation actions that may save money under any sea level rise scenario. Users can specify various other input assumptions as well, such as discount rates and changes in value of the vulnerable asset over time. Importantly, in addition to structural adaptation approaches such as sea walls and road elevation, nonstructural approaches including floodproofing, acquisition, and zoning changes can also be modeled. This helps communities begin discussions about trade-offs between candidate adaptation approaches, for example between shore hardening and wetland loss.

Although COAST is expected to be available for free download in 2012 shortfalls of the approach include that in most cases substantial external assistance will still be required to coordinate each iteration, and funds need to be arranged to support this. Other limitations include that like any model, the ability to address particular questions depends on quality of available data. Nevertheless on balance the COAST approach is proving to help communities begin discussing questions of whether to fortify their assets, relocate them, accommodate higher water levels, or remain in denial of likely events.

Box 6.4: PlaNYC2030

New York City is committed to addressing both the causes and the effects of climate change. Created in 2007 and updated in 2011, PlaNYC comprises Mayor Michael Bloomberg's plan for meeting the challenges of a growing population, aging infrastructure, a changing climate, and an evolving economy, while also building a greener, greater New York. PlaNYC establishes goals to reduce the city's contributions to climate change by reducing greenhouse gas emissions 30% by 2030, and to address the effects of climate change by increasing the resilience of New York City's communities, natural systems, and infrastructure to climate risks. (City of New York, 2011).

PlaNYC outlines a five-pronged approach for increasing resilience that includes the following:

1. **Assessing vulnerabilities and risks from climate change**

- Regularly assess climate change projections (Initiative 3)
- Partner with FEMA to update flood insurance rate maps (Initiative 4)
- Develop tools to measure the city's current and future climate exposure (Initiative 5)

2. **Increasing the resilience of the city's built and natural environments**

- Update regulations to increase the resilience of buildings (Initiative 6)
- Work with the insurance industry to develop strategies to encourage the use of flood protections in buildings (Initiative 7)
- Protect New York City's critical infrastructure (Initiative 8)
- Identify and evaluate citywide coastal protective measures (Initiative 9)
- Protecting public health from the effects of climate change
- Mitigate the urban heat island effect (Initiative 10)
- Enhance understanding of the impacts of climate change on public health (Initiative 11)
- Increasing the city's preparedness for extreme climate events
- Integrate climate change projections into emergency management and preparedness (Initiative 12)
- Creating resilient communities through public information and outreach
- Work with communities to increase their climate resilience (Initiative 13)

PlaNYC also includes 30 separate initiatives in other parts of the plan that will increase the city's climate resilience. For example, the city's efforts to plant 1 million trees and to invest $1.5 billion in green infrastructure over the next 20 years will help cool the city and better manage rainfall.

To support these efforts, the city is developing a number of partnerships and tools.

New York City Climate Change Adaptation Task Force and New York City Panel on Climate Change

To protect the city's critical infrastructure (Initiative 8), Mayor Bloomberg launched the New York City Climate Change Adaptation Task Force (Task Force) in 2008, which is composed of 41 public and private entities that operate or regulate critical infrastructure in the city. The Task Force's mission is to assess how climate change could affect the city's infrastructure and to develop coordinated measures to increase the city's climate resilience.

In 2008, Mayor Bloomberg also convened the New York City Panel on Climate Change (NPCC) – a body of climate scientists, and legal, insurance, and risk management experts – to develop climate change projections for New York City and support the Task Force's work (Rosenzweig and Solecki, 2010).

The Task Force used the climate change projections for the city to identify more than 100 types of transportation, energy, water supply, storm- and wastewater, solid waste, telecommunications, and natural infrastructure that climate change could affect and to qualitatively assess climate risks to that infrastructure. The Task Force developed over 300 adaptation strategies to address high priority risks, which were defined as those impacts that were likely to occur during the asset's useful life and for which the magnitude of consequence was high.

The city recently reconvened the Task Force to review its inventory of at-risk infrastructure and quantify climate risks using a tool it is developing called the Natural Hazard Risk Model (Model) (Initiative 5). By quantifying climate risks over time by hazard, sector, and geography, the Model will help the city and Task Force members prioritize investments, develop cost-benefit estimates for potential adaptation strategies, and track progress toward reducing climate risks.

Current Actions

The city and Task Force members will work to refine a set of adaptation strategies for implementation based on the quantitative assessment of climate risks and a cost-benefit analysis of potential strategies. Refined adaptation strategies may include changes to design standards, and capital planning, and operational and maintenance practices to ensure that infrastructure is designed, operated and maintained to reflect climate risks. Strategies may also include changes to citywide policies that facilitate coordinated approaches for increasing resilience.

In addition to the Task Force's work, the city is also moving forward with other efforts under PlaNYC to increase resilience, some of which were identified through the Task Force process:

- Incorporating consideration of climate change into New York City's Waterfront Revitalization Program to ensure that actions within the coastal zone are consistent with city policies (Initiative 6);
- Exploring opportunities to work with the insurance industry to develop strategies to encourage the use of flood protections in buildings (Initiative 7);
- Taking additional steps to cool the city by coating 3 million square feet of roofs with a cool coating through the NYC CoolRoofs Program (Initiative 10);
- Identifying and evaluating citywide coastal protective measures (Initiative 9);
- Analyzing the impacts of climate change on public health through a grant from the Center for Disease Control (Initiative 11); and
- Working to integrate climate resilience into outreach on emergency preparedness (Initiative 12).

Continuing Challenges

Despite the comprehensiveness of its process, the city has identified significant gaps in information regarding likely changes. Examples include how changes in precipitation and sea level will affect inland flooding and flooding in different waterfront areas, and how surface and air temperature relate to mitigating the urban heat island effect. The city has preliminary heat island maps, but the connection between the air temperature and surface temperature is unknown. Similarly, climate change projections for the city are presented in predictive ranges over decades. Dealing with the uncertainty surrounding climate projections, and determining the best way to use these ranges to inform capital investments also requires further clarification. Addressing these questions is part of the city's ongoing efforts to translate climate science into information that can be utilized by infrastructure operators, the private sector, and the public to make decisions that increase resilience. While major progress has been made over the last four years, the city finds that it is a continuing challenge to make good science information usable to decision-makers and integrate it into their decision-making processes.

Summary

Generally, decision support tools consist of software or documented methods to assist in data collection and/or management, modeling and analysis of environmental or socio-economic systems, illustration or analysis of the consequences of management decisions, facilitation of stakeholder involvement, or project management. Some tools are in the public domain, others must be purchased or licensed, and the degree of technical training required to operate them varies considerably. Often a combination of tools are used together to provide for a complete planning process.

Adaptation planning processes include methods that are qualitative and those that are quantitative, from informal panels of experts to software tools that are intended to aid in risk-based adaptation planning. Many tools used in the context of adaptation planning were not developed specifically to assist in climate change adaptation but are drawn from other disciplines (e.g., land-use planning, environmental monitoring). This section addressed tools designed to generate and deliver actionable information to assist states and communities in assessment of climate change vulnerability and risk, quantification of effects, and identification of adaptive strategies in the context of adaptation planning across inter-annual/seasonal and multi-decadal time scales, as used in the Northeast.

With a few exceptions, most applications of adaptation decision support tools in the Northeast have been made by local governments and have been focused on hazards posed by sea level rise, storm surge and coastal erosion. Most of these local efforts, however (New York City being a significant exception), have been facilitated by either state agencies or nongovernmental organizations (NGOs), often to pilot datasets or processes developed by those agencies or NGOs.

Numerous decision-support tools have been made available through federal and state agencies and NGOs. While an analysis of "gaps" in tool availability was beyond the scope of this work, it appears likely that availability of decision-support tools is not a significant barrier to adaptation planning. Rather, the low number of local governments undertaking adaptation planning efforts independent of "external" assistance likely reflects both limited focus on climate change and limited local capacity to apply available tools in rigorous adaptation planning. Local officials report being overwhelmed by the number and complexity of decision-support tools and the lack of relevant data. Even when data are available their usage generally requires substantial GIS capability that is often lacking in local communities.

Organizations interested in promoting use of adaptation decision-support tools would likely find their efforts more profitably spent in building the planning capacity of local governments to undertake planning than in developing new tools. Capacity building could include continued development of relevant datasets and improvements in accessibility and ease of use; localized training and technical support in use of tools; and direct support and facilitation of additional pilot projects to demonstrate usefulness of available tools.

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6.4 Data, Monitoring, and Indicators

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Adaptive management requires data and indicators to assess the state of ecosystems and natural as well as human resources managed, including change over time to verify whether or not management strategies are effective. This is especially important in view of a changing climate, with direct and indirect consequences on the resources managed. Nevertheless, monitoring programs to systematically gather and analyze such data are rare, often opportunistic, and not necessarily driven by the needs of adaptive management efforts. Monitoring efforts are also expensive, and difficult to maintain over time; therefore, there is a need for strategic and targeted efforts with sustained sources of dedicated funding. Finally, ecosystems and natural resources do not recognize political barriers, and it is a significant challenge for states and governmental entities to work together to plan and execute truly regional efforts. This section presents examples of monitoring efforts for a coastal ecosystem and an inland mountain ecosystem, as well as climate and weather monitoring efforts using remote sensing-based indicators. Those include climate change in estuarine and coastal ecosystems of New York and Connecticut for bi-state planning and monitoring; climate change impacts on ecosystem dynamics along the Appalachian Trail corridor as a cross region mega-transect perspective along the Appalachian mountains; and monitoring weather and climate using the Global Climate Observing System (GCOS), which provides a list of sustained global observations of established Essential Climate Variables (ECVs) in the atmosphere, ocean, and land. It is noteworthy that, despite the differences in the nature of those efforts, successful monitoring benefits from well-defined indicators (whether they be referred to as "sentinels", "vital signs" of "climate variables"), and requires extensive collaborations across agencies and state lines.

Sentinel Monitoring for Climate Change in the Long Island Sound Estuarine and Coastal Ecosystems of New York and Connecticut

With more than 8 million people living in its watershed, and 20 million people within 50 miles of its shores, Long Island Sound (LIS) is one of the nation's preeminent urban estuary, providing natural resources and commercial and recreational opportunities valued at more than $5.5 billion annually. This region's strong urban footprint threatens the sustainability of ecological services and natural resources. The states of Connecticut and New York border Long Island Sound, and partner with EPA Regions 1 and 2 to jointly manage LIS through the Long Island Sound Study (LISS), a National Estuary Program. LISS has recognized the need to address climate change as a driver of ecosystem changes in LIS and has initiated efforts for strategic bi-state planning for an effective, science-based monitoring program.

A sentinel can be defined as an early warning system to detect significant threats, such as the proverbial canary in the coalmine. The Sentinel Monitoring for Climate Change in Long Island Sound Program is a multidisciplinary scientific approach to provide early warning of climate change impacts to Long Island Sound ecosystems, species and processes to facilitate appropriate and timely management decisions and adaptation responses (see http://longislandsoundstudy.net/research-monitoring/sentinel-monitoring/). These warnings will be based on assessments of climate-related changes to a set of indicators and sentinels recommended by technical advisory work groups.

The Sentinel Monitoring for Climate Change in Long Island Sound Program was developed to quantify local changes in the environment brought about by climate change. The goals of the program are:

1) To collect and synthesize data that will indicate how Long Island Sound is changing
2) Provide scientists and managers with the information necessary to prioritize climate change impacts on the LIS and determine appropriate adaptation strategies.

These impacts include but are not limited to loss or changes in ecosystem functions and processes; disruption in fisheries, aquaculture and other economic commodities; and changes in species population dynamics, including both the loss of and introduction of new species.

A strategic planning effort was initiated as a bi-state partnership including the EPA Long Island Sound Office, National Oceanic and Atmospheric Administration, New York Department of Environmental Conservation, Connecticut Department of Energy and Environmental Protection, New York Sea Grant and Connecticut Sea Grant. The technical advisory groups include over 60 federal, state, NGO, and university partners who have contributed to all stages of the strategic plan development.

The workgroup's first step was the development of criteria to identify the ideal attributes of sentinels, such as the applicability at different sites, specificity to climate change (vs. anthropogenic or other stressors), representativeness of regional biological communities that may be at the fringe of their ranges, relevance for management, and prevalence of existing high-quality records. A complex matrix of potential sentinels was developed according to the principles above through surveys of experts to generate an implementable list of pilot-specific indicators, which was vetted through presentations both to the LISS and at national conferences, resulting in a strategic plan.[52]

Core parameters, including physical or chemical factors that are typically part of most monitoring programs, should be measured to help in the interpretation of the sentinel data. These core parameters should include precipitation, streamflow (runoff and baseflow), sea level, water temperature, water salinity, water pH, wind (speed and direction),relativehumidity and groundwater levels.

The sentinels most appropriate for an initial pilot-scale effort were identified as:

1. Distribution, abundance, and species composition of marsh birds, colonial nesting birds, shorebirds, waterfowl
2. Finfish biomass, species composition, and abundance
3. Lobster abundance (based on fishery-independent measurements)
4. Phytoplankton biomass, species composition, and timing of blooms

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[52] (http://longislandsoundstudy.net/wp-content/uploads/2011/04/LIS_SMstrategy_v1.pdf).

5. Species composition within coastal forests, shrublands, and grasslands
6. Areal extent, diversity, composition, and marine transgression of salt marshes

Implementation of the sentinel monitoring program will yield results on current conditions in LIS and, over time, will highlight resources or processes that are vulnerable to climate change. This strategy is intended to be dynamic and involve future re-evaluation and synthesis in order to redirect efforts and identify data gaps. This effort represents one of the first regional sentinel monitoring programs that was designed specifically for climate change, and as a bi-state effort with help from federal partners.

Climate Change Impacts on Ecosystem Dynamics along the Appalachian Trail

The Appalachian Trail traverses most of the high elevation ridges of the eastern United States, extending 2,175 miles (3,676 kilometers) across 14 states, from Springer Mountain in Northern Georgia to Mount Katahdin in central Maine. The Appalachian Trail intersects 8 National Forests and 6 National Park units, crosses more than 70 State Park, Forest, and Game Management units, and passes through 287 local jurisdictions. Its gradients in elevation, latitude, and climate sustain a rich biological assemblage of temperate-zone forest species. The Appalachian Trail and its surrounding protected lands harbor forests with some of the greatest biological diversity in the U.S., including rare, threatened, and endangered species, and diverse bird and wildlife habitats. They also are the source of the headwaters of important water resources of millions of people. The north-south alignment of the trail represents a cross-section mega-transect of the eastern United States forests and alpine areas, and offers a setting for collecting data on the health of the ecosystems and the species that inhabit them. The high elevation setting and its protected corridor provide a barometer for early detection of undesirable changes (Dufour and Crisfield, 2008). Within the corridor the decrease of mean temperature toward the north becomes evident around the 39^{o}N illustrating latitudinal variation of climate (**Figure 6.1**). The northern section of the corridor provides an important reference for monitoring the effects of climate change in the Northeastern U.S.

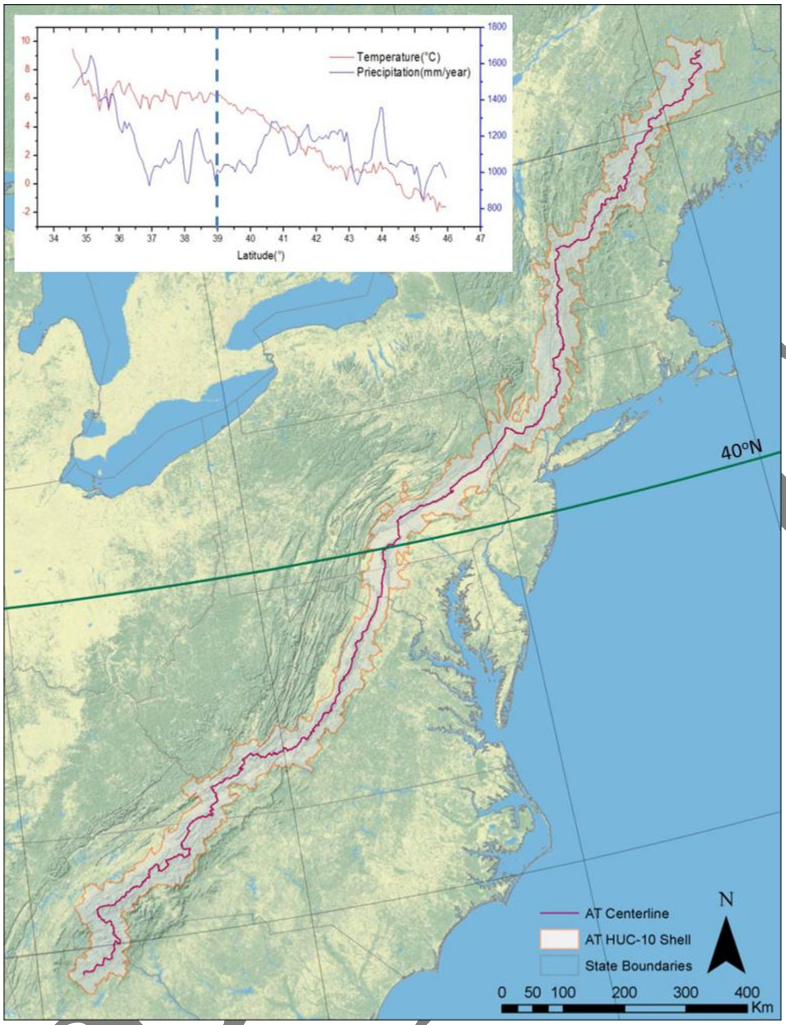

Figure 6.1. The figure illustrates spatial extent of the Appalachian Trail corridor and the patterns of decreasing of mean temperature at around 39°N with variations of precipitations toward northern latitudes *(see inset)* that reflect latitudinal effects of the climate.

The current patterns in climate and vegetation along the Appalachian Trail corridor indicate that:

1. Mean temperature increases from north to south with a difference of over 10°C between the northern terminus in Maine and southern terminus in Georgia;
2. Most of the study area receives more than 900 mm/year of precipitation. Precipitation decreases from 35°N to 37°N by 500 mm/year, increases from 37°N to 41°N, and then decreases again north of latitude 41°N;
3. Annual peak leaf area index (LAI) shows a large decline from 39°N to 41°N due to the amount of cropland and urban area in the landscape;
4. Net primary production (NPP) decreases from South to North, and the decrease can be explained by the temperature gradient with the exception of a decline induced by cropland and urban area around 40°N (Hashimoto et al., 2011). A comparison between climate variables and

NPP shows that the latitudinal gradient of NPP is mostly controlled by temperature through its effect on modulating growing season length (Jenkins et al., 2002).

Hashimoto et al. (2011) analyzed timeseries data from MODIS and other remote sensing data products, Global Inventory Modeling and Mapping Studies (GIMMS), and Surface Observation and Gridding System (SOGS), using the Terrestrial Observation and Prediction System (TOPS). The study projected the regional impacts of climate change along the Appalachian Trail corridor area by downscaling general circulation model (GCM) scenarios, and using the scenarios to drive dynamic ecosystem models to assess the vegetation response to the projected climate scenarios. The study used climate scenarios derived from the World Climate Research Program (WCRP) Coupled Model Intercomparison Project (CMIP3) multi-model data sets, which are based on the climate scenarios produced for the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC 2007). The study used the outputs from 11 models for the Special Report on Emission Scenarios A1B (SRES A1B), which assumes a future with high economic growth, a well-balanced energy resource portfolio, and new technology development, with atmospheric CO_2 concentration stabilizing at 720 ppm.

The study found that all the climate models project a steady temperature increase, ranging from 2°C to 6°C by the end of the 21st century. The ensemble mean temperature increased from 11°C to 14.5°C, while precipitation did not show a clear trend (**Figure 6.2**). To evaluate the regional impacts of climate scenarios on ecosystems and protected areas, the study ran a dynamic ecosystem model to simulate the ecosystem response to changes in climate from 1980 to the end of the 21st century. The simulated NPP is projected to increase. Measured in grams of carbon bound into organic material per square meter per year ($gC/m^2/yr$), the ensemble mean NPP increases from 60 to 80 $gC/m^2/year$. The increase can be attributed to the effect of increasing atmospheric CO_2 concentrations and CO_2 fertilization on the vegetation in the region. However, the net ecosystem exchange (NEE) is predicted to be constant at a rate of approximately -10 $gC/m^2/year$. Negative NEE indicates a flux of carbon from terrestrial ecosystems to the atmosphere. This means that the predicted increase in respiration due to rising temperature exceeds the predicted increase in NPP. The results suggest that the current carbon sink in the eastern United States could turn into a carbon source in the future under the SRES A1B scenario. If we were to use the projections that follow the trajectory of the highest emission scenarios, the forests along the Appalachian Trail corridor would be expected to start releasing even more carbon and eventually decline in growth.

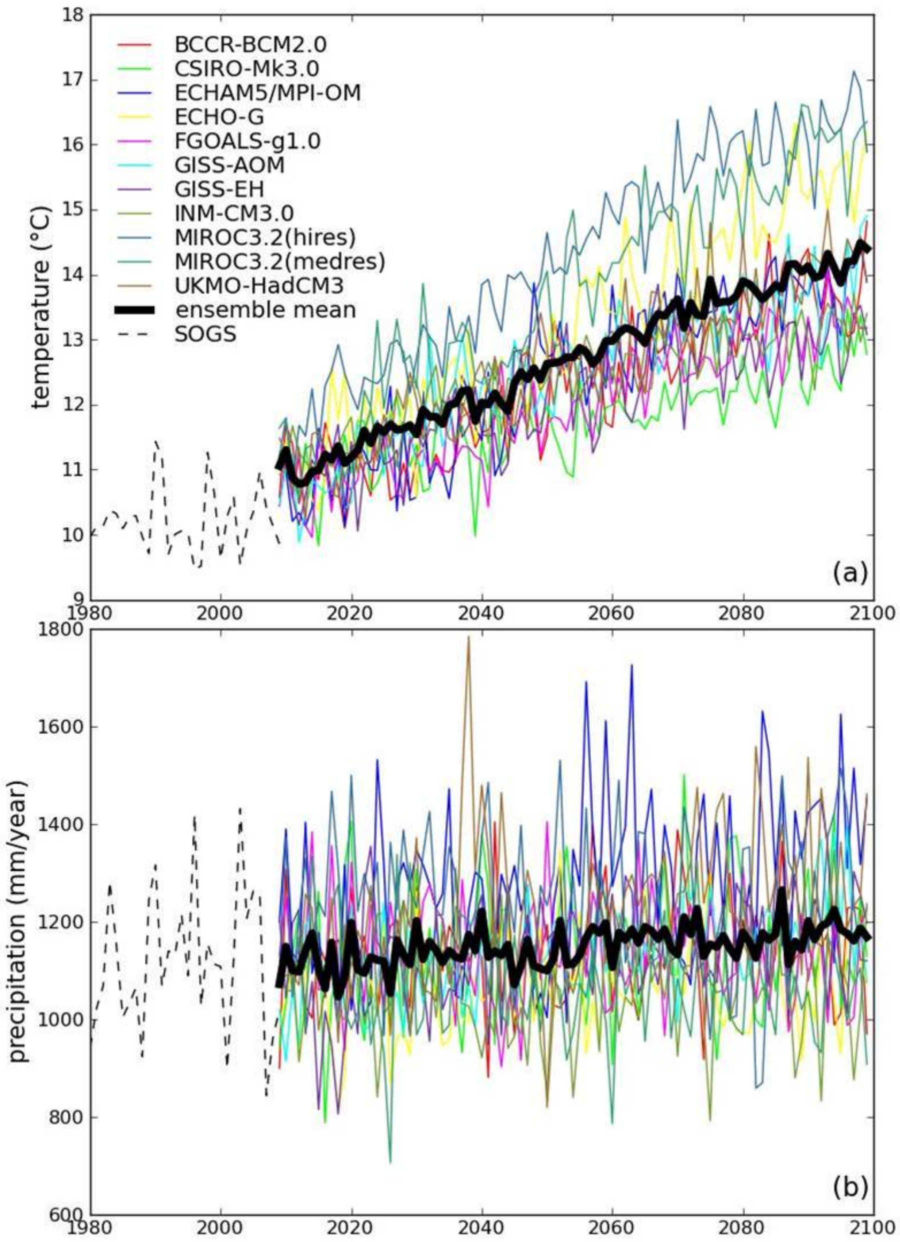

Figure 6.2. Projected mean temperature (a) and precipitation (b) through the end of the 21st century downscaled from Coupled Model Intercomparison Project (CMIP3) multi-model dataset of SRES A1B scenario for eleven global climate models (GCMs). (Source: Hashimoto et al., 2011)

Land surface phenology (LSP) is one of the measures of landscape dynamics. As an indicator, LSP reflects the response of vegetated surfaces to seasonal and annual changes in climate, including the hydrologic cycle. An increasing number of studies reported on phenology shifts in spatial pattern and timing of the growing season (e.g., Wolfe et al., 2005; Jeong et al., 2011;

Wang et al., 2011). Using data from time series satellite remote sensing, LSP metrics typically retrieve the time of onset greenness as the start of the season (SOS); onset of senescence or time of end of greenness as the end of the season (EOS), timing of maximum of the growing season by peak vegetation indices, and growing season length or duration of greenness (LOS) (de Beurs et al., 2010). Studies of LSP in the Appalachian Trail corridor for the 25 years between 1982 and 2006 reveal trends of 2.6 days delay for SOS and 9.7 days delay for EOS, respectively. The trend of delayed EOS was more evident for the sections within the northern provinces of ecosystem regions, e.g., in the Adirondack-New England Mixed Forest-Coniferous Forest-Alpine Meadow Province than that within the Central Appalachian Broadleaf Forest–Coniferous Forest–Meadow Province in the south (**Figure 6.3**). For the corridor area from 39°N north, the SOS shows a trend of advances over three days in the period between 1982 and 1998 and delayed over two days in the later period between 1999 and 2006, respectively. The trend of EOS was delayed over seven days between 1982 and 1998 and delayed more for the 25 years between 1982 and 2006.

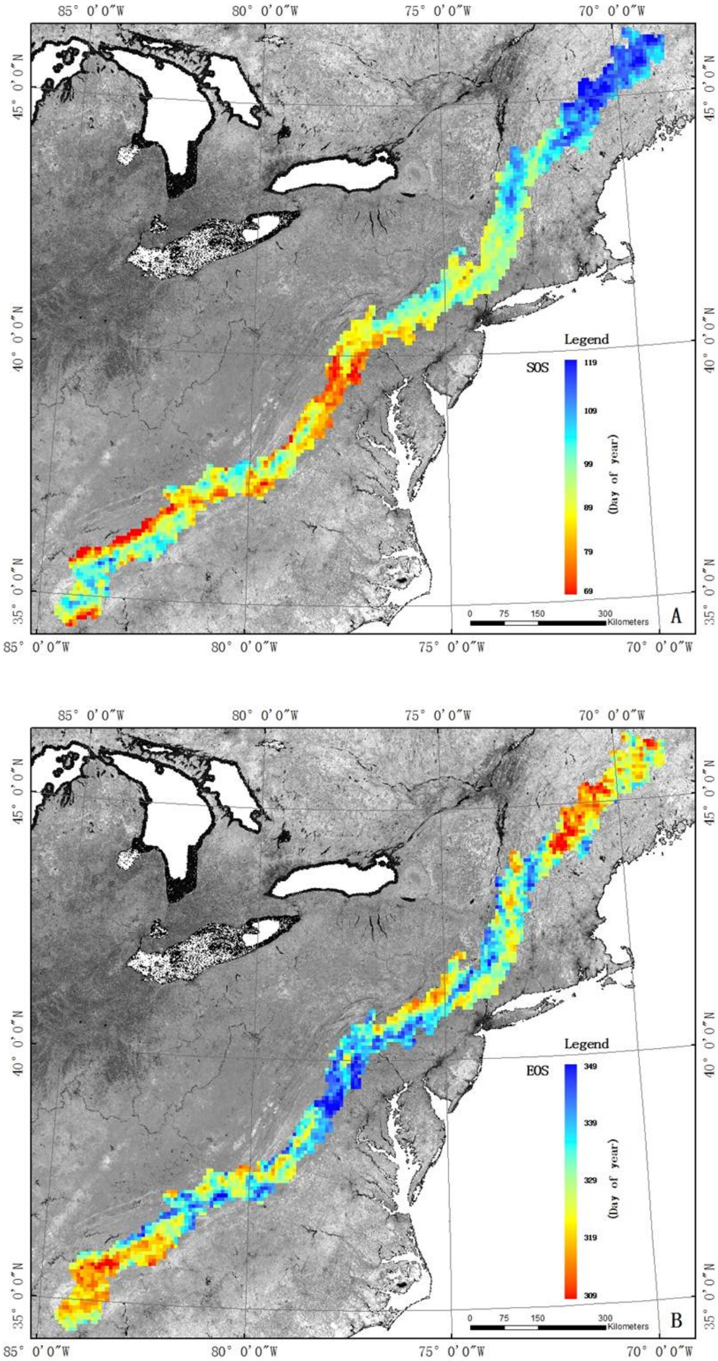

Figure 6.3. This figure illustrates the spatial distribution of SOS (a) and EOS (b) within the Appalachian Trail corridor area from 1982 to 2006.

Changes in the seasonal distribution of runoff have a great impact on downstream water availability and potentially affect water allocation planning. Although the projected annual runoff does not show a clear trend, the peak in runoff is projected to take place earlier in the year, advancing from April to March by the end of the 21^{st} century for the region as a whole. Also, the cumulative winter runoff is projected to increase, while peak runoff is projected to decrease. This projected change in runoff can be attributed to increased winter snowmelt caused by higher temperatures and increased winter rainfall (Hashimoto et al., 2011).

The outcome of this case study provides information and insights about the effects of climate change along the ridges of Appalachian Mountains in the eastern United States. The data and scientific conclusions are being adopted and imbedded into an Internet-based decision support system (DSS) for monitoring, reporting and forecasting ecological conditions of the Appalachian Trail.

The purpose of the Appalachian Trail Decision support System (A.T.-DSS) is to improve the decision-making system that exists between the Appalachian Trail Park Office, the Appalachian Trail Conservancy, the National Park Service and the U.S. Forest Service, and to provide a means to convey meaningful information to the American public. The Appalachian Trail along the ridges of the Appalachian Mountains encompasses ecotones that are the transition areas and/or the tension between ecosystems. Ecotones are composed of species from adjacent communities with high biodiversity. Ecotone areas are most sensitive to climate and ecological changes and should be a monitoring attention. The A.T.-DSS integrates multi-platform sensor data, TOPS models, and *in situ* measurements to address identified natural resource priorities and improve resource management decisions for conservation of biodiversity. The objectives of the decision support system include developing a comprehensive set of seamless indicator data layers that are consistent with the Appalachian Trail Vital Signs. The *Vital Signs* are considered as the “key” to monitoring the long-term ecosystem health of the Appalachian region (Shriver et al., 2009).Vital signs are defined as a subset of physical, chemical, and biological elements and processes that represent the overall health or condition of different natural resources. A.T.-DSS targeted three primary vital signs of *Phenology and Climate Change*; *Forest Health*; and *Landscape Dynamics* for data development and modeling. For example, Tree of Heaven (*Ailanthu altissima*) is a wide-spread fast growing deciduous invasive species and a concern of the Appalachian Trail area. The A.T.-DSS incorporates habitat suitability and the risk analysis by integration of *in situ* observations from Forest Service Forest Inventory and Analysis data, remote sensing and modeling-derived indicator data layers and other geospatial data as a prototype of system applications.

The Internet-based A.T.-DSS (http://www.edc.uri.edu/ATMT-DSS/) allows users and decision makers to build a comprehensive understanding of the current status and trends in terms of driving factors and responsive conditions, and helps to characterize habitat condition and primary drivers for simulation and prediction exercises. The visualization and implementation provide effective tools for accessing remote sensing and geospatial data and research conclusions to improve understanding of the changing Appalachian Trail environments (Wang et al., 2010).

Among the toolsets, the *Mapping Viewer* is an ArcGIS interactive mapping tool that allows users to pan or zoom to areas of interest, turn data layers on/off, and display the output of spatial queries. Specific tools were added to the viewer to aid in decision-making, such as the time-series slider for visualizing land-cover change and dynamics of the landscape, elevation surface profile mapping, and habitat conditions effects of climate change. The *Mapping Viewer* was developed using the ArcGIS Flex viewer. The software is fully customizable and easily allows system users to develop new visualization or analysis tools as priorities change. The *Viewshed* toolset provides a suite of on-line visualization tools that allow users to investigate the viewsheds of landscape patterns and land cover types. This suite of visualization tools also incorporates real-time data to inform system users of current conditions within the trail region, such as weather (NOAA) and possible fires (NASA MODIS). The *Reporting and Forecasting* interfaces provide summaries of the vital sign indicators under the categories of phenology and climate, forest health, and landscape dynamics for the past, present, and future. The *Data Download* interfaces allow users to select data for local processing, analysis and mapping.

Remote Sensing Based Indicators

The daily synoptic global view of the Earth has transformed Earth studies and exposes dynamics at all accessible spatial and temporal scales, even in remote areas. The diverse geography and varied levels of urbanization in the Northeast region calls for a well formulated strategy to quantify the magnitude of climate dynamics and climate related occurrences. Satellite climate data records (CDRs) possess the necessary metrics to enable reasonably credible climate monitoring and provide copious information for both the decisions makers who are accountable for the status and fate of our environment as well as the innovators who aspire to unearth the fortune that nature provides society. According to a National Academies of Science report, a CDR is defined as "a time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change" [NRC 2004]. Further, that same report distinguishes a satellite based Fundamental CDR (FCDR) that represents the kernel of the information presented by a calibrated and quality controlled sensor (e.g. the integrated power within a certain spectral range) from a satellite based Thematic CDR (TCDR) which is a geophysical variable derived from the FCDR by applying an algorithm on the FCDR (e.g. sea surface temperature.)

Satellite observations often reveal that seemingly simple phenomena and processes are more complex than previously understood. This exemplifies the benefits of multiple synergistic observations, including in situ, orbital, and suborbital measurements, coupled to dynamical models. A number of ground based observations and observation products, using both remote and in situ techniques, provide a complementary set of information to decision makers and innovators. Satellite TCDRs are often generated by blending satellite observations, in situ data, and model output. Combining satellite CDRs and ground based CDRs have been a useful method to allow for cross validation between various measurement platforms. In addition, the use of CDRs for validating historical instances of climate models is necessary for proper model testing and training, and helps enhance the precision (quantifies the uncertainty) of the models future projections, as mentioned in the climate modeling sections of the report. Throughout the climate assessment report, the use of the word "monitor" might be loosely associated with an FCDR and similarly, the word "indicator" may sometimes be thought of as analogous to a TCDR.

Global Climate Observing System (GCOS) provides a list of sustained global observations of established Essential Climate Variables (ECVs) in the atmosphere, ocean, and land. The **Table 6.1.** below shows the list of variables that are currently measured by several satellite based programs by NASA, NOAA and European agencies. Some of these variables are the subjects of current on-going research, but are not currently ready for global implementation on a systematic basis.

Table 6.1. List of sustained global satellite based program of Essential Climate Variables (ECVs) in the atmosphere, ocean, and land.

Domain	Essential Climate Variables	Satellite based Programs
Atmospheric (over land, sea and ice)	Precipitation	TRMM, GPCP, CMAP
	Earth radiation budget (including solar irradiance)	CERES, ERBE, GEWEX, ISCCP.
	Upper-air temperature, Water vapor	AIRS, AMSU-A
	Cloud properties	CloudSat, MODIS, MISR, and HIRS.
	Ozone	TOMS, SBUV, GOMOS, MIPAS and SCIAMACHY
	Carbon dioxide and Methane	AIRS, MOPITT, GOSAT
	Aerosol properties	MODIS, MISR, AERONET
	Wind speed and direction	SSM/I, AMSR-E, QuikSCAT, ASCAT.
Oceanic	Sea-surface temperature	AVHRR, MODIS, and AMSR-E
	Sea-surface salinity.	SMOS, SMAP (2015 launch date)
	Sea Ice	AMSR-E, SSM/I, AVHRR, MODIS, MISR, QuikSCAT
	Sea level	TOPEX and Jason
Terrestrial	Ground water	GRACE
	Glaciers and ice caps	ICESat
	Snow cover	AMSR-E, MODIS, AVHRR
	Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (FAPAR), Leaf area index (LAI) and Biomass	AVHRR, MODIS, MERIS
	Fire disturbance	MODIS
	Soil moisture	AMSR-E, ASCAT, SMOS

TRMM - Tropical Rainfall Measuring Mission, GPCP - Global Precipitation Climatology Project, NOAA-CMAP - Merged Analysis of Precipitation, CERES - Clouds and the Earth's Radiant Energy System, ERBE - Earth Radiation Budget Experiment, GEWEX - Radiation Flux Assessment (NASA/ASDC), ISCCP - International Satellite Cloud Climatology Project, AMSU-A - Advanced Microwave Sounding Unit, AIRS - The Atmospheric Infrared Sounder, MODIS - Moderate Resolution Imaging Spectro-Radiometer, MISR- Multi-angle Imaging Spectro-Radiometer, HIRS - The High-resolution Infrared Radiation Sounder, TOMS - Total Ozone Mapping Spectrometer, SBUV - solar backscattered ultraviolet, GOMOS – Global Ozone Monitoring by Occultation of Stars, MIPAS - Michelson Interferometer for Passive Atmospheric Sounding, SCIAMACHY - Scanning Imaging Absorption Spectrometer for Atmospheric CHartographY, MOPITT - Measurements of Pollution in the Troposphere, GOSAT - Greenhouse Gases Observing Satellite, ASCAT - Advanced Scatterometer, AMSR-E - Advanced Microwave Scanning Radiometer-EOS, SSM/I - Special Sensor Microwave Imager, SMOS - Soil Moisture and Ocean Salinity Satellite, SMAP - Soil Moisture Active Passive Satellite, GRACE - Gravity Recovery And Climate Experiment.

Carbon dioxide (CO_2)

Carbon dioxide (CO_2) is a greenhouse gas, released through human activities such as deforestation, burning fossil fuels, and natural processes such as respiration and volcanic eruptions. Knowledge of temporal variations of carbon sources and sinks are essential for estimating the radiative forcing and understanding Earth's climate and global change. **Figure 6.4** shows time series of monthly variation of CO_2 in parts per million (ppmv) measured using Atmospheric Infrared Sounder (AIRS) at an altitude range of 3-13 kilometers (1.9 to 8 miles) in Northeastern region of U.S. increase by 2 ppmv per year (http://aqua.nasa.gov).

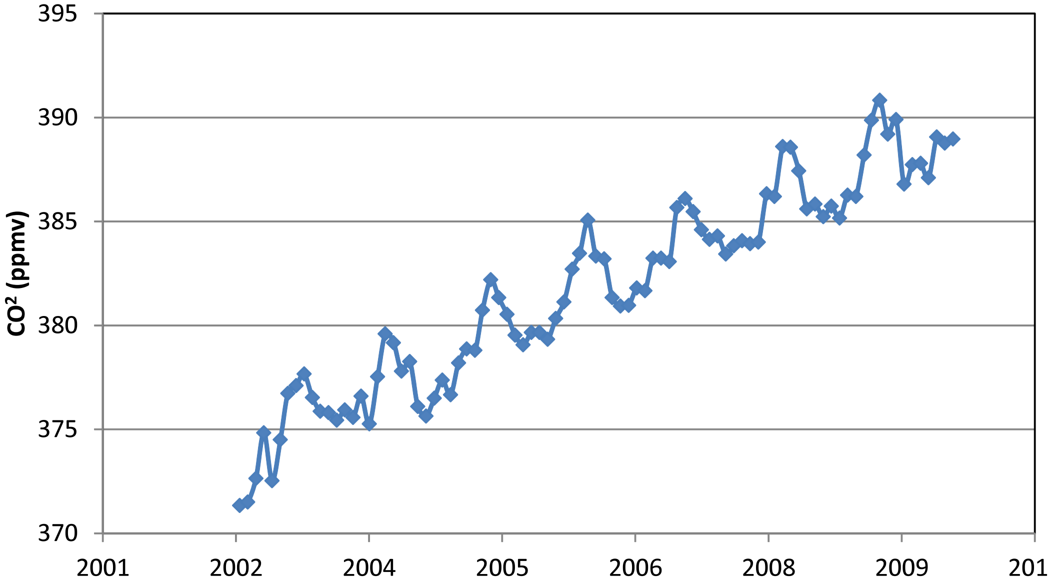

Figure 6.4 Time Series of monthly variation in mid tropospheric carbon dioxide in Northeastern USA measured by AIRS on Aqua satellite. (Data source: http://climate.nasa.gov/keyIndicators)

Snow Cover Extent

Rain-on-snow with warm air temperatures accelerates rapid snow-melt, which is responsible for the majority of the spring floods. Snow-cover extent is produced daily by NOAA using remote sensing satellites in the visible and near infrared part of spectrum (**Figure 6.5 and 6.6**). Further, studies reported that the reduction on snow cover extent and total number of days with snow on the ground for a given year is due to both snowfall amounts and temperature fluctuations. The snow on ground measured at Northeast stations were on average 16 fewer days in 2001 than in 1970, which is consistent with increase in temperature in study area (Burakowski et al 2008).

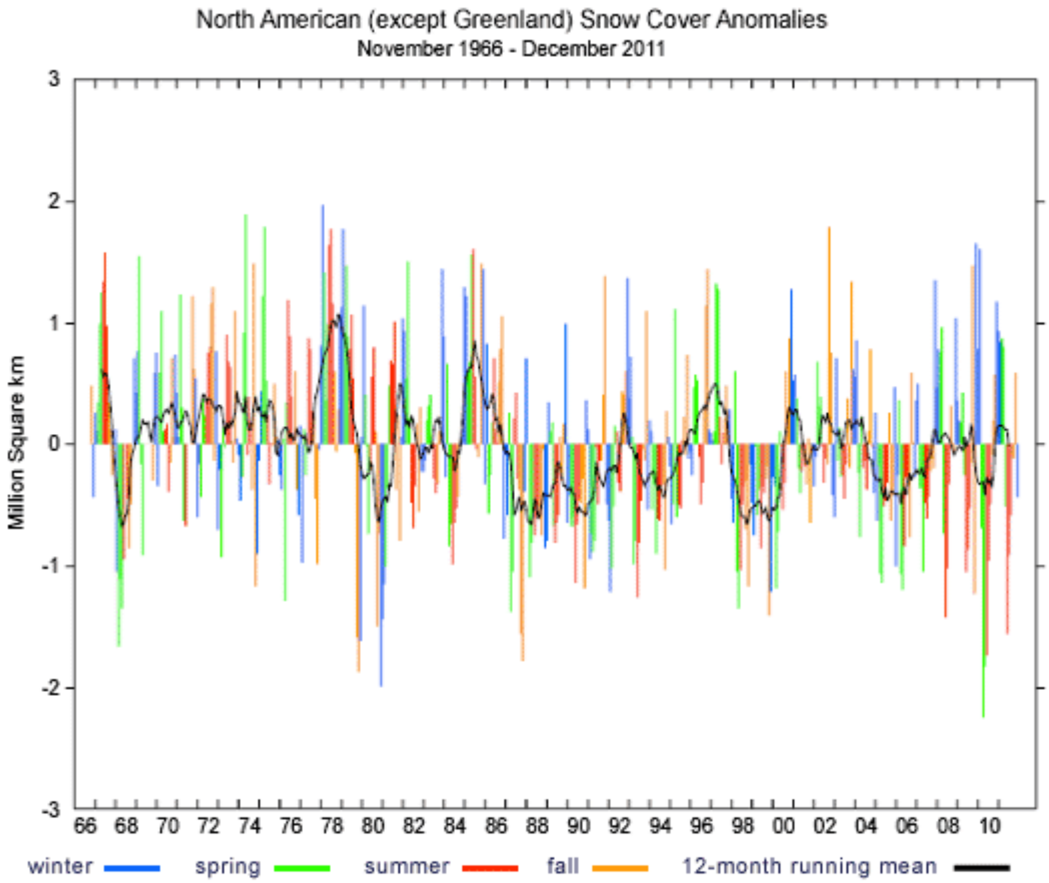

Figure 6.5. Timeseries of monthly snow cover anomalies observed by satellite data for North America. (Source: http://climate.rutgers.edu/snowcover)

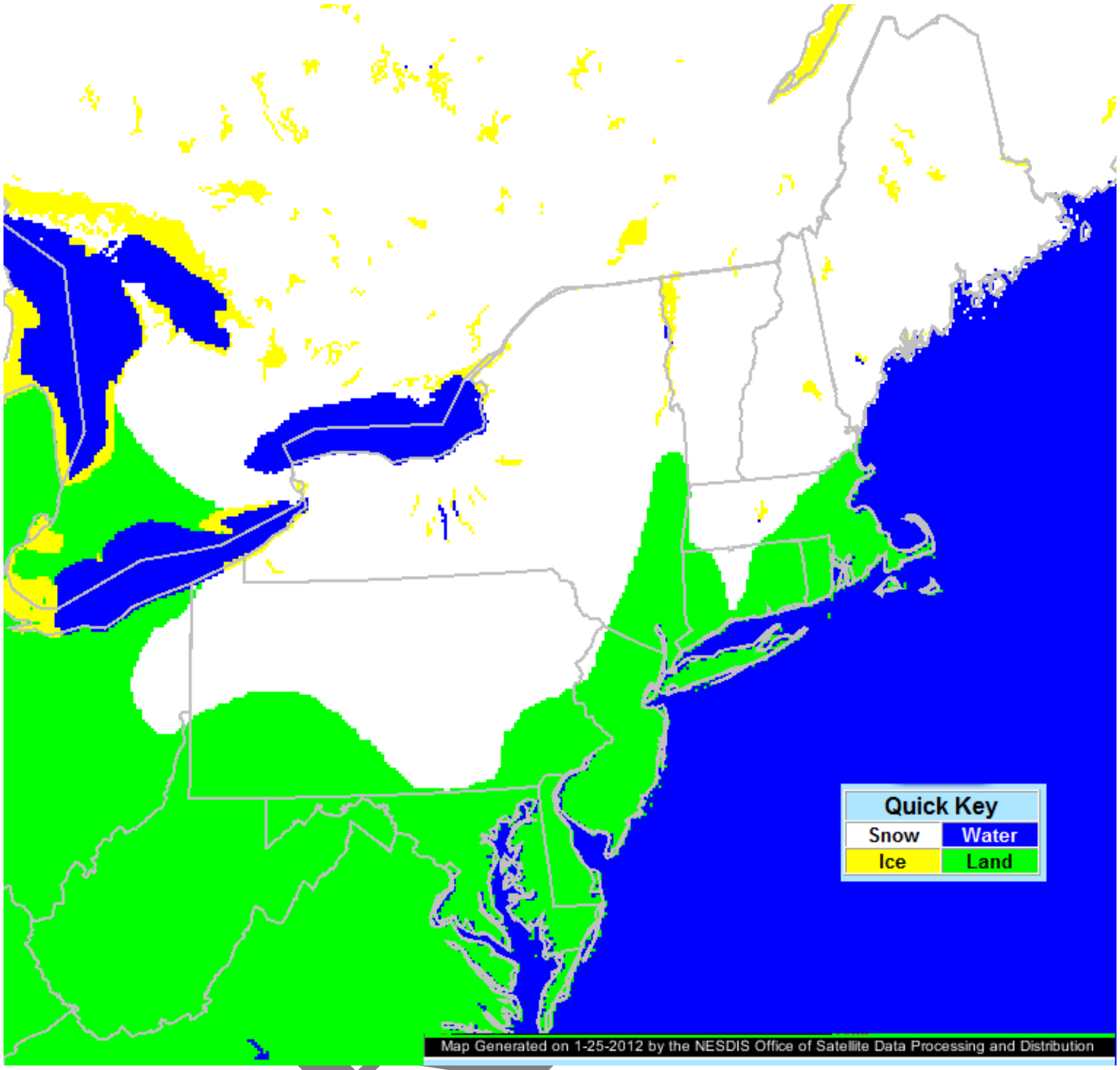

Figure 6.6. NOAA-Interactive Snow Cover Maps produced daily using visible/Infrared and microwave remote data. (Source: http://www.natice.noaa.gov/ims)

Sea level

The continuous increase in global land and ocean temperature is responsible to continues increase in the mean sea level. **Error! Reference source not found.**Since 1993, TOPEX and Jason series of satellite radar altimeters measured the global mean sea level (**Figure 6.7**) satellite measured sea level data are continuously calibrated with tide gauges. Studies from individual tide gauge records shows that northeastern coastal area will observe larger decadal variability originates from North Atlantic wind forcing (Kolker and Hameed 2007).

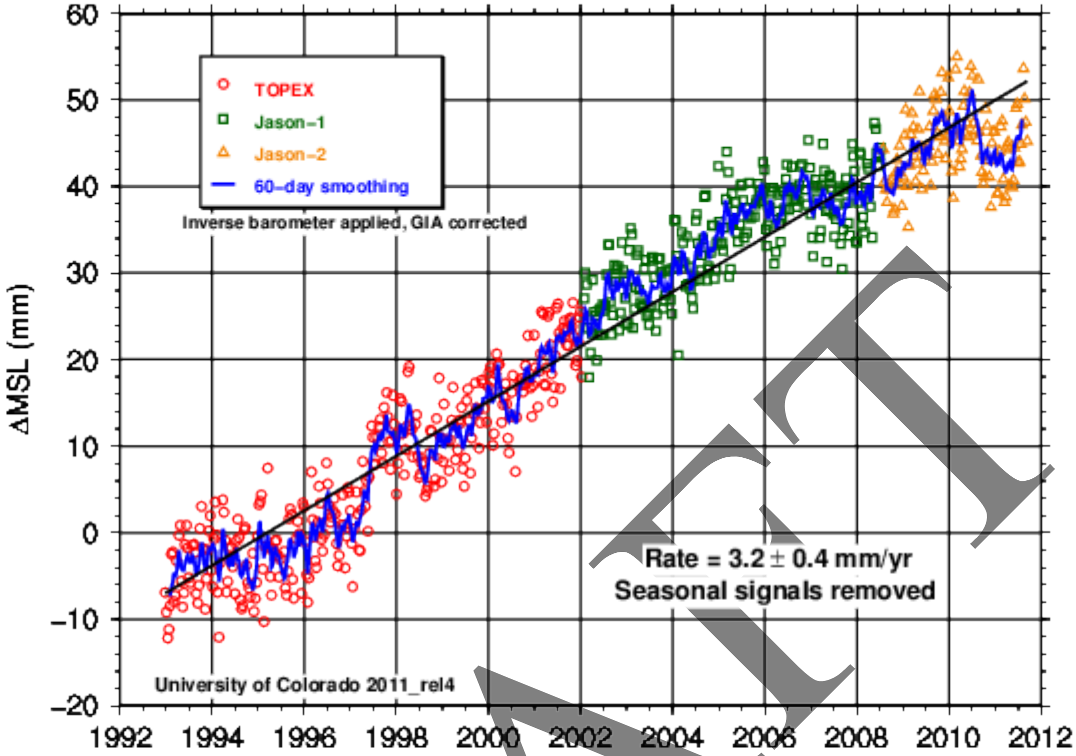

Figure 6.7. Time series of change in annual mean sea level measurements from the TOPEX and Jason series of satellite radar altimeters (Source: http://sealevel.colorado.edu)

Climate Extreme Index

Karl et al. (1996) proposed U.S. Climate Extremes Index (CEI) based on an aggregate set of conventional climate extreme indicators includes: monthly maximum and minimum temperature, daily precipitation, monthly Palmer Drought Severity Index (PDSI), and landfalling tropical storm and hurricane wind velocity. Over the most recent 10-yr period (2000–2010), there has been considerable year-to-year variability in the percent of the United States affected by extremes, with 5 of the 15 most extreme years on record occurring since 1997 (**Figure 6.8**). Extremes in 1-day precipitation have been above the expected value of 10% in 10 of the 12 years over the period 1995–2006. In 2011, CEI was significantly higher in due to above normal warm temperature and flood events compared to other part of United States. United States climate has been getting more extreme since 1970.

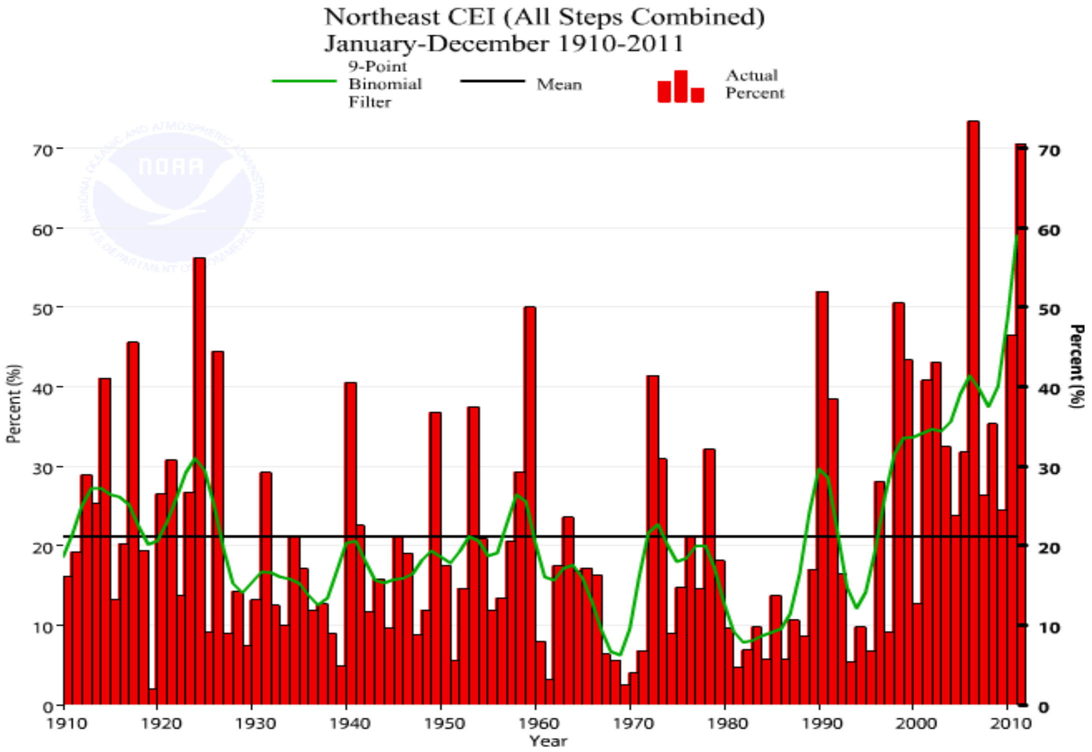

Figure 3.8. The Climate Extreme Index for Northeast region. (Source: http://www.ncdc.noaa.gov/extremes/cei/)

Severe Storms

Figure 6.9 shows a MODIS satellite image during the August 28, 2012 passing of Hurricane Irene over the eastern seaboard alongside **Figure 6.10** showing the horizontal wind speed and direction wind barb plot of the vertical wind profile as recorded by the CCNY radar wind profiler on that same day. This is just another example how satellite imagery, when combined with ground based remote sensing monitoring, provides enhanced situational awareness of extreme events as they happen in real time. Such monitoring capabilities are useful for defining the need and magnitude of importance of climate change adaptation strategies.

Figure 6.9. MODIS image Aug 28 2011 – Hurricane IRENE passing over NYC.

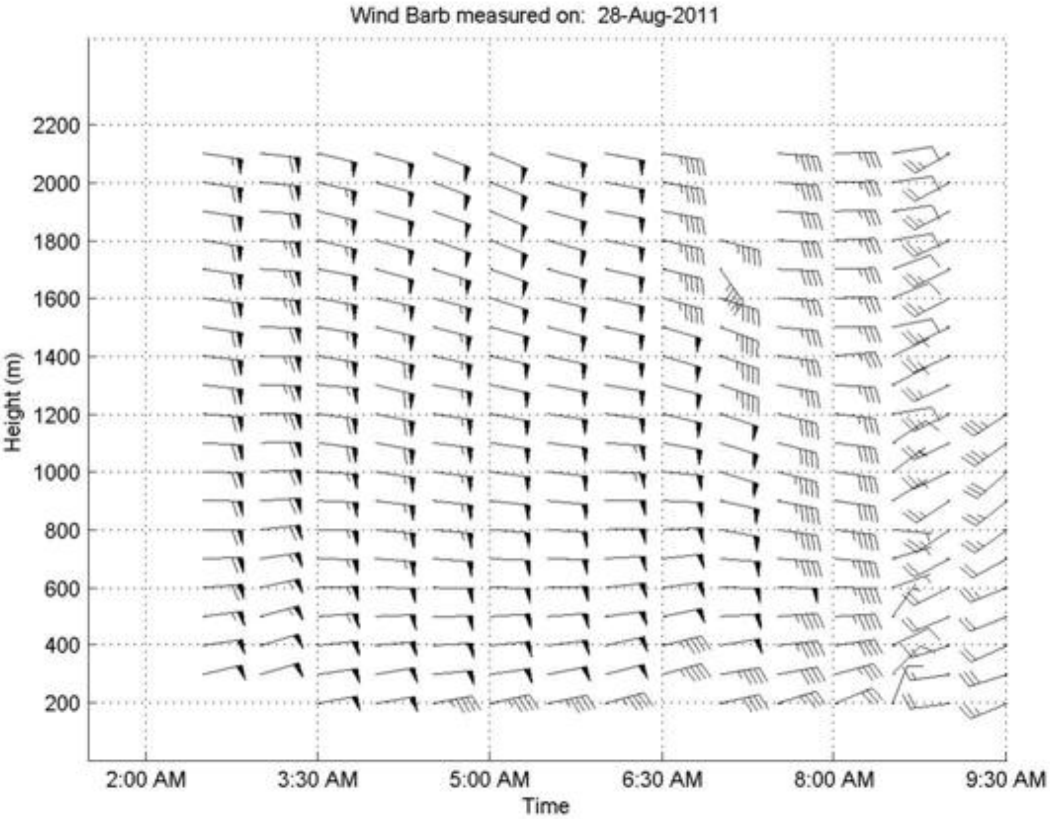

Figure 6.10. CREST/CCNY Radar Wind Profiler Aug 28 2011.

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Acknowledgements

The following authors contributed to the ***'Climate Change Impacts on Ecosystem Dynamics along the Appalachian Trail'*** piece in this section. Hirofumi Hashimoto (NASA Ames Research Center), and Jianjun Zhao, Peter August, Roland Duhaime, Christopher Damon, and John Clark (all from the University of Rhode Island)

6.5 The Law as a Tool for Adaptation

Lead Authors - Scott Schwarz, Robi Schlaff, and Joe Siegel

To meet the climate change challenge, decision makers require well-grounded technical information as well as the will to take actions to protect people, their accompanying infrastrucutre and natural resources from harms way. The ability to take action based on new technical information is often dependent on both existing and new laws and regulations. In some situations, the law can be a tool to implement adaptation strategies. In other situations, the law can present barriers to action. As data gaps are filled and the best available data is brought to bear at decision points through an adaptive management approach, legal tools should also be evaluated to determine the extent to which they can support assessment and implementation of strategies. Legal tools tend to focus more on implementation rather than assessment, and , as our first section illustrates, legal authority has been the stimulus to get the ball rolling in many states.

Enabling Authorities for State and Local Adaptation Planning

As an important first step in gathering information for decision makers to begin planning, statewide adaptation plans have been directed by state legislative or executive orders. These plans include recommended actions, including changes to laws, regulations and codes for implementation on local, state and national levels. Mechanisms to enact proposals include home rule, local or state agency or statewide directives. Efforts have been funded by foundation and government grants, general funds or have been directed as part of an agency's work product. States have prepared comprehensive State Adaptation Plans (**Table 6.2**) pursuant to the authority provided by enabling legislation and executive orders.

Table 6.2. Examples of state adaptation planning

State	Example of State Adaptation Planning
New Hampshire	Chapter 3: Adapting to Change in *New Hampshire Climate Action Plan* (New Hampshire Climate Change Policy Task Force, 2009)
Pennsylvania	Pennsylvania Climate Adaptation Planning Report: Risks and Recommendations (PADEP, 2011)
New York	Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation (Rosenzweig et al., 2011) New York State Sea Level Rise Task Force (2010) New York State Climate Action Plan (2010)

In addition to State Adaptation Plans, there are also State Climate Change Acts (**Table 6.3**):

Table 6.3. State Climate Change Acts

State	State Climate Change Act
Connecticut	Conn. Gen. Stat, Ch. 446c §§ 22a-200-22a-201c.
Maine	38 Maine R. Stat. Ann. ch. 3-A, §§ 574–579
Massachusetts	2008 Mass. Acts Ch. 298, codified as amended throughout Ch. 21 of the General Law.
New Hampshire	No single law, Executive Order ordered development of a plan
Rhode Island	R.I Gen. Laws §§ 23-84-1 to 23-84-3.
Vermont	2008 Vt. Acts & Resolves 209, codified as amended throughout the Vermont Statutes.
New Jersey	NJ 26:2C-37 - 26:2C-44
Pennsylvania	71 P.S. §§ 1361.1-1361.8

Many earlier reports focused mainly on mitigation of greenhouse gases with targeted reductions tied to a future year (for example New York's 80% reduction of greenhouse gases by the year 2050.), but states are beginning to include adaptation planning in their enabling authorities and planning efforts. One example is Rhode Island's Climate Risk Reduction Act of 2010, which established a commission to study the projected impacts of climate change, to identify and report methods of adapting to these climate change impacts in order to reduce likely harm and increase economic and ecosystem sustainability, and to identify potential mechanisms to mainstream climate adaptation into existing state and municipal programs including, but not limited to, policies plans, infrastructure development and maintenance)

Local governments also have prepared climate adaptation plans under the authority of local laws, ordinance and executive orders. Climate adaptation planning at the local level has ranged from stand-alone comprehensive climate adaptation plans to consideration of climate adaptation as a part of local comprehensive plans, district master plans, and long-term capital improvement plans. The U.S. Sustainability Directors Network has established a Climate Change Adaptation User Group for the purpose of allowing local governments to collaborate and work together to advance adaptation progress at the local level.

A 2011 report prepared by Columbia University for the City of Philadelphia is an example of a comprehensive look at climate impacts and solutions, and examines adaptation plans created for other cities.[53] Many other municipalities have also developed adaptation plans which serve as good examples of local climate adaptation planning (**Table 6.4**):

Table 6.4. Examples of local adaptation planning

Municipality	Plan
Keene, New Hampshire	(City of Keene, 2007)
Lewes, Delaware	(City of Lewes, 2011)
Philadelphia, Pennsylvania	(Philadelphia Industrial Development Corporation, 2011)

Existing Statutes, Ordinances, and Regulations

Table 6.5 summarizes some climate adaptation measures taken by local governments through ordinances and regulations.

Table 6.5. Adaptation measures taken by local governments

Type of Ordinance or Rule	**Adaptation Feature of Ordinance or Rule**
Zoning or Zoning Overlay; Comprehensive Plans; Floodplain Regulations; Setbacks/Buffers; Rebuilding Restrictions	(1) Improve emergency response capability (2) Reduce cost of replacing and repairing infrastructure and buildings after extreme weather events
Conditional Development and Exactations	
Subdivision and Cluster Development	
Hard and Soft Armoring Permits	
Rolling Coastal Management/Rolling Easement Ordinances	
Green Building Ordinances; Building Codes; Ordinances or Design Standards adopting standards of associations	(1) lower energy use creates less demand on the grid during extreme heat; (2) increase ability of buildings to withstand extreme weather events (3) better insulated buildings reduce public health risk from heat and cold
Street Tree Ordinances;	(1) Reduce stormwater water runoff and vulnerability to

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[53] Available online at: http://www.earth.columbia.edu/sitefiles/file/education/capstone/fall2011/Climate%20Change%20Adaptation%20A%20Framework%20for%20the%20City%20of%20Philadeplia_FINAL.pdf

Open Space Ordinances; Cool Roof Ordinances; Cool Pavement Ordinances; Green Roof Ordinances	flooding (2) Counteract urban heat island impacts
Water Conservation Ordinances	(1) More water available during droughts (2) lower energy use results from lower water use

Examples of climate adaptation involving the use of technical design and engineering standards by specific departments of local governments, such as water departments and airports, include the following:

- New York City Panel on Climate Change: Chapter 5 of the New York City Panel on Climate Change 2010 Report (Sussman et al., 2010) examines federal, state and local environmental laws and regulations relevant to climate adaptation efforts in New York City.

- City of Philadelphia: Division of Aviation's 2010 report, *Climate Change: Impacts and Adaptation Strategies for Philadelphia International Airport* includes excerpts from the LAWA[54] guidelines that outline performance standards of airport projects related to climate change adaptation planning.

- New York City Department of Environmental Protection (NYCDEP 2008), Climate Change Program, *Assessment and Action Plan*, May 2008.

- Green Building Ordinances: Columbia University Law School's Center for Climate Change Law has drafted model ordinances for green buildings.[55]

Regulatory and Permitting

Regulation and permitting are very useful tools to protect against climate impacts. As the implementation components of larger laws, they become the way things get done on the ground affecting the public most directly. Many of these serve not only to create more climate resilience, but have an added benefit of reducing GHG's.

For example, the New York City Green Stormwater Infrastructure (NYCDEP, 2006) program is an innovative and climate sensitive mechanism for complying with the Federal Clean Water Act.

Another example is Philadelphia's Green City, Clean Waters Plan (Philadelphia Water Department, 2011) – a 25-year plan to protect and enhance the City's watersheds by

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[54] Available online at http://www.lawa.org/uploadedFiles/LAWA/pdf/LSAG%20Version%205.0%20021510.pdf

[55] Available online at: http://www.law.columbia.edu/centers/climatechange/resources/municipal

managing stormwater with innovative green infrastructure pursuant to a June 2011 Consent Order and Agreement between the City and PADEP.

Specific features of these plans include:

- The components of the plan that cover implementation of green stormwater infrastructure to manage runoff strongly tie to adaptation: tree trenches, green roofs, rain gardens as well as initiatives like Green Streets, Green Alleys, and Green Parking.
- Restoring streams and setting controls to maintain water quality standards strengthen the City's resilience during times of drought, when quality and supply are critical.
- The plan also supports adaptation planning for other climate issues like urban heat island effect and energy efficiency.

Federal Authorities

There are numerous federal statutes and regulations that could be used as tools in adaptation planning. Federal Government agencies are beginning to recognize the need to identify legal opportunities and the responsibility to carry out adaptation planning, and they are urging staff to consult with their legal offices about adaptation. (US EPA, 2011) This is consistent with recommendations of a federal adaptation task force[56] and implementing instructions of the Council on Environmental Quality[57], both required by E.O. 13514, Federal Leadership in Environmental, Energy, and Economic Performance. The recommendations of the task force repeatedly stress the importance of coalitions that intersect state, local, regional, and tribal governance structures. Building partnerships that incorporate all levels of governance promote efficiency in implementation and eliminate possible redundancies. Leveraging federal laws in such partnerships can make adaptation planning more effective at the state and local level. [58]

Potential opportunities under existing federal authorities include the National Environmental Policy Act,[59] which could be a vehicle for incorporating adaptation planning into federal government decision-making. (CEQ, 2010) The Rivers and Harbors Act[60] could provide authority to require property owners to remove seawalls and armoring devices as sea levels rise, assuming abandonment is considered a desirable approach in the region. (Rinder, 2011) The Coastal Zone Management Act requires states to anticipate and plan for the serious adverse

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[56] Progress report available at: http://www.whitehouse.gov/sites/default/files/microsites/ceq/Interagency-Climate-Change-Adaptation-Progress-Report.pdf

[57] http://www.whitehouse.gov/sites/default/files/microsites/ceq/adaptation_final_implementing_instructions_3_3.pdf

[58] From the above Progress Report.

[59] 42 U.S.C. §§4321 *et seq.*

[60] 33 U.S.C. § 403 (2006).

effects of climate change-related sea level rise in their coastal management programs.[61] Regulations promulgated under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) to effectuate remedy selection under Section 121 require assessment of the long term reliability of remedial measures[62]. These and other federal statutes that present opportunities for adaptation planning are referenced in a NOAA Planning Guide for State Coastal Managers.(NOAA)

In addition to using federal authorities to require consideration of adaptation in federal actions, there may be grant and funding opportunities under some of the federal statutes for the study of and response to climate change impacts. For example, Section 104 of the Clean Water Act can be invoked to provide grant money for research and studies.[63] Funding for technical assistance for habitat restoration projects may be available under the Estuary Restoration Act.[64] Many other federal statutes provide the opportunity for adaptation-related funding.

Barriers/Challenges

While the law can sometimes present opportunities for adaptation planning, it can also be a barrier. Many laws were enacted or promulgated before climate change impacts and adaptation planning were considerations for many government authorities. Without amendment to existing legislation, regulations, and local ordinances, the law could impede earnest efforts to adapt even where widespread agreement exists. Examples of strategies to overcome legal obstacles, absent amendment of existing laws, have begun to emerge in the Northeast region.

The Georgetown Climate Center (Center) considered legal barriers in a project it undertook to develop a model sea level rise overlay zone for local governments in Maryland. Among the potential barriers identified in the report issued by the Center were the Americans with Disabilities Act (ADA) and historic preservation laws. (Grannis et al., 2011) Elevating buildings to prepare for sea level rise could conflict with accessibility requirements under the ADA. While some property owners will qualify for exemptions under the ADA, others will not. Therefore, the Report recommends that policymakers consider flood-proofing options and possibly relocation as alternatives to building elevation in flood-prone locations· Historic preservation laws in Maryland are administered at the local level and can limit elevation requirements and rebuilding restrictions intended to address sea level rise. (Grannis et al., 2011) One option, identified in the Center's Report, to overcome the limiting effect of the historic preservation laws, is instituting a state program that provides incentives for elevation and relocation of historic properties and instructions for homeowners on local appropriateness and elevation plan reviews. (Grannis et al., 2011)

Legal barriers to adaptation planning may be found not only in statutes and regulations but also in court-entered consent decrees or other legally binding agreements. The City of New York is

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[61] 16 U.S.C. § 1451

[62] 40 C.F.R. §300.430(e)(9)(iii)(C).

[63] Section 104 of the Clean Water Act, 33 U.S.C. § 1254

[64] Section 109, Estuary Restoration Act

amending an existing Order on Consent to include green infrastructure improvements which will reduce Combined Sewer Overflows (CSO's).(NYCDEC, 2011) CSOs are discharges that occur when wet weather flows exceed the capacity of combined sewer systems and/or the water pollution control plants they serve. A 2005 Order on Consent included significant gray infrastructure requirements such as installation of "CSO storage facilities, sewer, pumping station, regulator, and interceptor improvements." (NYSDEC, 2011) The 2005 Order did not include green infrastructure improvements, which can be a useful adaptation response in the Northeast given the projections for increased extreme rainfall events in the region. Although not explicitly labeled as an adaptation strategy, the parties to the 2005 Order renegotiated a new Order on Consent with green infrastructure provisions rather than remaining locked into the 2005 Order. The amended Order on Consent will result in green infrastructure projects worth up to $187,000,000. (NYC, 2010)

A less subtle option for overcoming a legal barrier is outright waiver of permit requirements following extreme weather events to expedite emergency efforts to protect life and property. In the wake of Hurricane Irene, New York Governor Andrew M. Cuomo announced a waiver of environmental permit requirements to speed emergency repairs and stabilization of waterfronts, roads and bridges. (Cuomo, 2011) Although permitting was suspended, emergency workers were encouraged to consult with the New York State Department of Environmental Conservation to minimize adverse impact to natural resources. (Cuomo, 2011) The efficacy of this approach was questioned by environmental groups after noting that the permit waivers led to actions that caused "serious long-term damage" to fish and wildlife and, in the future, will result in river water moving more swiftly and with greater force during climate-change induced extreme precipitation events. (Adirondack Council, 2011)

Home Rule and Lack of Cross-Jurisdictional Authority

Some states in the Northeast Region, such as a number of the New England states, New York, Pennsylvania and Maryland, operate under a form of "home rule" in which the states have legislatively granted authority to towns to pass laws and ordinances (Stultz and Pagach, 2011). As a result, most land use decisions are made at the local level, by town boards, planning boards, and zoning commissions. While States retain certain authorities, for example, permitting below the high tide line in Connecticut, coordination of adaptation strategies can be difficult given the disparate array of local laws. (Stultz and Pagach, 2011)The challenges become even greater when multi-state action is necessary for adaptation planning. The Long Island Sound Study, ICLEI-Local Governments for Sustainability USA (ICLEI) and the Connecticut Department of Environmental Protection (CT DEP) partnered with the town of Groton, Connecticut to analyze how federal, state, and local stakeholders could collaborate to enhance resilience at the local level. (Stultz and Pagach, 2011) One of the lessons learned in the Groton study was that collaboration by local government with nearby municipalities, regional organizations, and at the state level can more effectively achieve the community's resilience goals.

Regulatory Takings

Regulators must be mindful of the regulatory takings doctrine.[65] Strategies to avoid regulatory takings include basing government decisions on sound science and avoiding imposition of gratuitous or sudden losses on landowners.(Byrne and Grannis, 2012) Among other strategies to avoid a regulatory taking, government authorities can also adopt and conform to a comprehensive plan, regulate similarly situated properties in the same way, and conduct careful and appropriate mini-NEPA analyses. In the Northeast, state and local governments, academic institutions, and others have begun to consider how to avoid regulatory takings when planning for adaptation.(Pace Land Use Law Center, 2011)

The next section covers insurance, reinsurance and other financial incentives, a topic that overlaps with legal issues. For example, there is a new requirement from insurance commissioners in the states of California, New York and Washington State mandating that companies disclose how they intend to respond to the risks their businesses and customers face from increasingly severe storms and wildfires, rising sea levels and other consequences of climate change.

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[65] The Fifth Amendment to the United States Constitution prohibits taking private property for public use without just compensation. U.S. Const. amend. V. In addition, state constitutions prohibit regulatory takings.

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6.6 Insurance, Reinsurance, and Other Financial Incentives

Lead Author - Lindene Patton

Introduction

Insurance, reinsurance, and other financial incentives can play a meaningful role in addressing the climate change-related risk facing the Northeast. If permitted to operate as a market based tool, insurance has the potential to encourage risk reduction by establishing risk-based pricing signals in the form of premium charges (i.e., riskier behavior or conditions result in higher premiums). Putting a price tag on risks should incentivize communities to move towards greater resiliency. However, insurance is often regulated in a manner that blunts the risk based signal (CBO, 2009)

Further, historical approaches to underwriting and rating of insurance assume that history of risk of loss is an indicator and should be the basis for prediction of future loss. This assumption must be altered in the face of uncertainty presented by climate change (Nicholls and Bruch, 2008). The industry and society at large are experiencing increased losses arising out of severe weather events globally and in the North Eastern US region (Munich RE, 2011). Whether increased losses experienced over time by the insurance industry for severe weather events are caused by natural events, anthropogenic actions, changing demographics, increased concentrations of assets or value of assets placed in harm's way or another cause is somewhat academic, since the impact to society at large, individual asset holders and / or taxpayers in any event is a need to devise a way to pay for these increased losses or find a way to better manage the risks or both. In fact, the insurance industry has taken steps to include some climate change impacts in its natural catastrophe modeling (Bouwer, 2011; RMS, 2011). Similarly, as a result of Congressional Budget Office audits and other market drivers, proposals now in Congress would reform the National Flood Insurance Program (NFIP) to better reflect risk, and Florida is begining to consider options in face of inability to meet expected ex-post financing needs (Glans, 2012; Scism, 2012).

Insurance can be issued by private companies or by government entities or by a combination of actors. Private insurance is largely categorized by its ex-ante financing structure - e.g. premiums are collected and managed in a pool in advance of predicted events in amounts sufficient to have sufficient liquidity pay for losses at the time of their occurrence. By contrast, the largest government or public insurance programs, like the NFIP, Florida Citizens Insurance, and the Federal Emergency Management programs are largely based upon ex-post financing structures planning to pay for loss after the event – often redistributing the loss repayment and / or recovery costs to parties who neither suffered loss nor benefitted from the loss payments. In other words, these ex-poste financing programs often place the risk and ultimate cost of loss with parties who have no control over the creation of the risk, management of the risk or recovery of damages caused by the risk. In extreme cases, when the risk of loss is disconnected from all the benefits associated from creating the risk (such as living in a beautiful spot, etc.), a moral hazard often emerges and the risk becomes accretive at a rate inconsistent with the benefit. As the climate and risks associated therewith becomes more extreme, so does this moral hazard. In some cases, the theory of the viability of ex-poste financing is being challenged by economic reality of the imbalance between the risk created (loss cost recovery / repayment needs) and the financial value and viability of the assets or impacted economies themselves (Scism, 2012). In short, when the association between the creation and benefit associated with the risk become too removed from the liability/cost of the risk, the theory of ex-post financing may fail or be rejected by the marketplace or society at large.

As such, it is critical to focus on risk management because neither insurance nor any other financial, engineering, social or political tool can make a bad risk a good risk. Each can only, at best, manage and reduce risk to an optimal engineering, economic and socially efficient pattern. In the face of climate change, the challenge is to determine how each of these tools can be deployed to achieve optimal efficiency in a changing climatic environment.

Investments in physical adaptation measures are important to keep risk transfer premiums affordable and ensure the long-term insurability of climate risks. Local, regional, and national decision-makers will face challenges in mobilizing the requisite financing for both mitigation and adaptation strategies. Utilized appropriately, innovative insurance solutions present a cost-effective way to deal with low probability, high severity weather events, providing a mechanism to finance a disaster before it strikes. Conversely, climate change related response strategies that do not include insurance solutions or discourage true risk-based pricing of insurance mechanisms have the potential to exacerbate climate change exposure in the Northeast and elsewhere for years to come.

Impact of Climate Change on Insured and Uninsured Assets in the Northeast

As discussed elsewhere in this Report, Northeastern communities face mounting challenges (and concomitant costs) of protecting lives and assets against extreme weather and other climate-related risks. These range from more frequent and severe storms, floods, droughts and other natural disasters to sea level rise, crop failures, and water shortages. (*See generally* Sec. 3.2, Baseline Climatology and Observations, Regional Climate Vulnerabilities and Trends Northeast).

Low lying coastal lands are particularly vulnerable. Worldwide, estimates of sea-level rise range from about 4 inches to more than 13 feet during the next century (IPCC, 2007). Data shows that the rise in sea level along the Northeast Coast has accelerated during the 20th century. (*See* Sec. 3.2, Baseline Climatology and Observations, Regional Climate Vulnerabilities and Trends Northeast). Focusing on the New England region, Massachusetts has assumed a 1 to 3 foot rise in its coastal planning recommendations, and the Rhode Island Coastal Resources Management Council amended its coastal program with Section 145 – Climate Change and Sea-level Rise – which anticipates 3 to 5 feet of sea level rise by 2100 (Massachusetts Office of Coastal Zone Management, 2012) Mid-Atlantic states also are planning for significant sea-level rise, with the Maryland Commission on Climate Change basing its Climate Action Plan recommendations on a 1 foot rise in sea level by mid-century and a rise of 2-4 feet by late in the century.[66]

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[66] Maryland Commission on Climate Change, *Comprehensive Assessment of Climate Change Impacts in Maryland*

The concentration of inhabitants and high value assets throughout the Northeast generally presents special challenges from the standpoint of assessing and planning for climate change risk. A recent global screening study conducted by the Organisation for Economic Co-operation and Development (OECD) examined exposure of the world's large port cities to coastal flooding due to storm surge and damage due to high winds, as well as how climate change is likely to impact each port city's exposure to coastal flooding by the 2070s (alongside subsidence and population growth and urbanization). (Nicholls et al., 2007) According to the study, New York/Newark ranks 17th in the world in terms of population exposed to coastal flooding in the 2070s (including both climate change and socioeconomic change). (Nicholls et al., 2007) In terms of assets exposed to coastal flooding in the 2070s, New York/Newark and Virginia Beach rank 3rd and 19th in the world, respectively. (Nicholls et al., 2007)

Communities throughout the Northeast already are wrestling with the impact of flooding and other severe weather events, raising questions in the process about responsibility for related losses.

Box 6.5: Billion Dollar Weather/Climate Disasters (2011)

According to NOAA's National Climatic Data Center, the economic damage costs associated with weather/climate disasters for 2011 alone totals approximately $55 Billion. (NOAA/NCDC, 2011) One major disaster that hit the Northeast region particularly hard was Tropical Storm Lee. The September 2011 storm inflicted wind and flood damage across the Southeast (LA, MS, AL, GA, TN), but considerably more damage was incurred due to record flooding across the Northeast (PA, NY, NJ, CT, VA, MD). (NOAA/NCDC, 2011) Pennsylvania and New York were most affected. Total losses exceeded $1.0 billion; there were also 21 deaths. (NOAA/NCDC, 2011) Another 2011 weather/climate disaster affecting the Northeast, Hurricane Irene, made landfall over coastal NC in August 2011 and moved northward along the Mid-Atlantic Coast (NC, VA, MD, NJ, NY, CT, RI, MA, VT), causing torrential rainfall and flooding across the Northeast. (NOAA/NCDC, 2011) Wind damage in coastal NC, VA, and MD was moderate with considerable damage resulting from falling trees and power lines, while flooding caused extensive flood damage across NJ, NY, and VT. (NOAA/NCDC, 2011) Over seven million homes and businesses lost power during the storm. (NOAA/NCDC, 2011) Numerous tornadoes were also reported in several states, further adding to the damage. Damages/costs from Hurricane Irene exceeded $7.3 billion, and authorities reported at least 45 deaths. (NOAA/NCDC, 2011) Where, as in these cases, private insurance is not available to cover the full range of losses (which is particularly the case when flooding is involved), government insurance programs like the NFIP often are called upon to make up the difference. The sheer magnitude of the losses associated with Tropical Storm Lee and Hurricane Irene have had a significant, negative impact on the fiscal strength of the NFIP. (Berkowitz, 2011)

Many Northeastern assets vulnerable to the effects of climate change are insured. As of 2007, for example, the total value of insured coastal exposure in the Northeast was as follows:

State	Exposure (Billions)
New York	$2,378.9
Massachusetts	$772.8
New Jersey	$635.5
Connecticut	$479.9
Virginia	$158.8
Maine	$146.9
Delaware	$60.6
Rhode Island	$54.1
Maryland	$14.9

Source: AIR Worldwide[67]

Many other Northeastern assets vulnerable to the effects of climate change, however, are not insured. (By way of comparison, the most expensive catastrophe in world history, Hurricane Rita, generated approximately $72.3 Billion in insured losses, while uninsured losses are estimated at $125 Billion).[68] This is due in part to the fact that as insurance providers are dealing with a greater number of claims and suffering greater losses, they are responding in some instances by increasing the cost of coverage, declining to write new policies, or withdrawing coverage altogether. (Nichols and Bruch, 2008) In other cases, individuals simply chose not to purchase insurance.

Insurance Basics

An insurance policy is essentially a promise to provide assistance (subject to the policy's terms and conditions) in exchange for the payment of the premium. The Insurance Risk Management Institute (IRMI) defines insurance underwriting as "the process of determining whether to accept a risk and, if so, what amount of insurance the company will write on the acceptable risk, and at what rate."[69] Stated another way, underwriting involves the assessment, management, and transfer of risks. For an insurer to consider underwriting a risk, the risk must be quantifiable and occur fortuitously as respects the insured. Additionally, the insured must have a demonstrable interest in the subject risk. (Zurich Financial Services, 2009)

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[67] Reproduced in Reinsurance Association of America, *Drowning and Drought: Extreme Weather Impacts on our Economy and Society* (2011), *available at* http://www.c2es.org/docUploads/Nutter-Extreme-Weather-Hill-Briefing.pdf.

[68] Reinsurance Association of America. *Drowning and Drought: Extreme Weather Impacts on our Economy and Society* http://www.c2es.org/docUploads/Nutter-Extreme-Weather-Hill-Briefing.pdf

[69] IRMI Online, Glossary of Insurance & Risk Management Terms, http://www.irmi.com/online/insurance-glossary/terms/u/underwriting.aspx.

With regard to weather or climate related risk in the United States, the two principal categories of insurance in play are federal disaster relief programs (like NFIP) and traditional private insurance.(Nichols and Bruch, 2008) Climate change has affected at least one core industry assumption, which is that understanding the past enables insurers to predict what will occur in the future. While the past historically has served as a fairly reliable indicator of future events when calculating the risks associated with insurance coverage, climate change has introduced new and uncertain risks into these calculations. (Nichols and Bruch, 2008) Whether one other foundational assumption of underwriting –namely, that risk is spread over large and diverse groups to minimize the likelihood of having to pay everyone off at once -- is also voided by climate change remains to be seen. (Nichols and Bruch, 2008)

Insurance as a Tool to Address the Impacts of Climate Change

Insurers and reinsurers have much to contribute towards an integrated approach to climate related risk management. The industry has extensive experience in modeling, pricing, and managing risk. These capabilities are important in understanding and responding to the total climate change risk faced by a local community. Additionally, because insurance companies are expert managers of risk, they are in a strong position to persuade policymakers to undertake proactive measures and promote greater resilience.(Nichols and Bruch, 2008)

Insurance itself can aid communities in becoming more resilient by protecting them against residual risk from low frequency, high severity weather events. (Swiss Re, 2010) Insurance reinforces risk prevention measures by incentivizing investments in activities with net economic benefits and helping to free up resources for other capital-intensive investments. (Swiss Re, 2010) Insurance also can support the construction of climate adaptation infrastructure, such as with engineering covers and surety bonds, and in widespread adaptation to the physical risks resulting from climate change, such as supporting the deployment of building code requirements and new technologies. (Swiss Re, 2010) As regards property damage, having adequate insurance enables property to be repaired and returned to use so that the people and businesses associated with it can resume economic activity, which has broad public benefit. Insurance thus can play a valuable role in both the societal mitigation of and adaptation to climate related risk.(Zurich Financial Service, 2009)

Box 6.6: Resilient Rebuild Extensions to Property Coverage

Property policy coverage extensions could provide a means to adapt current buildings to future needs. For example, after a hurricane or other triggering event, existing materials could be replaced with weather-resilient materials, such as improved roof attachments or wind resistant glass, to the extent that portions of the structure damaged by an extreme weather event were deemed insufficiently resilient to anticipated weather conditions in the future. In this way, insurance could be used as a mechanism to achieve existing building stock improvement to better adapt to anticipated climate change. (Zurich Financial Service, 2009) Using insurance in this manner is consistent with prior industry practice: insurance codes often include provisions requiring any repair or rebuild to comply with current code standards. Whereas insurers today typically provide adaptive coverage extensions of this nature on a voluntary purchase basis, the speed of adaptation likely would increase if policy makers were to change building code standards to make such resilience mandatory. (Zurich Financial Service, 2009)

Other tools available to insurers for practicing catastrophic risk management include pooling through the traditional reinsurance mechanism and/or capital market activities such as insurance-linked securities (ILS). (Zurich Financial Service, 2009) ILS are financial instruments whose performance is primarily driven by insurance or reinsurance loss events. They are used by insurers to take property damage from climate-related events and distribute it through the capital markets. (Zurich Financial Service, 2009) Investors in these securities essentially bet that catastrophic risks will not happen, in which case they receive high returns. If the event does happen, however, some or all of the investment is used to pay losses resulting from the catastrophe. (Kampa, 2010) With the growth of the ILS market, insurers and reinsurers are able to facilitate a broader social preparation for peak natural catastrophe risks that may be on the rise with climate change, such as hurricanes, windstorms, or flooding. (Zurich Financial Service, 2009)

Insurers additionally can encourage reductions in greenhouse gas emissions (GHGs) using various insurance structures, including specialized liability coverages and property liability coverage extensions. One example of the former is liability coverage for the operational phases of carbon capture and sequestration (CCS) deployment, which will allow business to proceed with solid risk management as CCS is deployed. (Zurich Financial Service, 2009) Insurance can also facilitate emissions reductions by providing property insurance extensions which repair, restore, or rebuild using energy efficient appliances and engineering systems. Like the extension of coverage to incorporate climate appropriate weather resilience, insurance can be used to incorporate energy efficient systems and goods into existing building stock after triggering events like hurricanes or storms. As with weather resilient extensions, a public mandate, such as a building code change that effectively makes this coverage extension mandatory, would have the effect of expediting conversion of existing building stock towards greater energy efficiency and mitigation of climate risk. (Zurich Financial Service, 2009)

Insurance Industry Responses to Climate Change

Many insurers have begun adapting their business models to account for the potential impacts of climate change. Principal drivers in this area include mainstream science and insurance customers, which, in response to climate change and energy volatility, are increasingly changing the way they construct buildings, transport people and goods, design products and produce energy. In addition to customers, regulators and shareholders also are pressing insurers to provide more "green" products and services, to provide greater assistance in terms of improving disaster resilience, and to become more proactive about assessing and responding to climate change risk. Insurers, for their part, increasingly are identifying climate change as an enterprise risk management issue that cuts across the areas of underwriting, asset management and corporate governance. (Mills, 2009a)

Insurer responses to climate change are becoming correspondingly sophisticated. A 2009 report published by the Geneva Association identified 643 specific climate change-related activities from 244 insurance entities in 29 countries, representing a 50 per cent year-over-year increase in activity. These entities collectively represent $1.2 trillion in annual premiums and $13 trillion in assets. In addition to activities on the part of 189 insurers, eight reinsurers, 20 intermediaries and 27 insurance organizations, at least 34 non-insurance entities have collaborated in these efforts. (Mills, 2009b)

Challenges and opportunities facing the industry include creating and delivering promising products and services to customers and working to identify and fill market and coverage gaps.

There is also need for convergence between sustainability and disaster resilience, greater engagement by insurers in adaptation to unavoidable climate changes, and clarification of the role that regulators will play in moving the market. (Mills, 2009a)

On a more granular level, insurers have taken concrete action in response to increased risk from climate change. For example, private insurance companies have responded with financial strategies to reduce risk in coastal areas, including by raising premiums, increasing deductibles, and sometimes limiting or discontinuing coverage. (Nichols and Bruch, 2008)

In reaction to the risk reduction strategies employed by private insurers, states are stepping in to fill coverage gaps, assuming substantial risk in the process. To mitigate their own exposures, states increasingly are appealing to the federal government for help, such as a proposal for a national catastrophe fund that would allow state funds and private insurers to buy lower cost reinsurance from the federal government. (Nichols and Bruch, 2008)

Climate considerations also are being evaluated in connection with public insurance programs. In 2007, the U.S. Government Accountability Office (GAO) issued a report recommending that the Secretaries of Agriculture and Homeland Security analyze the potential, long-term fiscal implications of climate change for the Federal Crop Insurance Corporation's (FCIC's) crop insurance program and for the NFIP, respectively.(US GAO, 2007) The FCIC report was completed by the Department of Agriculture's Risk Management Agency in 2010. (USDA, 2010) The evaluation of the NFIP, including an examination of the impacts of sea-level rise and changes in storm characteristics on coastal floodplains, is currently nearing completion.

Impediments to the Effective Use of Insurance In Addressing Climate Change And Resulting Consequences

There are three principal impediments to effectively using insurance in addressing the risks associated with climate change. First, insurance is most effective in protecting private assets, while climate change affects both private assets and public goods. Second, insurance works best in undistorted markets, while proposals to combat climate change routinely mention grants, subsidies, penalties, and the creation of additional rights and obligations. Third, whereas insurance (like most businesses) requires a stable, consistent, and predictable environment to thrive, the current inconsistency in rules and regulations embeds significant political risk. (Zurich Financial Services, 2009)

For insurance to serve as an effective tool in responding to climate change risk, public policy must permit insurers to reflect the cost of prospective risk that is accepted by insurers to assure efficient use of scarce economic resources. Policymakers must take steps to ensure that private incentives to mitigate and manage risk are not undermined or distorted by public policy solutions. Incentives to individually manage risk are undercut by public disaster relief schemes that are overly broad or significantly underprice risks. (Zurich Financial Services, 2009)The prevalence of such schemes undermines the viability of a private insurance market, with the result that governments are forced to take on an above-optimal amount of risk. (Scism, 2012)

Such is the case with the NFIP, which is severely underfunded and, in its current form, creates a moral hazard by enabling people to choose to live in places that require society to pay for multiple and repeated re-buildings. Much the same phenomenon is observed at the state level, where 6 of the 10 state natural disaster funds investigated by GAO in 2010 charged rates that were not actuarially sound (based on available risk data). (US GAO, 2010)

Box 6.7: Case Study - Florida, A Cautionary Tale

State-run entities that expanded over the past decade to provide affordable homeowners insurance in Florida are in danger of becoming so big that they pose a significant threat to the local economy. (Scism, 2012) Citizens Property Insurance Corp. (CPIC), for example, has 1.5 million policyholders and a total exposure of $511 billion, about one-quarter of the Florida homeowners insurance market. The Florida Hurricane Catastrophe Fund would be required to reimburse insurers operating in the state up to $18.4 billion in the event of losses from major storms, despite having only about $7 billion on its books from accumulated premiums. Observers are concerned that in the event of a major hurricane, if these two entities were unable to sell post-disaster bonds as planned, some insurers could become insolvent, homeowner repair claims could go unpaid, and assessments and surcharges on policyholders statewide could damage the economy. (Scism, 2012)

Efforts are underway to try to address some of the problems with the current structure of publicly subsidized disaster relief programs. At both the state and federal levels, stakeholders have proposed granting these entities greater authority to raise insurance rates. Current legislative proposals relating to the NFIP, for example, would increase the annual limitation on premium increase from the current 10% level to either 15% or 20%. (Flood Insurance Reform Act, 2011) Other measures being explored at the state level include seeking to reduce the size of state disaster relief funds and move more of the funding for losses to the global reinsurance market. (Scism, 2012)

Such measures are steps in the right direction, although concern persists about the pace and scale of reform. Historic experience in the insurance industry has shown that subsidies of any nature, as contrasted with rights and liability creation, result in business models that contain an unacceptable level of political risk. Subsidies may actually discourage active participation by the financial services industry in innovative and beneficial activities unless the business or technology supported can survive without the subsidy. (Zurich Financial Services, 2009)

In addition to reforming the NFIP and state-level equivalents, other promising public/private adaptation strategies include requiring that insurance in areas vulnerable to climate affected extreme events is risk based; requiring insurers to credit hazard mitigation; limiting the number of times coastal residents receive insurance reimbursement; reducing public aid incrementally for repeat disasters; and creating a revolving fund to offer loans to homeowners who want to strengthen their property[70]

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[70] Reinsurance Association of America. *Drowning and Drought: Extreme Weather Impacts on our Economy and Society*

A significant consequence of the failure to address impediments to the effective use of insurance in addressing climate change risk involves the flow of capital. Insurance capital should be actively encouraged to flow into insurance markets. In the right circumstances, insurers could provide significant financing for both adaptation and mitigation measures. Ex-ante financed schemes of this nature have proven to be more efficient and effective than pure ex-post compensation schemes, as they contribute to the awareness of (and hence, stronger involvement of) both public and private stakeholders. Absent a coordinated effort to permit the meaningful use of insurance as a tool for managing climate change-related risk, significant insurance capital is likely to flow not into insurance markets but into the costs of defending and paying claims for severe weather/climate-related losses. Only the former course will permit use of insurance as a tool to slowly transform and improve resilience over time.

Conclusions

Insurance, reinsurance, and other financial incentives can provide powerful tools in the adaptation to and mitigation of climate risk. The ability of the insurance industry to assist public policy-makers in the effective and efficient implementation of climate change policy is to a large extent dependent on their willingness to resist the temptation to distort markets in a manner that interferes with the role and ability of insurers to send price signals about risk. If these pitfalls can be avoided, the way is made clear for engaging the insurance mechanism in the conversion to a lower carbon economy and adaptation to climate change.

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6.7 Evaluation

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This sections summarizes and synthesizes lessons learned in the Northeast in the context of evaluation methods.

Continual Identification of Best Practice: Evaluation

The development of decision support services and products based on climate science is in the early stages (see for example NRC 2009, pp. 1-2). Learning how well different service and product designs work is important in order to synthesize a code of best practices that can inform the design of products and services for different types of decisions in different types of environments. We also need evidence regarding effective institutional arrangements that can continue to deliver decision support over time. Systematic learning that can produce an understanding of best practices requires more formal evaluations of decision support services and products than have been undertaken thus far. As the authors of NRC (2009) note,

> "In the past, formal evaluations have not commonly been undertaken as part of decision support efforts, but they are increasingly recognized as an important element of deliberate efforts to improve decision support services." (p. 58).

The authors also add that

> "…formal evaluation is often neglected…" (p. 59).

This section will discuss briefly the major types of evaluation, provide examples of evaluations conducted in the Northeast, and discuss obstacles to more systematic evaluation of decision support as well as ways to move forward.

Evaluation has been used systematically and rigorously for many decades to assess the effectiveness of social programs, such as educational initiatives, health initiatives, welfare programs, job training, and others. Funding for these programs is often contingent on the results of the evaluation. Approaches to evaluation and evaluation methods are the subject of academic inquiry as well as applied policy research and the resulting literature is vast.

Evaluation is a systematic process of gathering data and information for the purpose of assessing what an intervention is achieving and how and/or the extent to which it is making progress toward a particular objective and how it is doing so.[71] The term "intervention" in this section will refer to any decision support service and/or product, such as a partnership between scientists and decision makers that allows a continuous exchange of information about the changing nature of

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[71] The definition contains the most common ingredients present in definitions of evaluation. The exact definition varies from author to author. For examples see Trochim (2006) or Owen (2007) p. 18.

heat waves to inform the planning of public health resources and early heat warning programs or a map of predicted flooding probabilities that can help to inform adaptation strategies in coastal areas.

Different types of evaluation address a range of questions at different stages of planning and/or implementation of an intervention. Providing a guidebook to evaluation is far beyond the scope of a brief review section such as this one. The evaluation approach and methodology need to be tailored to the problem at hand, which is defined by the evaluation objectives, the type of intervention, how far along is the implementation of the intervention, the funding available for the evaluation, the amount of time available for the evaluation, information and data accessible to the evaluator, and relevant political constraints. We do not provide a comprehensive classification of types of evaluation. [72] We adopt the most basic distinction that has endured for a long time in the field of evaluation, between formative and summative evaluation, and we provide examples within each of these categories.

Monitoring

A monitoring plan is perhaps the most widely familiar and used evaluation tool. It does not constitute a type of evaluation, but is a necessary input into one. Monitoring here refers to collecting information about the progress of an intervention and possibly about the conditions that affect the need for and the effectiveness of the intervention. Monitoring climate conditions and climate impacts, as described in section 6d, may constitute a component of the type of monitoring that we discuss here, since climate conditions and impacts affect both the need for and the effectiveness of any decision support service.

Most monitoring systems focus on activities. They document whether the planned activities are being carried out according to schedule and whether they are reaching the target audience. Such monitoring documents what has been done but it does not evaluate the effects that what has been done has had. More sophisticated monitoring plans also gather information about conditions that determine the need for the service and/or product and conditions that may affect how effective is the service and/or product. Monitoring conditions that should change if a service is effective is not sufficient to show that the service is effective unless the information is analyzed in the framework of an evaluation.

For example, consider a partnership between university-based climate scientists and decision makers in a coastal city such as New York City or Boston for the purpose of improving the city's resilience to the changing nature of coastal storms. Monitoring the decision support service provided by the scientists may document that scientists have provided probabilistic coastal flooding forecasts. The monitoring has not informed the service providers whether the forecasts are being used and whether their use has resulted in any reduction in vulnerability. A monitoring system that also monitors the conditions of success may collect information about whether decision makers are using the forecasts. The information is useful only if analyzed within the framework of an evaluation. Forecasts that are being used do not necessarily improve decision making and outcomes. Forecasts that are not being used are not necessarily useless. The decision

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[72] Owen (2007) provides one of the most recent classifications.

makers may have had access to similar information from other sources, so the forecasts may have been redundant. Also, decision makers may have been unable to implement the actions that forecasts informed due to a variety of constraints. Similarly gathering information on indicators of vulnerability to damage from coastal storms is necessary for an evaluation but is not sufficient to show that the forecasts affected vulnerability. Actions undertaken by decision makers and/or individual residents uninformed by the forecasts may have been responsible for any observed reductions in vulnerability.

Ongoing monitoring of performance is widely accepted as essential in both private and public organizational cultures. Almost all climate action plans adopted by states and municipalities in the Northeast note that a monitoring system should be put in place to track the progress of proposed activities and programs (see for example Boicourt and Johnson 2010; City of Albany 2011; City of Boston 2011; City of Lewes 2011; City of New York 2011, 2007; City of Philadelphia 2007; City of Portland 2008; Commonwealth of Massachusetts 2011; CT DEP 2009; Delaware Coastal Management Programs 2011; ME DEP 2010; NYC DEP 2008; NYSERDA 2010; PE DEP 2011). Fewer plans provide a detailed account of how they will monitor.

Some of the more established climate action plans have published outcomes of some of their monitoring efforts. New York City's PlaNYC report and updates (City of New York 2011, 2010, 2009a, 2008, 2007) document initiatives completed or ongoing under PlaNYC. For example, the most recent PlaNYC update (City of New York 2011) lists how many trees have been planted as part of the Million Trees NYC Initiative, and that the next 650,000 trees will be planted by December 31st, 2013 to continue reaching their initiative goal of planting one million trees (City of New York 2011, pg. 184). Another example is the Delaware Coastal Programs' Sea Level Rise Initiative Project Compendium, which provides an inventory of the projects and initiatives implemented as part of the initiative (Delaware Coastal Management Programs 2011, pg. 6). The document introduces each project, summarizes the project outcomes that have been monitored, and provides the status or estimated date of completion of individual components of the projects

Formative Evaluation

The following definition of formative evaluations appears in Trochim (2006):

> "Formative evaluations strengthen or improve the object being evaluated -- they help form it by examining the delivery of the program or technology, the quality of its implementation, and the assessment of the organizational context, personnel, procedures, inputs, and so on."

Formative evaluations may address a range of questions depending on the stage of the intervention, such as (1) what is the nature of the problem and what are the needs that a particular intervention aims to address, (2) what is the logic of an existing intervention that explains how the intervention works in practice and through which causal mechanisms its various components may or may not result in desired outcomes, (3) what are the expected outcomes that a particular intervention is likely to produce, (4) how is the implementation of the intervention working in reality and is the intervention meeting its targets – often referred to as process evaluation.

An important type of formative evaluation, which also provides a foundation for a summative evaluation, is the development of a program theory. A program theory elaborates the mechanisms through which each of the components of an intervention may influence outcomes of interest as well as produce positive or negative unintended consequences (see for example White 2009 or Funnell and Rogers 2011). A program theory often serves an essential formative role by clarifying the structure of the intervention, which components are well designed to serve the intended purpose and which components are not.

An example of the use of program theory in the context of decision support for response to climate risks in the Northeast is the adaptive management approach employed by the United States Fish and Wildlife Service (FWS) at the Maine Coastal Islands National Wildlife Refuge, at Blackwater National Wildlife Refuge in Maryland, and at a number of other FWS stations in the Northeast (US Fish and Wildlife Service 2008). The approach is designed to enable managers, scientists and other stakeholders to learn how to build and maintain sustainable ecosystems on National Wildlife Refuges under uncertainty. In the approach, which FWS terms structured decision making (SDM), scientists model what outcomes should result from a particular approach to managing a particular resource such as salt marshes, native shrublands, or seabirds nesting on islands. These models are examples of program theories. Scientists and managers then use the program theories to identify the most effective approach through a process that is an example of summative evaluation discussed in the next section. They implement the modeled management strategy, documenting the management actions that were taken, and documenting the outcomes. They use the results to revise the program theories in an iterative process.

Another type of formative evaluation that has been applied to valuing decision support services for adaptation is ex ante evaluation. Ex ante evaluation provides a projection of the likely impacts of an intervention based on modeling, simulations, and/or expert opinion. Modeling has been applied extensively to understanding the likely value of seasonal climate forecasts in several sectors, especially in agriculture and water though not specifically in the Northeast (see for example Climate Research 2006; U.S. Climate Change Science Program and Subcommittee on Global Change Research 2008).

Cost-benefit analysis may be an outcome of formative or summative evaluation, the latter of which is described in the next section. Most often policy makers are interested in cost-benefit analysis as a tool for informing the decision whether or not to undertake a particular intervention. In this case, the analysis is a result of a formative evaluation in which the evaluator estimates the present value of the difference between likely benefits that the intervention will realize and the likely costs that it will incur before the intervention is implemented.

Several studies assess the present value of likely net benefits of adaptation actions undertaken in response to information about the future climate. These are not analyses of decision support services per se, but rather assessments of the benefits that actions undertaken with the help of a decision support service based on climate science may deliver. Leichenko et al. (2011) present a cost benefit analysis of adaptations to climate in a number of sectors in New York State. They show that in general adaptations reduce the negative impacts of climate change by much more than they cost. Benefits to adaptation are particularly large in New York because of the state's vulnerability to climate change, particularly along the coasts. Leichenko et al. (2011) also provide a review of the literature on cost benefit analysis of adaptation in the global context as well as at the national and regional scale in the U.S. Kirshen et al. (2004) conduct a cost benefit analysis of potential adaptation measures in the Boston area. Raucher (2009) and Philadelphia Water Department (2011) compare the potential net benefits of relying on green infrastructure, such as planted areas in the street and green roofs, as opposed to relying on grey infrastructure, such as underground tunnels, to control sewer overflows. They find that the green infrastructure option yields benefits that are an order of magnitude greater than those of grey infrastructure because of lower costs and benefits beyond controlling sewer overflows. City of New York (2009b) conducts a similar analysis and has similar findings for New York City.

Perhaps the primary weaknesses of the existing cost benefit studies is the uncertainty associated with the benefits of adaptation actions. The uncertainty has a number of sources: (1) the uncertainty of the climate system, (2) uncertainty of climate outcomes due to human actions, (3) uncertainty associated with benefits that will be produced by any given approach to adaptation that has not yet been tested and whose benefits depend on other adaptation and mitigation actions. To some extent, the first and second source of uncertainty can be addressed if cost benefit analyses estimate the net benefits of a given action under different scenarios, including extreme scenarios that may have a low probability of happening but entail very costly impacts. One complication is that cost benefit analyses use a discount rate to value future costs and benefits in present dollar terms. Generally analyses use prevailing short-term interest rates as the discount rate. The choice is fine for projects with short time horizons. However, the value of costs and benefits that are far in the future is much more sensitive to the choice of the discount rate, and the choice becomes much more controversial (Weitzman 2010).

The third source of uncertainty listed above requires progress on adaptation actions. Benefits can be more usefully estimated based on an evaluation of a pilot program designed to test a particular approach to adaptation or, further in the future, based on evaluations of fully implemented programs that have some similarities to the approach whose benefits need to be understood.

Leichenko et al. (2011) provide a review of other issues that affect the usefulness of cost benefit analyses of adaptation. One of the big issues is the availability of data necessary for reliably assigning monetary values to climate impacts that would occur in the absence of adaptation as well as to the costs and benefits of adaptation.

An important and very common type of formative evaluation is process evaluation. An example of this type of evaluation is contained in an important body of evidence about the experience thus far with decision support services provided in several evaluations of the Regional Integrated Sciences and Assessments (RISA) programs funded by the National Oceanic and Atmospheric Administration (McNie et al. 2007; McNie 2008; Pulwarty et al. 2009; Kirchhoff 2010). The evidence is not specific to the Northeast but is applicable since the RISAs comprise perhaps the most extensive and comprehensive effort to date in the US to provide climate decision support services on a regional scale. The studies provide information about selected aspects of the decision support process such as the nature of the interaction between climate scientists and stakeholders and the use of climate information provided by the RISA scientists. The studies are descriptive rather than formally evaluative in the sense that they do not establish causal linkages between the RISAs and the aspects of the process that they describe. A number of assessments of the RISA experience

> "… have identified "evaluation" as maybe the most prominent gap in RISA activities to date. Most of the available evidence on the results from the RISA centers takes the form of experience-based judgments by RISA funders, staffs, and users." (NRC 2009, p. 58).

Summative Evaluation

The purpose of a summative evaluation is to assess the outcomes that resulted from an intervention. Did the intervention work, for whom did it work, under what conditions did it work, and why did it work or not work? A summative evaluation can be completed at the end of an intervention if the objective is to learn how effective a given approach was for potential application elsewhere. However, despite its somewhat misleading name, a summative evaluation is also a vital learning tool that can help to revise an approach in the course of an intervention if the required information collection and analysis are carried out periodically during the intervention. A summative evaluation can serve several purposes: (1) to redesign approaches that did not work well under certain conditions, (2) to design approaches for new environments, and to expand the interventions to reach larger numbers of people/institutions, (3) to communicate what has been learned from the project to others, so that the lessons can be applied elsewhere, (4) to influence funding decisions.

The central problem in a summative evaluation is to establish a causal relationship between the intervention and its outcomes (see for example Trochim 2006; Leeuw and Vaessen 2009, p. ix; Shadish et al. 2001). Understanding the causal relationship is difficult. However evidence that documents which changes in the social or natural system are the result of the intervention rather than of the many other factors that determine the outcomes of interest and how and why an intervention resulted in these changes is necessary in order to design interventions that are effective under given conditions and for given populations. A correlation observed between an intervention and outcomes may be the result of factors other than the intervention that were active at the same time as the intervention.

A range of quantitative and qualitative approaches have been described that can establish causal relationships in different settings. The methodological literature is vast. Generally a summative evaluation should begin with the development of a program theory and proceed to test the possible pathways proposed in the program theory.

A summative evaluation can assess the effect of an intervention on outcomes or impacts at various stages. The terms "outcome" and "impact" are often used interchangeably. In some branches of the literature, "outcome" refers to early changes that happen as a result of an intervention that will eventually lead to the impacts that are the ultimate objective of the intervention. "Impact" then is reserved for those final changes that an intervention intends to realize. For example, consider an early warning system that a municipal government may use to reduce the impact of heat waves on health. Such early warning systems function in many of the Northeastern cities, such as Boston, New York City, and Philadelphia. An evaluation of an early warning system may examine who receives a warning and what actions occur when a warning is issued, such as does the city open cooling centers? Are there provisions made for people who cannot get to cooling centers? Do public health providers increase certain heat-related services?

The evaluation of early outcomes of an intervention rather than only final impacts serves a number of purposes. It enables the project staff to evaluate the project "mid-stream" and redesign dimensions that are not working as intended even before final impacts are realized. Also, it helps to understand the mechanisms through which the final impacts are occurring (how and why the final impacts are occurring). If the intended impacts do not occur, an evaluation of early outcomes may reveal why not. If the intended impacts do occur, it may reveal that they are occurring for different reasons than motivated the design of the intervention and therefore the intervention should be redesigned. For example, the intervention may have unnecessary components. Also, evaluation of early outcomes may help to anticipate positive and negative unintended outcomes of the intervention.

One of the decision support services that have undergone some summative evaluation in the Northeast are the early warning systems for heat waves that seek to mitigate the impacts of the growing number of heat waves on mortality and morbidity in the densely populated urban areas of the Northeast.[73] The warning systems use information on heat and humidity from the National Weather Service (NWS) to provide advance warning of a heat wave. Some cities, such as Philadelphia, Washington, D.C., and Baltimore base heat wave warnings on a more complex prediction approach developed by a team at the University of Delaware led by Dr. Laurence Kalkstein (Kalkstein et al. 1996; Sheridan and Kalkstein 1998). Once a warning is issued, the city implements certain actions to spread information and provide assistance to those who may need it. There are a limited number of studies that look at the effectiveness of U.S. public health interventions in reducing morbidity and mortality during heat waves (Alberini et al. 2008; Ebi et al. 2004; Kalkstein et al. 2007; Palecki et al. 2001; Smoyer 1998; Weisskopf et al. 2002). Two studies relevant to the Northeast show that these decision systems are saving lives.

Alberini et al. 2008 have estimated the reduction in excess mortality due to heat waves that can be attributed on average to the warning systems in all US cities that have warning systems (Alberini et al. 2008). They note that the resulting reduction in excess mortality varies across regions in the U.S. and the benefits of the warning systems are among the largest in the Northeast. The reduction in excess mortality is the decrease in the number of additional deaths that occur on days on which temperature and humidity exceed a certain threshold and a heat warning is issued compared to number of deaths that occur under similar temperature and humidity conditions in the absence of a heat warning. They use a statistical methodology called the regression discontinuity design to estimate impacts that can be attributed to the warning system itself, ruling out the effects of confounding factors.

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[73] The following cities in the Northeast have heat early warning systems Pittsburgh, P.A., New Haven, C.T., Boston, M.A., Jersey City, N.J., New York City, Philadelphia, P.A., Baltimore, M.D., and Washington, D.C. (Alberini et al 2008).

Another study, Ebi et al. 2004, focuses on the heat warning system in Philadelphia and shows that excess deaths declined after the system was introduced. However, the reductions in excess mortality observed in the study could be due to other factors such as overall improvements in the delivery of health care to populations that are particularly vulnerable to heat waves that may have occurred contemporaneously with the introduction of the early warning system and that would reduce mortality among those populations on any day, not just during heat waves. Their approach does not eliminate the influence of such confounding factors.

The two studies provide a helpful indication of the benefits of the warning systems. However, much remains to be understood about designing effective heat warning systems. We do not know in which parts of the population the reductions in deaths are occurring, whether there are parts of the population that are not experiencing any benefits under the current designs of the warning systems such as the disabled or minority groups. We do not know through what mechanisms the lives are being saved, whether the warning systems include costly components that are not useful and/or whether they are missing pieces needed to address the needs of certain populations. Local Weather Forecast Offices (WFO) and city mayors' offices consider threshold values of weather variables as only one of the factors that determine whether a warning should be issued or not. Several studies note that considerable excess mortality occurs on days that meet the threshold criteria but on which a warning is not issued (see for example Ebi et al 2004, p. 1068; Alberini et al. 2008, p. 26). It would be useful to understand the distribution of impacts on mortality as well as the costs of the warning system if the warning systems were to issue warnings more often. In the absence of evidence regarding for whom the warning systems are effective, under what conditions, and why, the guidance for designing effective systems is incomplete.

Ebi et al. (2004) is an example of a cost benefit analysis that is based on a summative evaluation of an intervention. Ideally the benefits valued in a cost benefit analysis of an intervention should be those that can be attributed to that intervention and that have been shown to occur as a result of that intervention. A summative evaluation of pilot programs can demonstrate the likely benefits of the full-scale intervention.

Several studies have carried out summative evaluations of the value of seasonal climate forecasts, particularly in agriculture (see for example Mjelde et al. 1988; Lybbert et al. 2007; Roncoli et al. 2009). Most of these studies analyze applications of seasonal climate forecasts in developing countries and none are specific to the Northeast.

Relevant evaluations that do not focus specifically on the decision support system assess whether a technology whose implementation may result from a decision process supported by climate information achieves certain results. For example Rosenzweig et al. 2006 assess how effectively several types of green infrastructure reduce the urban heat island effect. Another example is Roseen et al 2009, who assess the effectiveness of porous pavement as a storm water management technology. Pyke et al. 2011 assess the potential effectiveness of low impact development for reducing stormwater impacts under changing precipitation patterns.

Obstacles to evaluation and ways forward

The evaluation of climate decision support services will have to overcome a number of obstacles in order to expand. Many of these obstacles are common to evaluations in all sectors of decision making. The common obstacles are that evaluations require funding, time, and appropriate data and information.[74] Costs vary widely depending on the evaluation design. Some of the most expensive evaluations are ones that involve extensive collection of original data. In sectors in which evaluation has become established, the predominant view is that even expensive evaluation can save much more money than it costs to implement by helping decision makers to avoid making large investments in programs that are not effective. Evaluation is too resource-intensive to be implemented for all interventions. Evaluation of climate decision support should be strategically targeted to provide evidence about effective approaches to a broad range of decision problems under different environmental and socio-economic conditions at different temporal, institutional, and geographical scales. Meta-analyses of the targeted evaluations should synthesize the lessons learned.

An evaluation is useful only if the results are available in time to influence decisions about program design, renewal, or expansion. Frequently, decision makers begin to think about an evaluation toward the end of a program cycle, when they need to report results. At that point, available time may not allow for a very useful evaluation. Whenever possible, evaluation planning should begin at the same time as program planning, and evaluation should be integrated into the program from the beginning in order to maximize the opportunity to produce useful results.

Another set of constraints is related to the capacity and incentives of the relevant decision makers as well as the communication skills of the evaluators.[75] Decision makers need to have the capacity to understand and use the evaluation results, and the evaluators need to communicate the results in a way that is understandable to decision makers. Communication can be particularly difficult when the evaluation uses sophisticated statistics and the evaluators present the results in a technical way. Decision makers who are involved in climate decision support services may have an advantage in navigating the communication challenges associated with evaluation because of their experience in interacting with scientists to produce climate information that is useful for decision making.

Putting the evaluation results to use may encounter a range of problems. Decision makers as well as researchers may be reluctant to accept results that suggest that the program is less than successful, especially if they are more likely to be held accountable for the problems revealed rather than receiving credit for improving the design in the next phase. The decision makers who are blamed for poor performance may not have the authority to make the changes needed to improve the program. Other political problems or problems due to institutional cultures may pose obstacles.

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[74] For a description of commonly encountered issues and some solutions see for example Bamberger et al 2006.

[75] Bamberger 2006 discusses some relevant issues under the heading of political constraints.

The area of climate decision support lacks evaluation expertise (NRC 2009, p. 59). Few evaluators are aware of the decision support initiatives and even fewer are engaged in assessing them.

Climate decision support is still in early stages of development. As authors of NRC (2009) note

> “One reason formal evaluation is often neglected may be that program goals, which must be measurable to make formal evaluation possible, are not often articulated clearly enough for measurement, especially at the outset.” (p. 59).

Goals do not need to be measurable quantitatively, but they do need to be clear enough that evaluators can assess progress toward them. In addition, important aspects of the decision support process may be difficult to evaluate. As NRC (2009) notes again,

> “It is critical but difficult for evaluation to assess candidly the partnership between scientists and decision makers and the quality of relationships. Sometimes, the greatest value of evaluation is not to provide the equivalent of a final grade, but to elicit qualitative feedback (Jacobs, Garfin, and Lenart, 2005) that can be shared with those involved in order to enhance transparency and legitimacy, build trust, and foster the ongoing collaboration. In short, evaluation may be most useful as part of a learning process, to facilitate the evolution of decision support efforts and inform leaders about how to promote needed change.” (p. 59).

Evaluation design can address the latter challenge.

Finally, another complication inherent in evaluating climate decision support is that, just as adaptation strategies are difficult to design in the face of uncertainty about future climate and its impacts, the effectiveness of those strategies is difficult to assess when we have not yet observed a wide range of possible climate outcomes. Evaluation of climate decision support needs to be embedded in the risk management approach to adaptation elaborated in Major et al. 2010. Strategic evaluation efforts need to continue to assess the effectiveness of different approaches as the climate evolves. Strategic evaluation should be part of step 8 in Figure 1 on p. 240 of Major et al. 2010, which presents the eight adaptation assessment steps as part of the flexible adaptation pathways paradigm. Ex ante evaluation based on modeling possible outcomes for different climate scenarios is another tool that can provide information in the face of uncertainty.

Conclusion

Evidence provided by evaluation is essential for learning how to design effective decision support. Systematic, rigorous evaluation is not yet being undertaken as a part of decision support efforts. However, the need for the evidence that can inform future decision support efforts is being increasingly recognized. Evaluation is resource-intensive therefore it should be undertaken as a targeted, strategic learning tool that provides evidence about effective approaches to a range of problems under different environmental, socio-economic, and political conditions and at different temporal, geographical, and institutional scales. Evaluation should be embedded in a risk management approach in order for funders, researchers, and decision makers to continue learning what works well in decision support and what does not as the climate conditions to which decision support needs to respond evolve. Evaluation should be integrated into decision support efforts from the beginning, not after services have already been implemented.

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Appendix 6.A. Planning Tool Matrix

Tools for climate change adaptation planning used or applicable in the Northeast.   1 of 7

Tool Name	Adaptation Database for Planning Tool (ADAPT)	Adaptation Checklist	CanVis	Climate Adaptation Knowledge Exchange (CAKE)
Tool Type				
Analytical				
Data Portal				x
Process	x	x		
Socio-economic		x		
Tool Portal				x
Visualization			x	
Description	Five-milestone adaptation planning process	Questionnaires to guide vulnerability and risk assessment	Allows visualization of potential effects of coastal development or sea level rise.	Georeferenced case studies, tools, resources.
Source	ICLEI	Major, D.C., and M. O'Grady, 2010	NOAA CSC	EcoAdapt/Island Press
Link	http://www.icleiusa.org/	http://onlinelibrary.wiley.com/	http://www.csc.noaa.gov/digitalcoast/tools/canvis/index.html	www.cakex.org
Additional Software Needed	NA		none	none
Sectors				
Agriculture	x		x	x
Coastal Zones	x	x	x	x
Ecosystems	x		x	x
Energy	x	x	x	x
Public Health	x			x
Telecommunications	x	x	x	x
Transportation	x	x	x	x
Water Resources	x	x	x	x
Adaptation Assessment Steps				
Identify Hazards	x	x		
Prioritize Risk	x	x	x	x
Characterize Risk	x	x	x	x
Develop Strategies	x	x	x	x
Link to Decision Making	x	x	x	x
Plan	x	x	x	x
Implement Adaptation Plans	x	x		
Monitor, Reassess	x	x		
Cases		New York City	Small docks in Massachusetts http://www.csc.noaa.gov/digitalcoast/action/docksma.html	
			Condominiums in Pennsylvania http://www.csc.noaa.gov/digitalcoast/action/waterpa.html	

Adapted from a summary sheet created by EcoAdapt. The original sheet, including additional information, may be found at http://ebmtoolsdatabase.org/sites/default/files/sources/cctoolmatrix_mod_111511.pdf .

Tools for climate change adaptation planning used or applicable in the Northeast. 2 of 7

Tool Name	Climate Change Vulnerability Index (CCVI)	Climate Risk Information	COAST
Tool Type			
Analytical	x	x	
Data Portal			
Process			
Socio-economic			x
Tool Portal			
Visualization		x	
Description	Scores species' predicted to climate change within an assessment area.	Projections of climate variables	Quantifies risks to infrastrucute and benefits of adaptation
Source	NatureServe	Horton, R., et al., 2010	Sam Merrill, University of Southern Maine
Link	http://www.natureserve.org/climatechange		http://www.esri.com/news/arcuser/1010/coast.html
Additional Software Needed	Excel, GIS		
Sectors			
Agriculture		x	
Coastal Zones		x	x
Ecosystems	x	x	
Energy		x	
Public Health		x	x
Telecommunications		x	x
Transportation		x	x
Water Resources		x	
Adaptation Assessment Steps			
Identify Hazards	x	x	x
Prioritize Risk	x	x	x
Characterize Risk	x	x	x
Develop Strategies	x		x
Link to Decision Making	x		x
Plan	x		x
Implement Adaptation Plans	x		
Monitor, Reassess			
Cases	New York http://www.natureserve.org/prodServices/climatechange/pdfs/ccvi_report_ny.pdf	New York City http://www.nyc.gov/html/planyc2030/html/home/home.shtml	Groton, Ct. http://www.grotonct.gov/depts/plandev/docs/Final%20Report_Groton%20Coastal%20Climate%20Change%20ProjectJP.pdf
	Pennsylvania http://www.naturalheritage.state.pa.us/CCVI.aspx		

Adapted from a summary sheet created by EcoAdapt. The original sheet, including additional information, may be found at http://ebmtoolsdatabase.org/sites/default/files/sources/cctoolmatrix_mod_111511.pdf .

Tools for climate change adaptation planning used or applicable in the Northeast. 3 of 7

Tool Name	Coastal Atlas	Coastal Resilience	Getting to Resilience Community Questionnaire
Tool Type			
Analytical	x	x	
Data Portal	x		
Process			x
Socio-economic	x	x	
Tool Portal	x		
Visualization	x	x	
Description	Online mapping portal	Interactive web-mapping tool incorporating social and natural resource data, and inundation scenarios	Tool to assist communities assess and build their capacity for resilience.
Source	Maryland Department of Natural Resources	The Nature Conservancy	New Jersey Department of Environmental Protection
Link	http://www.dnr.maryland.gov/ccp/coastalatlas/index.asp	http://coastalresilience.org/	
Additional Software Needed			
Sectors			
Agriculture	x	x	
Coastal Zones	x	x	x
Ecosystems	x	x	x
Energy	x	x	x
Public Health		x	x
Telecommunications	x	x	x
Transportation	x	x	x
Water Resources	x	x	x
Adaptation Assessment Steps			
Identify Hazards	x	x	x
Prioritize Risk	x	x	
Characterize Risk	x	x	
Develop Strategies	x	x	x
Link to Decision Making			x
Plan		x	x
Implement Adaptation Plans			
Monitor, Reassess			
Cases	Maryland: Dorcester, Somerset and Worcester counties www.dnr.state.md.us/dnrnews/infocus/climatechange.asp	Long Island Sound http://coastalresilience.org	New Jersey: Cape May Point, Little Silver, Oceanport, Greenwich

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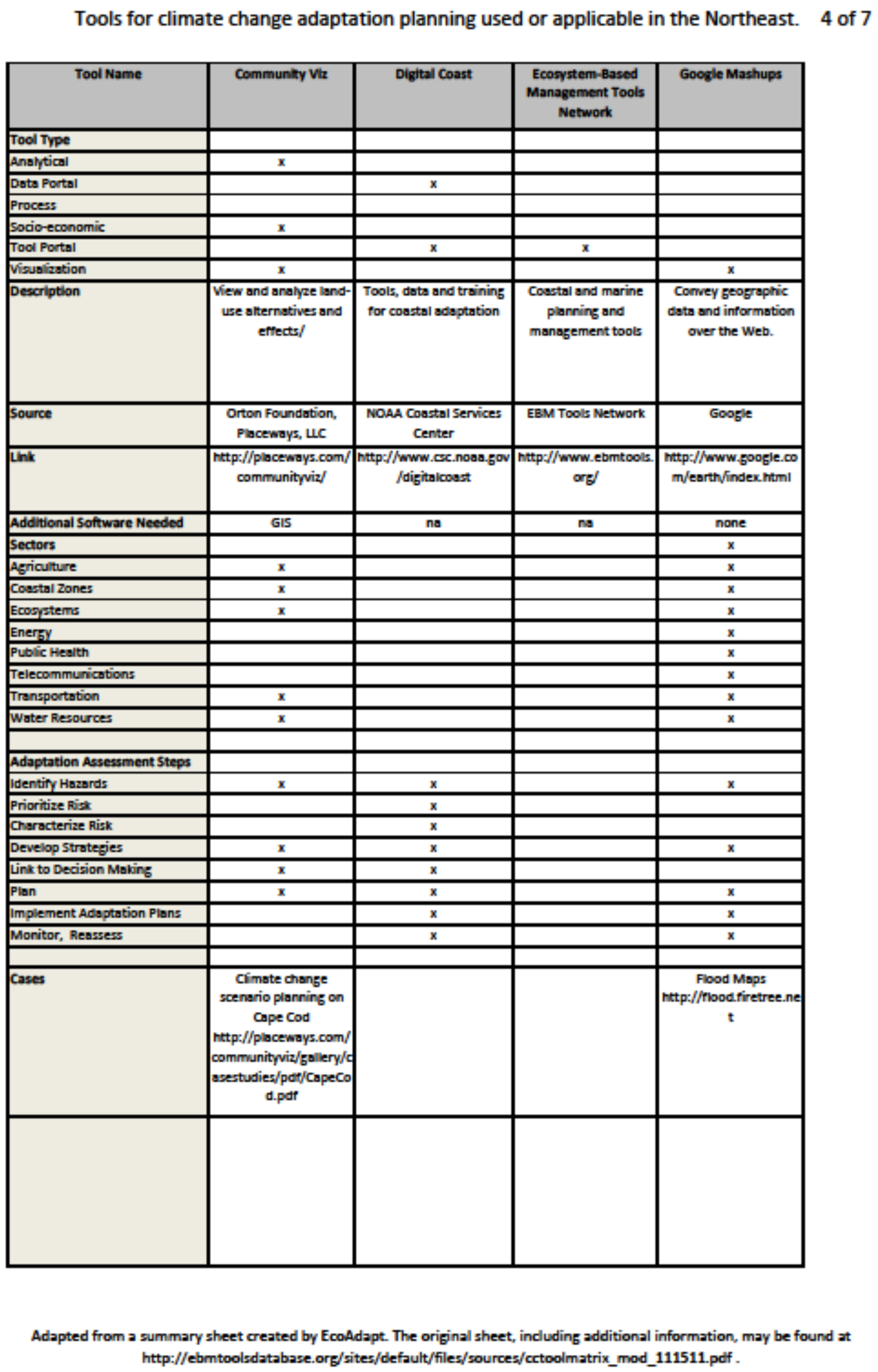

Tools for climate change adaptation planning used or applicable in the Northeast. 4 of 7

Tool Name	Community Viz	Digital Coast	Ecosystem-Based Management Tools Network	Google Mashups
Tool Type				
Analytical	x			
Data Portal		x		
Process				
Socio-economic	x			
Tool Portal		x	x	
Visualization	x			x
Description	View and analyze land-use alternatives and effects/	Tools, data and training for coastal adaptation	Coastal and marine planning and management tools	Convey geographic data and information over the Web.
Source	Orton Foundation, Placeways, LLC	NOAA Coastal Services Center	EBM Tools Network	Google
Link	http://placeways.com/communityviz/	http://www.csc.noaa.gov/digitalcoast	http://www.ebmtools.org/	http://www.google.com/earth/index.html
Additional Software Needed	GIS	na	na	none
Sectors				x
Agriculture	x			x
Coastal Zones	x			x
Ecosystems	x			x
Energy				x
Public Health				x
Telecommunications				x
Transportation	x			x
Water Resources	x			x
Adaptation Assessment Steps				
Identify Hazards	x	x		x
Prioritize Risk		x		
Characterize Risk		x		
Develop Strategies	x	x		x
Link to Decision Making	x	x		
Plan	x	x		x
Implement Adaptation Plans		x		x
Monitor, Reassess		x		x
Cases	Climate change scenario planning on Cape Cod http://placeways.com/communityviz/gallery/casestudies/pdf/CapeCod.pdf			Flood Maps http://flood.firetree.net

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Tool Name	**Habitat Priority Planner**	**Hazards U.S. Multi-Hazard (HAZUS-MH)**	**Inundation Coverage Map**
Tool Type			
Analytical	x		
Data Portal			
Process	x		
Socio-economic		x	
Tool Portal	x		
Visualization	x	x	x
Description	Assists in habitat conservation, restoration and land-use planning	Estimates physical, social and economic effects of disasters	Interactive, online map of sea level rise extent for entire Delaware and New jersey coastlines.
Source	NOAA CSC	FEMA	NOAA CSC
Link	http://www.csc.noaa.gov/digitalcoast/tools/hpp/index.html	http://www.fema.gov/plan/prevent/hazus	http://www.csc.noaa.gov/de_slr/index2.html
Additional Software Needed	GIS	GIS	
Sectors			
Agriculture		x	x
Coastal Zones	x		x
Ecosystems	x		x
Energy		x	x
Public Health			x
Telecommunications		x	x
Transportation		x	x
Water Resources		x	x
Adaptation Assessment Steps			
Identify Hazards	x	x	x
Prioritize Risk	x	x	x
Characterize Risk	x	x	
Develop Strategies	x		x
Link to Decision Making	x		x
Plan	x		x
Implement Adaptation Plans			
Monitor, Reassess			
Cases	Conservation goals in Maine http://www.csc.noaa.gov/digitalcoast/action/hppmaine.html	Long Island Sound (Coastal Resilience) http://coastalresilience.org	Delaware http://www.csc.noaa.gov/de_slr/index2.html
		New York City http://www.nyc.gov/html/planyc2030/html/home/home.shtml	

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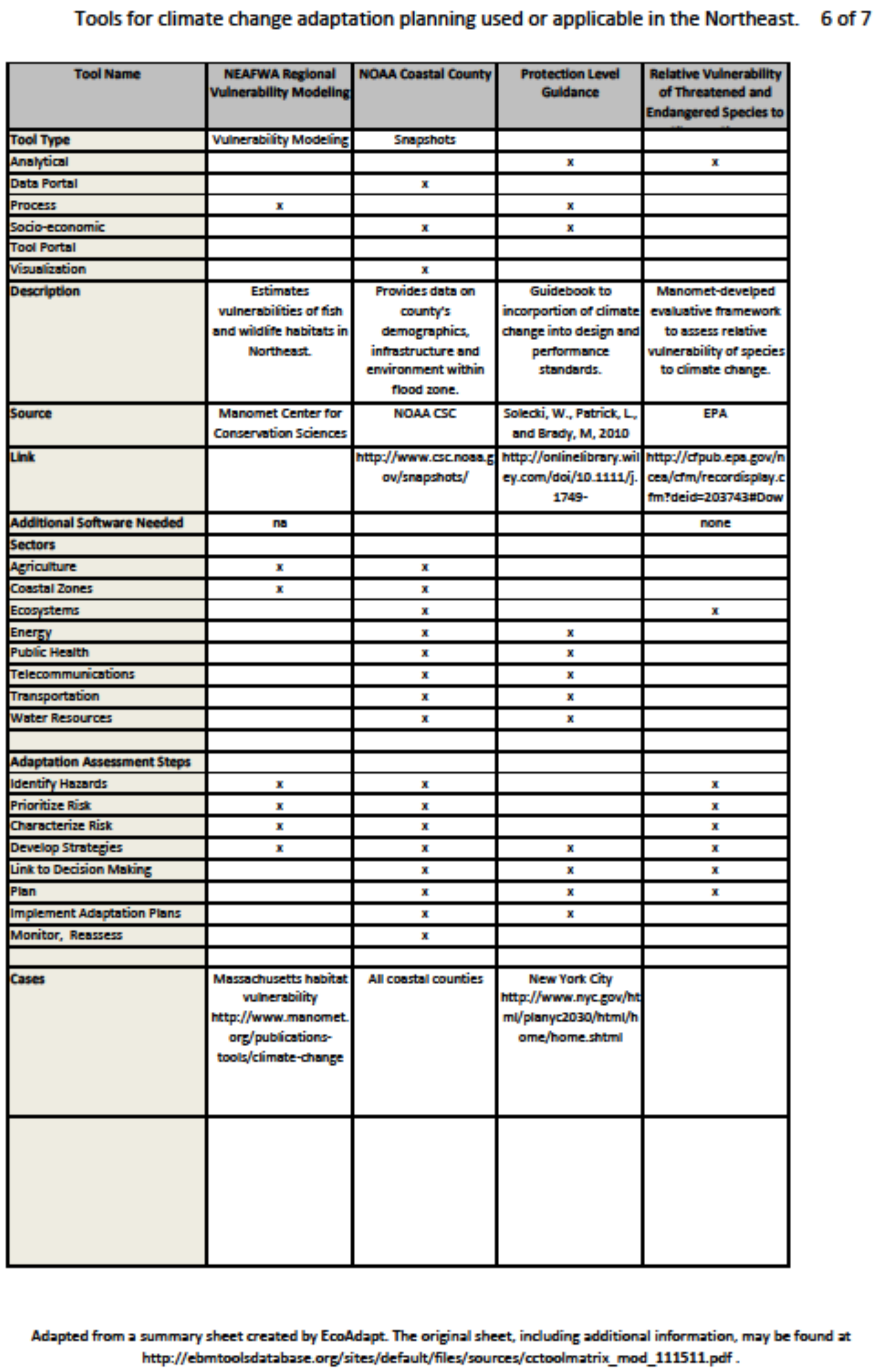

Tools for climate change adaptation planning used or applicable in the Northeast. 6 of 7

Tool Name	NEAFWA Regional Vulnerability Modeling	NOAA Coastal County	Protection Level Guidance	Relative Vulnerability of Threatened and Endangered Species to
Tool Type	Vulnerability Modeling	Snapshots		
Analytical			x	x
Data Portal		x		
Process	x		x	
Socio-economic		x	x	
Tool Portal				
Visualization		x		
Description	Estimates vulnerabilities of fish and wildlife habitats in Northeast.	Provides data on county's demographics, infrastructure and environment within flood zone.	Guidebook to incorportion of climate change into design and performance standards.	Manomet-develped evaluative framework to assess relative vulnerability of species to climate change.
Source	Manomet Center for Conservation Sciences	NOAA CSC	Solecki, W., Patrick, L., and Brady, M, 2010	EPA
Link		http://www.csc.noaa.gov/snapshots/	http://onlinelibrary.wiley.com/doi/10.1111/j.1749-	http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=203743#Dow
Additional Software Needed	na			none
Sectors				
Agriculture	x	x		
Coastal Zones	x	x		
Ecosystems		x		x
Energy		x	x	
Public Health		x	x	
Telecommunications		x	x	
Transportation		x	x	
Water Resources		x	x	
Adaptation Assessment Steps				
Identify Hazards	x	x		x
Prioritize Risk	x	x		x
Characterize Risk	x	x		x
Develop Strategies	x	x	x	x
Link to Decision Making		x	x	x
Plan		x	x	x
Implement Adaptation Plans		x	x	
Monitor, Reassess		x		
Cases	Massachusetts habitat vulnerability http://www.manomet.org/publications-tools/climate-change	All coastal counties	New York City http://www.nyc.gov/html/planyc2030/html/home/home.shtml	

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Tools for climate change adaptation planning used or applicable in the Northeast. 7 of 7

Tool Name	Risk Matrix	Sea Level Rise Affecting Marshes (SLAMM)	SLAMM-Viewer	Social Vulnerability Index	Spatial Trends in Coastal Socioeconomics
Tool Type					
Analytical	x	x	x		x
Data Portal				x	x
Process	x				
Socio-economic					
Tool Portal					
Visualization	x	x	x	x	x
Description	Guidebook to assessment of hazard probability and consequences.	Identifies potential changes in extent and composition of wetlands	Portrays pairs of SLAMM simulation results and intgrates with other GIS data layers	Graphically illustrates geographic variation in social vulnerability.	Online socio-economic data, and analysis and display tools.
Source	Major, D.C., and M. O'Grady, 2010	Warren Pinnacle Consulting, Inc.	Image Matters, USGS		NOAA CSC
Link	http://pubs.giss.nasa.gov/docs/2010/2010_Major_OGrady.pdf	http://warrenpinnacle.com/prof/SLAMM/	http:/www.slammview.org	http://webra.cas.sc.edu/hvri/products/sovi.aspx	http://marineeconomics.noaa.gov/
Additional Software Needed		GIS	GIS	none	none
Sectors					
Agriculture	x				
Coastal Zones	x	x	x		x
Ecosystems	x	x	x		
Energy	x				
Public Health	x				
Telecommunications	x				
Transportation	x				
Water Resources	x				
Adaptation Assessment Steps					
Identify Hazards	x	x	x	x	x
Prioritize Risk	x			x	x
Characterize Risk	x			x	x
Develop Strategies		x	x	x	x
Link to Decision Making		x	x	x	x
Plan		x	x	x	x
Implement Adaptation Plans				x	x
Monitor, Reassess				x	
Cases	New York City http://www.nyc.gov/html/planyc2030/html/home/home.shtml	Delaware http://www.dnrec.delaware.gov/coastal/Pages/SeaLevelRiseAdaptation.aspx		Long Island Sound (Coastal Resilience) http://coastalresilience.org	South Wilmington, De. Socioeconomic Profile http://coastalsocioeconomics.noaa.gov/assessment/de_samp/sw_sep_final.pdf
		Long Island Sound (Coastal Resilience) http://coastalresilience.org		Sea Level Rise and Coastal Flooding Impacts Viewer http://www.csc.noaa.gov/digitalcoast/tools/slrviewer/index.htm	

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7. Conclusions and Recommendations

Coordinating Lead Authors - Radley Horton, William Solecki, and Cynthia Rosenzweig

This chapter contains: 1) report conclusions organized by chapter and sections, based on the key conclusions brought forward by the Northeast authors, and 2) recommendations based on the conclusions described below.

Conclusions

Chapter 2

In the Northeast, there is a historical precedent for coordinated regional problem-solving. The majority of states in the region have begun mitigating and adapting to climate change, and there are several examples of regional partnerships.

Chapter 3

Sources of Vulnerability in the Region

Concentration of high population and high value assets in an area vulnerable to sea level rise and storm surge, in addition to other climate hazards

Many of the region's systems are already stressed, and because they are tightly coupled cascading impacts could set in motion a wide set of impacts

Many of these systems are already stressed.

Observed Climate Changes

Sea levels are rising approximately 1 inch per decade along the Northeast Coast.

Upward trends in extreme rainfall have been especially pronounced in the Northeast, relative to other regions

Recent trends toward earlier high river flows, reduced snow cover and decreased lake ice occurrence highlight the impacts of continued winter warming in the region.

Climate Projections

Rates of temperature increase and sea level rise are expected to exceed those experienced during the past decades.

Mean precipitation changes are expected to be relatively small compared to the large year to year variability that occurs naturally.

The frequency, intensity, and duration of many types of extreme events are expected to change. For example, heat waves and storm surge flood events are expected to become far more frequent and intense during the 21st century. Intense precipitation events are likely to become more frequent as well, while extreme cold events are expected to decrease in frequency and intensity.

Chapter 4

Water

Concerns in the region are largely related to possible increases in excess water events, including flood risk and the management of stormwater.

Forests and Ecosystems

In the near term, it is likely that productivity of forests has already or will soon increase. However, the unfolding direct and indirect effects of this climate change on forests of the northeastern United States, both alone and in combination with other vectors of change such as acid deposition, Nitrogen (N) and Mercury (Hg) deposition, ozone, and changes in land use are comprehensive, complex, and not likely beneficial.

Agriculture and Food Systems

The direct impacts on crops, livestock, and pests, and the costs of farmer adaptation, will have cascading effects beyond the farm gate and throughout the Northeast economy.

While climate change will create unprecedented challenges, there are likely to be new opportunities as well, such as developing new markets for new crop options that may come with a longer growing season and warmer temperatures.

Along with integrating climate change adaptation into business planning, farmers can play a significant role in climate change mitigation by improving farm energy efficiency, and managing crops, soils, and livestock to reduce greenhouse gas emissions and sequester soil carbon.

Oceans and Coasts

Recent high-end sea level rise scenarios imply heightened exposure of Northeast coastal cities and natural ecosystems to more frequent storm surge flooding and other adverse effects. Low-lying and subsiding areas will be the most affected.

Changing ocean currents could enhance sea level rise and also affect marine ecosystems in the Northeast to a greater extent than in other parts of the country.

Human Health

A changing climate is expected to result in adverse health impacts in the Northeast particularly due to extreme heat and changes in air quality, and potentially due to waterborne disease.

Wide ranging adaptation efforts involving vulnerability assessments, improvements in healthcare infrastructure improvements, and early warning systems could considerably reduce the public health burden from climate-sensitive environmental exposures.

Infrastructure - Transportation

Like much of the infrastructure in the Northeast, the transportation system was built to withstand the historically expected range of climatic conditions.

Because future sea levels, temperature and precipitation patterns are expected to deviate from these historical experiences due to climate change, much of this infrastructure could be at risk.

However, as this aging infrastructure is rebuilt or upgraded, there are opportunities to take into consideration the changing climate and to strengthen this infrastructure to meet these future challenges.

Infrastructure - Telecommunications

Telecommunications in the northeastern US has proved to be vulnerable to extreme weather events under current climate conditions. It is likely that extreme weather conditions will become more frequent and more severe as a consequence of the predicted climate change.

Telecommunications has a unique opportunity to build-in climate robustness as it replaces part of its infrastructure when periodically introducing new technologies. Remaining older systems may need to be retrofitted, or in some cases relocated.

Infrastructure - Energy

Some climate-related impacts may be very localized, affecting a single power line, power plant, or neighborhood, while others may have ripple effects that carry across a much broader region, reflecting the highly interconnected nature of today's energy system and markets. Supply-side impacts may be extremely costly and logistically challenging, because replacing lost supply capacity or transmission and distribution assets can take some time and be highly disruptive and involve significant capital investment.

Community/Urban

Physical, social, and economic density and complexity, as well as age and geographic reach, multiply the vulnerability of Northeast cities to the entire range of climate-change risks.

Many Northeast cities have begun to address climate adaptation, frequently linking it to existing planning or infrastructure-improvement processes.

Municipal governments can draw on a wide variety of local governance tools for adaptation—including zoning, permitting, planning, stakeholder engagement, and leading by example—but face limitations of authority, geographical jurisdiction, and resources that will require effective engagement with other levels of government.

Chapter 5

Hydroclimatic process, including changes in snowfall, river flows, and lake ice-cover have been observed and projected to change in New England, a region defined by water resources.

The coastal urban corridor can increase vulnerabilities, but cities are leading the way in mitigation and adaptation

The interactions of the climate system, physical landscape, and socioeconomic system of Central Appalachia suggest that a large proportion of the rural population is extremely vulnerable to the impacts of climate change.

The combination of the uncertain impacts of climate change and large-scale energy development – mountaintop-removal coal mining, shale gas extraction, and wind turbine siting – are putting the most- vulnerable natural and human populations of Central Appalachia at increasing risk.

Chapter 6

Decision Support

Climate decision support includes a range or continuum of activities from exploratory scientific, legal, and planning efforts to place-based or problem-focused research and assessment to the development of specialized or tailored information tools and services.

Communication

Definitions used in climate change are not consistent which can lead to public misunderstanding and mistrust of climate science.

Policy makers and other decision makers need to be able to work with a common vocabulary with consistent meanings that are understandable by the public.

Planning Tools

Planning tools used for decision-support include methods to assist in data collection and/or management, modeling and analysis of environmental or socio-economic systems, illustration or analysis of the consequences of management decisions, facilitation of stakeholder involvement, or project management.

To date, most adaptation decision-support tools in the Northeast have been used by local governments focused on hazards posed by sea level rise, storm surge and coastal erosion.

The significant need expressed by local decision-makers is a simplified set of decision-tools as well as data relevant to their planning scales.

Data, Monitoring, Indicators

There is an overarching and pressing need for strategic and targeted monitoring efforts with sustained long-term funding sources in order to properly measure and document changes in natural resources over climate time-scales.

In addition, natural systems are not bounded by political lines, and thus there is a need for truly regional, multi-jurisdictional efforts to document changes on climate spatial-scales.

Legal

In the Northeast as in the rest of the United States, the legal structures dealing with climate change is varied, nascent in some states and more developed in others.

Without common and comprehensive federal or state laws, local governments have been the incubators; as such they have had the more active role in planning for climate change by requiring and preparing reports, developing new and revising zoning and planning codes and setting forth the agenda to meet the impacts projected for their communities.

Insurance

Insurance, reinsurance, and other financial incentives can provide powerful tools in the adaptation to and mitigation of climate risk. The ability of the insurance industry to assist public policy-makers in the effective and efficient implementation is dependent on a different way of doing business that better integrates pricing with risk.

Evaluation

As decision support becomes a mature field, it is essential that an evaluation of best practices be woven into efforts from inception.

A multi-disciplinary approach to decision-support allows for evaluation of processes in real-time which maximizes the efficiency of the investment for adaptive management.

Recommendations

- Iterative and sustained assessment efforts are needed.

- Existing regional entities and relationships should be supported in mitigation and adaptation efforts, both because many have been successful and because building something a new requires more effort and start up time.
- Adaptation co-benefits and 'win-wins' should be emphasized, including synergies between mitigation and adaptation.
- Coordinated planning efforts across regions and sectors should be encouraged, based on engagement with various levels of government, the private sector, NGOs, indigenous groups, and other communities.
- The broader national and international context should be considered when doing impact assessment and considering adaptation strategies.
- Reducing data gaps should be a high priority, as should be the protection of existing monitoring infrastructure.
- Additional research needs to be undertaken to identify engineering sector needs.
- The process of identifying new standards needs to articulated and encouraged.
- Future regulations, and future adaptation strategies should be flexible in the face of uncertainty, to the extent possible.
- Improved communication and education programs are needed around climate and vulnerability issues.